# UPSC ESE 2023 <br> Mains Exam Solution CIVIL ENGINEERING 

## Paper-I

## EXAM DATE: 25-06-2023 09:00 AM-12:00 PM

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## Q-1(a): (i) Explain the types of glazing used for clay products.

Sol: Clay products are glazed by an impervious film fused to a ceramic body through firing.
Glazing of products help to improve the following properties.
(a) Waterproof the products
(b) Colours and decorates the product
(c) Seals the inherent porosity of products.
(d) Protects the surface from chemical attack and different weathering agencies.

Different types of glazing in use are as follows:

1. Opaque Glazing :
(a) This is also known as enamelling.
(b) Borax, Kaolin chalk and colouring matter is fired with a part of feldspar, flint and lead oxide.
(c) The resulting molten glass is poured into water to give shattered frit.
(d) The frit is then ground with remaining material and water to attain a consistency of cream called slip.
(e) Fully burnt earthenwares known as biscuits are dipped in slip to absorb water and form a layer of glaze on the surface.
(f) After drying the products these are once again fired to a lower temperature so as to fuse the glaze.
2. Lead Glazing
(a) Clay items are burned and dipped in a solution of lead oxide and tin oxide.
(b) The particles of lead and tin adhere to the surface of clay items.
(c) After this the articles are returned in potter's kiln where these adhered particles melt and form a thin transparent layer on the surface.
3. Transparent Glazing
(a) There are many methods of imparting transparent glazing but salt glazing is most commonly used.
(b) It includes throwing sodium chloride in the kiln maintained at $\left(1200^{\circ}\right.$ to $\left.1300^{\circ} \mathrm{C}\right)$.
(c) The heat of Kiln volatises the salt, which enters into pores of burning item and combines with the silica in clay to make sodasilicate.
(d) The soda silicate so formed combines with alumina, lime and iron in the clay to form a permanent thin, transparent surface coating.

Q-1(a): (ii) What are the causes and remedies of efflorescence in bricks?
[6 MARKS]
Sol: This is a most common defect observed in clay bricks.

- This defect is caused because of alkalies present in bricks.
- Presence of excessive moisture in the atmosphere.
- When bricks come in contact with moisture, water is absorbed by them which evaporates with time leading to the crystallization of soluble salts on the surface.
- On drying grey or white powder patches appear on the surface of bricks.
- Bricks which have been saturated before their placement in masonry will be more prone to efflorescence than those under dry conditions.

Following measures can be taken to prevent the efflorescence of brick surface.
(a) By selecting proper clay material for the manufacturing of bricks.
(b) Proper measures should be taken to prevent the accumulation or contact of water with the brick surfaces.
(c) Use of water repellent material for manufacturing of building mortar which is to be used for brick masonry work.
(d) Use of water proof coping can be made to minimise efflorescence of bricks.
(e) Damp proof course should be laid properly to prevent the entry of moisture near the masonry walls.
(f) Proper storage of bricks at sites should be done to prevent direct contact with surrounding moisture.

## Q-1(b): Explain the specific reasons for the following:

(i) For prestressed concrete, the Code recommends to use high tensile steel and high strength of concrete.
[6 MARKS]

## Sol: Need for High Strength Concrete in Pre-stress Concrete

- High strength concrete offers high resistance to tension, shear, bond and bearing.
- In case of pre-tensioned members, tensile stress in steel of very high magnitude should be transferred to concrete as prestress through bonding between steel and surrounding concrete.
- In post-tensioned members transfer of stress is through bearing at end section. Hence concrete of appreciable bond and bearing strength is quite essential for pre-stressed concrete.
- In addition to above, use of high strength concrete has following advantages:

1. High strength concrete is less liable to shrinkage cracks and has higher modulus of elasticity and smaller ultimate creep strain. As a result loss of prestress in steel is reduced.
2. Use of high strength concrete results in reduction of cross sectional dimensions of prestressed concrete structural elements, with reduced dead weight longer spans becomes economically and practically viable.

## Need for High Strength Steel

- The strength of steel must be high enough for it be extended sufficiently to avoid excessive loss of tension due to elastic contraction, creep and shrinkage of concrete.
- If we use Fe 250 or Fe 415 all of the initial stress in it will be lost in due course. Hence there would not be any pressuressing force remaining in concrete, thus the beam will fail.
- Hence we use high strength steel such that the initial prestress in it would be $1200-2000 \mathrm{~N} / \mathrm{mm}^{2}$ in which the loss would be around $200 \mathrm{~N} / \mathrm{mm}^{2}$.

Q-1(b): (ii) Helically reinforced circular columns have better compressive strength than that of similar columns with lateral ties.
[6 MARKS]
Sol: - In helically reinforced column stirrups of spiral are wrapped around the longitudinal bars.


Spiral column
Spirals are more effective than ties in increasing a column's strength for the following reasons:

- Spirals better hold the longitudinal bars in place, and they also confine the concrete inside thus greatly increasing its resistance to axial compression.
- As the concrete inside the spiral tends to spread out laterally under the compressive load, the spiral restrains it. It is subjected in hoop tension, and the column will not fail until the spiral yields or breaks, permitting the bursting of the concrete inside.
- Spirals add to the resilience of columns
- Spirals provide considerable resistance to earthquake loadings.
- Spirals very effectively increase the ductility and toughness of columns.
- Hence, the code permit larger load in compression members with helical reinforcement because columns with helical reinforcement have greater ductility or toughness when they are loaded concentrically or with small eccentricity.
- As per the code, the strength of compression members with helical reinforcement satisfying the requirement given below shall be taken as 1.05 times the strength of similar members with lateral ties.
- Requirement the ratio of volume helical reinforcement to the volume of core shall not be less than $0.36\left(\frac{A_{g}}{A_{c}}-1\right) \frac{f_{c k}}{f_{y}}$
where, $\mathrm{A}_{\mathrm{g}}=$ Gross area of the section
$A_{c}=$ Area of core of the helically reinforced column measured to the outside diameter of the helix
$f_{y}=$ Characteirstic strength of helical reinforcement but not exceeding $415 \mathrm{~N} / \mathrm{mm}^{2}$.
Q-1(c): The rafter member of a truss consists of two angles ISA $75 \times 75 \times 8$ placed [back-to-back] both sides of the gusset of thickness 10 mm . It carries factored axial compressive force of 200 kN . Determine the number of 16 mm diameter, 4.6 grade ordinary bolts for the joint. Assume E250 grade of steel and the cross-sectional area in the threaded part for 16 mm diameter bolt is $157 \mathrm{~mm}^{2}$.
Use $K_{b}=0.49, \gamma_{m b}=1.25$. Use limit state method of design.
[12 MARKS]
Sol:



## Calculation of Bolt Value :

Bolt will be in double shear and bearing

$$
\text { Bolt value }=\min \left\{\begin{array}{l}
\text { shearing strength of bolt }\left(\mathrm{V}_{\mathrm{dsb}}\right) \\
\text { Bearing strength of Bolt }\left(\mathrm{V}_{\mathrm{dpb}}\right)
\end{array}\right.
$$

## Design Shearing strength of Bold $\left(\mathrm{V}_{\mathrm{dsb}}\right)$

Assuming both the shear planes pass through the threads i.e. $m=2, n_{n}=0$

$$
\begin{aligned}
V_{\text {dsb }} & =\frac{f_{\text {ub }}}{\sqrt{3} \gamma_{\text {mb }}} \times 2 \times 0.78 \mathrm{~A}_{\text {sb }} \\
& =\frac{400}{\sqrt{3} \times 1.25} \times 2 \times 0.78 \times \frac{\pi}{4} \times 16^{2} \times 10^{-3} \mathrm{kN} \\
& =57.95 \mathrm{kN}
\end{aligned}
$$

Bearing strength of Bolt ( $\mathrm{V}_{\mathrm{dpb}}$ )

$$
\mathrm{V}_{\mathrm{dpb}}=\frac{2.5 \mathrm{~K}_{\mathrm{b}} \mathrm{dtf}_{\mathrm{u}}}{\gamma_{\mathrm{mb}}}
$$



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Here,
and

$$
\mathrm{K}_{\mathrm{b}}=0.49
$$

$$
\begin{aligned}
\mathrm{t} & =\min \{(8+8) \mathrm{mm}, 10 \mathrm{~mm}\}=10 \mathrm{~mm} \\
\mathrm{~V}_{\mathrm{dpb}} & =\frac{2.5 \times 0.49 \times 16 \times 10 \times 410 \times 10^{-3}}{1.25} \\
& =64.288 \mathrm{kN}
\end{aligned}
$$

So,

$$
\text { Bolt value }=\text { minimum }\{57.95 \mathrm{kN}, 64.288 \mathrm{kN})
$$

$$
=57.95 \mathrm{kN}
$$

$$
\text { Number of Bolt required }=\frac{\mathrm{P}_{\mathrm{u}}}{\mathrm{~V}_{\mathrm{db}}}=\frac{200}{57.95}=3.45
$$

So, provide 4 bolts for connection.

Q-1(d): A bar specimen of 38 mm diameter was subjected to a pull of 98 kN during a tensile test. The extension on a gauge length of 200 mm was measured to be 0.092 mm and the change in diameter of 0.0048 mm . Determine the Poisson's ratio, modulus of elasticity, modulus of rigidity and bulk modulus of the material of bar specimen.
[12 MARKS]
Sol: Given,

$$
\begin{aligned}
\text { Diameter of specimen } & =38 \mathrm{~mm} \\
\text { Applied pull load } & =98 \mathrm{kN} \\
\text { Gauge length } & =200 \mathrm{~mm} \\
\text { Extension on gauge length } & =0.092 \mathrm{~mm}
\end{aligned}
$$

$$
\text { Change in the diameter }=0.0048 \mathrm{~mm}
$$

(i)

$$
\begin{aligned}
\text { Poisson's ratio }(\mu) & =-\frac{\text { Lateral strain }}{\text { Longitudinal strain }} \\
& =-\frac{\left(-\frac{0.0048}{38}\right)}{\frac{0.092}{200}}=0.2745
\end{aligned}
$$

(ii)

$$
\begin{aligned}
& \delta=\frac{\mathrm{PL}}{\mathrm{AE}} \\
& \mathrm{E}=\frac{\mathrm{PL}}{\mathrm{~A} \delta}=\frac{98 \times 1000 \times 200}{\frac{\pi}{4} \times 38^{2} \times 0.092} \\
& \mathrm{E}=187849.987 \mathrm{~N} / \mathrm{mm}^{2} \\
& \mathrm{E}=187.849 \mathrm{kN} / \mathrm{mm}^{2}
\end{aligned}
$$

(iii)

Modulus of rigidity $(\mathrm{G})=$ ?

$$
\begin{aligned}
& E=2 G(1+\mu) \\
& G=\frac{E}{2(1+\mu)}
\end{aligned}
$$

(iv)

Bulk modulus $(\mathrm{K})=$ ?
$E=3 K(1-2 \mu)$
$K=\frac{E}{3(1-2 \mu)}$
$K=\frac{187.849}{3(1-2 \times .2745)}$
$\mathrm{K}=138.83 \mathrm{kN} / \mathrm{mm}^{2}$

Q-1(e): (i) With the help of neat sketch of a typical grading curve, describe the term 'gap-graded aggregate' and the adverse effects of using such type of aggregates in concrete.
[6 MARKS]
Sol: One of the most important factor for producing a desirable concrete is the grading of aggregate.
Gradation of aggregate signifies the variation of particle size in the mixture.
An aggregate sample can be classified into several groups on the base of gradation with a gap graded aggregate being the most common.

Gap graded aggregate :

$$
\begin{aligned}
& G=\frac{187.849}{2(1+0.2745)} \\
& G=73.695 \mathrm{kN} / \mathrm{mm}^{2}
\end{aligned}
$$



A gap graded aggregate sample implies that a particle size range is found to be missing form the sample.
A flat portion in a gradation curve indicates that this particle size range is missing from the mix.
There are several adverse effects of a gap graded aggregate when used in concrete:
(a) A gap graded concrete need close supervision as it shows greater proneness to segregation.
(b) Gap graded concrete is difficult to be pumped to different places because of danger of segregation.
(c) Gap graded concrete may show significant change in the anticipated workability values.
(d) Gap graded concrete may show deficiency of certain aggregate fraction size which is necessary to occupy the voids in the mixture.

Q-1(e) (ii) How is PPC different from OPC on the basis of their ingredients? Describe the advantages of using PPC in comparison to OPC.
[6 MARKS]
Sol: Basic ingradients of OPC along with approximate composition limits are shown below in the table.

| Oxide | Percent content |
| :---: | :---: |
| CaO | $60-67$ |
| $\mathrm{SiO}_{2}$ | $17-25$ |
| $\mathrm{Al}_{2} \mathrm{O}_{3}$ | $3-8$ |
| $\mathrm{Fe}_{2} \mathrm{O}_{3}$ | $0.5-6.0$ |
| MgO | $0.1-4.0$ |
| Alkalies $\left(\mathrm{K}_{2} \mathrm{O.Na}\right.$ |  |
| $\left.\mathrm{SO}_{3} \mathrm{O}\right)$ | $0.4-1.3$ |

- Portland pozzolona cement (PPC) is manufactured by intergrinding of OPC clinkers with (15-35\%) of pozzolonic material.
- Pozzolonic material generally used for manufacturing of PPC are fly ash, calcined clay.


## Advantages of PPC

1. Long term strength of PPC is higher then OPC if enough moisture is available for pozzolonic action.
2. PPC produces less heat of hydration than OPC.
3. PPC offers greater resistance to the attack of aggresive water than OPC.
4. PPC being finer than OPC, it improves the pore size distribution and reduces the micro cracks as well.
5. PPC consumes calcium hydroxide and does not produce calcium hydroxide as much as that of OPC.
6. PPC gives more volume of mortar than OPC due to finer size \& lower density of fly ash.

Q-2(a): A room of effective span $16.50 \mathrm{~m} \times 11.00 \mathrm{~m}$ is surrounded by brick walls. In order to lay the RCC slab over it, the room is divided in four equal panels by providing two central beams. The slab is simply supported on all the four walls as shown in the figure below. Using limit state design, determine and provide main reinforcement in a single panel, using 12 mm diameter steel bars of Fe-415 grade. Consider the grade of concrete as M-20. Draw the reinforcement detail of a panel. Use the following additional data:

Total factored load on slab (dead load + live load) $=16 \mathrm{kN} / \mathrm{m}^{2}$
Thickness of slab $=175 \mathrm{~mm}$
Effective depth of slab $=150 \mathrm{~mm}$
Note: Refer Annex D of IS 456 : 2000 for finding the moments at different locations. The Annex is reproduced at Page Nos. 11 and 12.

[20 MARKS]
Sol: Effective span of complete room $16.50 \mathrm{~m} \times 11.00 \mathrm{~m}$

$$
\text { Effective span of one slab }=8.25 \mathrm{~m} \times 5.5 \mathrm{~m}
$$

$\Rightarrow \quad \ell_{y}=8.25 \mathrm{~m}$

$$
\ell_{x}=5.5 \mathrm{~m}
$$

$$
\frac{\ell_{y}}{\ell_{x}}=\frac{8.25}{5.5}=1.5<2
$$

$\Rightarrow \quad$ Two way slab
The slab has to be designed considering two adjacent edges discontinuous

## Short span coefficients

Negative moment at continuous edge $=0.075$

$$
\text { Positive moment at midspan }=0.056
$$

## Long span coefficients

Negative moment at continuous edge $=0.047$
Positive moment at continuous edge $=0.035$

## For shorter span

$$
\begin{aligned}
& M_{u x}^{+}=\alpha_{x}^{+} w_{u} \ell_{x}^{2}=0.056 \times 16 \times(5.5)^{2}=27.10 \mathrm{kNm} \\
& M_{u x}^{-}=\alpha_{x}^{-} w_{u} \ell_{x}^{2}=0.075 \times 16 \times(5.5)^{2}=36.30 \mathrm{kNm}
\end{aligned}
$$

## For longer span

$$
\begin{aligned}
& M_{u y}^{+}=\alpha_{y}^{+} w_{u} l_{x}^{2}=0.035 \times 16 \times(5.5)^{2}=16.94 \mathrm{kNm} \\
& M_{u y}^{-}=\alpha_{y}^{-} w_{u} \ell_{x}^{2}=0.047 \times 16 \times(5.5)^{2}=22.75 \mathrm{kNm}
\end{aligned}
$$

## Calculation of area of steel

Using,

$$
A_{s t}=\frac{\mathrm{f}_{\mathrm{ck}}}{2 \mathrm{f}_{\mathrm{y}}}\left[1-\sqrt{1-\frac{4.6 \mathrm{M}}{\mathrm{f}_{\mathrm{ck}} \mathrm{bd} d^{2}}}\right] \mathrm{bd}
$$

For short span

## $\mathrm{A}_{\text {st }}$ for $\mathrm{M}_{\mathrm{ux}}^{+}$

## Check:

$$
\begin{aligned}
\mathrm{A}_{\text {st }}, \mathrm{M}_{\mathrm{ux}} & =\frac{20}{2 \times 415}\left[1-\sqrt{1-\frac{4.6 \times 27.10 \times 10^{6}}{20 \times 1000 \times 150^{2}}}\right] 1000 \times 150 \\
& =541.15 \mathrm{~mm}^{2}
\end{aligned}
$$

$$
A_{\text {stmin }}=\frac{0.12 \mathrm{bD}}{100}=\frac{0.12 \times 1000 \times 175}{100}=210 \mathrm{~mm}^{2} \text { Okay }
$$

$$
\text { Spacing for } 12 \mathrm{~mm} \text { bar }=\frac{1000 \times \frac{\pi}{4} \times 12^{2}}{541.15}=208.99 \mathrm{~mm}
$$

$$
\text { Adopting spacing }=200 \mathrm{~mm} \mathrm{c} / \mathrm{c}
$$

## Check:

$$
\text { Maximum spacing }=\min \{3 \mathrm{~d}, 300 \mathrm{~mm}\}
$$

$$
=\min \{3 \times 150,300 \mathrm{~mm}\} \text { Okay }
$$

$A_{\text {st }}$ for $M_{\bar{U} X}$

$$
\begin{aligned}
\mathrm{A}_{\mathrm{st}}, \mathrm{M}_{\mathrm{U} \mathrm{X}} & =\frac{20}{2 \times 415}\left[1-\sqrt{1-\frac{4.6 \times 36.30 \times 10^{6}}{20 \times 1000 \times 150^{2}}}\right]^{2} \times 1000 \times 150 \\
& =748 \mathrm{~mm}^{2}>210 \mathrm{~mm}^{2} \\
\text { Spacing for } 12 \mathrm{~mm} \text { bar } & =\frac{1000 \times \frac{\pi}{4} \times 12^{2}}{748}=151.199 \mathrm{~mm}
\end{aligned}
$$

Adopting, $12 \mathrm{~mm} \phi$ @ $150 \mathrm{~mm} \mathrm{c} / \mathrm{c}$.
For long span,
$A_{\text {st }}$ for $M_{u y}$

$$
\begin{aligned}
\mathrm{A}_{\mathrm{st}}, \mathrm{M}_{\mathrm{uy}} & =\frac{20}{2 \times 415}\left[1-\sqrt{1-\frac{4.6 \times 16.94 \times 10^{6}}{20 \times 1000 \times 150^{2}}}\right] \times 1000 \times 150 \\
& =327.81 \mathrm{~mm}^{2}>210 \mathrm{~mm}^{2} \\
\text { Spacing for } 12 \mathrm{~mm} \phi \text { bar } & =\frac{1000 \times \frac{\pi}{4} \times 12^{2}}{327.81}=345.00 \mathrm{~mm}
\end{aligned}
$$

Adopting $12 \mathrm{~mm} \phi$ bar @ $300 \mathrm{~mm} \mathrm{c} / \mathrm{c}$
$A_{\text {st }}$ for $M_{\bar{u} y}$

$$
\begin{aligned}
\mathrm{A}_{\mathrm{st}}, \mathrm{M}_{\overline{\mathrm{uy}}} & =\frac{20}{2 \times 415}\left[1-\sqrt{1-\frac{4.6 \times 22.75 \times 10^{6}}{20 \times 1000 \times 150^{2}}}\right] \times 1000 \times 150 \\
& =448.05 \mathrm{~mm}^{2}
\end{aligned}
$$

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$$
\text { Spacing for } 12 \mathrm{~mm} \phi \text { bar }=\frac{1000 \times \frac{\pi}{4} \times 12^{2}}{448.05}=252.42 \mathrm{~mm}
$$

Adopting $12 \mathrm{~mm} \phi$ bar @ $203 \mathrm{~mm} \mathrm{c} / \mathrm{c}$


Q-2(b): Explain the mechanism of alkali-aggregate reaction in concrete. How can it be controlled?
[20 MARKS]
Sol: - Earlies aggregates were considered to be innert material, but this statement on later stages found not completely true.

- Some of the aggregates contain reactive silica, which reacts with alkalies present in cement i.e., sodium oxide and potassium oxide leading to alkali-Aggregate reaction.

The mechanism of Alkali-Aggregate reaction \& diteriotation can be explained as follow.

- The mixing water turns to be a strongly caustic solution due to solubility of alkalies from the cement.
- This caustic liquid attack reactive silica to form Alkali-silica gel of unlimited swelling, type. The reaction proceeds more rapidly for highly reactive substances.
- If continuous water supply and correct temperature available the formation for silica gel continues unabated.
- The continuous growth of silica gel exerts osmotic pressure to cause pattern cracking particularly in thinner section of concrete like pavement.
- Conspicuous effect may not be seen in mass concrete section.
- The formation of pattern crack due to the stress induced by the growth of silica gel results in subsequent loss in strength and elasticity.
- Alkali-Aggregate reaction also accelerates other process of deterioration of concrete due to the formation of cracks.
- Solution of dissolved carbon dioxide, converts calcium hydroxide to calcium carbonate with consequent increase in volume.
- Manydistructive forces become operative on concrete disrupted by alkali aggregate reaction which will further hasfen the total disintrigration of concrete.

Control of Alkali-Aggregate Reaction- Alkali-Aggregate reaction can be controlled by the following methods.

1. Selection of non-reactive aggregates.
2. By the use of low alkali cement.
3. By the use of corrective admixtures such as pozzolanas.
4. By controlling the void space in concrete.
5. By controlling moisture, condition and temperature.

Q-2(c): Draw the bending moment and shearing force diagrams for the overhanging beam loaded as shown in the figure below. Determine the positions of maximum bending moment, maximum shearing force and locate the locations of zero bending moment.

[20 MARKS]
Sol:


Support reactions $R_{B}$ and $R_{E}$
Equating net moment about E to zero.

$$
\begin{aligned}
& \left.\sum M_{E}\right)=0 \\
& \Rightarrow \quad R_{B} \times 4.5-25 \times 0.5\left(\frac{0.5}{2}+4.5\right)-95-45 \times 1.5+35 \times 0.5=0 \\
& \Rightarrow \quad R_{B}=45.41 \mathrm{kN} \\
& \left.\sum F_{Y}\right)=0 \\
& \Rightarrow \quad R_{E}=47.09 \mathrm{kN}
\end{aligned}
$$

Shear force diagram:


Maximum shear force acts in span EF equal to 35 kN .

## Bending moment diagram:



## Maximum bending moment:

From BMD
Maximum sagging BM acts at left of section C
and

$$
\begin{aligned}
& \mathrm{BM}_{\text {max, sagging }}=\mathrm{BM}_{\mathrm{C}^{-}}=29.785 \mathrm{kN}-\mathrm{m} \\
& \mathrm{BM}_{\text {max, hogging }}=\mathrm{BM}_{\mathrm{C}^{+}}=-65.215 \mathrm{kN}-\mathrm{m}
\end{aligned}
$$

## Location of zero B.M.:

Put P, Q and R as shown in BMD.

$$
\begin{aligned}
\mathrm{M}_{\mathrm{P}}-\mathrm{M}_{\mathrm{B}} & =\text { Area under SFD } \\
\Rightarrow \quad 0-(-3.125) & =32.91 \times \mathrm{x}_{\mathrm{P}} \\
\Rightarrow \quad \mathrm{x}_{\mathrm{P}} & =0.095 \mathrm{~m}
\end{aligned}
$$

i.e. $\rightarrow P$ at distance 0.595 m from A .

## Location of point $\mathbf{Q}$ :

$$
\mathrm{M}_{\mathrm{Q}}-\mathrm{M}_{\mathrm{C}^{+}}=\text {Area under SFD }
$$

$$
\begin{array}{rlrl} 
& & 0-(-65.215) & =32.91 \times \mathrm{x}_{\mathrm{Q}} \\
\Rightarrow & \mathrm{x}_{\mathrm{Q}} & =1.98 \mathrm{~m}
\end{array}
$$

i.e. point $Q$ is at distance 1.98 m from C as shown in BMD.

## Location of R:

$$
\begin{aligned}
M_{R}-M_{D} & =\text { Area under SFD } \\
\Rightarrow \quad 0-(0.605) & =-12.09 \times x_{R} \\
& x_{R}
\end{aligned}
$$

Q-3(a): (i) What is gel-space ratio? How is it estimated? Discuss its effect on the strength of concrete?
[10 MARKS]
Sol: - Gel-space ratio is defined as the ratio of volume of hydrated cement paste to the sum of the volumes of the hydrated cement and that of the capillary pares.

- Gel space ratio can be calculated at any age and for any fraction of hydration of cement.


## Calculation of gel/space ratio for complete hydration

$$
\begin{aligned}
\mathrm{C} & =\text { Weight of cement in } \mathrm{gm} \\
\mathrm{~V}_{\mathrm{c}} & =\text { Specific volume of cement } \\
& =0.319 \mathrm{ml} / \mathrm{gm} \\
\mathrm{~W}_{0} & =\text { Volume of mixing water in } \mathrm{ml} .
\end{aligned}
$$

1 ml , of cement on hydration will produce 2.03 ml , of gel.

$$
\begin{aligned}
& \text { Volume of gel }=\mathrm{C} \times 0.319 \times 2.06 \\
& \text { Space available }=\mathrm{C} \times 0.319+\mathrm{W}_{0} \\
& \text { Gel/space ratio }=\mathrm{x}=\frac{\text { Volume of gel }}{\text { Space available }} \\
& \mathrm{x}=\frac{0.657 \mathrm{C}}{0.319 \mathrm{C}+\mathrm{W}_{0}}
\end{aligned}
$$

## Calculation of gel/space ratio for partial hydration

Let,

$$
\begin{aligned}
\alpha & =\text { Fraction of cement that has hydrated } \\
\text { Volume of gel } & =\mathrm{C} \times \alpha \times 0.319 \times 2.06 \\
\text { Total space available } & =\mathrm{CV}_{\mathrm{C}} \alpha+\mathrm{W}_{0} \\
\text { Gel } / \text { space ratio } & =\mathrm{x}=\frac{2.06 \times 0.319 \times \mathrm{C} \alpha}{0.319 \mathrm{C} \alpha+\mathrm{W}_{0}}
\end{aligned}
$$

## Effects on strength of concrete

(i) Power's experiment showed that the strength of concrete bears a specific relationship with the gel/ space ratio, He found the relationship to be $240 \mathrm{x}^{3}$, where x is the gel/space ratio and 240 represent the intrinsic strength of the gel in MPa, for the type of cement and specimen used.
(ii) The relationship between the strength and gel/space ratio is independent of age.
(iii) Gel/space ratio can be calculated at any age and for any fraction or hydration of cement.

## Q-3(a): (ii) What are the factors affecting durability of concrete?

Sol: A durable concrete is one that performs satisfactorily under anticipated exposure conditions for stipulated life of the structure.

There are various factors affecting the durability of concrete under the prevailing conditions are explained below:
(i) Sugar: It is a retarding agent and gradually corrodes concrete, hence effecting its durability.
(ii) Cracks: Cracks are inherent in concrete and cannot be completely prevented but can be minimized. Use of unsound materials, high w/c ratio, freezing and thermal effect etc. lead to cracking of concrete.
(iii) Organic acids: Acetic acid, lactic acid and butyric acid severely attack concrete. Formic acid is corrosive to concrete.
(iv) Permeability: Almost all forms of deterioration in concrete are due to ingress of water.

Permeability of concrete effects the durability in the following ways :
(a) The chemicals in liquid form affect the concrete by penetrating inside it.
(b) Entered water may undergo frost action rusting in reduced durability.
(c) Water may result in rusting of steel.
(v) Sulphate attack:

- It denote an increase in the volume of cement due to chemical action between hydration of cement and solution containing sulphate.
- The sulphate solution react with $\mathrm{C}_{3} \mathrm{~A}$ forming a chemical which expands and causes disruption in concrete.
(vi) Thermal effect on concrete: Concrete is a heterogenous material. The ingredients of concrete have dissimilar thermal coefficients and effect durability.
(vii) Frost action: The concrete is effected by being permeable and also by the temperature below $0^{\circ} \mathrm{C}$.
- Damage is resulted from movement of water within concrete and on cooling below $0^{\circ} \mathrm{C}$ which builds up ice in the pores of concrete.
- The results in large expansions in local areas of concrete and causes disintegration.
(viii) Vegetable and animal oils and fats:

Vegetable oils contain small amount of free fatty essence and deteriorate concrete slowly.

- Fish and cotton seed oils are found to be the most corrosive
(ix) Carbonation:
- Concrete is alkaline in nature and has an initial pH value of $12-13$ and as long the steel reinforcement is in alkaline conditions, its corrosion is restricted.
- In the presence of moisture $\mathrm{CO}_{2}$ changes to carbonic acid and attack concrete causing the reduction in pH of concrete \& turing concrete to be acidic.
- As concrete turns acidic, corrosion ion of steel reinforcement begins resulting in increased concrete volume and cracking as well.
(x) Sewage:
$\mathrm{H}_{2} \mathrm{~S}$ gas evolved from septic sewage may promote formation of $\mathrm{H}_{2} \mathrm{SO}_{4}$ affecting the concrete and may result in corrosion of steel as well.

Q-3(b): A rectangular beam of size $\mathbf{3 0 0} \mathbf{~ m m} \times 600 \mathrm{~mm}$ is used over a simply supported effective span of 7 m . The beam supports a live load of $12 \mathrm{kN} / \mathrm{m}$. A straight tendon is provided at an eccentricity of 100 mm below the centroid of the beam section. Find the minimum prestressing force required for no tension condition at mid span under live load. Also, show the stress distribution under self weight only at mid-span and at the ends of the member.
[20 MARKS]
Sol:

$B M$ at mid span due to live load $\left(M_{l}\right)=\frac{W_{L L} \times \ell^{2}}{8}$

$$
=\frac{12 \times 7^{2}}{8}=73.5 \mathrm{kNm}
$$

Area of cross section of beam $=300 \times 600 \mathrm{~mm}^{2}$
Section modulus of top $=$ Section modulus of bottom $=\frac{\mathrm{bd}^{2}}{6}=\frac{300 \times 600^{2}}{6} \mathrm{~mm}^{3}$
Let the required prestressing force is PkN
For no tension condition at mid span, $\sigma_{\text {net }}=0$


Assuming tensile stress to be -ve
i.e.,

$$
-\frac{M_{\ell}}{Z}+\frac{P}{A}+\frac{P e}{Z}=0
$$

$$
\begin{array}{rlrl}
-\frac{73.5 \times 10^{6}}{\left(\frac{300 \times 600^{2}}{6}\right)}+\frac{P \times 1000}{300 \times 600}+\frac{P \times 1000 \times 100}{\left(\frac{300 \times 600^{2}}{6}\right)} & =0 \\
\text { or, } & \frac{P}{180}+\frac{P}{180} & =\frac{49}{12} \\
\therefore & P & =367.5 \mathrm{kN}
\end{array}
$$

## Stress distribution at mid span due to self weight

Assuming,

| $\gamma_{\text {concrete }}$ | $=24 \mathrm{kN} / \mathrm{m}^{3}$ |
| ---: | :--- |
| Load due to self weight | $=24 \times \frac{300}{1000} \times \frac{600}{1000}=4.32 \mathrm{kN} / \mathrm{m}$ |



Mid span moment due to self weight only

$$
=\frac{\mathrm{W}_{\mathrm{dL}} \ell^{2}}{8}=\frac{4.32 \times 7^{2}}{8}=26.461 \mathrm{kNm}
$$

## Calculation of stresses


and

$$
\begin{aligned}
\sigma_{\text {top }} & =+\frac{M}{Z} \\
\sigma_{\text {top }} & =\frac{26.46 \times 10^{6}}{\frac{300 \times 600^{2}}{6}}=1.47 \mathrm{MPa} \\
\sigma_{\text {bottom }} & =\sigma_{\text {top }}=1.47 \mathrm{MPa}
\end{aligned}
$$

So,


Fig. Stress distribution under self weight only at mid span.
$B M$ at end $A$ and $B=0$
Hence, stresses at end will be 0 .


Fig. Stress distribution under self weight only at ends.
Q-3(c): A uniformly distributed load of $45 \mathrm{kN} / \mathrm{m}$ longer than the span rolls over a simply supported girder of 35 m span. Using influence line diagram for shear force and bending moment, determine the maximum shear force and maximum bending moment at a section 14 m from left-hand support.
[20 MARKS]
Sol:


The beam is shown in the figure. For point $C$, which is at $z=14 \mathrm{~m}$ from A, ILD for shear force $F_{c}$ and bending moment $\mathrm{M}_{\mathrm{c}}$ are to be found.
ILD for $F_{c}$ : ILD ordinate at just to the left of $C$ is

$$
=-\frac{z}{L}=-\frac{14}{35}=-0.4
$$

ILD ordinate at just to right of $C=1-0.4=0.6$
$45 \mathrm{kN} / \mathrm{m}$


Maximum positive $\mathrm{SF}=\frac{1}{2} \times 0.6 \times 21 \times 45=283.5 \mathrm{kN}$


Maximum negative $\mathrm{SF}=-\frac{1}{2} \times 0.4 \times 14 \times 45=-126 \mathrm{kN}$

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So, the maximum shear force $=283.5 \mathrm{kN}$


ILD for moment at $C$ is as shown in figure in which

$$
y_{c}=\frac{z(L-z)}{L}=\frac{14 \times 21}{35}=8.4
$$

Maximum bending moment at $C=\frac{1}{2} \times 8.4 \times 35 \times 45=6615 \mathrm{kN}-\mathrm{m}$

Q-4(a): (i) For the vibrating system shown in the figure below, determine the following parameters:
(1) Natural frequency of the vibrating system.
(2) Critical damping of the vibrating system.
(3) Damping ratio.
(4) Damped natural frequency of the vibrating system.

[10 MARKS]
Sol-:


Mass (m) $=10 \mathrm{Kg}$
$\mathrm{k}=2400 \mathrm{~N} / \mathrm{m}$
$C=77 \mathrm{~N}-\mathrm{s} / \mathrm{m}$
(i) Natural frequency of the vibrating system

$$
\omega_{\mathrm{n}}=\sqrt{\frac{\mathrm{k}}{\mathrm{~m}}}=\sqrt{\frac{2400}{10}}=15.4919 \mathrm{rad} / \mathrm{sec} .
$$

(ii) Critical damping of the vibrating system

$$
\begin{aligned}
\mathrm{C}_{\mathrm{Cr}} & =2 \mathrm{~m} \omega_{\mathrm{n}} \\
& =2 \times 10 \times 15.4919 \\
& =309.838 \mathrm{~N}-\mathrm{s} / \mathrm{m}
\end{aligned}
$$

(iii) Damping ratio

$$
\xi=\frac{C}{C r}=\frac{77}{309.838}=0.2485
$$

(iv) Damped natural frequency of the vibrating system

$$
\begin{aligned}
& \omega_{\mathrm{d}}=\omega_{\mathrm{n}} \sqrt{1-\xi^{2}} \\
& \omega_{\mathrm{d}}=15.4919 \sqrt{1-0.2485^{2}} \\
& \omega_{\mathrm{d}}=15.006 \mathrm{rad} / \mathrm{sec}
\end{aligned}
$$

Q-4(a): (ii) A short braced reinforced concrete column has unsupported length of 3.5 m and size of 300 $\mathrm{mm} \times 360 \mathrm{~mm}$. Verify the applicability of simplified formula of $P_{u}$ (i.e., ultimate load-carrying capacity of a short axially loaded column) as given in the Code. Also, determine the design moments due to minimum eccentricity to be considered for this case if the column is subjected to an ultimate axial load of 1600 kN .
[10 MARKS]
Sol: As per clause 39.3 of IS 456:2000
[Clause 25.4 : Minimum eccentricity]

- All columns shall be designed for minimum eccentricity equal to unsupported length of column/500 plus lateral dimension $/ 30$ subject to a minimum of 20 mm .
- When the above eccentricity does not exceed 0.05 times the lateral dimension, the code permits the following simplified formula.

$$
P_{u}=0.4 f_{c k} A_{c}+0.67 f_{y} A_{s c}
$$


$=\max \left\{\begin{array}{c}\frac{3500}{500}+\frac{600}{30}=27 \mathrm{~mm} \\ 20 \mathrm{~mm}\end{array}\right.$
$=27 \mathrm{~mm}$

## Check :

$$
\begin{aligned}
0.05 \mathrm{D}_{\mathrm{x}} & =0.05 \times 600=30 \mathrm{~mm} \\
\mathrm{e}_{\mathrm{ymin}} & =\text { maximum }\left\{\begin{array}{l}
\frac{l}{500}+\frac{\mathrm{D}_{\mathrm{y}}}{30} \\
20 \mathrm{~mm}
\end{array}\right. \\
& =\text { maximum }\left\{\begin{array}{l}
\frac{3500}{500}+\frac{300}{30}=17 \mathrm{~mm} \\
20 \mathrm{~mm}
\end{array}\right. \\
& =20 \mathrm{~mm}
\end{aligned}
$$

## Check :

$$
0.05 \mathrm{Dy}=0.05 \times 300=15 \mathrm{~mm}
$$

Here,
Calculated eccentricities exceed 0.05 times the lateral dimension (in the plane considered)
So, the simplified formula of Pu cannot be used.

## Calculation of design moment due to minimum eccentricity



Q-4(b): (i) What are the factors affecting rheological properties of concrete?
[10 MARKS]

## Sol: Rheology :

- Rheology is science of flow and deformation of matter and describes one interrelation between force, deformation and time.
- Rheological principles and techniques as applied to concrete include the deformation of hardened concrete, handling and placing of freshly mixed concrete and the behavior of its constituent parts namely cement slurries and pastes.
- Rheology of fresh concrete like workability includes the parameters of stability, mobility and compatibility.
- Mechanical behaviour of hardened cement paste, which exhibits both elastic and inelastic deformations, can be expressed in rheological terms.


## Factors Affecting Rheological Properties :

1. Mix Proportions

- Concrete mix having an excess amount of coarse aggregate will lack sufficient mortar to fill the void system, resulting in a loss of cohesion and mobility. Such a mix is termed as harsh and requires a great amount of effort to place and compact.
- Whereas an excessive amount of fine aggregate or entrained air in a concrete mixture will greatly increase the cohesion and render the concrete difficult to move.

2. Consistency

- Consistency of concrete is measured by slump test and is an indicator of the relative water content in the concrete mix.
- An increase in the water content or slump above that required to achieve a workable mix produces greater fluidity and decreased internal friction.

3. RH cement and use of accelerating admixtures

- High temperature, increase the rate of hardening which will decrease the mobility of concrete.

4. Aggregate shape and texture

- Rough and highly angular aggregate particles will cause a high percentage of voids filled by mortar, requiring higher fine aggregate contents and correspondingly higher water content.
- Similarly an angular fine aggregate will increase internal friction in the concrete mixture and require higher water content than well rounded natural sands.

5. Aggregate grading

- Well graded aggregate gives good workability whereas Gap graded aggregate affects void and workability.

6. Maximum size of aggregate

- Increase in the maximum size of aggregate will reduce the fine aggregate requirement to maintain a given workability and will thereby reduce the surface area to be wetted and hence the cement content necessary for a constant water-cement ratio.


## 7. Admixtures

- Admixtures having significant effect on the rheology of concrete are plasticizers and super-plasticizers, air-entraining agents, accelerators and retarders.
- Super-plasticizers and plasticizers prevent the formation of flocculated structure by changing the interparticle attraction to repulsion.
- Air-entraining agents introduce spherical air bubbles of 10 to 25 mm diameter by modifying the surface tension of the aqueous phase in the mix. Bubbles act like ball bearings to allow larger particles to flow past each other more easily thus decreasing plastic viscosity.

Q-4(b) (ii) How are the properties of concrete affected by seawater and industrial wastewater, if they are used for making the concrete?
[10 MARKS]

Sol:

- The purpose of using water with cement is to cause hydration of the cement.
- Water in excess of that required for hydration act as a lubricant between coarse and fine aggregate and produce workable and economical concrete.
- The impurities in the water used for making mortar and concrete, or for curing may lead to their rapid deterioration.
- Excess impurites may affect setting time, strength durability and may cause efflorescence, surface discolouration and corrosion of steel.


## The properties of concrete affected by sewater is-

- $\quad$ Sea water is used if suitable fresh water is not available.
- The sea water geenrally contains $3.5 \%$ of salts with about $75 \%$ of sodium cloride, it has been found to reduce the strength of concrete by $10 \%$ to $20 \%$.
- $\quad$ Sea water slightly accelerate the setting time, of concrete.
- Sea water may lead to corrosion of the reinforcement.
- It has been found that the factor affecting corrosion are permeability of concrete and lack of proper cover.
- If these are ensured and adequate amount of entrained air is there, the problem of corrosion may be circumvented, weather it is pure water or seawater but with a difference in the rate of corrosion.
- Therefore sea water may be used for plane concrete only.
- $\quad$ The chlorides in sea water may cause efflorescence restricting it to be used in making mortars for plastering.
- The sea water is not recommended for prestressed concrete because of steel corrosion, and the small diameter wires, (if corroded may cause disaster).

The properties of concrete affected by industrial wastewater is

- Most water carrying industrial waste have less than 3000 ppm of total solids, when such water is used as mixing water in concrete the reduction of compressive strength is generaly less than $10 \%$.
- Wastewater from paint factories, coke plants chemical and galvanizing plant may contains harmful impurities and hence the durability of concrete decreases.

Q-4(c): Analyze the portal frame shown in the figure below by moment distribution method. The frame is fixed at $A$ and $D$, and has rigid joints at $B$ and $C$. Draw the bending moment diagram and sketch the deflected shape of the structure. Take El as constant:

[20 MARKS]

## Sol:



As the frame is symmetrical, concept of symmetrical approach will be used.

$$
\mathrm{K}_{2}=\frac{4 \mathrm{EI}}{\mathrm{~L}} \underbrace{\mathrm{~K}_{1}=\frac{2 \mathrm{El}}{\mathrm{~L}}}_{\text {mimm }}
$$

| Joint | Member | Stiffness factor | D.F. |
| :---: | :---: | :---: | :---: |
|  | BA | $\frac{4 E I}{3}$ | $\frac{8}{11}$ |
| B |  | $\frac{2 E I}{4}$ | $\frac{3}{11}$ |

Fixed end moments

$$
\begin{aligned}
M_{F B A} & =M_{F A B}=M_{F C D}=M_{F D C}=0 \\
M_{F B C} & =-M_{F C B}=-\frac{w L^{2}}{12}=-\frac{16 \times 4^{2}}{12} \\
& =-\frac{64}{3} \mathrm{kN}-\mathrm{m}=-21.33 \mathrm{kN}-\mathrm{m}
\end{aligned}
$$

| B |  |  |  |
| :--- | :--- | :--- | :---: |
| A | $8 / 11$ | $3 / 11$ |  |
| 0 | 0 | -21.333 |  |
|  | 15.515 | 5.818 |  |
| 7.758 |  |  |  |
| 7.758 | 15.515 | -15.515 |  |

The free body diagram will be as shown below.


$$
H_{A}=H_{B}=\frac{15.515+7.758}{3}=7.758 \mathrm{kN}
$$



## SECTION-B

Q-5(a): (i) Describe the mechanical properties of ceramics.
[6 MARKS]
Sol: Ceramics refers to polycrystalline materials and products formed by baking natural clay and mineral admixtures at high temperature and also by sintering oxides of various metals having high melting point.

Mechanical Properties of Ceramic Materials: Some of the mechanical properties of ceramic materials are as following:

1. Tensile strength
(a) Theoritically the tensile strength of ceramics is very high but in practice it is quite low.
(b) Tensile failures of ceramics are attributed to the stress concentrations at the pores and microcracks at grain corners.
(c) Glass fibres have tensile strength of the order $700 \mathrm{~N} / \mathrm{mm}^{2}$.
2. Compressive strength: The compressive strength is high and it is usual to use ceramics like clay, cement and glass products in compression.
3. Shear strength: Ceramics have very high shear strength with resistance to failing in a brittle manner.
4. Transverse strength: It is difficult to ascertain and ceramics are not used in place where such strength is the criteria.

Q-5(a): (ii) Explain roller compacted concrete. What are the advantages of roller-compacted concrete?
[6 MARKS]
Sol: Roller compacted concrete is a relatively recent development in the construction of dams \& locks.

- It is based on no slump concrete mix which can be transported placed and compacted with same construction equipment that is used for earth and rockfill dams.
- It is a mixture of aggregates, cement (with or without pozzolonas) water and sometimes water reducing admixtures.
- RCC differs from conventional concrete principally in it consistency requirement, for effective consolidation.
- The concrete must be dry to prevent sinking of the vibratory roller equipment but enough to permit adequate distribution of the binder mortar throughout the material during the mixing and vibratory compaction operations.
- The conventional concept of minimizing water cement ratio to minimize strength does not hold.
- The best compaction give best strength and and best compaction occurs at the wetted mix that will support on operating vibratory roller.
- As compared to conventional concrete, RCC contains less cement and cementitious material paste, ( $250-350 \mathrm{~kg} / \mathrm{m}^{3}$ ) \& significantly high fly ash proportion.
- The 28 days strength of RCC is better as compare to OPC.
- Since the drier consistency of RCC is low, the bonding of fresh concrete to hardened concrete is not adequate.
- The creep and thermal properties of RCC are within the range of those of conventional normal concrete.


## Advantages of roller compacted concrete are-

- Cement consumption is lower because much leaner concrete can be used.
- Form work costs are lower because of the layer placement method.
- Pipe cooling is unnecessary because of the temperature rise.
- The construction period can be shortened considerably.
- Rate of equipments and labour utilization are high which. However, are offset because of the higher speed fo concrete placement.
- RCC used for making dams, heavy duty parting runways, storage areas and yards.

Q-5(b): A steel cable of 12 mm diameter is stretched across two poles 80 m apart. If the central dip is 1.10 $m$ at normal temperature, determine the stress intensity in the cable. Also, determine the change in temperature necessary to raise the stress to 80 MPa . Take unit weight of steel $\gamma=78 \mathrm{kN} / \mathrm{m}^{3}$ and $\alpha=12 \times 10^{-6} /{ }^{\circ} \mathrm{C}$.
[12 MARKS]

Sol:


Given, $\mathrm{d}=12 \mathrm{~mm}, \ell=80 \mathrm{~m}, \mathrm{~h}=1.1 \mathrm{~m}$
$\gamma=78 \mathrm{kN} / \mathrm{m}^{3}, \alpha=12 \times 10^{-6} /{ }^{\circ} \mathrm{C}, \Delta \sigma=80 \mathrm{MPa}$ at $\Delta \mathrm{T}=?$

$$
\begin{aligned}
& \text { Length of cable, } \mathrm{L}=l\left[1+\frac{8}{3} \times \frac{\mathrm{h}^{2}}{l^{2}}\right]=0\left[1+\frac{8}{3} \times\left(\frac{1.1}{80}\right)^{2}\right]=80.04 \mathrm{~m} \\
& \text { Self weight of code }=\gamma \mathrm{AL}=\mathrm{W}=78 \times \frac{\pi}{4} \times(0.012)^{2} \times 80.04=706.1 \mathrm{~N}
\end{aligned}
$$

Now,

$$
\begin{aligned}
H & =\frac{w L}{8 \mathrm{~h}}=\frac{706.1 \times 80}{8 \times 1.1}=6419.09 \mathrm{~N} \\
\mathrm{~V}_{\mathrm{A}} & =\mathrm{V}_{\mathrm{B}}=\frac{\mathrm{W}}{2}=\frac{706.1}{2}=353.05 \mathrm{~N} \\
\mathrm{~T}_{\max } & =\sqrt{\mathrm{H}^{2}+\mathrm{V}^{2}}=\sqrt{(6419.09)^{2}+(353.05)^{2}}=6428.79 \mathrm{~N} \\
\text { Maximum stress } & =\frac{\mathrm{T}_{\max }}{\mathrm{A}}=\frac{6428.79}{\frac{\pi}{4} \times 12^{2}}=56.84 \mathrm{~N} / \mathrm{mm}^{2}
\end{aligned}
$$

Let's assume fall of temperature $=t^{\circ} \mathrm{C}$

$$
\text { Change in displacement, } \delta \mathrm{h}=\frac{3}{16} \frac{l^{2}}{\mathrm{~h}} \alpha \mathrm{t}
$$

Now,

$$
\begin{aligned}
& =\frac{3}{16} \times \frac{80^{2}}{1.1} \times 12 \times 10^{-6} \times t=\frac{18}{1375} \mathrm{t} \\
\frac{\delta f}{f} & =\frac{\delta h}{h} \\
\frac{80-56.84}{56.84} & =\frac{\frac{18}{1375} \mathrm{t}}{1.1} \\
t & =34.24^{\circ} \mathrm{C} \rightarrow \text { Falling temperature. }
\end{aligned}
$$

Q-5(c): A T-beam is continuous over a span of 10 m . The sectional parameters of the beam are as below:
Width of web $=250 \mathrm{~mm}$
Width of flange $=1100 \mathrm{~mm}$
Effective depth of beam $=460 \mathrm{~mm}$
Area of steel in tension $=1800 \mathrm{~mm}^{2}$

## Consistency in results since over a decade



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Area of steel in compression $=1000 \mathrm{~mm}^{2}$
Use M-20 grade of concrete and Fe-415 grade of steel. Estimate the safety of the beam for deflection control using the empirical method given in the Code IS 456 : 2000. The corresponding graphs are reproduced at Page Nos. 13-15.
[12 MARKS]
Sol: We have, span of continuous beam $=10 \mathrm{~m}$


Assuming, area of cross section of steel required is exactly equal to area of cross-section provided.

$$
f_{s}=0.58 f_{y} \times 1=0.58 \times 415=240.7 \mathrm{~N} / \mathrm{mm}^{2}
$$

## Modification factor for tension reinforcement $\left(F_{1}\right)$



Adopting design curve for $\mathrm{f}_{\mathrm{s}}=240 \mathrm{MPa}$

$$
\text { Percentage tensile reinforcement }\left(p_{t} \%\right)=\frac{1800}{1100 \times 400} \times 100=0.3557 \%=0.36 \%
$$

| $\mathrm{p}_{\mathrm{t}} \%$ | $\mathrm{~F}_{1}$ |
| :---: | :---: |
| 0.2 | 1.7 |
| 0.4 | 1.38 |

Assuming the variation of $p_{t}(\%)$ to be linear with $F_{1}$
So, for $p_{t}=0.36 \%$

$$
F_{1}=1.7+\frac{1.38-1.7}{0.4-0.2}(0.36-0.2)
$$

## $=1.444=1.44$

## Modification factor for compression reinforcement ( $\mathrm{F}_{2}$ )



$$
F_{2}=1+\frac{1.08-1}{0.25-0} \times(0.2-0)
$$

## Modification factor for width of flange $\left(F_{3}\right)$

$$
\begin{aligned}
& \text { Ratio }=\frac{250}{1100}=0.227 \simeq 0.23 \\
& \text { Mofidication factor }\left(\mathrm{F}_{3}\right)=0.80 \\
& \text { Modified ratio }=\text { Basic ratio } \times \mathrm{F}_{1} \times \mathrm{F}_{2} \times \mathrm{F}_{3} \\
& =26 \times 1.44 \times 1.064 \times 0.8=31.868 \simeq 31.87
\end{aligned}
$$

Now, ratio of effective span to depth provided $=\frac{10 \times 1000}{460}=21.739<31.87$
Beam is safe in deflection.

Q-5(d): A single angle ISA $100 \times 100 \times 10$ is connected to a gusset plate of thickness 10 mm by weld along two parallel edges. The size of weld (fillet) is 6 mm . The member is subjected to an axial compressive load of 150 kN (factored). Find the weld length along two parallel edges. Assume E250 grade of steel and shop welded. For ISA $100 \times 100 \times 10, c_{y}=c_{z}=27.6 \mathrm{~mm}$. Use limit state method.
[12 MARKS]
Sol:


Given,

$$
\begin{aligned}
\text { Factored compressive load }\left(\mathrm{P}_{\mathrm{u}}\right) & =150 \mathrm{kN} \\
\text { Size of weld }(\mathrm{S}) & =6 \mathrm{~mm} \\
\text { For E250 grade steel, } \mathrm{f}_{\mathrm{u}} & =410 \mathrm{MPa} \\
\text { For, shop welding, } \gamma_{\mathrm{mw}} & =1.25
\end{aligned}
$$

Let $l_{\mathrm{w} 1}$ and $l_{\mathrm{w} 2}$ be the length of weld provided along of weld provided along parallel edges as shown.

$$
\begin{equation*}
P_{1}+P_{2}=150 \tag{i}
\end{equation*}
$$

$$
\text { Design strength of weld }\left(\mathrm{P}_{\mathrm{dw}}\right)=l_{\mathrm{w}} \mathrm{t}_{\mathrm{t}} \frac{\mathrm{f}_{\mathrm{u}}}{\sqrt{3} \gamma_{\mathrm{mw}}}
$$

Taking moment about line $x-x$

$$
\begin{aligned}
150 \times 10^{3} \times 27.6 & =P_{1} \times 100 \\
P_{1} & =\frac{150 \times 10^{3} \times 27.6}{100}=41400 \mathrm{~N}
\end{aligned}
$$

Also,

$$
\begin{aligned}
& \mathrm{P}_{1}=l_{\mathrm{w} 1}(0.7 \times 6) \times \frac{410}{\sqrt{3} \times 1.25} \\
& l_{\mathrm{w} 1}=\frac{41400 \times \sqrt{3} \times 1.25}{0.7 \times 6 \times 410}=52.05 \mathrm{~mm}
\end{aligned}
$$

Hence,

$$
P_{2}=150-P_{1}=150 \times 10^{3}-41400=108600 \mathrm{~N}
$$

$$
\begin{aligned}
\mathrm{P}_{2} & =l_{\mathrm{w} 2}(0.7 \times 6) \times \frac{410}{\sqrt{3} \times 1.25} \\
l_{\mathrm{w} 2} & =\frac{108600 \times \sqrt{3} \times 1.25}{0.7 \times 6 \times 410}=136.54 \mathrm{~mm}
\end{aligned}
$$

Adopt

$$
l_{\mathrm{w} 1}=53 \mathrm{~mm} \text { and } l_{\mathrm{w} 2}=137 \mathrm{~mm}
$$



Q-5(e): Determine the maximum principal stress developed in a cylindrical shaft 10 cm in diameter, subjected to a BM of $3.0 \mathrm{kN}-\mathrm{m}$ and twisting moment of $4.50 \mathrm{kN}-\mathrm{m}$. If the yield stress of the shaft material is $230 \mathrm{MN} / \mathrm{m}^{2}$, determine the factor of safety according to the maximum shearing stress theory of failure.
[12 MARKS]
Sol: Given,

$$
\begin{aligned}
\text { Cylindrical shaft dia } & =10 \mathrm{~cm} \\
\text { Bending moment }(\mathrm{M}) & =3 \mathrm{kNm} \\
\text { Twisting moment }(\mathrm{T}) & =4.5 \mathrm{kNm} \\
\text { Yield stress }\left(\mathrm{f}_{\mathrm{y}}\right) & =230 \mathrm{MN} / \mathrm{m}^{2} \\
\text { Factor of safety } & =?
\end{aligned}
$$

Using max shearing stress theory of failure.

$$
\begin{aligned}
\text { Max. shear stress } & \leq \frac{f_{y}}{2 \times F O S} \\
\frac{16 T_{e}}{\pi D^{3}} & \leq \frac{f_{y}}{2 \times F O S} \\
T_{e} & =\sqrt{M^{2}+T^{2}} \\
T_{e} & =\sqrt{(3)^{2}+(4.5)^{2}} \\
T_{e} & =\sqrt{29.25} \\
T_{e} & =5.4083 \mathrm{kNm} \\
\frac{16 \times 5.4083}{\pi D^{3}} & \leq \frac{230 \times 1000}{2 \times F O S} \\
\text { FOS } & \leq \frac{230 \times 1000 \times \pi \times(0.1)^{3}}{2 \times 16 \times 5.4083} \\
\text { FOS } & \leq 4.175
\end{aligned}
$$

Q-6(a): Determine the vertical and horizontal deflections at the free end of the frame shown in the figure below. Take EI $=12 \times 10^{4} \mathrm{kN}-\mathrm{m}^{2}$.

[20 MARKS]

## Sol:



Calculation of vertical deflection at the free end by using castigliano's theorem.


Applying pseudo force P at point D in vertical direction.

| Segment | $M$ | $\frac{\partial M}{\partial P}$ | limit of $x(m)$ |
| :---: | :---: | :---: | :---: |
| $D C$ | 0 | 0 | $0-2$ |
| $C B$ | $-P x-17.5 x^{2}$ | $-x$ | $0-4$ |
| $A B$ | $-(45 x+4 P+280)$ | -4 | $0-3.5$ |

$$
\begin{aligned}
\Delta & =\int_{0}^{L} \frac{M \frac{\partial M}{\partial P}}{E l} d x \\
\Delta_{V} & =\int_{0}^{2}(0)(0)+\int_{0}^{4} \frac{\left(-P x-17.5 x^{2}\right)(-x)}{E I} d x+\int_{0}^{3.5} \frac{(45 x+4 P+280) \times 4}{E l} d x[P=0] \\
& =0+\int_{0}^{4} \frac{17.5 x^{3}}{E I} d x+\int_{0}^{3.5} \frac{4(45 x+280)}{E l} d x \\
& =\frac{1120}{E l}+\frac{1102.5}{E l}+\frac{3920}{E l}=51.18 \mathrm{~mm}
\end{aligned}
$$

Calculation of horizontal deflection at free end by using castigliano's theorem.

$$
\Delta_{H}=\int_{0}^{L} \frac{M \cdot \frac{\partial M}{\partial P}}{E l} d x
$$



Applying psudo force at point D in horizontal direction, where horizontal deflection ( $\Delta_{H}$ ) has to be calculated.

| Segment | $M$ | $\frac{\partial M}{\partial P}$ | Limit of $x$ |
| :---: | :---: | :---: | :---: |
| DC | Px | x | $0-2$ |
| CB | $2 \mathrm{P}-17.5 \mathrm{x}^{2}$ | 2 | $0-4$ |
| AB | $(-45 \mathrm{x}+(2-\mathrm{x}) \mathrm{P}-280$ | $2-\mathrm{x}$ | $0-3.5$ |

$\Delta_{H}=\int_{0}^{2} \frac{P(x)(x)}{E l} d x+\int_{0}^{4} \frac{\left(2 P-17.5 x^{2}\right)(2)}{E l} d x+\int_{0}^{3.5} \frac{\{-45 x-280+(2-x) P\}(2-x)}{E l} d x$
Put ( $\mathrm{P}=0$ )
$=0+\int_{0}^{4}-\frac{35 x^{2}}{E l} d x+\int_{0}^{3.5} \frac{(-45 x-280)(2-x) d x}{E l}$
$=\frac{-2240}{3 \mathrm{El}}-\frac{153.125}{\mathrm{El}}=-7.498 \times 10^{-3} \mathrm{~m}=7.5 \mathrm{~mm} \leftarrow$

Q-6(b): A cantilever beam (ISMB 500) is connected of the flange of the column (ISHB 450) by fillet weld of size 5 mm . The beam is subjected to a vertical load $P$ and a horizontal load P/2 at a distance of $\mathbf{2 0 0} \mathbf{~ m m}$ from the flange of the column as shown in the figure below. Find the factored $P$ that can be applied for the joint. Assume E250 grade of steel, site weld. Given, $f_{e}=\sqrt{f_{a}^{2}+3 q^{2}}$. Use limit state method. Assume that the beam section is safe:

[20 MARKS]
Sol: Due to the vertical and horizontal load the weld is subjected to direct load and bending moment.
Point ' $A$ ' will be critical as maximum bending stress will be there.


$$
\begin{aligned}
\text { Vertical load } & =P \\
\text { Bending moment about z-axis } & =200 \times P \times 10^{-3}=0.2 \mathrm{P} \mathrm{kN}-\mathrm{m} \\
\text { Horizontal load } & =P / 2 \\
\text { Bending moment about y-axis } & =200 \times \frac{P}{2} \times 100^{-3}=0.1 \mathrm{P} \mathrm{kNm}
\end{aligned}
$$

## Due to vertical load

$$
\begin{aligned}
\text { Direct shear stress }\left(\mathrm{q}_{1}\right) & =\frac{P \times 10^{3}}{(4 \times 90+4 \times 20) \times 0.7 \times 5}=0.2463 \mathrm{P} \mathrm{~N} / \mathrm{mm}^{2} \\
\mathrm{I}_{\bar{z}} & =\left[\frac{0.7 \times 5 \times 400^{3}}{12}+0.7 \times 5 \times 180 \times 250^{2}\right] \times 2 \\
& =11.60 \times 10^{7} \mathrm{~mm}^{4} . \\
\Rightarrow \quad \text { Bending stress }\left(\mathrm{f}_{\mathrm{a}_{1}}\right) & =\frac{\mathrm{M}}{\mathrm{~T}} \cdot \mathrm{y}
\end{aligned}
$$

$$
=\frac{0.2 \mathrm{P} \times 10^{6}}{11.60 \times 10^{7}} \times 250=0.43 \mathrm{P} \mathrm{~N} / \mathrm{mm}^{2}
$$

## Due to horizontal load

$$
\begin{aligned}
\text { Direct shear stress }\left(\mathrm{q}_{2}\right) & =\frac{0.1 \mathrm{P} \times 10^{3}}{(4 \times 90+4 \times 200) \times 0.7 \times 5}=0.1232 \mathrm{MPa} \\
\mathrm{I}_{\mathrm{yy}} & =\left[\frac{0.7 \times 5 \times(180)^{3}}{12}+0.7 \times 5 \times 400 \times\left(\frac{10}{2}\right)^{2}\right] \times 2 \\
& =0.347 \times 10^{7} \mathrm{~mm}^{4} . \\
\text { Bending stress }\left(\mathrm{f}_{\mathrm{az}}\right) & =\frac{\mathrm{M}}{\mathrm{l}} \cdot \mathrm{y} \\
& =\frac{0.1 \mathrm{P} \times 10^{6}}{0.347 \times 10^{7}} \times 90=2.59 \mathrm{PN} / \mathrm{mm}^{2}
\end{aligned}
$$

The resultant shear stress

$$
\begin{aligned}
q & =\sqrt{\left(q_{1}\right)^{2}+\left(q_{2}\right)^{2}}=\sqrt{(0.2463 P)^{2}+(0.1232 P)^{2}} \\
& =0.2754 P \mathrm{~N} / \mathrm{mm}^{2}
\end{aligned}
$$

The resultant bending stress

$$
f_{a}=f_{a_{1}}+f_{a_{2}}=0.43 P+2.59 P=3.02 P \mathrm{~N} / \mathrm{mm}^{2}
$$

For safety $\sqrt{f_{a}^{2}+3 q^{2}} \leq \frac{f_{u}}{\sqrt{3} \gamma_{m w}}$

$$
\begin{aligned}
& & \sqrt{(3.02 \mathrm{P})^{2}+3 \times(0.2754 \mathrm{P})^{2}} & \leq \frac{410}{\sqrt{3} \times 1.5} \\
\Rightarrow & & \mathrm{P} & \leq 51.61 \mathrm{kN}
\end{aligned}
$$

The following table gives the details of various activities of a construction project:

| Activity | Optimistic time <br> (months) | Most likely <br> (months) | Pessimistic time <br> (months) |
| :---: | :---: | :---: | :---: |
| $1-2$ | 2 | 2 | 8 |
| $1-3$ | 2 | 5 | 8 |
| $1-4$ | 3 | 3 | 9 |
| $2-5$ | 2 | 2 | 4 |
| $3-5$ | 3 | 6 | 15 |
| $4-6$ | 3 | 6 | 9 |
| $5-6$ | 4 | 7 | 16 |
| $6-7$ | 2 | 2 | 2 |

(i) Draw the network for the project.
(ii) Find the expected duration and variance of each activity.
(iii) What is the expected project length?
(iv) What is the probability that the project will be compected at leat 3 months earlier than expected?
(v) What will be the time required for $95 \%$ probability of its completion?
[20 MARKS]
Sol: (i) The network diagram for the construction project is shown below :

(ii) Calculation of expected duration and variance of each activity.

As, Expected time of each activity $\left(\mathrm{t}_{\mathrm{e}}\right)=\frac{\mathrm{t}_{0}+4 \mathrm{t}_{\mathrm{m}}+\mathrm{t}_{\mathrm{p}}}{6}$
and Variance of each activity $\left(\sigma^{2}\right)=\left(\frac{t_{p}-t_{0}}{\sigma}\right)^{2}$
where, $t_{p}=$ Pessimistic time
$\mathrm{t}_{0}=$ Optimistic time
$\mathrm{t}_{\mathrm{m}}=$ Most probable time

The calculations for expected time $\left(\mathrm{t}_{\mathrm{e}}\right)$ and variance $\left(\sigma^{2}\right)$ is done in table shown below:

| Activity | Optimistic time <br> $\left(\mathrm{t}_{0}\right)($ months $)$ | Most likely time <br> $\left(\mathrm{t}_{\mathrm{m}}\right)($ months $)$ | Pessimistic time <br> $\left(\mathrm{t}_{\mathrm{p}}\right)($ months $)$ | Expected time <br> $\left(\mathrm{t}_{\mathrm{e}}\right)($ months $)$ <br> $\mathrm{t}_{\mathrm{e}}=\frac{\mathrm{t}_{0}+4 \mathrm{t}_{\mathrm{m}}+\mathrm{t}_{\mathrm{p}}}{}$ | Variance $\left(\sigma^{2}\right)$ <br> $\sigma^{2}=\left(\frac{\mathrm{t}_{\mathrm{p}}-\mathrm{t}_{0}}{\sigma}\right)$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $1-2$ | 2 | 2 | 8 | 3 | 1 |
| $1-3$ | 2 | 5 | 8 | 5 | 1 |
| $1-4$ | 3 | 3 | 9 | 4 | 1 |
| $2-5$ | 2 | 2 | 4 | 2.33 | 0.111 |
| $3-5$ | 3 | 6 | 15 | 7 | 4 |
| $4-6$ | 3 | 6 | 9 | 6 | 1 |
| $5-6$ | 4 | 7 | 16 | 8 | 4 |
| $6-7$ | 2 | 2 | 2 | 2 | 0 |

(iii) Estimation of expected project length


Clearly,

- The expected project length $\left(\mathrm{T}_{\mathrm{E}}\right)=22$ months.
- Also, critical path is the path joining events having zero slack and longest duration is 1-3-5-6-7.
(iv) Probability that the project will be completed atleast 3 months earlier than expected. For this,

Scheduled completion time $\left(\mathrm{T}_{\mathrm{S}}\right)=22-3$
i.e.
$\mathrm{T}_{\mathrm{S}}=19$ months
Step-1: Determination of standard deviation ( $\sigma$ ) along critical path using central limit theorem.

$$
\begin{aligned}
& \sigma=\sqrt{\sigma_{1-3}^{2}+\sigma_{3-5}^{2}+\sigma_{5-6}^{2}+\sigma_{6-7}^{2}} \\
& \sigma=\sqrt{1+4+4+0}=3 \text { months }
\end{aligned}
$$

Step 2: Determination of probability or normal deviate (z)

As

$$
Z=\frac{T_{S}-T_{E}}{\sigma}=\frac{19-22}{3}=\frac{-3}{3}=-1
$$

Step 3: Determination of probability corresponding to normal deviate.
As for $z=-1, p=15.9 \%$
So, probability of completion of project in scheduled time of $T_{S}=19$ Months is $15.9 \%$
(v) Time required for $95 \%$ probability of its completion.

Let the time required corresponding to $95 \%$ probability of project completion is ' $\mathrm{T}_{\mathrm{S}}$ '.
As table between normal deviate $(z)$ and corresponding probability is not given so interpolating between $p=84 \%$ to $p=97.5 \%$

As we know,
for $p=97.7 \%, z=2$
for $p=84.1 \%, z=1$
so,

$$
\begin{aligned}
& (z)_{p=95 \%}=2+\frac{(1-2)}{(84.1-97.7)}(95-97.7) \\
& (z)_{p=95 \%}=1.8014
\end{aligned}
$$

So, using

$$
\begin{aligned}
Z & =\frac{T_{S}-T_{E}}{\sigma} \\
014 & =\frac{T_{S}-22}{3} \\
T_{S} & =27.40 \text { months }
\end{aligned}
$$

So, time required to complete the project with $95 \%$ probability is 27.40 months.

Q-7(a): Determine the forces in the member of the braced frame as shown in the figure below. Also, determine the drift due to shear in each storey. Areas of diagonals and horizontal girders are shown in brackets and they are in $\mathrm{mm}^{2}$. Take $E=205 \mathrm{kN} / \mathrm{mm}^{2}$.

[20 MARKS]

Sol: The frame is highly indeterminate and moment of inertia of the section is also not given. Since the frame is a braced frame as mentioned in the question, the connection of bracing with the beam column joint has also not been specified. On this account solution can not be done.

Q-7(b): A member of a transmission tower is composed of two angles ISA $75 \times 75 \times 8$ in star configuration as shown in the figure below. The angles are tack welded by a gusset plate of thickness 10 mm suitably. Find the axial compressive load carying cpacity of the memeber under dead and live load condition. The nodal length of the member is $\mathbf{3} \mathbf{m}$. Assume $K=0.85$ and E250 grade of steel the properties of ISA $75 \times 75 \times 8$ are as follows:
$A=1140 \mathrm{~mm}^{2}, I_{y y}=I_{z z}=59 \mathrm{~cm}^{4}, c_{y}=c_{z}=21.4 \mathrm{~mm}, r_{u u}=28.8 \mathrm{~mm}, r_{v v}=14.5 \mathrm{~mm}$ Given:

| $K L / r$ | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $f_{\text {cr }}$ (Mpa) | 168 | 152 | 136 | 121 | 107 | 94.6 | 83.7 | 74.3 |



Use limit state method.
[20 MARKS]
Sol: We have,


Nodal length $=3 \mathrm{~m}, \mathrm{~K}=0.85$
For ISA $75 \times 75 \times 8 \mathrm{~mm}$

$$
r_{y}=r_{z}=\sqrt{\frac{\left(I_{z z}=I_{y y}\right)}{A}}=\sqrt{\frac{59 \times 10^{4}}{1140}}=22.749 \mathrm{~mm}
$$

The properties of star connection are:

$$
\begin{aligned}
A & =2 \times A_{\text {one angle }}=2 \times 1140=2280 \mathrm{~mm}^{2} \\
r_{z z}=r_{y y} & =\sqrt{r_{y}^{2}+\left(C_{y y}+5\right)^{2}} \\
& =\sqrt{(22.749)^{2}+(21.4+5)^{2}} \\
& =34.849 \mathrm{~mm} \\
r_{v} & =\sqrt{r_{w v}^{2}+2\left(C_{y y}+5\right)^{2}} \\
& =\sqrt{14.5^{2}+2 \times(21.4+5)^{2}}=40.05 \mathrm{~mm} \\
r_{u} & =\sqrt{\frac{2 \mathrm{I}_{u u}}{2 A}}=r_{u u}=28.8 \mathrm{~mm}
\end{aligned}
$$

Hence,

$$
\begin{aligned}
r_{\min } & =r_{u}=28.8 \mathrm{~mm} \\
\lambda & =\frac{\ell_{\text {eff }}}{r_{\text {min }}}=\frac{0.85 \times 3 \times 1000}{28.8}=88.54
\end{aligned}
$$

## Calculation of $f_{c r}$

For $\lambda=88.54$

$$
\begin{aligned}
\mathrm{f}_{\mathrm{cr}} & =136+\frac{121-136}{90-80} \times(88.54-80) \\
& =123.19 \mathrm{MPa}
\end{aligned}
$$

## Calculation of axial compressive load carrying capacity ( P )

Here,

$$
\begin{aligned}
& \text { Here, } \\
& \therefore
\end{aligned}
$$

$$
\begin{aligned}
P_{u} & =A_{e} f_{c r} \\
A_{e} & =2 \times 1140=2280 \mathrm{~mm}^{2} \\
P_{u} & =2280 \times 123.19 \times 10^{-3} \mathrm{kN} \\
& =280.87 \mathrm{kN}
\end{aligned}
$$

$$
\Rightarrow \quad \text { Axial load carrying capacity }(P)=\frac{280.87}{1.5}=187.25 \mathrm{kN}
$$

Q-7(c): (i) What are the precautions to be taken for labour safety during formwork construction?
[10 MARKS]
Sol: Precautions to be taken for labour safety during formwork construction are as following:

- Construction procedure should be planned in advance to ensure the safety of personnel and equipments and the integrity of the finished structure.
- Erection of safety signs and barricades to deep unauthorised personnel clear of areas in which erection, concrete placing or stripping is under way.


# GIVIL ENGINEERING - Paper I 

- Providing experienced form watchers during concrete placement to assure early recognition of possible form displacement or failure. A supply of extra shores or other material and equipment that might be needed in an emergency should be readily available.
- Provision for adequate illumination of the formwork and work area.
- Inclusion of lifting points in the design and detailing of all forms, which will be crane, handled. This is especially important in flying forms or climbing forms. In the case of wall formwork, consideration should be given to an independent scaffold bolted to the previous lift.
- Incorporation of scaffolds, working platforms and guard rails into formwork design and all formwork drawing.
- A programme of field safety inspections of formwork.
- In case structural elements such as cantilever, beams/slabs, where overturning is an important parameter, stripping of formwork should be done only after mobilization of full restraining forces.

Q-7(c): (ii) Discuss the parameters influencing the degree of compaction achieved by a vibratory roller. [10 MARKS]

Sol: Following parameters influence the degree of compaction achieved by a vibratory roller:
(i) Static weight: When the static weight of a vibratory roller is increased, keeping other factors unchanged, the static and dynamic pressures in the soil will increase more or less proportional to the weight. The depth effect of a vibratory roller is approximately proportional to the roller weight.
(ii) Number of vibratory drums: With two vibrating rolls, the number of passes can be decreased and the capacity is thereby increased.
(iii) Roller speed: An optimum roller speed is generally between 3 to $6 \mathrm{~km} / \mathrm{h}$. The speeds 3 to $4 \mathrm{~km} /$ hr is recommended for high density requirements, soils which are difficult to compact and on thick layers. Whereas higher speeds (above $4 \mathrm{~km} / \mathrm{hr}$ ) are recommended for low density requirements, and for less thick layers and on soils which are easily to compact.
(iv) Drum diameter: The drum diameter should be related to the static load. For high static weight rollers, the drum diameters must also be large and vice versa.
(v) Frequency and amplitude: Results have shown that the compaction effect has a maximum value at frequencies between 25 and 50 Hz ( 1500 and 3000 vibrations $/ \mathrm{min}$ ). An increase in amplitude gives a pronounced increase in compaction and depth effect in the entire frequency range.
For large volume soils and rock fill materials, large amplitude ranging 1.5 to 2.0 mm and frequency of 25 to 30 Hz ( 1500 to $1800 \mathrm{vibr} / \mathrm{min}$ ) are suitable. For granular base materials also the same vibration data are suitable. For asphalt compaction the optimum amplitude is 0.4 to 0.8 mm and frequency range is 33 to 50 Hz ( 2000 to 3000 vibrations $/ \mathrm{min}$ ).
(vi) Relationship between frame and drum weight: A heavy frame is advantageous, as the drum thereby is pressed down against the soil and more regular vibrations are obtained. However, there exists an upper limit for the weight of the frame above which the frame begins to excessively dampen the vibrations.
(vii) Driven or Non driven drum: A driven drum on a vibratory roller has less tendency to push the surface layer of a fill than a non driven drum. Hence, the driven drum also reduces the risk for surface cracks.
(viii) Centrifugal force: Centrifugal force does not have relationship with vibrating force transmitted to the ground. Centrifugal force increases with the square of the frequency, while the vibrating force is mainly dependent of the amplitude. A centrifugal force gives, however, a general measure of the vibration intensity (acceleration) of the drum. A vibratory roller should not have a lower drum acceleration then 4 to 5 g . At equal static weights and frequencies, the centrifugal force can also be used for a direct comparison between two roller models, since it then shows the relative difference in amplitude.
(ix) Total applied force: The total applied force defined as the sum of the static weight and centrifugal force was commonly used earlier. Since the centrifugal force is not related to the compaction effect, the total applied force can not give a correct measure of the compaction effect. Hence, the term total applied force is not used now.

Q-8(a): (i) A mass of 1000 kg is placed at the free end of a cantilever beam of span 3 m . Assume that the beam is massless compared to applied mass. The flexural rigidity of the beam is $10^{3} \mathrm{kN}$ $\mathrm{m}^{2}$. Determine the natural time period of the system. (Assume $\mathrm{g}=\mathbf{1 0} \mathrm{m} / \mathrm{s}^{2}$ )
[10 MARKS]
Sol: Given:

$$
\begin{aligned}
\mathrm{m} & =1000 \mathrm{Kg} \\
\mathrm{El} & =10^{3} \mathrm{kN}-\mathrm{m}^{2}, \\
\mathrm{~g} & =10 \mathrm{~m} / \mathrm{s}^{2} \\
\longrightarrow & \boxed{\mathrm{~m}}
\end{aligned}
$$

Flexural stiffness of a cantilever beam

$$
\mathrm{k}=\frac{3 \mathrm{EI}}{\mathrm{~L}^{3}}=\frac{3 \times 10^{3}}{3^{3}}=\frac{1000}{9} \frac{\mathrm{kN}}{\mathrm{~m}}=\frac{10^{6}}{9} \mathrm{~N} / \mathrm{m}
$$

Natural frequency $\left(\omega_{n}\right)=\sqrt{\frac{\mathrm{k}}{\mathrm{m}}}=\sqrt{\frac{\frac{10^{6}}{9}}{1000}}=10.54 \mathrm{rad} / \mathrm{sec}$
Cyclic frequency $=\frac{\omega_{n}}{2 \pi}=\frac{10.54}{2 \times \pi}=1.677 \mathrm{~Hz}$ or CPS
Natural time period of the system $=\frac{1}{f}=0.596 \mathrm{sec}$
Q-8(a): (ii) A trapezoidal combined footing supports two columns of sizes $450 \mathrm{~mm} \times 450 \mathrm{~mm}$ and 550 $m m \times 550 \mathrm{~mm}$ carrying service load of 750 kN and 1250 kN respectively. The CG of smaller column lies at $0.45 \mathbf{m}$ from the property lines. The centre-to-centre distance of two columns is 4.4 m . The total length of footing is to be restricted to 5.6 m . Determine the show the layout plan of the above footing. Consider safe bearing capacity of soil $=155 \mathbf{k N} / \mathbf{m}^{2}$.
[10 MARKS]

## Sol:



In order to obtain uniform base pressure, the C.G. of column loads should match the centroid of footing.
Total length of footing $=0.45+4.4+x$
$\begin{array}{lrl}\Rightarrow & 0.45+4.4+x & =5.6 \\ \Rightarrow & x & =0.75 \mathrm{~m}\end{array}$
Consider the weight of footing and soil weight as $10 \%$ of columns service load,

$$
\text { Centroid of load from property line }=\frac{750 \times 0.45+1250 \times(4.4+0.45)}{750+1250}=3.2 \mathrm{~m}
$$

$$
\text { Centroid in terms of } B_{1} \text { and } B_{2}=\frac{5.6}{3} \times \frac{\left(2 B_{2}+B_{1}\right)}{\left(B_{1}+B_{2}\right)}
$$

$$
\Rightarrow
$$

$$
\frac{5.6}{3} \times \frac{\left(2 \mathrm{~B}_{2}+\mathrm{B}_{1}\right)}{5.07}=3.2
$$

$$
\Rightarrow \quad 2 B_{2}+B_{1}=8.69 \mathrm{~m}
$$

$$
B_{1}+B_{2}=5.07 \mathrm{~m}
$$

$$
2 \mathrm{~B}_{2}+\mathrm{B}_{1}=8.69 \mathrm{~m}
$$

$$
\mathrm{B}_{2}=3.62 \mathrm{~m}
$$

$$
\mathrm{B}_{1}=1.45 \mathrm{~m}
$$

$$
\begin{aligned}
& \Rightarrow \quad \text { Area of footing required }=\frac{1.1 \times(1250+750)}{155}=14.19 \mathrm{~m}^{2} \\
& \text { Area of trapezoidal footing }=\frac{\left(\mathrm{B}_{1}+\mathrm{B}_{2}\right)}{2} \times 5.6=14.19 \\
& \Rightarrow \quad \mathrm{~B}_{1}+\mathrm{B}_{2}=5.07 \mathrm{~m}
\end{aligned}
$$

The layout plan of the above footing is


Q-8(b): Find the designed plastic moment for the portal frame as shown in the figure below under collapse condition for the factored (applied) loads. Assume that the frame has uniform cross-section. Also, find the minimum section required for the frame for E250 grade of steel.

Given:

| Section | ISMB | ISMB | ISMB | ISMB | ISMB | ISMB | ISMB | ISMB |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 125 | 150 | 175 | 200 | 225 | 250 | 300 | 350 |
| Plastic section modulus $\left(\mathrm{cm}^{3}\right)$ | 81 | 110 | 184 | 255 | 348 | 466 | 651 | 889 |
| 50 kN |  |  |  |  |  |  |  |  |


[20 MARKS]
Sol:


## Beam Mechanism:



From principle of virtual work

$$
\begin{aligned}
4 \mathrm{M}_{\mathrm{P}} \theta & =50 \times(3 \theta) \\
\mathrm{M}_{\mathrm{P}} & =37.5 \mathrm{kNm}
\end{aligned}
$$

## Sway Mechanism:



## Combined Mechanism:



Adopting ISMB 200 as design section.

Q-8(c): (i) Explain different types of contract. Discuss the importance of each type of contract.
[10 MARKS]

## Sol: Following are different types of contract:

1. Item rate contract or schedule contract or unit price contract.
2. Percentage rate contract.
3. Lump sum contract or fixed price contract.
4. Labour contract.
5. Material supply contract.
6. Piece work agreement.
7. Cost plus percentage rate contract.
8. Cost plus fixed fee contract.
9. Cost plus sliding or fluctuating fee scale contract.
10. Target contract.
11. Negotiated contract.
12. Turn key contract.

## Item Contract or Schedule Contract or Unit Price Contract

- In this form, the contractor undertakes the execution of a work on the item rate basis (cost per unit each item).
- For item rate contracts, contractors are required to quote rates for individual items of work on the basis of schedule of quantities furnished by the department.


## Importance:

- This type of contract is followed by Central Public work department and Railway.
- The element of uncertainty and guess is absent in item-rate contract.
- Tenders with high rates quoted by contractors may be avoided which leads smooth progress and timely completion of work.
- Detailed drawing is not required at the time of issuing of contract.
- Payment to the contractor is made by detailed measurement of different items of work actually executed.


## Percentage Rate Contract

- This is a modified form of item rate contract.
- In this form of contract, the department draws up schedule of items according to description of items mentioned in the estimate with quantities, rates, unit and amount.
- Here, contractors compete the tender by quoting their percentage rates. The contractors are to write down only the percentage above or at per or below.


## Importance:

- On the opening of the tender, the lowest rate and comparative position amongst the contractors are known.
- There is no possibility of unbalanced tender.
- Comparative statement can be prepared quickly.
- No possibility to tamper the rates by a contractor in order to be a lowest tenderer.


## Lump Sum Contract or Fixed Ratio Contract

- In this form of contract, owner provides the design, drawing, specification, schedule of rates and specifies time limit.
- In this form of contract the contractor is required to quote a fixed sum for execution of a work complete in all respects. The contractor undertakes the execution of work with all its contingencies.
- The quantities of different items of work are not provided, the contractor has to complete the work as per plan and specification irrespective of quantities of different items.
- On completion of the work no detailed measurement of different items of work is required but the whole work is compared and checked with plans and drawings.


## Importance:

- This type of contract is suitable for repetitive type works. Example: building construction etc.
- The owner has complete knowledge of the cost.
- Detailed measurements of the work done are not required to be recorded except of additions and alterations.
- Low financial risk to owner.
- The possibility of unbalanced tender is not present.


## Labour Contract

- In labour contract, the contractor undertakes contract for the labour portion.
- All materials for the construction are arranged and supplied at the site of work by the department or owner.
- The contract is on item rate basis for labour portion only.


## Importance:

- Contractor uses his own tools for working, but plants and machineries are arranged by the department or owner.
- This system of contract is not generally adopted in the Government department. Private buildings are however constructed by labour contract system.


## Material Supply Contract

- In the form of contract, contractors offer their rates for supply of the required quantity of materials of inclusive of all local taxes, carriage and delivery to the specified stores within the time fixed in the tender.


## Importance:

- It is generally for purchase of materials, viz., Bricks, stone chips, furniture, pipes etc.


## Cost Plus Percentage Rate Contract

- In this system, contractor arranges materials and labour at his cost and keeps proper account and the contractor is paid by the department or owner the whole cost together with certain percentage as profit as agreed upon before hand.
- In this case proper control in the purchase of the materials and in labour shall have to be exercised by the department or owner.


## Importance:

- This type of contract is generally adopted when labour and materials rates are liable to fluctuate.
- Contracts can quickly be drawn up and agreed.
- Work of an urgent nature can be done without delay.
- Useful to a large extent during war period when urgency prevails.
- Suitable when work cannot be executed by other type of contracts at a competitive rate due to uncertainty and fluctuation in the market rates of labour and materials.


## Cost Plus Fixed Fee Contract

- In this type of contract, the contractor is paid by the owner an agreed fixed lump sum amount above the actual cost of the work.


## Importance:

- The fixed fee paid covers overheads and profit to the contractor.
- The fee does not vary with the actual cost of the work as in the case of cost plus percentage rate contract.


## Cost Plus Sliding or Fluctuating Fee Contract

- In this type of contract, the contractor is paid by the owner the actual cost of construction plus an amount of fee inversely variable according to the increase or decrease in the estimated cost agreed earlier by both the parties.
- Thus, higher the actual cost, lower will be the value of fee and vice versa.


## Importance:

- In this case a contractor shall not try to increase the actual cost. Because interest of a contractor is totally involved with the variation of the actual cost. This is the best of the cost plus type contract.


## Target Contract

- In this type of contract, the contractor is paid on cost-plus percentage basis for work and in addition the contractor receives a percentage plus or minus on savings or excess effected against either a prior agreed estimate of total cost or a target value arrived at by measuring the work on completion and valuing prior agreed rates.


## Measured Contract or Schedule Contracts

- In this case the total cost of a work is worked out by detailed measurement of different items of work after its completion.

Note: Except lump-sum contract all other types of contracts are measured contract.

- A bill is then prepared by multiplying the measured quantities by their respective rates.
- Examples of measured contract: item rate contract, percentage contract, cost-plus type contract, material supply contract.


## Negotiated Contract

- In this form of contract, work is awarded on contract by mutual negotiation between the parties without call of tenders.

Note: The end result of negotiated contract can be lump sum or cost plus type.

## Turn Key Contract

- In this form of contract, owner deals with contractor who performs all the aspects of the project like planning, drawing, execution, maintenance etc.

Q-8(c): (ii) On a homogenous embankment, compacting rollers are used to compact silty clay soil. Determine the quantity of earth compacted if the sheeps-foot roller travels at $\mathbf{4 k m} / \mathbf{h r}$, time of rolling is 50 min, length of drum is 2.4 m , number of drums is one, fraction of overlap is $\mathbf{1 / 8}$, layer thickness is $0.45 \mathbf{m}$ and number of passes given is 5 .
[10 MARKS]

Sol:

$$
\begin{aligned}
\text { Speed of sheep foot roller }(\mathrm{V}) & =4 \mathrm{~km} / \mathrm{hr} \\
\text { Time of rolling }(\mathrm{t}) & =50 \mathrm{~min}=5 / 6 \mathrm{hr} \\
\text { Length of drum }(\ell) & =2.4 \mathrm{~m} \\
\text { Thickness of layer }(\mathrm{d}) & =0.45 \mathrm{~m} \\
\text { No. of passes }(\mathrm{N}) & =5 \\
\text { Fraction of overlap } & =\frac{1}{8} \\
\text { Correction factor for overlap }(\mathrm{C}) & =\left(1-\frac{1}{8}\right)=\frac{7}{8} \\
\text { Output of roller }\left(\mathrm{m}^{3} / \mathrm{hr}\right) & =\frac{\mathrm{V} \times \mathrm{t} \times \ell \times \mathrm{d} \times \mathrm{C}}{\mathrm{~N}} \\
\text { Output of roller }\left(\mathrm{m}^{3} / \mathrm{hr}\right) & =\frac{(4 \times 1000) \times \frac{50}{60} \times 2.4 \times 0.45 \times \frac{7}{8}}{5} \\
\text { Quantity of earth compacted } & =630 \mathrm{~m}^{3} / \mathrm{hr}
\end{aligned}
$$

