



POSTAL BOOK PACKAGE 2027

CIVIL ENGINEERING

CONVENTIONAL PRACTICE SETS **VOLUME - II**

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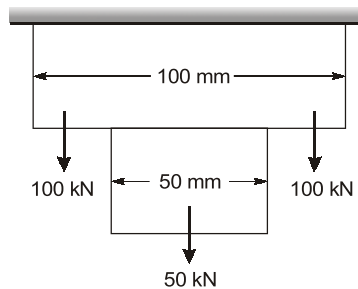
STRENGTH OF MATERIALS

CONVENTIONAL PRACTICE SETS

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Simple Stress Strain and Elastic Constants

- Q1** A bar of varying square cross-section is loaded symmetrically as shown in the figure. Loads shown are placed on one of the axes of symmetry of cross-section. Ignoring self-weight, calculate the maximum tensile stress anywhere in the section

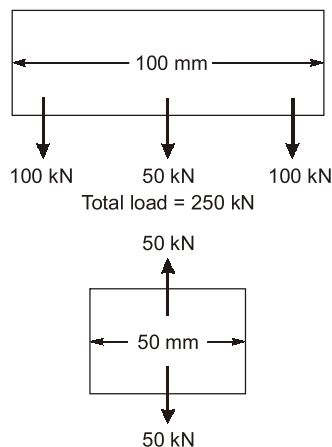


Solution:

$$\text{The stress in lower bar} = \frac{50 \times 1000}{50 \times 50} = 20 \text{ N/mm}^2$$

$$\text{The stress in upper bar} = \frac{250 \times 1000}{100 \times 100} = 25 \text{ N/mm}^2$$

Thus the maximum tensile stress anywhere in the bar is 25 N/mm².



- Q2** A metal bar of length 100 mm is inserted between two rigid supports and its temperature is increased by 10°C. If the coefficient of thermal expansion is 12×10^{-6} per °C and the Young's modulus is 2×10^5 MPa, then calculate the stress in the bar

Solution:

Method-I

$$\text{Temperature stress} = \alpha TE$$

$$= 12 \times 10^{-6} \times 10 \times 2 \times 10^5 = 24 \text{ MPa}$$

Method-II

Due to temperature,

$$\Delta L = L\alpha\Delta T$$

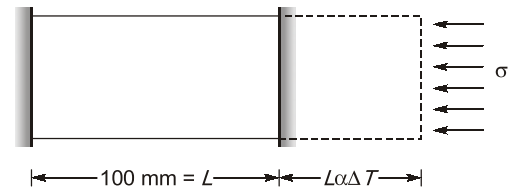
But since support is fixed so, expansion is not allowed so stress is developed in the bar which is compressive in nature.

Now,

$$\text{Expansion due to temperature} = \text{Compression due to stress}$$

$$L\alpha\Delta T = \frac{\sigma}{E} \times L$$

$$\begin{aligned}\sigma &= E\alpha\Delta T \\ &= 1 \times 10^5 \times 12 \times 10^{-6} \times 10 \\ &= 24 \text{ MPa}\end{aligned}$$



- Q3** A mild steel specimen is under uniaxial tensile stress. Young's modulus and yield stress for mild steel are $2 \times 10^5 \text{ MPa}$ and 250 MPa respectively. Calculate the maximum amount of strain energy per unit volume that can be stored in this specimen without permanent set

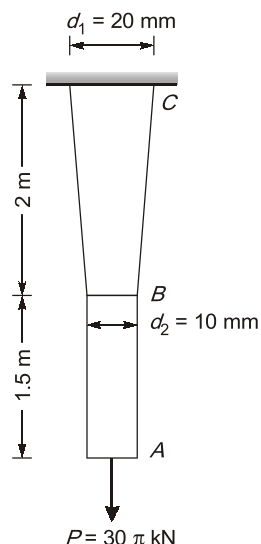
Solution:

The strain energy per unit volume may be given as

$$u = \frac{1}{2} \times \text{Stresses} \times \text{Strain}$$

$$\begin{aligned}u &= \frac{1}{2} \times \frac{\sigma_y^2}{E} = \frac{1}{2} \times \frac{(250)^2}{2 \times 10^5} \\ &= 0.156 \text{ N-mm/mm}^3\end{aligned}$$

- Q4** A tapered circular rod of diameter varying from 20 mm to 10 mm is connected to another uniform circular rod of diameter 10 mm as shown in the following figure. Both bars are made of same material with the modulus of elasticity, $E = 2 \times 10^5 \text{ MPa}$. If load subjected is $30\pi \text{ kN}$, then calculate deflection at point A (in mm)



Solution:

Total elongation,
AB is uniform

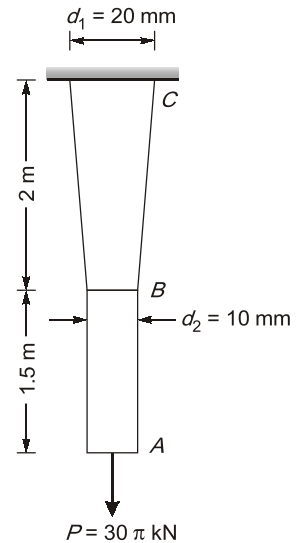
$$\text{So, } \Delta = \frac{PL}{AE}$$

BC is tapered

$$\Delta = \frac{PL}{\frac{\pi}{4} d_1 d_2 E}$$

$$\begin{aligned} \Delta &= \Delta_{AB} + \Delta_{BC} \\ &= \frac{PL}{AE} + \frac{4PL}{\pi d_1 d_2 E} \end{aligned}$$

$$\begin{aligned} &= \frac{30\pi \times 10^3 \times 1.5 \times 10^3}{\frac{\pi}{4} \times (10)^2 \times 2 \times 10^5} + \frac{30\pi \times 10^3 \times 2 \times 10^3}{\frac{\pi}{4} \times 10 \times 20 \times 2 \times 10^5} \\ &= (9 + 6) \text{ mm} = 15 \text{ mm} \end{aligned}$$



Q5 A steel specimen of 12 mm diameter extends by 6.31×10^{-2} mm over a gauge length of 150 mm when subjected to an axial load of 10 kN. The same specimen undergoes a twist of 0.5° on a length of 150 mm over a twisting moment of 10 N-m. Using the above data, determine the elastic constants E , μ , G and K .

Solution:

Tensile Test: $P = 10 \text{ kN}$

Length of specimen, $L = 150 \text{ mm}$

Cross-sectional area, $A = \frac{\pi}{4} \times 12^2 = 113.09 \text{ mm}^2$

Change in length of specimen, $\Delta = 6.31 \times 10^{-2} \text{ mm}$

Let $E \text{ N/mm}^2$ is modulus of elasticity of material.

We know, axial deformation due to axial load is given by

$$\Delta = \frac{PL}{AE}$$

$$\therefore E = \frac{PL}{A\Delta} = \frac{10 \times 1000 \times 150}{113.09 \times 6.31 \times 10^{-2}} = 2.10 \times 10^5 \text{ N/mm}^2$$

Torsion test:

We know,

$$\frac{T}{I_p} = \frac{G\theta}{L}$$

...(i)

\therefore Modulus of rigidity,

$$G = \frac{TL}{I_p\theta}$$

$$I_p = \frac{\pi}{32} D^4 = \frac{\pi}{32} \times (12)^4 = 2035.75 \text{ mm}^4$$

Angle of twist, $\theta = \frac{0.5 \times \pi}{180} \text{ radian} = 8.73 \times 10^{-3} \text{ radian}$

From eq. (i), we get

$$G = \frac{10 \times 10^3 \times 150}{2035.75 \times 8.73 \times 10^{-3}} = 8.44 \times 10^4 \text{ N/mm}^2$$

We know,

$$E = 2G(1 + \mu)$$

$$\frac{E}{2G} = 1 + \mu$$

∴

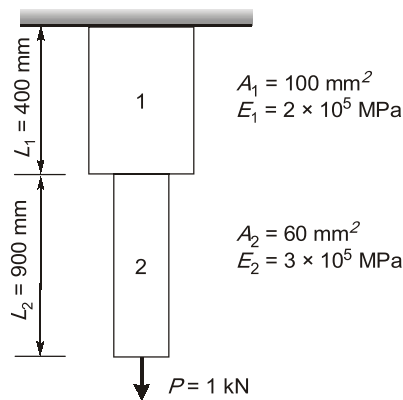
$$\mu = \frac{E}{2G} - 1 = \frac{2.10 \times 10^5}{2 \times 8.44 \times 10^4} - 1 = 1.24 - 1 = 0.24$$

Also

$$E = 3k(1 - 2\mu)$$

$$k = \frac{E}{3(1 - 2\mu)} = \frac{2.10 \times 10^5}{3(1 - 2 \times 0.24)} = 1.35 \times 10^5 \text{ N/mm}^2$$

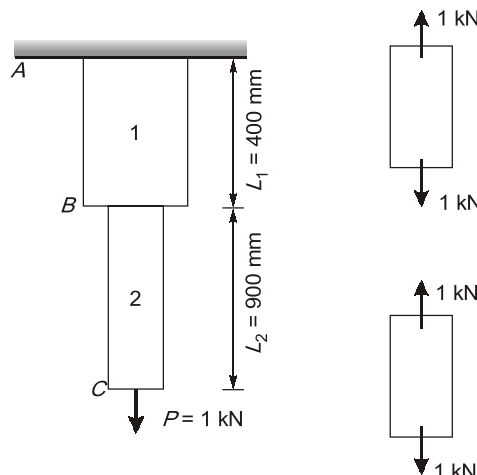
Q.6 Consider the stepped bar made with a linear elastic material and subjected to an axial load of 1 kN, as shown in the figure.



Segments 1 and 2 have cross-sectional area of 100 mm² and 60 mm². Young's modulus of 2 × 10⁵ MPa and 3 × 10⁵ MPa, and length of 400 mm and 900 mm, respectively. Calculate the strain energy stored in the bar (in N-mm) due to the axial load

Solution:

$$A_1 = 100 \text{ mm}^2, E_1 = 2 \times 10^5 \text{ MPa}, \quad A_2 = 60 \text{ mm}^2, E_2 = 3 \times 10^5 \text{ MPa}$$



$$\Delta_{AC} = \Delta_{AB} + \Delta_{BC}$$

$$= \frac{1 \times 10^3 \times 400}{100 \times 2 \times 10^5} + \frac{1 \times 10^3 \times 900}{60 \times 3 \times 10^5} = 0.02 + 0.05 = 0.07 \text{ mm}$$

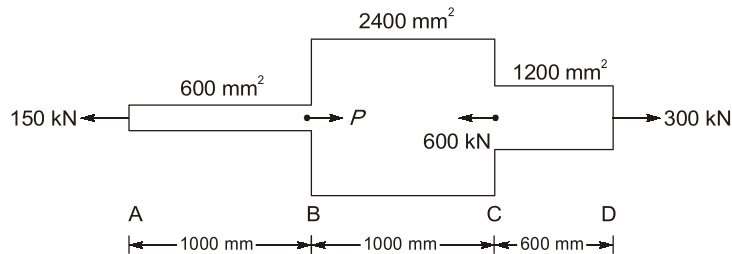
$$U = \frac{1}{2} \times P \times \Delta = \frac{1}{2} \times 1 \times 1000 \times 0.07 = 35 \text{ N-mm}$$

Q7 A member ABCD is subjected to concentrated loads as shown. Calculate

(i) Force P necessary for equilibrium

(ii) Total elongation of bar

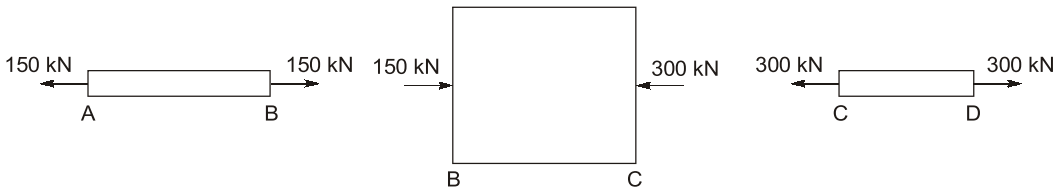
$$E = 2 \times 10^5 \text{ N/mm}^2$$



Solution:

(i)

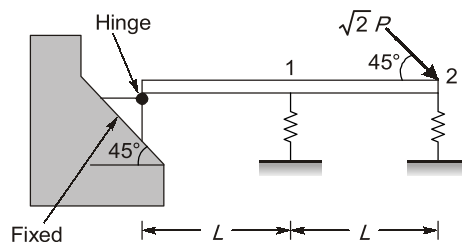
$$\begin{aligned} \Sigma F &= 0 \\ (P + 300) - (150 + 600) &= 0 \\ P &= 450 \text{ kN} \end{aligned}$$



(ii)

$$\begin{aligned} \Delta_{\text{Total}} &= \Delta_{AB} + \Delta_{BC} + \Delta_{CD} \\ &= \frac{150 \times 1000 \times 1000}{600 \times 2 \times 10^5} - \frac{300 \times 1000 \times 1000}{2400 \times 2 \times 10^5} + \frac{300 \times 600 \times 1000}{1200 \times 2 \times 10^5} \\ &= 1.25 - 0.625 + 0.75 \\ &= 1.375 \text{ mm (elongation)} \end{aligned}$$

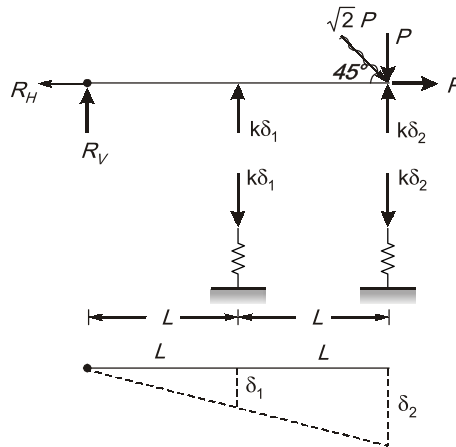
Q8 A rigid beam is hinged at one end and supported on linear elastic springs (both having a stiffness of ' k ') at points '1' and '2', and an inclined load acts at '2', as shown in figure in term of P .



Find the deflections at point (1) and (2) as shown in figure in terms of P .

Solution:

The free diagram of the beam is shown below,



From similar triangles, we get,

$$\frac{L}{\delta_1} = \frac{2L}{\delta_2}$$

⇒

$$\delta_2 = 2\delta_1$$

...(i)

Taking moments about hinge, we get,

$$P \times 2L - k\delta_2 \times 2L - k\delta_1 \times L = 0$$

⇒

$$2P - k(2\delta_2 + \delta_1) = 0$$

[∴ from (i)]

⇒

$$2P - k(4\delta_1 + \delta_1) = 0$$

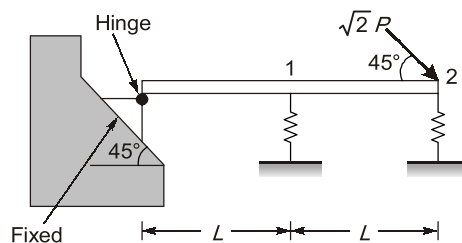
⇒

$$\delta_1 = \frac{2P}{5k}$$

From (i), we get,

$$\delta_2 = 2 \times \frac{2P}{5k} = \frac{4P}{5k}$$

Q9 A rigid beam is hinged at one end and supported on linear elastic springs (both having a stiffness of 'k') at points '1' and '2', and an inclined load acts at '2', as shown in figure in term of P.



If the load P equals 100 kN, then calculate reaction force at (1) and (2) respectively (in kN).

Solution:

From previous questions,

$$R_1 = k\delta_1 = k \times \frac{2P}{5k} = \frac{2 \times 100}{5} = 40 \text{ kN}$$

$$R_2 = k\delta_2 = k \times \frac{4P}{5k} = \frac{4 \times 100}{5} = 80 \text{ kN}$$

CONSTRUCTION MATERIALS

CONVENTIONAL PRACTICE SETS

Page No. 168 - 210

Q1 Name the four important constituents of cement and state the role of each in achieving its properties.

Solution:

The four important constituents of cement are:

- | | |
|---|---|
| (i) Lime (CaO) – 60 to 67% | (ii) Silica (SiO ₂) – 17 to 25% |
| (iii) Alumina (Al ₂ O ₃) – 3 to 8% | (iv) Iron oxide (Fe ₂ O ₃) – 0.5 to 6% |

All these oxides interact with one another in the kiln at high temperature to form more complex compounds. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement in addition to rate of cooling and fineness of grinding. The complex compounds which are formed due to the combination of these oxides are called Bogue's compounds and four of them are usually regarded as major compounds. They are tricalcium silicate (C₃S), dicalcium silicate (C₂S), tricalcium aluminate (C₃A) and tetra calcium aluminoferrite (C₄AF).

The two silicates namely C₃S and C₂S which together constitute about 70 to 80 per cent of the cement constituents control the most of the strength giving properties. Upon hydration, both C₃S and C₂S give the same product called calcium silicate hydrate (C₃S₂H₃) and calcium hydroxide [Ca(OH)₂]. C₃S gives a faster rate of reaction accompanied by a greater heat evolution thereby giving early strength. On the other hand, C₂S hydrates and hardens slowly and responsible for the ultimate strength. But the hydration of C₃S liberates nearly three times more calcium hydroxide as compared to C₂S. That's why C₂S provides more resistance to chemical attack.

The compound tricalcium aluminate (C₃A) is characteristically fast reacting with water and may lead to an immediate stiffening of paste, and this process is termed as flash set. The role of gypsum added during the manufacture of cement is to prevent such a fast reaction. The hydrated aluminates do not contribute anything to the strength of concrete. On the other hand, their presence is harmful to the durability of concrete particularly where the concrete is likely to be attacked by sulphates. As it hydrates fast it may contribute a little to the early strength.

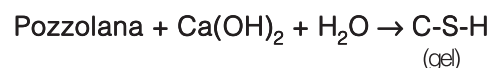
On hydration, C₄AF is form a system of the form CaO–Fe₂O₃–H₂O. A hydrated calcium ferrite of the form C₃FH₆ is comparatively more stable. This hydrated product also does not contribute anything to the strength. The hydrates of C₄AF show a comparatively higher resistance to the attack of sulphates than the hydrates of calcium aluminate.

Q2 Explain pozzolanic action.

Solution:

A pozzolana is a finely ground siliceous material which as such does not possess cementitious property in itself but reacts in the presence of water with calcium hydroxide at normal temperature to form compounds of low solubility having cementitious properties. The action is known as pozzolanic action.

The reaction can be shown as



This reaction is called pozzolanic reaction. The characteristic feature of pozzolanic reaction is initially slow, with the result that heat of hydration and strength development will accordingly be slow. The reaction involves

the consumption of Ca(OH)_2 and not production of Ca(OH)_2 . It may be noted that on hydration of C_3S and C_2S present in cement, Ca(OH)_2 is formed as one of the products of hydration. This compound has no cementitious value and it is soluble in water and may be leached out by the percolating water. It is pointed out that Ca(OH)_2 , otherwise, a water soluble material is converted into insoluble cementitious material by reaction of pozzolanic materials.

The reduction of Ca(OH)_2 also improves the durability of cement paste by making the paste dense and impervious. Pozzolanic materials can be natural or artificial. Clay and shales, opaline cherts, diatomaceous earth and volcanic tuffs are natural pozzolanic materials. Fly ash, blast furnace slag, silica fume, rice husk ash are artificial pozzolanic materials.

The pozzolanic action also reduce the expansion caused by the alkali-aggregate reaction in concrete. Excessive expansion causes pattern cracking of concrete. This expansion can usually be controlled by using of pozzolana ranging from 2 to 35% by mass of cement depending upon the type of aggregate and alkali content of cement.

Q3 Differentiate between flash set and false set.

Solution:

Flash set : When portland Clinker is ground alone and mixed with water, the aluminate (C_3A) phase initially reacts rapidly and if C_3A level is appreciable, then flash set or quick set is likely to happen.

- Since plasticity of mix is not restored after flash setting, it is deteterious to concrete production.
- In order to prevent flash set, gypsum is added to cement to ensure smooth set regulation prior to normal setting.

False set : False set is sometimes also known as early stiffening or premature stiffening or gum set. It refers to cement which when gauged with water and mixed for short while, stiffens up and appears to set. Remixing breaks up this stiffening and cement proceeds to the normal sets.

Q4 Explain the difference between various grades of OPC.

Solution:

The commonly used portland cement in India is branded as **33-grade (IS:269-1989)**, **43-grade (IS:8112-1989)** and **53 grade (IS:12269-1987)** having 28 days mean compressive strengths exceeding 33 MPa, 43 MPa and 53 MPa respectively. All the three grades are produced from same materials. The higher strengths are achieved by increasing C_3S content and also by finely grinding the clinker. The fineness of 53-grade OPC obtained by Blaine's air permeability test is specified to be of the order of 350000 mm^2/g . The initial and final setting times are same for all the three grades. The 33-grade cement has virtually disappeared and has been replaced by high strength 43-grade cement. The minimum compressive strengths of the 43-grade cement are 23 MPa and 33 MPa at the end of 3 and 7 days respectively. At higher water cement ratio, the concrete produced with high strength cement has about 80% higher strength and at lower water cement ratio, it has 40% higher strength than that of concrete using 33-grade cement. Greater fineness of 43 and 53 grade cements increase workability due to reduction of friction between aggregates. Moreover, due to shorter setting time and faster development of strength, the stripping time is shorter. Although cements of grade 43 and 53 are desirable for economical design of high grade concretes but they can also be used for lower grade concretes.

Q5 List the various laboratory tests for assessing the quality of cement and their importance.

Solution:

The following tests are usually conducted in laboratory to assess the quality of cement:

- Fineness test:** The fineness of cement affects the rate of hydration and hence the rate of gain of strength and also the rate of evolution of heat. Fineness of cement can be tested in two ways viz. by sieving and by determination of specific surface using air permeability apparatus.

- (ii) **Setting time test:** In actual construction dealing with cement paste, mortar or concrete, certain time is required for mixing, transporting, placing, compacting and finishing. During this time cement paste, mortar or concrete should be in plastic condition. This time is known as initial setting time. Once the concrete is placed in the final position, compacted and finished, it should lose its plasticity in the earliest possible time so that it is least vulnerable to damages from external destructive agencies. This time is known as final setting time. Setting time test is carried out with the help of Vicat apparatus.
- (iii) **Compressive strength test:** The compressive strength of hardened cement is the most important of all the properties. Therefore, it is not surprising that the cement is always tested for its strength in laboratory before the cement is used in important works.
- (iv) **Soundness test:** It is very important that the cement after setting shall not undergo any appreciable change of volume. The testing of soundness of cement, to ensure that the cement does not show any appreciable subsequent expansion is of prime importance. Unsoundness in cement is due to excess of lime, excess of magnesia or excessive proportions of sulphates. Unsoundness due to lime can be tested using Le Chatelier apparatus. Unsoundness due to magnesia can be tested using Autoclave test. Unsoundness due to calcium sulphate can be tested using chemical analysis.
- (v) **Heat of hydration test:** The reaction of cement with water is exothermic. It is estimated that about 120 calories of heat is generated in the hydration of 1 gm of cement. The total quantum of heat produced in a conservative system such as the interior of a mass concrete dam, a temperature rise of about 50°C has been observed. This unduly high temperature developed at the interior of a concrete dam causes serious expansion of the body of dam and with the subsequent cooling considerable shrinkage takes place resulting in serious cracking of concrete. Heat of hydration test can be easily carried out over a few days by vacuum flask methods, or over a longer period in an adiabatic calorimeter.
- (vi) **Chemical composition test:** The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement, in addition to rate of cooling and fineness of grinding. Thus the chemical composition test is carried out in laboratory.

Q6 Write brief note on white and colored cements.**Solution:****White Cement:**

- This is just a variety of ordinary cement and it is prepared from such raw materials which are practically free from colouring agents like oxides of iron, manganese or chromium.
- For burning of this cement, the oil fuel is used instead of coal.
- It is white in colour and it is used for floor finish, plaster work, ornamental work, etc.
- It should not set earlier than 30 minutes. It should be carefully transported and stored in closed containers only.
- It is more costly than ordinary cement because of specific requirements imposed upon the raw materials and the manufacturing process.
- It is quick drying, possesses high strength and has superior aesthetic values.

Coloured Cement:

- The cement of desired colour may be obtained by mixing mineral pigments with ordinary cement.
- The amount of colouring material may vary from 5 to 10%. If this percentage exceeds 10%, the strength of cement is affected.
- The chromium oxide gives green colour. The cobalt imparts blue colour. The iron oxide in different proportions gives brown, red or yellow colour. The manganese dioxide is used to produce black or brown coloured cement.

- The coloured cements are widely used for finishing of floors, external surfaces, artificial marble, window sill slabs, textured panel faces, stair treads, etc.

Q.7 Describe the hydration of portland cement and outline the ways in which the Vicat apparatus and the Le-Chatelier apparatus can be used to assess the properties of fresh and hardened cement paste.

Solution:

The chemical reactions that takes place between cement and water is known as hydration of cement. On account of hydration certain products are formed. These products are important because they have cementing or adhesive properties. The quality, quantity, continuity, stability and the rate of formation of the hydration products are important.

Anhydrous cement compounds when mixed with water, react with each other to form hydrated compounds of very low solubility. The hydration of cement can be visualized in two ways. The first is "through solution" mechanism. In this the cement compounds get dissolved to produce a super saturated solution from which different hydrated products get precipitated. The second possibility is that water attacks cement compounds in the "solid state" converting the compounds into hydrated products starting from the surface and proceeding to the interior of the compounds with time. It is probable that both "through solution" and "solid state" types of mechanism may occur during the course of reactions between cement and water. The former mechanisms may predominate in the early stages of hydration in view of large quantities of water being available and the latter mechanism may operate during the later stages of hydration.

The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This liberation of heat is called heat of hydration. The hydration process is not instantaneous. The reaction is faster in the early period and continues indefinitely at a decreasing rate. Complete hydration can not be obtained under a period of one year or more unless the cement is very finely ground and reground with excess of water. During the course of reaction of C_3S and C_2S with water, calcium silicate hydrate (C-S-H) and calcium hydroxide $Ca(OH)_2$ are formed. Calcium silicate hydrate is the essence that determines the properties of concrete. It makes up 50-60 per cent of the volume of solids in a completely hydrated cement paste. On the other hand, calcium hydroxide is a compound which is responsible for the lack of durability. The calcium hydroxide also reacts with sulphates presents in soils or water to form calcium sulphate which reacts further with C_3A and cause deterioration of concrete which is known as sulphate attack. The only advantage of $Ca(OH)_2$ is that, being alkaline in nature, it maintains pH value around 13 in the concrete which resist the corrosion of reinforcements.

The hydration of aluminates (C_3A) results in a calcium aluminate system $CaO-Al_2O_3-H_2O$. This compound do not contribute anything to the strength of concrete. On the other hand their presence is harmful to the durability of the concrete particularly where the concrete is likely to be attacked by sulphates. As it hydrates fast it may contribute a little to the early strength of concrete.

On hydration, C_4AF is believed to form a system of the form $CaO-Fe_2O_3-H_2O$. The hydrates of C_4AF also do not contribute anything to the strength but they show a comparatively higher resistance to the attack of sulphates than the hydrates of calcium aluminate.

Vicat apparatus is used for determining the normal consistency and setting time for cement. A known weight of cement is taken and a paste is prepared with a weighed quantity of water (24% by weight of cement) for the first trial. The paste is then filled in a mould and the plunger of the apparatus is brought down to touch the surface of the paste in test block and quickly released allowing it to sink into the paste by its own weight. Similar, trials are conducted with higher and higher water cement ratios till such time the plunger penetrates for a depth of 33-35 mm from the top. That particular percentage of water is known as the percentage of water required to produce a cement paste of standard consistency.

For setting times, the plunger is replaced by a needle (for initial setting time) or a circular attachment (for final setting time).

Le Chatelier apparatus can be used to determine soundness in cement. Unsoundness in cement is due to

excess of lime, magnesia or sulphates. Cement is gauged with 0.78 times the water required for standard consistency in a standard manner and filled into the mould kept on a glass plate. The mould is covered on the top with another glass plate. The whole assembly is immersed in water at a temperature of 27°C - 32°C and kept there for 24 hours. Now the distance is measured between the indicator points. The mould is again submerged in water and water is heated to brought to boiling point in about 25-30 minutes and it is kept boiling for three hours. The mould is now removed from water and allowed to cool. The distance between indicator points is measured again. The difference between these two measurements represent the expansion of cement. This must not exceed 10 mm. The Le Chatelier test detects the unsoundness due to free lime only.

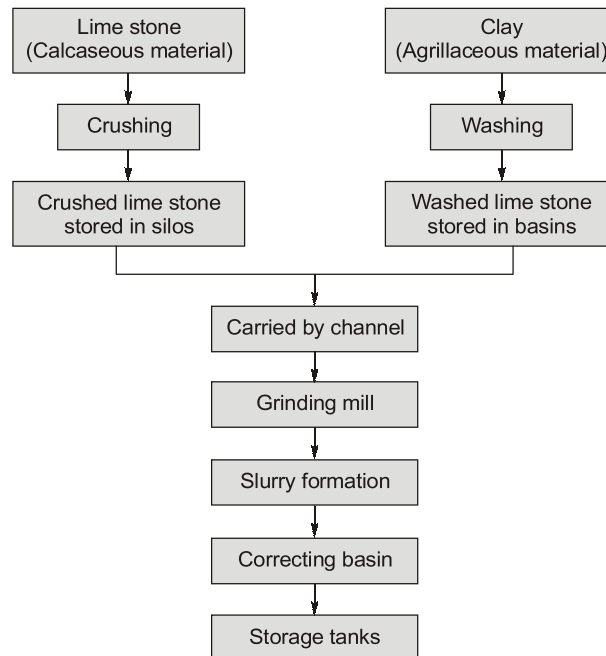
Q.8 Explain the manufacturing of cement by wet process.

Solution:

Wet process of cement manufacturing: Wet process was the earlier method of manufacturing cement. The argillaceous material such as clay is thoroughly mixed with water in a container called as wash mill. This washed clay is kept in the basins. Crushed lime stone from silos and washed clay from basins are allowed to fall in a channel in the required proportions. The channel carries the material to grinding mills where they get properly mixed to form slurry. This slurry is then taken to a correcting basin where it is constantly stirred. Chemical composition is also adjusted at this stage only. This slurry is stored in storage tanks and is kept as a charge to be fed to rotary kiln.

Burning: After slurry formation, burning is carried out in a rotary kiln. The kiln rotates at 1-3 rpm about its longitudinal axis. The rotary kiln is slightly inclined at 2°-2.5° with the horizontal. The slurry is injected at the upper end of kiln. The hot gases for drying are injected through the lower end of kiln. In the kiln, the small lumps formed known as nodules are converted into dark greenish blue balls known as clinkers.

Grinding: The clinkers obtained from the rotary kiln are ground finely in ball mills. During this process, 3-4% gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is also added which controls the initial setting time of cement. Gypsum acts as a retarder in cement and prevents immediate setting of cement as soon as water is added.



RCC & PRESTRESSED CONCRETE

CONVENTIONAL PRACTICE SETS

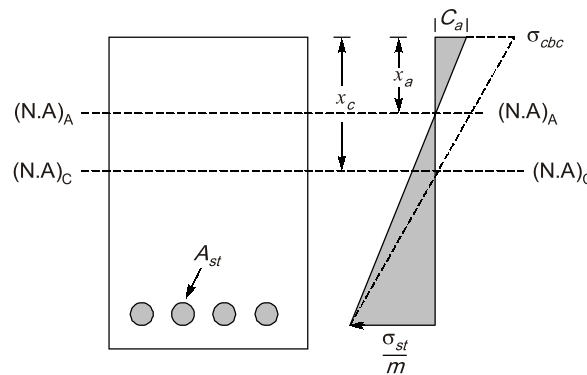
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Working Stress Method

Q1 Explain under reinforced and over reinforced failure of a reinforced concrete beam.

Solution:

Under reinforced failure: An 'under reinforced section' is one in which the area of tension steel (A_{st}) is such that the permissible stress is reached in the steel before the permissible stress is reached in the extreme fibre of the concrete.



In this case,

(i) $x_a < x_c$

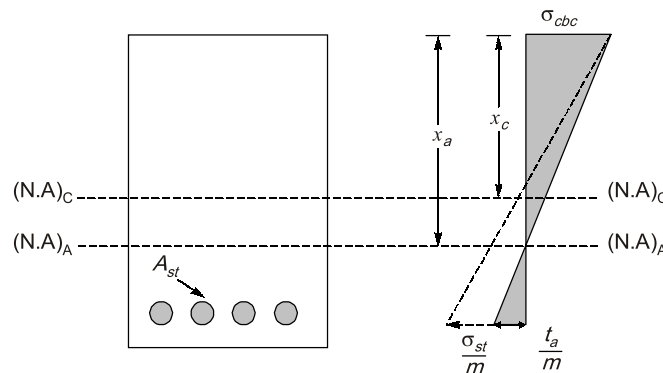
(ii) $C_a < \sigma_{cbc}$

(iii) $t_a = \sigma_{st}$

(iv) $A_{st \text{ provided}} < A_{st \text{ balanced}}$

A slight increase in the load, at this stage causes the beam to yield and elongate. In this case failure is due to failure of steel. It is known as tension failure or ductile failure. This gives sufficient warning before failure. Hence an under reinforced section is always preferred.

Over reinforced failure: An 'over reinforced' section is one in which the area of tension steel (A_{st}) is such that permissible stress in extreme fibre of concrete is reached before the permissible stress in the steel.



In this case,

(i) $x_a > x_c$

(ii) $C_a = \sigma_{cbc}$

(iii) $t_a < \sigma_{st}$

(iv) $A_{st \text{ provided}} > A_{st \text{ balanced}}$

The concrete fails in compression before the steel reaches its permissible stress. Hence this type of failure is known as compression failure or Brittle failure. The failure occurs without warning, hence an over reinforced section is always undesirable.

Q2 Analyze the balance concrete section:

- (i) When M20 concrete and Fe250 steel is used.
 - (ii) When M20 concrete and Fe415 steel is used.
- Use W.S.M.

Solution:

(i) $\sigma_{cbc} = 7 \text{ N/mm}^2$
 $\sigma_{st} = 140 \text{ N/mm}^2$

$$m = \frac{280}{3\sigma_{cbc}}$$

From similarity condition in the stress diagram,

$$\frac{C}{T} = \frac{x_c}{d - x_c}$$

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 7} = 13.33$$

$$\therefore \frac{7}{140} = \frac{x_c}{13.33(d - x_c)}$$

$$x_c = 0.4d$$

Lever arm $LA = d - \frac{x_c}{3} = 0.87d$

$$\text{Moment of resistance} = \frac{1}{2}bx_c \cdot C_x \cdot L.A.$$

$$= \frac{b(0.4d)7}{2} \times 0.87d = 1.213bd^2$$

Equating total compression = Total tension

$$\frac{1}{2}bx_c \sigma_{cbc} = A_{st} \cdot \sigma_{st}$$

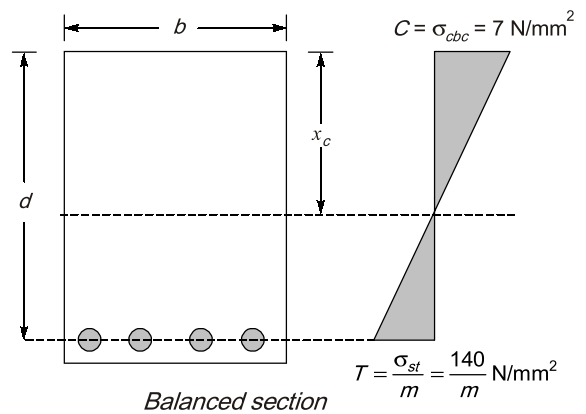
$$\frac{1}{2}b(0.4d) \times 7 = A_{st} \cdot 140$$

$$\frac{A_{st}}{bd} = 0.01$$

- Hence, $A_{st} = 1\%$ of bd for balanced section
- if $A_{st} < 1\%$ of $bd \Rightarrow$ underreinforced section
- if $A_{st} > 1\%$ of $bd \Rightarrow$ overreinforced

(ii) $\sigma_{cbc} = 7 \text{ N/mm}^2$
 $\sigma_{st} = 230 \text{ N/mm}^2$

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 7} = 13.33$$



From similarity condition in stress diagram,

$$\frac{C}{T} = \frac{x_c}{d - x_c}$$

$$\frac{7}{13.33} = \frac{x_c}{d - x_c}$$

$$x_c = 0.289 d$$

$$\text{Lever arm L.A.} = d - \frac{x_c}{3} = 0.904 d$$

$$\begin{aligned} \text{Moment of resistance} &= \frac{1}{2} b x_c \cdot c \times \text{L.A.} \\ &= \frac{1}{2} \times b \times 0.289 d \times 7 \times 0.904 d \\ &= 0.914 b d^2 \end{aligned}$$

Equating total compression = Total tension

$$\frac{1}{2} b x_c \sigma_{cbc} = A_{st} \times \sigma_{st}$$

$$\frac{1}{2} b (0.289 d) \times 7 = A_{st} \times 230$$

$$\frac{A_{st}}{bd} = 0.0044$$

Hence, $A_{st} = 0.44\%$ of bd for balanced section

if $A_{st} < 0.44\%$ of $bd \Rightarrow$ underreinforced section

if $A_{st} > 0.44\%$ of $bd \Rightarrow$ overreinforced

Q3 A rectangular RC section 25 cm wide and 50 cm overall deep is reinforced with 3-16 mm diameter HYSD bars at an effective cover of 4 cm from bottom face. If permissible stresses in concrete in bending compression and steel are 50 kg/cm² and 2300 kg/cm² respectively, modular ratio $m = 19$, calculate the moment of resistance of the section using WSM.

Solution:

Given data: $B = 25 \text{ cm} = 250 \text{ mm}$, $D = 50 \text{ cm} = 500 \text{ mm}$, $A_{st} = 3 \times \frac{\pi}{4} \times 16^2 = 603.19 \text{ mm}^2$, Effective cover = 4 cm = 40 mm, $\sigma_{cbc} = c = 50 \text{ kg/cm}^2 = 5 \text{ N/mm}^2$, $\sigma_{st} = t = 2300 \text{ kg/cm}^2 = 230 \text{ N/mm}^2$, $m = 19$, $d = D - 40 = 500 - 40 = 460 \text{ mm}$

(i) Calculating critical depth of NA:

$$\begin{aligned} x_c &= \left(\frac{mc}{t + mc} \right) d \\ &= \left(\frac{19 \times 5}{230 + (19 \times 5)} \right) 460 = 134.46 \text{ mm} \end{aligned}$$

(ii) Calculating actual depth of NA by equating moment of area of compression side and tension side about NA.

$$\Rightarrow \frac{B x_a^2}{2} = m A_{st} (d - x_a)$$

$$\Rightarrow \frac{250}{2} x_a^2 = 19 \times 603.19 \times (460 - x_a)$$

$$\Rightarrow x_a = 164.578 \text{ mm}$$

$\therefore x_a > x_c$, therefore section is over reinforced.

i.e. $C_a = \sigma_{cbc} = c$

$$t_a < \sigma_{st} = t$$

$$\therefore MR = B \cdot x_a \cdot \frac{C_a}{2} \left(d - \frac{x_a}{3} \right)$$

$$= 250 \times 164.578 \times \frac{5}{2} \times \left(460 - \frac{164.578}{3} \right)$$

$$MR = 41.67 \text{ kN-m}$$

Q4 Design a rectangular RCC beam for a simply supported span of 8 m subjected to a load of 45 kN/m (excluding the self wt.). Use M25 and Fe 500. Size of beam is restricted to 400 × 850 mm

Solution:

$$\sigma_{cbc} = 8.5 \text{ MPa} \quad \sigma_{st} = 275 \text{ MPa} \quad m = 11$$

(i) Calculating Load and B.M.

$$\text{D.L.} = 0.4 \times 0.85 \times 25 = 8.5 \text{ kN/m}$$

$$\text{L.L.} = 45 \text{ kN/m}$$

$$\text{Total load} = 53.5 \text{ kN/m}$$

$$\text{Bending Moment} = \frac{wl^2}{8} = 428 \text{ kN-m}$$

(ii) Calculating steel requirement

$$MR_1 = B \cdot x_c \cdot \frac{\sigma_{cbc}}{2} \left(d - \frac{x_c}{3} \right)$$

$$= \frac{1}{2} \times 8.5 \times 0.9154 \times 0.2537 \times 400 \times 800^2 = 252.98 \text{ kN-m}$$

For Balanced Section:

$$A_{st1} = \frac{MR_1}{\sigma_{st} \left(d - \frac{x_c}{3} \right)}$$

$$= \frac{252.98 \times 10^6}{275 \left(800 - \frac{202.96}{3} \right)} = 1256.13 \text{ mm}^2$$

$$MR_2 = 428 - 252.98 = 175.02 \text{ kN-m}$$

$$\Rightarrow \sigma_{st} \cdot A_{st2} (d - d_c) = 175.02 \times 10^6$$

$$\Rightarrow A_{st2} = 848.58 \text{ mm}^2$$

$$175.02 \times 10^6 = (1.5 \text{ m} - 1) A_{sc} (d - d_c)$$

$$\Rightarrow A_{sc} = \frac{15055.48}{C'}$$

$$\frac{C'}{152.96} = \frac{C}{202.96}$$

$$C' = 6.406 \text{ MPa}$$

$$A_{sc} = 2350.2 \text{ mm}^2$$

$$A_{st} = A_{st_1} + A_{st_2} = 2104.61 \text{ mm}^2$$

Q5 A rectangular RC beam simply supported at ends over an effective span of 5.0 m carries a UDL of 2000 kg/m including its own weight. If $\sigma_{cbs} = 70 \text{ kg/cm}^2$, $\sigma_{st} = 1900 \text{ kg/cm}^2$ and $m = 13$, design the beam section for flexure only by WSM. The size of the beam is restricted to 40 cm wide \times 40 cm overall deep. Assume effective cover = 4.0 cm. Stress in compression reinforcement, if needed may be taken as 1.5 m times the stress in surrounding concrete.

Solution:

Given: $l_{\text{eff}} = 5 \text{ m}$, $w = 2000 \text{ kg/m} = 20 \text{ kN/m}$, $\sigma_{cbc} = c = 70 \text{ kg/cm}^2 = 7 \text{ N/mm}^2$, $t = \sigma_{st} = 1900 \text{ kg/cm}^2 = 190 \text{ N/mm}^2$, $m = 13$, $B = 40 \text{ cm} = 400 \text{ mm}$, $D = 40 \text{ cm} = 400 \text{ mm}$, Effective cover = 4.0 cm = 40 mm, $d = D - 40 = 400 - 40 = 360 \text{ mm}$

(i) Maximum $BM = \frac{w l_{\text{eff}}^2}{8} = \frac{20 \times 5 \times 5}{8} = 62.5 \text{ kN-m}$

(ii) Design constants:

$$k = \left(\frac{mc}{t + mc} \right)$$

$$= \frac{13 \times 7}{190 + (13 \times 7)} = 0.3238$$

$$j = 1 - \frac{k}{3}$$

$$= 0.8920$$

$$Q = \frac{1}{2} c j k$$

$$= \frac{1}{2} \times 7 \times 0.8920 \times 0.3238 = 1.011$$

(iii) MR of the balanced section:

$$M_1 = Q B d^2$$

$$= 1.011 \times 400 \times 360 \times 360 = 52.41 \text{ kN-m}$$

(iv) $BM > M_1$, therefore a doubly reinforced section is required.

(v) Calculating area of steel for singly reinforced balanced section.

$$A_{st_1} = \frac{M_1}{\sigma_{st} \left(d - \frac{x_a}{3} \right)}$$

$$= \frac{52.41 \times 10^6}{190 \left(360 - \frac{0.3238 \times 360}{3} \right)} \quad [\because x_a = x_c = kd]$$

$$A_{st_1} = 858.94 \text{ mm}^2$$

(vi) A_{st_2} , area of remaining tensile steel in the section with compression reinforcement

$$A_{st_2} = \frac{M_2}{\sigma_{st} (d - d_c)}$$

$$= \frac{BM - M_1}{\sigma_{st}(d - d_c)} = \frac{(62.5 - 52.41) \times 10^6}{190 \times (360 - 40)}$$

$$A_{st2} = 165.95 \text{ mm}^2$$

(vii) Total tensile steel, $A_{st} = A_{st1} + A_{st2} = 858.94 + 165.95 = 1024.89 \text{ mm}^2$.

(viii) A_{sc} , area of compression reinforcement,

$$A_{sc} = \frac{m(d - x_a)}{(1.5m - 1)(x_a - d_c)} \times A_{st2} \quad [\because x_a = x_c = kd]$$

$$= \frac{13 \times (360 - 116.57)}{(1.5 \times 13 - 1)(116.57 - 40)} \times 165.95$$

$$A_{sc} = 370.74 \text{ mm}^2$$

Q.6 A rectangular RC slab 2 m × 3 m is simply supported along shorter edges such that clear distance between the supporting wall is 2.7 m. The slab is 15 cm thick and reinforced with 16 mm diameter mild steel bars spaced at 25 cm c/c at effective cover of 25 mm along longer edges and with 10 mm diameter bars along shorter edges spaced at 25 cm c/c. Concrete used is M15 grade for which permissible stresses in bending, shear (nominal) and bond are 50, 3 and 6 kg/cm² respectively. Permissible tensile stresses in mild steel = 1400 kg/cm², $m = 19$. Calculate maximum safe intensity of load that the slab can carry in addition to its self-weight.

Solution:

Assuming clear cover = 25 mm,
Width of support = 150 mm

Effective span for simply supported slab:

- (i) Clear span + effective depth
 $= L_0 + d = 2.7 + 0.125$
 $= 2.825 \text{ m}$
- (ii) Centre to centre distance between supports
 $= L_0 + L_s = 2.7 + 0.15$
 $= 2.850 \text{ m}$

Lesser of (i) and (ii) is adopted.

\therefore Effective span, $l_e = 2.825 \text{ m}$

Let the total load including self-weight of slab that can be carried by slab = $w \text{ kN/m}^2$

$$\text{Maximum bending moment} = \frac{wl_e^2}{8} = \frac{w \times (2.825)^2}{8}$$

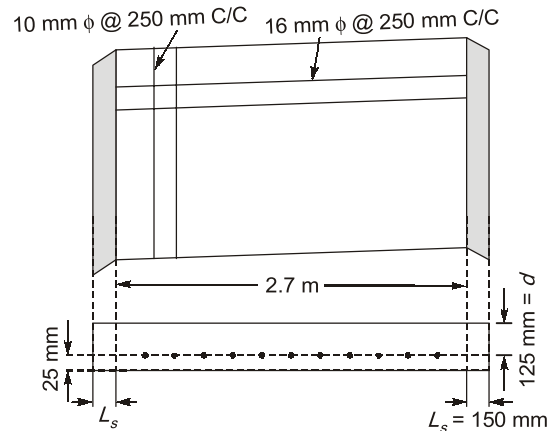
$$= 0.998 w \text{ kN-m} = 0.998 \times 10^6 w \text{ N-mm}$$

Now, $m = 19$, $c = 50 \text{ kg/cm}^2 = 5 \text{ MPa}$, $t = 1400 \text{ kg/cm}^2 = 140 \text{ MPa}$

$$x_c = \left(\frac{mc}{t + mc} \right) d$$

$$= \left[\frac{19 \times 5}{140 + (19 \times 5)} \right] \times 125 = 50.53 \text{ mm}$$

$$A_{st} = \frac{1000}{250} \times \frac{\pi}{4} \times 16^2 = 804.25 \text{ mm}^2$$



Location of actual neutral axis:

$$\frac{Bx_a^2}{2} = m A_{st} (d - x_a)$$

$$\Rightarrow \frac{1000 \times x_a^2}{2} = 19 \times 804.25 (125 - x_a)$$

$$\Rightarrow 500x_a^2 + 15280.75x_a - 1910093.75 = 0$$

$$\Rightarrow x_a = 48.38 \text{ mm}$$

$\therefore x_a < x_c$, section is under reinforced

Thus $\sigma_{st} = 140 = t$ and $c = \sigma_{cbc} > c_a$.

$$\therefore \frac{c_a}{x_a} = \frac{t/m}{d - x_a}$$

$$\Rightarrow c_a = \frac{140}{19} \times \frac{48.38}{(125 - 48.38)}$$

$$\Rightarrow c_a = 4.65 \text{ N/mm}^2$$

Thus equating with MR formula, we have

$$0.998 \times 10^6 w = B \cdot x_a \cdot \frac{c_a}{2} \left(d - \frac{x_a}{3} \right)$$

$$\Rightarrow 0.998 \times 10^6 \times w = 1000 \times 48.38 \times \frac{4.65}{2} \left(125 - \frac{48.38}{3} \right)$$

$$\Rightarrow w = 12.27 \text{ kN/m}^2$$

Checking for Shear:

$$\text{Maximum shear force} = \frac{wl_e}{2} = \left(\frac{w \times 2.825}{2} \right) \text{ kN} = 1412.5 w \text{ N} \quad (\text{where } w \text{ is in kN/m})$$

$$\tau_v = \frac{V}{Bd} = \frac{1412.5 w}{1000 \times 125} = 0.0113 w \text{ N/mm}^2$$

Permissible stress in shear = $3 \text{ kg/cm}^2 = 0.3 \text{ MPa}$

$$\therefore 0.0113 w = 0.3$$

$$\Rightarrow w = 26.55 \text{ kN/m}^2$$

Checking for Bond:

$$k = \frac{mc}{t + mc} = \frac{19 \times 5}{140 + (19 \times 5)} = 0.404$$

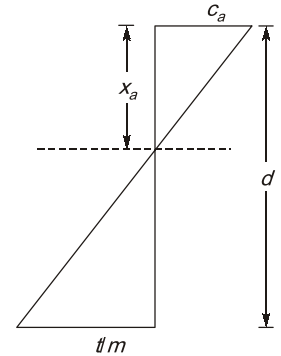
$$j = 1 - \frac{k}{3} = 1 - \frac{0.404}{3} = 0.865$$

$$\text{Number of bars} = \frac{1000}{250} = 4$$

Shear force, $V = 1412.5 w \text{ N}$

$$\begin{aligned} \Sigma O &= \text{Sum of perimeters of steel bars} \\ &= 4 \times \pi \times 16 = 64 \pi \end{aligned}$$

$$\text{Now, } \tau_{bd} = \frac{V}{\Sigma O \cdot jd} = \frac{1412.5 w}{64 \pi \times 0.865 \times 125}$$



Permissible value of bond stress = $6 \text{ kg/cm}^2 = 0.6 \text{ MPa}$

$$\therefore \frac{14125 w}{64\pi \times 0.865 \times 125} = 0.6$$

$$\Rightarrow w = 9.24 \text{ kN/m}^2$$

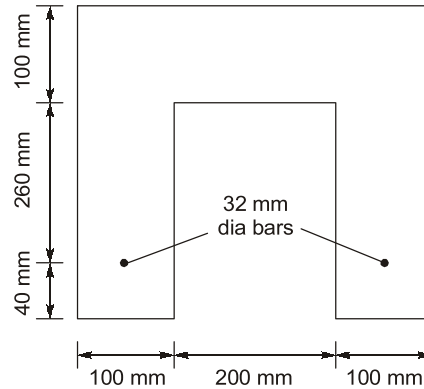
The value of total load will be the lesser of the loads calculated in bending, shear and bond.

$$\therefore w = 9.24 \text{ kN/m}^2$$

Maximum safe intensity of load excluding self-weight

$$= 9.24 - (0.150 \times 1 \times 1 \times 25) = 5.49 \text{ kN/m}^2$$

Q7 Find the moment of resistance of the RCC Beam shown in the below figure using working stress method. M20 concrete and Fe 415 steel are used. Do not neglect any portion of concrete on compression side. Allowable stress in concrete in bending compression is 7 MPa and allowable stress in steel in tension is 230 MPa. Modular ratio is 13.33. The critical neutral axis is $0.289 'd'$ and actual neutral axis is 153.5 mm, where ' d ' is the effective depth.



Solution:

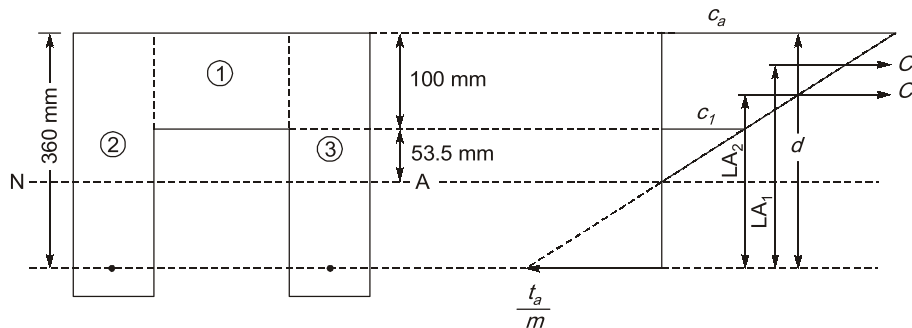
Effective depth, $d = 100 + 260 = 360 \text{ mm}$

Critical depth of neutral axis, $x_c = 0.289 \times d$
 $x_c = 0.289 \times 360 = 104.04 \text{ mm}$

Actual depth of Neutral axis, $x_a = 153.5 \text{ mm}$
 $x_a > x_c$

\Rightarrow Section is over-reinforced.

\therefore Stress at top most compressed fibre, $c_a = \sigma_{cbc}$
 $c_a = 7 \text{ N/mm}^2$



$$\frac{c_a}{153.5} = \frac{c_1}{53.5}$$

$$\therefore c_1 = \frac{7 \times 53.5}{153.5} = 2.44 \text{ N/mm}^2$$

Considering portion (1):

$$\text{Compressive force } C_1 = \left(\frac{c_a + c_1}{2} \right) \times 200 \times 100 \times 10^{-3} \text{ kN} = 94.4 \text{ kN}$$

$$y_1 = \left(\frac{c_a + 2c_1}{c_a + c_1} \right) \times \frac{100}{3} = \left(\frac{7 + 4.88}{7 + 2.44} \right) \times \frac{100}{3} = 41.95 \text{ mm}$$

$$(\text{Lever Arm})_1, \quad LA_1 = d - y_1 = 360 - 41.95 = 318.05 \text{ mm}$$

$$\text{Considering portion (2) and (3), } C_2 = \frac{c_a}{2} \times (2 \times 100) \times 153.5 = \frac{7}{2} \times 200 \times 153.5 \times 10^{-3} \text{ kN}$$

$$= 107.45 \text{ kN}$$

$$y_2 = \frac{x_a}{3} = \frac{153.5}{3} = 51.17 \text{ mm}$$

$$(\text{Lever Arm})_2 = (LA)_2 = d - y_2 = 360 - 51.17 = 308.83 \text{ mm}$$

$$\text{Moment of Resistance} = C_1 \times LA_1 + C_2 \times LA_2$$

$$= \{(94.4 \times 318.05) + (107.45 \times 308.83)\} \times 10^{-3} \text{ kN-m}$$

$$= 63.21 \text{ kN-m}$$

