CBCS SCHEME

USN   15CV82

Eighth Semester B.E. Degree Examination, June/July 2019
Design of Pre-Stressed Concrete Elements

Time: 3 hrs.   Max. Marks: 80

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. Use of IS 1343 is permitted.

Module-1

1 a. Define pre-stressed concrete. Write any three differences between pre-tensioning and post-tensioning. **(05 Marks)**

b. Explain with neat sketch Gifford Udal system of pre-stressing. **(05 Marks)**

c. What is pressure line? plot the pressure line for a simply supported rectangular beam of size bxh subjected to uniformly distributed load and pre-stressed by a force P at a constant eccentricity of h/6 such that bottom fibre stress at midspan due to all loads and P equal to zero. **(06 Marks)**

OR

2 a. Explain the concept of load balancing in pre-stressed concrete design. **(06 Marks)**

b. A concrete beam of symmetrical I section of simply supported span 10m has width and thickness of flange 250mm and 80mm respectively. thickness of web is 80mm and overall depth of section is 500mm. The beam is pre-stressed by a parabolic cable with an eccentricity of 150mm below centriodal axis at midspan and concentric at supports. The initial and final pre-stressing force in the cabl eis 250 kN and 200 kN respectively. The beam supports a live load of 3 kN/m. Calculate the fibre stress in concrete at transfer and at working loads sketch the stress distribution. **(10 Marks)**

Module-2

3 a. List the various types of losses in pre-stressed concrete members. Explain the types of loss of pre-stress in post tensioned members only. **(06 Marks)**

b. A PSC beam 200mm × 300mm is pre-stressed with wires of area 300mm² located at an eccentricity of 100mm below centriodal axis at midsapn and zero at supports. Initial pre-stress in the wires is 1 kN/mm². The span of the beam is 10m. Calculate the loss of pre-stress and total percentage of loss of pre-stress in wires if i) the bema is pre-tensioned ii) the beam is post tensioned, using the following data :
Grade of concrete M_{40}, E_s = 210 kN/mm² shrinkage strain in concrete for pre tensioned member = 300×10^{-6}. Age of concrete at transfer for post tensioned beam = 8 days, creep coefficient = 1.6. Slip at anchorage = 2mm coefficient of friction between concrete and cable duct = 0.55. Friction coefficient for wave effect = 0.0015/m. **(10 Marks)**

OR

4 a. What are the factors affecting deflection of a PSC beam? (04 Marks)

b. A PSC beam span supported over a span of 8m is of rectangular section of size 150mm × 300mm. The beam is pre-stressed by a parabolic cable having an eccentricity of 80mm below centriodal axis at mid span and 30mm above the centriodal axis at the ends. The intial pre-stressing force in the cable is 350 kN. The beam supports a concentrated load of 10kN at midspan and uniformly distributed load of 2 kN/m over the entire span. Grade of concrete is M_{40}. Estimate the following deflection :

i) Short term deflection due to pre-stress and self weight
ii) Long-term deflection due to pre-stress, self weight and imposed loads, allowing 20% loss of pre-stress and taking creep coefficient of 1.80
iii) Check the deflection as per IS 1342–1980 requirements. (12 Marks)

Module-3

5 a. A post tensioned unbounded beam section 120mm × 300mm is pre-stressed by 7 wires of 5mm diameter with an effective cover of 50mm and effective stress of 1200 N/mm². The beam is of 7.5m span. If M_{40} concrete is used and f_p = 1600 MPa, find the ultimate flexural strength of the section. (08 Marks)

b. A post tensioned bounded Tee section has a flange width of 800m and thickness of 250mm. The thickness of web is 200mm. The area of high tensile wire is 4000 mm² located at 1200mm from top of flange. The characteristic strength of steel and concrete are 1500 N/mm² and 40 N/mm² respectively. Calculate the ultimate moment capacity of the section using IS 1343 recommendation. (08 Marks)

OR

6 Design a pre-stressed concrete beam as Type–1 member to carry a superimposed load of 12 kN/m over a simply supported span of 25m. The permissible stress in compression for concrete at transfer and working loads are 14 N/mm² and 12 N/mm² respectively. Initial stress in pre-stressing cable is 1000 N/mm². Loss of pre-stress is 20%. Adopt Freyssenet cables each of 12 wires of 5 mm diameter. (16 Marks)

Module-4

7 a. Explain different methods of improving shear resistance of PSC members. (05 Marks)

b. Explain the mechanism of shear failure in PSC beams. (05 Marks)

c. The support section of PSC beam 120mm × 250mm is required to carry an ultimate shear force of 70kN. The compressive stress at the centriodal axis is 5MPa and f_{ck} = 40 MPa, f_y = 415 MPa cover to reinforcement = 50mm. Design the suitable shear reinforcement at the section as per IS – 1343 recommendation. (06 Marks)

OR

8 a. Differentiate between web shear, flexural and flexure shear cranks in PSC members with neat sketches. **(06 Marks)**

b. A PSC beam 300mm × 1000mm is subjected to a shear force of 500kN under working loads near support section. The effective pre stressing force in the tendon is 800kN. The cable is parabolic with zero eccentricity at support and 300mm below centroidal axis at midspan. The span of the beam is 12m. If M_{40} concrete is used estimate the principal tension in concrete at support section and if required design the shear reinforcement. **(10 Marks)**

Module-5

9 a. Write a note on anchorage zone stresses. **(05 Marks)**

b. Explain end zone reinforcement. **(05 Marks)**

c. The end block of a post tensioned beam 500mm × 1000mm is pre-stressed 2 cables each comprising of 5 wires of 7mm diameter. The cable is anchored by square anchor plates 400mm × 400mm with their centre loctaed at 240mm from the top and bottom edges of the beam. The jacking force in the cable is 3000kN. Design a suitable anchorage zone reinforcement as per IS-1343 code provisions. **(06 Marks)**

OR

10 A pre tensioned rectangular beam of size 120mm × 240mm is simply supported over a span of 6m. The beam is prestressed by tendons carrying on initial pre-stressign force of 225 kN at a constan eccentricity of 40mm. The loss of pre-stress is assumed to be 15%. The beam is incorporated in a composite T-beam by casting a top flange of 450mm wide and 40mm thick. Live load on composite beam is $8kN/m^2$. Calculate the resultant stress developed in the beam assuming the pre tensioned beam is unpropped during casting of top flange if the modulus of elasticity of the flange portion and the pre tensioned beam are $28\ kN/mm^2$ and $35kN/mm^2$ respectively. Also check the composite T-beam for limit state of deflection. **(16 Marks)**

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Design of Prestressed Concrete Elements
(15CV82/17CV82) Sem: VIII

Prof. Vijaylaxmi. V.

Module-1.

Q1. a Define pre-stressed concrete. Write any three differences between pretensioning and post tensioning. (5 Marks)

Sol:- Prestressed Concrete is that compressive stresses induced by high strength steel tendons in a concrete member before loads are applied with balance the tensile stresses imposed in the member during service.

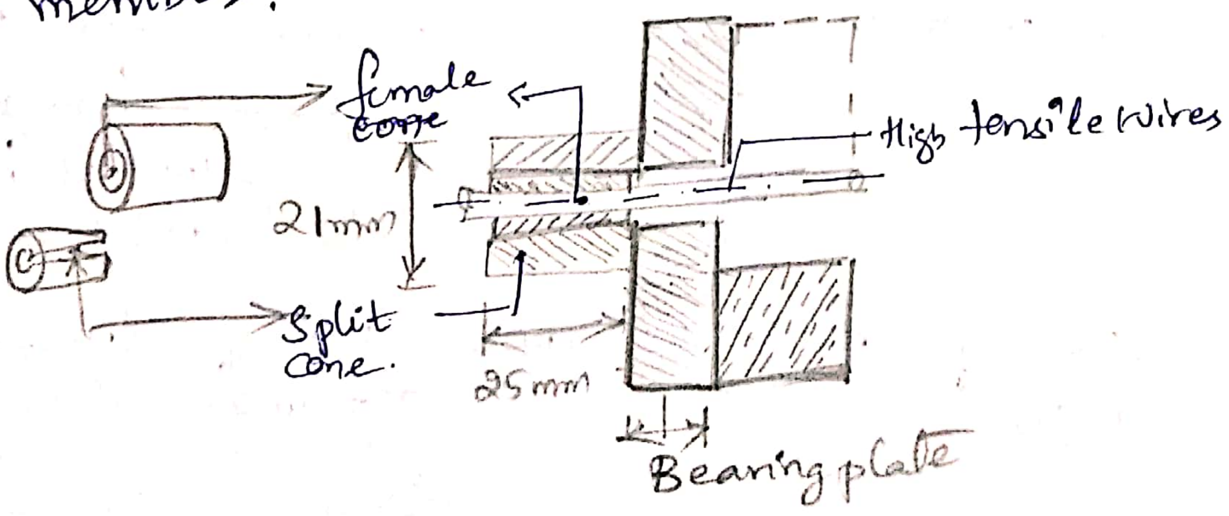
Difference between pretensioned and Post-tensioned

	Pretensioned	Post-tensioned
1.	Pretension is the technique in which we are imparting tension in strands before placing the concrete	Post tensioning is done by forming a duct in which strands are pulled (tensioned) after the concrete grain's full strength
2.	Small sections are constructed	Size of a members is not limited. Heavy long span bridges can be constructed by using this technique.
3.	Loss of strength is above 17%.	loss of strength is not more than 15%.

4.	This method is done due to bonding between Concrete and steel.	This is developed due to bearing.
5.	It is cheaper because the cost of sheathing is not involved in pretensioning	It is Costlier because cost of sheathing is required.
6.	It is more durable and reliable	Its durability depends upon the two anchorage mechanism.

b. Explain with neat sketch Gifford Udal System of pre-stressing. (05 Marks)

Sol:- This system developed in UK consists of steel split-cone and cylinderical female-cone anchorage to house the high-tensile wires bearing against steel plate. Each wire is tensioned separately and anchored by forcing a sleeve wedge into a cylinderical grip resting against a bearing plate. The ducts are generally formed by metal sheaths cast into a concrete members.



C. What is pressure line. Plot the pressure line for a simply supported ~~reg~~ rectangular beam of size b x h subjected to uniformly distributed load and prestressed by a force P at a constant eccentricity of h/6 such that bottom fibre stress at midspan due to all loads and P equal to zero. (06 Marks)

Sol:- At any given section of prestressed concrete beam, the combined effect of the prestressed force and the externally applied load will result in distribution of concrete stresses that can be resolved into a single force. The locus of the point of application of this resultant force in any structure is termed as "pressure line". The concept of pressure line is very useful in understanding the load carrying mechanism of a prestressed concrete section. Pressure line depends on magnitude and direction of the moment applied at the cross section.

* So consider a beam which is prestressed by a force P acting at eccentricity $e = \frac{h}{6}$ carrying UDL of intensity 'q'. The load is of such magnitude that the bottom fibre stress at the central span section of the beam is zero.

* At the centre of span section the ~~extoal~~ external loading is such that the resultant stress developed is maximum at the top fibre and zero at the bottom fibre and for this section the pressure line has shifted towards the top fibre by an amount equal to h/3 from its initial position.

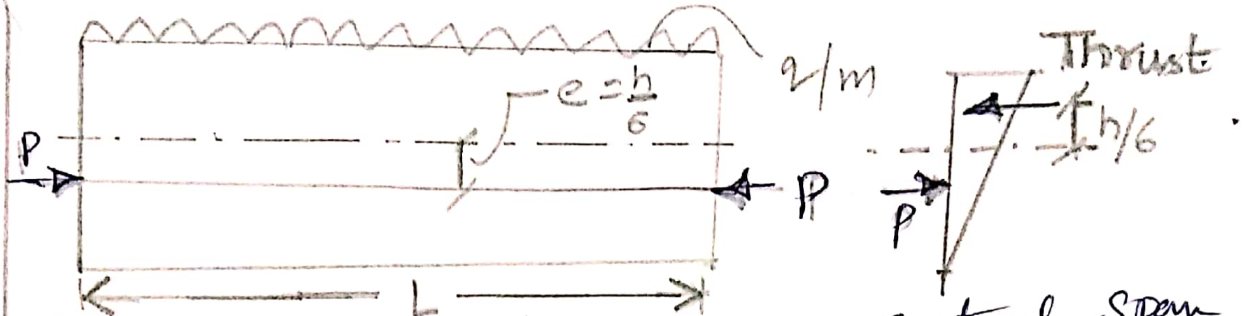
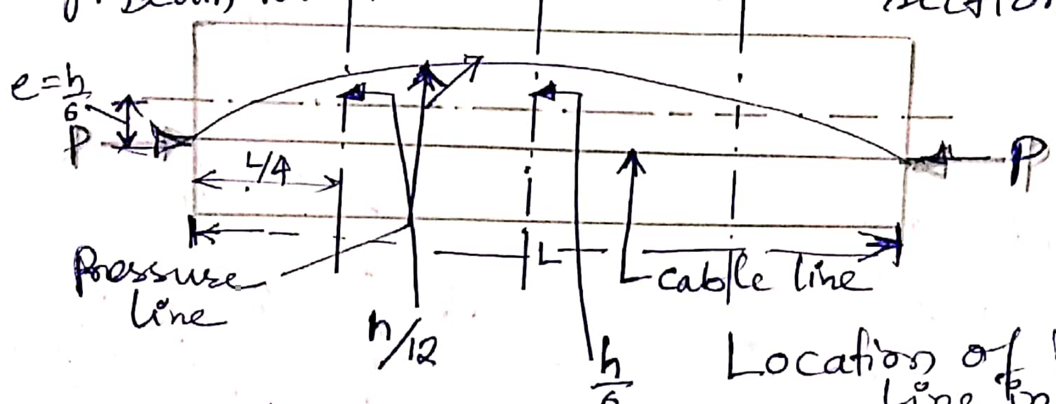


fig: Beam with Eccentric Tendons



Location of Pressure Line in PSC beam

Q2a Explain the concept of load Balancing in prestressed concrete design. (6Marks)

Sol: load Balancing is defined as the methodical and efficient distribution of Network or ~~applied~~ application traffic across multiple servers in a server farm. Each load balancers sits between client devices and backend servers, receiving and then distributing incoming requests to any available server capable of fulfilling them.

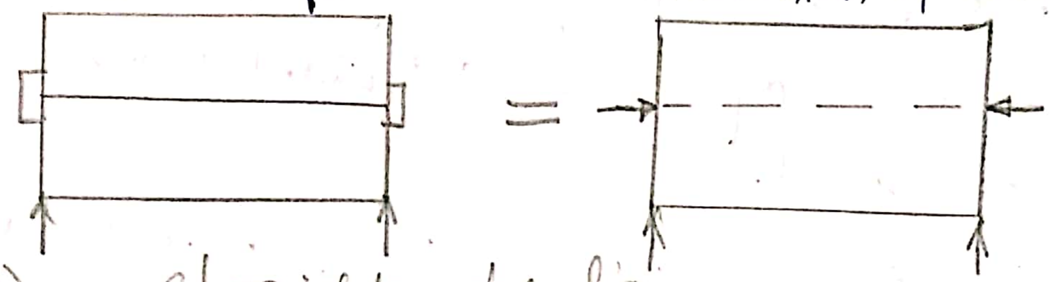
Concept: The concept of load balancing is introduced for prestressed Concrete Structures as a third approach after the elastic stress and the ultimate strength methods of design and analysis. It is first applied to simple beams and cantilever and then to continuous Beams and Rigid frames. Principles of load balancing for flat slabs, grid system and certain forms of shell and folded plates are introduced.

→ To select suitable Cable profile in a prestressed concrete member such that the transverse component of the Cable force balance the given type of external load, this can be done by load balancing concept.

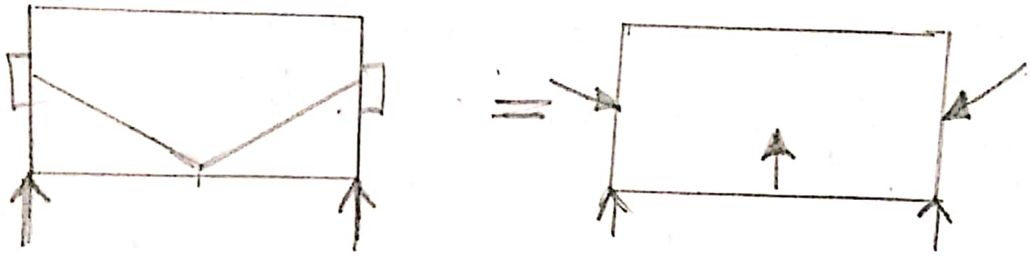
→ The various types of reactions of a Cable upon a concrete Member depend upon the shape of a Cable profile. Straight portion of the Cable do not induce any reaction except at the end, while curved Cable result in uniformly distributed loads. sharp angles in a Cable induce concentrated loads. The concept of load balancing is useful in selecting the tendon profile, which can supply the most desirable system of forces in concrete.

→ This requirement can be satisfied if the Cable profile in a prestressed member corresponds to the shape of the bending Moment diagram resulting from the extranal external load. Thus, if the beam supports two concentrated loads, the Cable should follow a trapezoidal profile. If the beam is supports uniformly distributed loads, the corresponding tendon should follow a parabolic profile. The principle of load balancing is shown

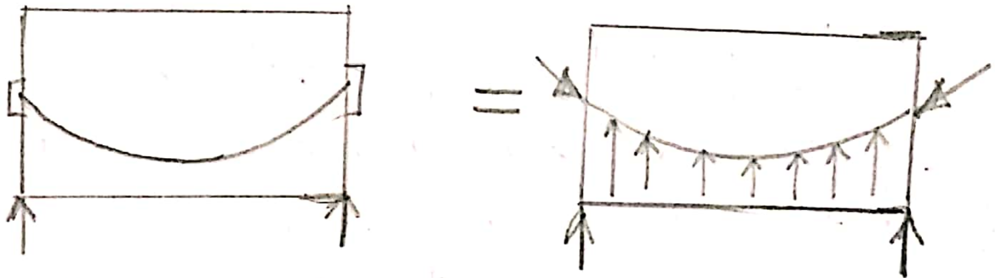
Cable Profile | Reaction of Cable



a) straight tendon.



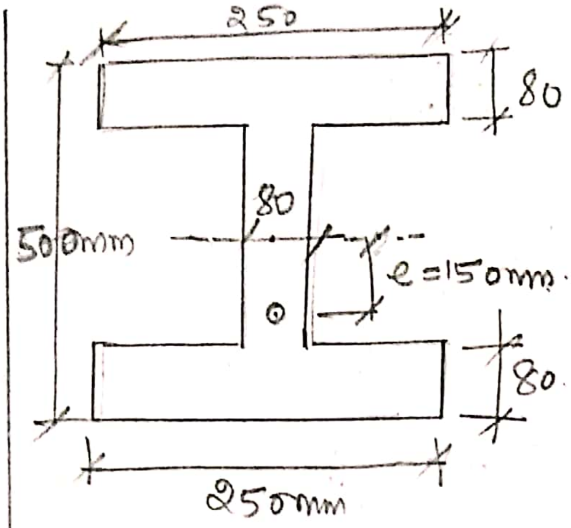
b) Bent tendon.

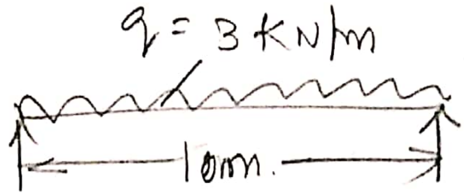


c) Curved tendon.

Q 2 b A Concrete beam of Symmentrical I section of SSB span 10m has width and thickness of flange 250mm and 80 mm respectively, thickness of Web is 80mm and over all depth of section is 500mm. The beam is prestressed by a parabolic Cable with an eccentricity of 150mm below Centriodal Axis at Midspan and concentric at supports. The initial and final prestressing force in the Cable is 250 KN and 200 KN respectively. The beam supports a live load of 3 KN/m Calculate the fibre stress in Concrete at transfer and at Working load, sketch the stress distribution. (10 Marks)

Sol:-





P = 50 kN (Since initial Prestressing = 250 & final Prestressing 200 KN).

e = 150 mm

q = 3 KN/m

L = 10m

$\therefore$ Area = $(2 \times 250 \times 80) + (340 \times 80)$

$= 67200 \text{ mm}^2$

$g = (0.0672 \times 24) = 1.6128 \text{ KN/m}$

$\therefore I = \left(\frac{250 \times 500^3}{12}\right) - \left(\frac{(250-80) \times 340^3}{12}\right)$.

$= \left(\frac{250 \times 500^3}{12}\right) - \left(\frac{170 \times 340^3}{12}\right) = 2.0472 \times 10^9 \text{ mm}^4$

$Z = Z_t = Z_b = \frac{I}{y} = \frac{2.0472 \times 10^9}{250} = 8.18 \times 10^6 \text{ mm}^3$

$M_g = \frac{wL^2}{8} = \frac{1.6128 \times 10^2}{8} = 20.16 \text{ KNm}$

$M_q = \frac{wL^2}{8} = \frac{3 \times 10^2}{8} = 37.5 \text{ KNm}$

Resultant stress.

$\frac{P}{A} = \frac{50 \times 10^3}{67200} = 0.744$ ~~KNm~~ N/mm^2

$\frac{Pe}{Z} = \frac{50 \times 10^3 \times 150}{8.18 \times 10^6} = 0.916$ ~~KN/m~~ m^2

$\frac{M_g}{Z} = \frac{20.16 \times 10^6}{8.18 \times 10^6} = 2.464 \text{ N/mm}^2$.

$$\frac{M_q}{Z} = \frac{37.5\times10^6}{8.18\times10^6} = 4.584\ N/mm^2$$

Case 1) Prestress + Self weight

Top fibre = $f_t = 0.744 - 0.916 + 2.464 = 2.292\ N/mm^2$

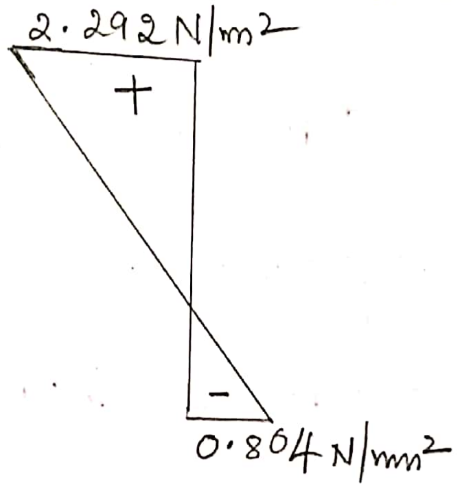
Bottom fibre = $f_b = 0.744 + 0.916 - 2.464 = -0.804\ N/mm^2$

Case 2) Prestress + Selfweight + Liveload.

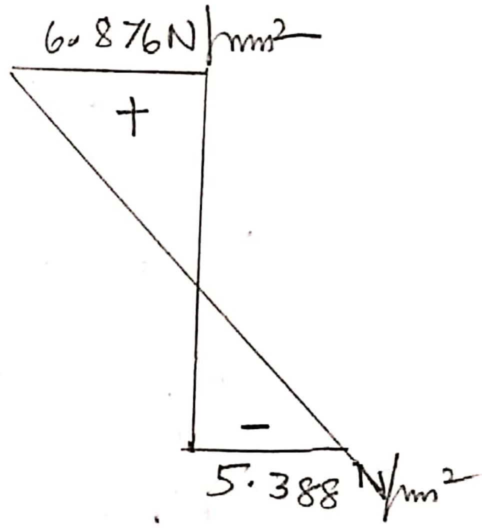
Top fibre $f_t = 0.744 - 0.916 + 2.464 + 4.584$
$= 6.876\ N/mm^2$

Bottom fibre $f_b = 0.744 + 0.916 - 2.464 - 4.584$
$= -5.388\ N/mm^2$

1).



2).



Module-2

Q3a List various types of losses in Prestressed Concrete members. Explain the types of loss of Prestress in Post tensioned Members only. (6 Marks)

Sol:- Different types of losses:-

1) Elastic deformation of Concrete
2) Relaxation of stress in steel.

3) Shrinkage of Concrete
4) Creep of Concrete
5) Friction
6) Anchorage slip.

I Explaination - for loss of Prestress due to Friction.

In Case of Post-tensioned members, the tendons are housed in duct preformed in Concrete. The ducts are either straight or follow a curved profile depending upon the design requirement Loss of Stress occur in Post tensioned member due to friction between the tendon and the surroundi-ng concrete duct. The magnitude of this loss is of the following type-

1) Loss of stress due to the Curvature effect which dependsupon the tendon form or alignment which follow curved profile along the length of the beam

2) Loss of Stress due to the Wobble effect, which depends upon the local deviations in the alignment of the Cable. The Wobble or Wave effect is the result of accidental or un-avoidable misalignment, since ducts or sheath cannot be perfectly located to follow a predet-ermined profile throughout the length of the beam.

The magnitude of the Prestressing force P_x at a distance 'x' from the tensioning end follows an exponential function of the type.

$$P_x = P_0 e^{-(\mu\alpha + Kx)}$$

where P_0 = prestressing force at the Jacking end

μ = coefficient of friction between the Cable and Duct

0.55 for steel moving on smooth Concrete

0.35 for Steel moving on steel fixed to duct.

α = the Cumulative angle in radians through which the tangent to the Cable profile has turned between any two points under consideration.

K = friction Co-efficient for wave effect

e = 2.7183

value for the friction Coefficient for wave effect K:

0.15 per 100m for normal Condition.

1.5 per 100m for thin walled duct and where heavy vibrations are encountered.

III loss of Prestress due to Anchor slip.

When the Cable is tensioned and the Jack is released to transfer prestress to Concrete the friction Wedges, employed to grip the wires slip over a small distance before the wire are firmly housed between the Wedges. The magnitude of slip depends upon the type of wedge and the Stress in the Wires.

Scanned with CamScanner

The magnitude of the loss of stress due to the slip in anchorage is computed as

if Δ = slip of anchorage mm

L = length of the cable mm

A = Cross sectional area of the cable mm^2

E_s = Modulus of Elasticity of steel N/mm^2

P = prestressing force in the cable N.

$$\left(\frac{PL}{AE_s}\right) = \Delta.$$

∴ loss of stress due to anchorage slip

$$\frac{P}{A} = \frac{E_s \Delta}{L}$$

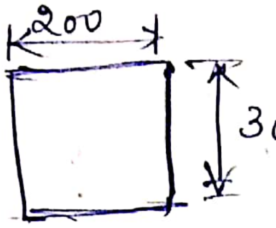
Q3 b A PSC beam 200x300 is prestressed with wire of area 300 mm^2 located at an eccentricity of 100mm below centroidal axis at Midspan and zero at supports. Initial prestress in the wires is 1 kN/mm^2. The span of the beam is 10m. Calculate the loss of Prestress and total percentage of loss of Prestress in wires if 1) The Beam is Pre-tensioned 2) The beam is post-tensioned, using the following data.

E_s = 210 kN/mm^2, Shrinkage Strain in concrete for pretensioned member = 300×10^{-6}, Age of concrete at transfer for Post tensioned = 8 days

Creep coefficient = 1.6 slip at anchorage = 2mm

Coefficient of friction between the concrete and Cable Just = 0.55. Friction coefficient for Wave effect = 0.0015m

(10Marks)



$A = 300 mm^2$

Initial Prestress $= 1 \, KN/mm^2$

$= 1000 \, N/mm^2$

Span of beam $= 10m$

Prestressing force $= \frac{300 \times 1000}{1000} = 300 \, KN$.

$A = 6 \times 10^4 mm^2$; slope $\frac{2 \times 4e}{L} = \frac{2 \times 4 \times 0.1}{10} = 0.08$

$\alpha = \frac{210}{40} = 5.25$

$I = \frac{bd^3}{12} = \frac{200 \times 300^3}{12} = 450 \times 10^6 mm^4$

Stress in Concrete at the level of steel

$= \left[\frac{300 \times 10^3}{6 \times 10^4} + \frac{300 \times 10^3 \times 100 \times 100}{450 \times 10^6}\right] = f_c$

$5 + 6.67 \Rightarrow 11.67 \, N/mm^2$.

The Various losses are:-

Type of loss	Pretensioned	Post tensioned.
1) Elastic Deformation of Concrete	$\alpha_e \times f_c = 5.25 \times 11.67 = 61.26 \, N/mm^2$	—
2) Relaxation of Stress in Steel	5% of 1000 = 50 N/mm^2	5% of 1000 = 50 N/mm^2
3) Creep of Concrete	$\phi \times f_c \times \alpha_e = 1.6 \times 5.25 \times 11.67 = 98.02 \, N/mm^2$	$1.6 \times 5.25 \times 11.67 = 98.02 \, N/mm^2$
4) Shrinkage of Concrete	$300 \times 10^{-6} \times 210 \times 10^3 = 63 \, N/mm^2$	$\frac{200 \times 10^{-6}}{\log_{10}(8+2)} \times 210 \times 10^3 = 42 \, N/mm^2$
5) Slip at anchorage.	—	$\frac{2 \times 210 \times 10^3}{10 \times 10^3} = 42 \, N/mm^2$

6)	Friction effect	—	$P_o(\mu\alpha + Kx)$ $= 1000 \times (0.55 \times 0.08 + 0.015 \times 10)$ $= 59\ N/mm^2$

∴ Total loss →

1) Pretensioned = 272.28 N/mm²

∴ Percentage loss of stress = 27.2% ~~N/mm²~~
27.2 %

2) Post-tensioned = 291.02 N/mm²

∴ Percentage loss of stress = 29.10 %

Q4a What are the factors affecting deflection of a PSC beam? (4Marks)

Sol: 1. Imposed load and self weight
2. Magnitude of the prestressing force
3. Cable Profile
4. Second Moment of area of cross-section
5. Modulus of Elasticity of concrete
6. Shrinkage, creep and relaxation of steel stress
7. Span of the Member
8. Fixity Conditions.

Q4 b. A PSC beam span supported over a span of 8m is of ~~rec~~ rectangular section of size 150mm x 300mm. The beam is prestressed by a parabolic cable having an eccentricity of 80 mm below centroidal axis at midspan and 30mm above the centroidal axis at the ends. The initial prestressing force in the cable is 350KN. The beam (12Marks) supports a Concentrated load of 10 kN at Mid span and UDL of 2 kN/m over the entire span Grade of Concrete of M_{40}. Estimate the following deflection

1) Short term deflection due to Prestress and Self weight

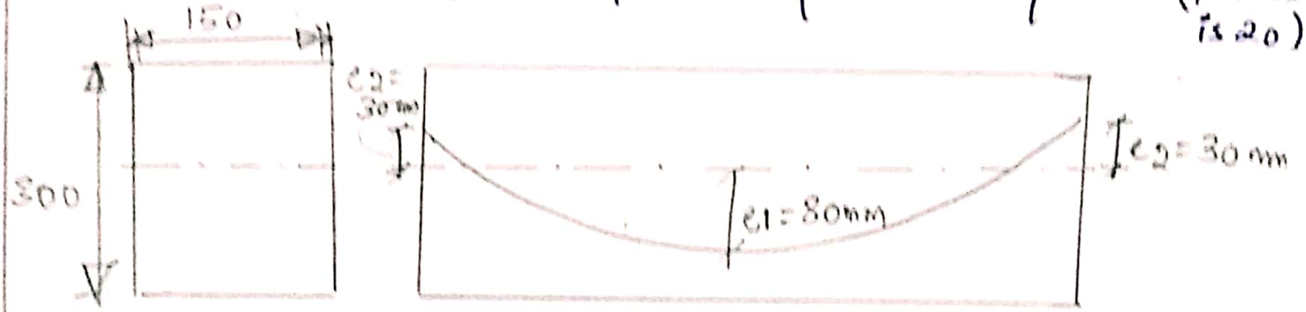
2) long term deflection due to prestress, self weight and imposed load allowing 20% loss of prestress and take Creep coefficient of 1.8

3) check the deflection per IS 1343-1980 req.

(12 Marks)

Sol: $P = 350\,kN$ $e_1 = 80\,mm$ $e_2 = 30\,mm$

$L = 8\,m$ $E_c = 40\,kN/mm^2$ $\phi = 1.8$ $\eta = 0.8$ (% loss is 20)



$Q = 10\,kN$ $q = 2\,kN/m = 0.002\,kN/mm$

$g = 0.15 \times 0.3 \times 24 = 1.08\,kN/m = 0.00108\,kN/mm$.

$I = \frac{bd^3}{12} = \frac{150 \times 300^3}{12} = 3.375 \times 10^8\,mm^4$

Deflection due to selfweight $a_g = \frac{5 g L^4}{384 EI}$

$= \frac{5 \times 0.00108 \times 8000^4}{384 \times 40 \times 3.375 \times 10^8} = 4.26$ (Downward)

Deflection due to Prestress $\frac{PL^2(-5e_1+e_2)}{48EI}$

$\frac{350\times 8000^2(-5\times 80+30)}{48\times 40\times 3.375\times 10^8} = -12.79$ mm (Upward)

Deflection due to Concentrated load $= \frac{QL^3}{48EI}$

$= \frac{10\times 8000^3}{48\times 40\times 3.375\times 10^8} = 7.90$ mm.

i) Short term Deflection = Prestress + selfweight

$-12.79+4.26 = -8.53$ mm (Downward)

ii) Long-term Deflection = Prestress + selfweight + imposed load $\Rightarrow [\eta\times \text{Prestress} + \text{Selfwt} + \text{Con. load}]\times(1+\phi)$

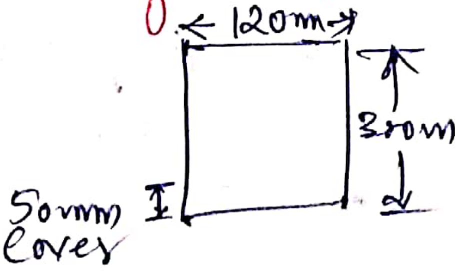
$\Rightarrow [0.8(-12.79)+4.26+7.9](1+1.8)$

$= 5.398$ mm (Downward).

Module 3.

Q5a. A Post tensioned Unbounded beam section 120mm x 300mm is Prestressed by 7 Wires of 5mm Diameter with an effective Cover of 50mm and effective stress of 1200 N/mm². The beam is 7.5m span If M_{40} Concrete is used and $f_p = 1600$ MPa. Find the Ultimate flexural Strength of the section. (8 Marks)

Sol:



$f_{ck} = 40$ N/mm²

$f_p = 1600$ MPa

$A_p = \frac{\pi}{4}\times 5^2\times 7 \text{ Nos} = 137.4 \text{ mm}^2$

Effective depth = 300 − 50 = 250 mm.

Span of Beam = 7.5 m = 7500 mm.

$\therefore \dfrac{\text{Effective span}}{\text{Effective depth}} = \dfrac{7500}{250} = 30$

Effective Reinforcement Ratio is

$\dfrac{f_{pe} A_p}{b d f_{ck}} = \dfrac{1200 \times 137.4}{120 \times (300-50) \times 40} \Rightarrow 0.1374$.

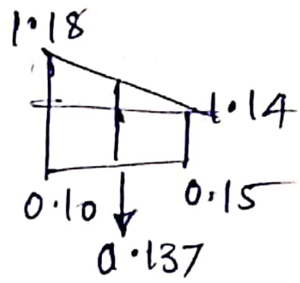
Refer Table 12 of IS 1343-1980

For $\dfrac{f_{pu}}{f_{pe}}$ – By interpolation.

0.10 → 1.18

0.137

0.15 → 1.14



$\Rightarrow \dfrac{0.04}{0.05} = \dfrac{?}{0.013}$

$\Rightarrow 0.0104 + 1.14 = 1.1504$

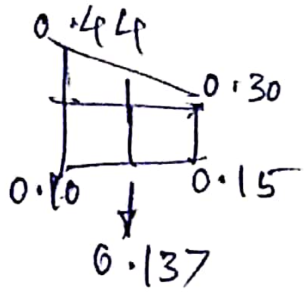
$\dfrac{f_{pu}}{f_{pe}}$ $\therefore f_{pu} = 1200 \times 1.1504 = 1380.4\ N/mm^2$

For $\dfrac{x_u}{d}$ – By interpolation.

0.10 → 0.30

0.137

0.15 → 0.44



$\Rightarrow \dfrac{0.14}{0.05} = \dfrac{?}{0.013}$

$\Rightarrow 0.0364 + 0.30 = \underline{0.3364}$

$\frac{x_u}{d} = 0.3364$

$\therefore x_u = 0.3364 \times 250 = 84.1\,mm.$

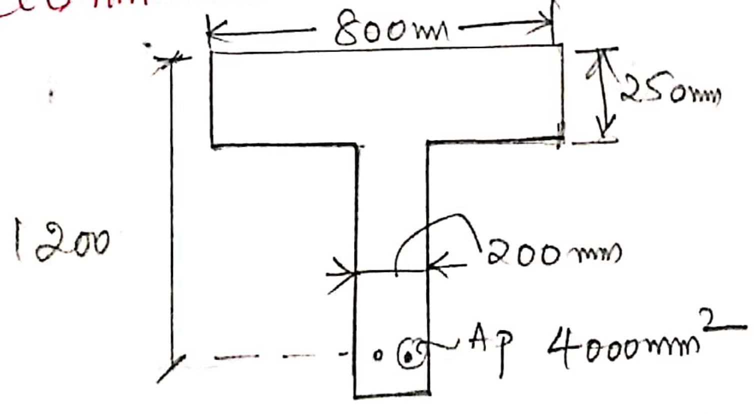
$x_u < D_f$ or D, The Neutral Axis lies with in the flange.

The Ultimate flexural strength of the un bonded beam is $= M_u = A_p \times f_{pu} \times (d - 0.42 x_u)$

$M_u = 137.4 \times 1380.4 \times (250 - 0.42 \times 84.1)$

$= M_u\ \underline{40.71 \times 10^6}\ Nmm.$

b. A Post tensioned Tee section has a flange width of 800mm and thickness of 250mm. The thickness of Web is 200mm. The area of high tensile wire is 4000 mm^2 located at 1200 mm from top of flange. The characteristic strength of steel and Concrete are 1500 N/mm^2 and 40 N/mm^2 respectively. Calculate the ultimate Moment Capacity of the Section using IS 1343 recommended. (8 Marks)



$f_{ck} = 40\,N/mm^2$

$f_p = 1500\,N/mm^2$

$b_w = 200mm$

$$\frac{A_p f_p}{b d f_{ck}} = \frac{4000 \times 1500}{800 \times 1200 \times 40} = 0.156$$

Refer Table.

$$A_p = (A_{pw} + A_{pf})$$

$$A_{pf} = 0.45 f_{ck} (b - b_w) \times \frac{D_f}{f_p}$$

$$= 0.45 \times 40 (800 - 200) \times \frac{250}{1500}$$

$$= 1800 \ mm^2$$

$$A_{pw} = 4000 - 1800 = 2200 \ m^2$$

$$\therefore A_{pw} = 2200 \ m^2$$

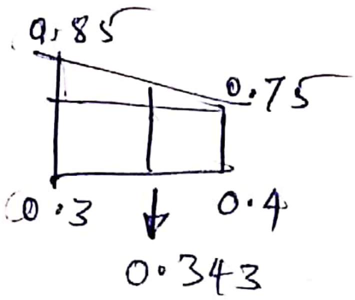
Also

$$\frac{A_{pw} \times f_p}{b_w d f_{ck}} = \frac{2200 \times 1500}{200 \times 1200 \times 40} = 0.343$$

Refer Table-11 pg-59 IS 1343-1986

$$\frac{f_{pu}}{0.87 f_p} =$$

0.30	0.85
0.343 →	?
0.40	0.75



$$\frac{0.1}{0.1} = \frac{?}{0.057}$$

$$\Rightarrow 0.057 + 0.75 = 0.807$$

$f_{pu} = 0.87 \times f_p \times 0.807$

$= 0.87 \times 1500 \times 0.807$

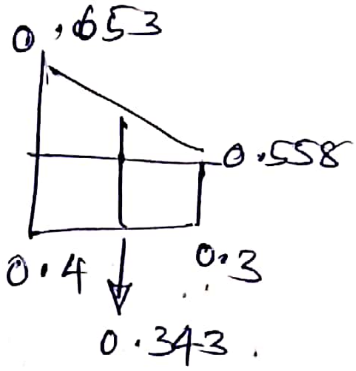
$1053.13 \ N/mm^2$

For $\frac{x_u}{d}$ Refer Table 11 pg 59 IS43-1980.

$0.3 \rightarrow 0.558$

0.343

$0.4 \rightarrow 0.653$



$\frac{0.095}{0.1} = \frac{?}{0.043}$

$\Rightarrow 0.040 + 0.558 = \underline{0.598}$

$\therefore x_u = 0.598 \times d = 0.598 \times 1200 = 717.6$ mm.

Hence $x_u > D_f$

$M_u = f_{pu} A_{pw} (d - 0.42 x_u) + 0.45 f_{ck} (b - b_w) D_f (d - 0.5 D_f)]$

$= [1053.13 \times 2200 (1200 - 0.42 \times 717.6) + 0.45 \times 40 (800 - 200) \times 250 (1200 - 0.5 \times 250)]$

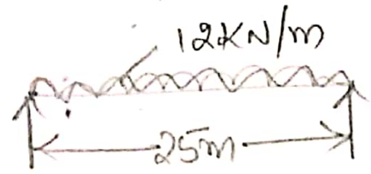
$\Rightarrow 1053.13 \times 2200 \times (898.6) + 0.45 \times 40 \times 600 \times 250 \times 1075$

$= M_u = 4.98 \times 10^9$ N mm.

Q6. Design a prestressed Concrete Beam of Type I member to carry a super imposed load of 12 KN/m over a SSB of span 25m

The permissible stress in Compression for Concrete at transfer and working load are 14 N/mm² and 12 N/mm². Initial Stress in Prestressing Cable is 1000 N/mm², Loss of Prestress is 20%. Adopt Freyssinet Cable each of 12 Wires of 5mm diameter. (16 Marks)

Sol:-



Effective span 25m ; $q = 12\ KN/m$; $f_{ck} = 50\ N/mm^2$
(Assuming f_{ck})

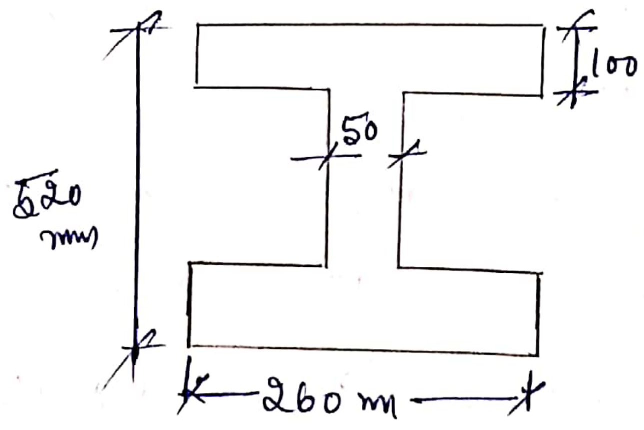
$f_{ct} = 14\ N/mm^2$; $f_{cw} = 16\ N/mm^2$; $\eta = 0.8$

Area = $12\ Nos \times \frac{\pi}{4} \times 5^2 = 235.62\ mm^2$

Assuming a cross section for I member

Initial stress in steel = $1000\ N/mm^2$

Loss Ratio = 0.8



$A = 68000\ mm^2$

$Z = 9.51 \times 10^6\ mm^3$

Design Calculation -

i) Ultimate Moment and shear

$$\frac{W_{min}}{W_{ud}} = \frac{7.5 \times 2400 \times 9.81 \times 0.125 \times 25 \times 25}{50 \times 10^6 \times 0.85^2}$$

$$= 0.381$$

there,

$\frac{L}{h}$ is 25 for SSB, 32 for fixed beam, 15 for Cantilever,

$\frac{d}{h} = 0.85$ to 0.95

$K = 6$ to 7.5 for Rectangular section & I Section & 4 to 5 for flanged T or I section girder

g = acceleration due to gravity

$\beta = 0.125$

$$\frac{W_{min}}{W_{ud}} = \left[\frac{K D g \beta (L/h) L}{f_{cu} (d/h)^2}\right]$$

$$W_{ud} = \left[\frac{\gamma_{f_1} q}{1 - \gamma_{f_2} \left(\frac{W_{min}}{W_{ud}}\right)}\right] = \left[\frac{2.5 \times 12}{1 - 1.5 \times 0.381}\right]$$

$W_{ud} = 70.0$ KN/m

(By Taking factored load $\gamma_{f_1} = 2.5$, $\gamma_{f_2} = 1.5$ for dead load & live load).

$W_{min} = 0.381 \times 70 = 26.67$ KN/m

$M_u = 0.125 \times 70 \times 25^2 = 633.75$ kNm

$V_u = 0.5 \times 70 \times 25^2 = 875$ kN

$M_g = 0.125 \times 26.67 \times 25^2 = 2083.59$ kNm

$M_q = 0.125 \times 12 \times 25^2 = 937.5$ kNm

2) Cross Sectional dimensions.

for flanged section $M_u = 0.10 f_{ck} b d^2$

if $b = 0.5d$

$$\therefore d = \sqrt[3]{\frac{633.75 \times 10^6}{0.1 \times 50 \times 0.5}} = 632.88 \simeq 635 \text{ mm}$$

$d = 635$ mm.

$$\frac{d}{h} = 0.85 \quad \therefore h = 747.05$$

Take $h = 750$ mm.

1) Adopt effective depth = 635 mm

2) Over all depth = 720 mm.

The dimension adopted will be redesign for I Section.

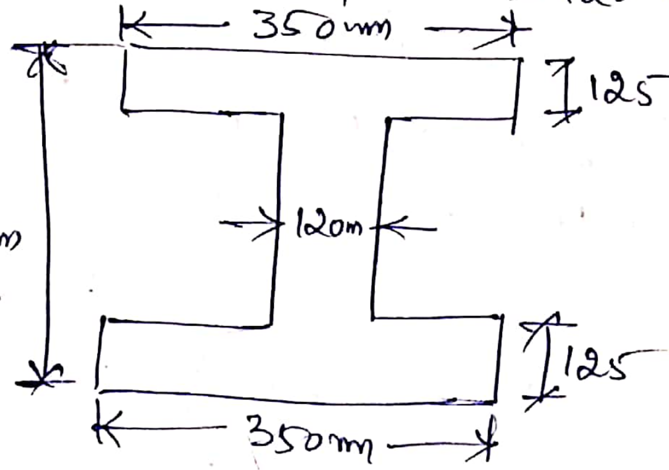
∴ Width of flange = 260 mm (earlier)

3) Adopt 350 mm

4) Thickness of flange = $0.2 \times 635 = 127$ mm

5) Adopt thickness of Web = 120 mm. ≈ 125 mm (Adopt)

∴



$$A = (350 \times 125 \times 2) + 470 \times 120$$
$$= 1.43 \times 10^5 \text{ mm}^2$$

$$I = \frac{350 \times 720^3}{12} - \frac{230 \times 470^3}{12} \Rightarrow 8.89 \times 10^9 \text{ mm}^4$$

$$Z = \frac{I}{y} = 2.469 \times 10^7\ mm^3$$

3) Minimum Section Modulus :-

$f_{br} = \eta f_{ct} - f_{tw}$ For type 1 Members

$f_{tt} = f_{tw} = 0 \therefore f_{tw} = 0.$

$$Z_b = \left[\frac{M_q + (1-\eta) M_g}{f_{br}}\right]$$

So here $f_{br} \Rightarrow (\eta f_{ct} - f_{tw}) = (0.8 \times 14 - 0) = 11.2$

$f_{br} = 11.2\ N/mm^2$

$$\therefore Z_b \geq \left[\frac{937.5 + (1-0.8) 2083.59}{11.2}\right]$$

$120.91\ mm^3$

Provided is greater than permissible value.

4). Prestressing force & Eccentricity

The Number of 12 Wires of 5mm ϕ stress by $1000\ N/mm^2$ is given by

$S = \frac{F}{A}$ Therefore Prestressing force is $F = S \times A$

$$F = \frac{1000 \times \frac{\pi}{4} \times 5^2 \times 12}{1000} = 235.62\ KN.$$

$$P = \frac{A (f_{int} Z_b + f_{sup} Z_t)}{Z_t + Z_b}.$$

$$f_{int} = \frac{f_{tw}}{\eta} + \frac{M_q + M_g}{\eta Z_b} = \left[0 + \frac{3021.09}{0.8 \times 2.469 \times 10^7}\right]$$

$f_{inf} = 1.53 \times 10^{-4}\ N/mm^2$

$f_{sup} = f_{tt} - \frac{M_g}{Z_t} = 0 - \frac{2083.59}{2.469 \times 10^{7}} = -8.43 \times 10^{-5}\ N/mm^2$

$$P = \frac{1.43 \times 10^5 \times (1.53 \times 10^{-4} - 8.43 \times 10^{-5})\ 2.469 \times 10^7}{2 \times 2.469 \times 10^7}$$

$\therefore P = 4.912\ kN.$

Hence Sufficient.

Eccentricity $e = \frac{Z_t Z_b (f_{inf} - f_{sup})}{A (f_{sup} Z_t + Z_{inf} Z_b)}$

$$e = \frac{(2.469 \times 10^7)^2 (1.53 \times 10^{-4} + 8.43 \times 10^{-5})}{1.43 \times 10^5 \times (-8.43 \times 10^{-5} + 1.53 \times 10^{-4}) \times 2.469 \times 10^7}$$

$e = \frac{1.4465 \times 10^{11}}{242.55 \times 10^6} = 596.37\ mm.$

5) Check for Ultimate Strength

$A_{ps} = \frac{\pi}{4} \times 5^2 \times 12 = 235.6\ mm^2$

$f_{pu} = 1600\ N/mm^2 \quad f_{cu} = 50\ N/mm^2$

(Assuming) $b = 350\,mm \quad d = 635\,mm$

$\frac{A_{ps} f_{pu}}{b d f_{cu}} = \frac{235.6 \times 1600}{350 \times 635 \times 50} = 0.034$

$\frac{f_{pe}}{f_{pu}} = 0.5$

Refer Table No. 7.3 of Design of Prestressed Concrete.

$$\frac{f_{pb}}{0.87 f_{pu}} = 1.0$$

$\Rightarrow f_{pb} = 1.0 \times 0.87 \times 1600 = 1392\ N/mm^2$

$$\frac{x}{d_o} = 0.11$$

$\therefore x_u = 0.11 \times 635 = 69.85$ mm 635 69.85

$M_u = A_{ps} f_{pb} (d - 0.45x) = 235.6 \times 1392 (d - 0.45 x_u)$

$M_u =$ ~~197.94 KNM~~ 197.94×10^6 Nmm.

6) check for limit state of Deflection.

Permissible deflection $= \frac{Span}{250} = \frac{25 \times 10^3}{250} = 100$ m.

Deflection due to Prestress

$a_p = \frac{PeL^2}{8EI} = 7.57 \times 10^{-4}$ mm By Taking $P = 235.62$ KN

$a_p = 36.32$ mm

By Assuming $E = 34 KN/mm^2$

Deflection due to live load & Dead load

$$a(g+q) = \frac{5}{384}\left(\frac{(g+q)L^4}{EI}\right)$$

$$= \frac{5}{384}\left[\frac{(3.43+12)(25\times10^3)^4}{34\times10^3 \times 8.89 \times 10^9}\right] = 1.66 \times 10^{-7} mm$$

There $g =$ Area $\times$ ρ_e $= 3.43$ KN/m

$q = 12$ KN/m

The long term Modulus of Elasticity of Concrete is expressed a

$$\frac{E_c}{1+\phi}$$

Assume $\phi = 1.6$

$E_c = 2.6\ E_{ce}$

Using long term Modulus for dead load and short term Modulus for live loads, the resultant deflection is estimated to be

$$\left[(2.6 \times \text{Def. due to selfwt}) + (\text{Def. due to live load}) - 0.8 \times \text{Def. due to Prestressing}\right]$$

∴ Deflection due to Dead load

$$\frac{5}{384}\left(\frac{gL^4}{EI}\right) = \frac{5}{384}\left(\frac{3.43 \times (25000)^4}{34 \times 10^3 \times 8.89 \times 10^9}\right)$$

$\Rightarrow$ 57.51 mm.

Deflection due to live load.

$$\frac{5}{384}\left(\frac{qL^4}{EI}\right) = \frac{5}{384} \times \left(\frac{12 \times (25000)^4}{34 \times 10^3 \times 8.89 \times 10^9}\right)$$

$\Rightarrow$ 201.93 mm.

$\Rightarrow$ $2.6 \times 57.51 + (201.93) - (0.8 \times 36.32)$

322.4 mm

Module - 4

Q7a Explain different Methods of improving Shear resistance of PSC Members. (5 Marks)

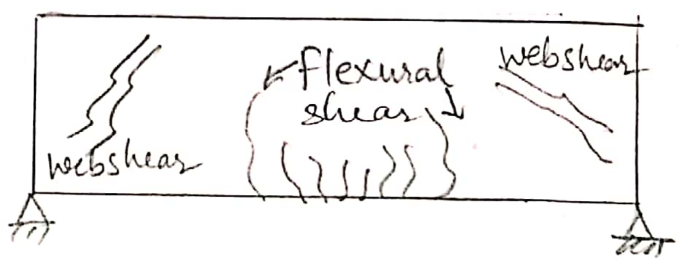
Sol. 1) Horizontal or axial Prestressing

2) Prestressing by inclined or sloped cables

3) Vertical or transverse Prestressing.

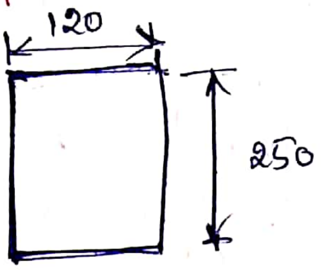
Q7b. Explain the Mechanism of shear failure in PSC beams. (05Marks)

Sol. In PSC beams two major Modes of shear cracking take place. Web shear and flexure shear. Web shear start from a interior point when the local principal tensile stress exceeds the tensile strength of concrete. Web shear crack are likely to develop in highly Prestressed beams with thin webs when the beam is subjected to Large concentrated load near a simple support.
Flexure shear cracks are first initiated by flexural cracks in the inclined direction. Flexure shear cracks develop when the combined shear & flexural tensile stresses produce a principal tensile stress exceeding the tensile strength of concrete. The inclined shear cracks extend to the compression face resulting in sudden explosive failure. This is called as diagonal tensile Mode of failure.



Q7 b The support section of PSC beam 120mm x 250mm is required to carry an ultimate shear force of 70kN. The compressive stress at the centroidal axis is 5MPa and $f_{ck} = 40$ MPa

$f_y = 415\,MPa$ cover to reinforcement = 50mm.
Design of shear reinforcement at the section as per IS 1343-1980 recommendation (6 Marks)



$D = 250$ m
$b = 100$ m
$V = 70$ KN.
$f_{cp} = 5\,N/mm^2$

$f_t = 0.24\sqrt{f_{ck}}$
$\Rightarrow 0.24\sqrt{40}$
$= 1.517\,N/mm^2$

For the support section uncracked in flexure

$$V_{co} = 0.67\,bD\sqrt{f_t^2 + 0.8 \times f_{cp}\,\alpha\, f_t}$$

$$= 0.67 \times 100 \times 250 \times \sqrt{1.517^2 + 0.8 \times 5 \times 1.517}$$

$V_{co} = 48.45$ KN

Balance shear force $= V_s = (V - V_{co}) = (70 - 48.45)$

$V_s = 21.55$ KN

Using 6mm diameter two legged stirrups
Spacing is given by.

$$S_v = \left(\frac{A_{sv}\,0.87 f_y d}{V - V_{co}}\right)$$

6ϕ -2L stp.
$\frac{\pi}{4} \times 6^2 \times 2$
$= 56.54\,m^2$

$$= \frac{2 \times 28.2 \times 0.87 \times 415 \times 200}{21.55 \times 10^3}$$

$=$ 188.98 mm.

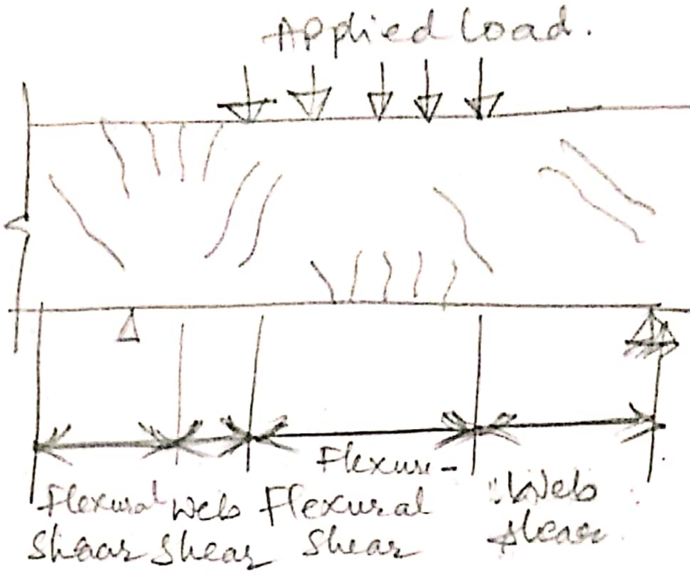
Max. Spacing $S_v \ngtr 0.75d$
$S_v \ngtr 150$ mm.

Adopt 6mm ϕ 2L stirrups at 150mm c/c.

Q.8. a. Differentiate between web shear, flexural shear cracks in PSC Members with neat Sketch. (6 Marks)

* Flexure shear is the empirical calculation model used to determine shear capacity in a section that is cracked in flexure, so there it is combined flexure and shear affect the shear capacity.
In this case cracks are first initiated by flexural cracks in the inclined direction flexural shear cracks develop when the combined shear and flexural tensile stresses produce a principal tensile stress exceeding the tensile strength of concrete. The inclined shear crack extend to the compression face resulting in sudden explosive failure.

*. Web shear or principal tensile shear in the calculation model for a section that is uncracked in flexure. So there is only shear stress at the section with a small amount of flexure. The cracks start from an interior point, when the local principal tensile stress exceeds the tensile of concrete. Web shear cracks are likely to develop in highly PSC with thin webs when the beam is subjected to large concentrated loads near a simple support.



Q8 b. A PSC beam 300mm × 1000 mm is subjected to shear force of 500 KN under working load near support section. The effective prestressing force in the tendon is 800KN. The cable is parabolic with zero eccentricity at support and 300mm below centriodal axis at Midspan. The Span of the beam is 12m If M40 concrete is used estimate the principal tension in concrete at support section and if required design for shear Reinforcement. (10 Marks)

Sol:- $A = 300 \times 1000 = 300 \times 10^3 \, mm^2$

$I = \frac{bd^3}{12} = 2.5 \times 10^{10} \, mm^4$

Slope of Cable at Support $= \frac{4e}{L} = \frac{4 \times 300}{12 \times 1000}$

$= 0.1$ radian.

Vertical Component of the Prestressing force

$= 800 \times 0.1 = 80 KN$.

Horizontal Component of the Prestressing force

$= 800 KN$.

$\therefore$ Max. shear Stress $= \frac{3}{2}\left(\frac{V}{bh}\right)$

$V = 500 - 80 = 420 KN$.

Scanned with CamScanner

$\tau_v = \frac{3}{2} \times \left(\frac{420 \times 10^3}{300 \times 1000} \right) = 2.1 \ N/mm^2$

Axial Prestress $= \frac{800 \times 10^3}{300 \times 1000} = 2.67 \ N/mm^2$

$\therefore f_x = 2.67 \ N/mm^2$.

$f_{\max, \min} = \frac{2.67}{2} \pm \frac{1}{2}\sqrt{(2.67)^2 + 4 \times 2.1^2}$

$f_{\max, \min} = 1.36 \pm 2.49$

$\therefore f_{\max} = 3.85 \ N/mm^2 \quad f_{\min} = -1.13 \ N/mm^2$

Module-5

(05 Marks)

Q9 a Write a Note an Anchorage Zone Stresses

Sol:- The stress distribution in the anchorage zone using empirical equation or theoretical solution based on two or three dimensional elasticity or experimental techniques. The aim of stress analysis in the anchorage zone is to obtain the transverse tensile stress distribution in the end block from which the total transverse bursting tension could be computed.

Magnel's Method.

In this Method, the end block is considered as a deep beam subjected to Concentrated Load due to anchorage on one side and to normal and tangential distribution loads from the linear direct stress and shear stress distribution from the other side. The force acting on the end block and the stresses acting on any point on the horizontal axis parallel to the beam.

The stress distribution across the section can be determined by equation

$$f_v = K_1\left(\frac{M}{bh^2}\right) + K_2\left(\frac{H}{bh}\right)$$

$$\tau = K_3\left(\frac{V}{bh}\right)$$

$$f_h = \frac{P}{bh}\left(1 + 12\frac{e'^2}{h'^2}\right)$$

where K_1 K_2 K_3 are varying distance from the end face of the beam.

Guyon's Method

In this Method, guyon's developed design tables for the Computation of Bursting tension in end blocks which are based on his earlier Mathematical investigations concerning the distribution of stresses in end block subjected to Concentrated load. The concept of symmetrical or equivalent prism for eccentric Cables and the Method of partitioning for the analysis of stresses developed due to multiple Cables which was introduced by Guyon

According to Guyon the bursting tension is expressed as

$$F_{bst} = 0.3P\left(1 - \frac{y_{Po}}{y_o}\right)^{0.58}$$

According to Magnel's Method

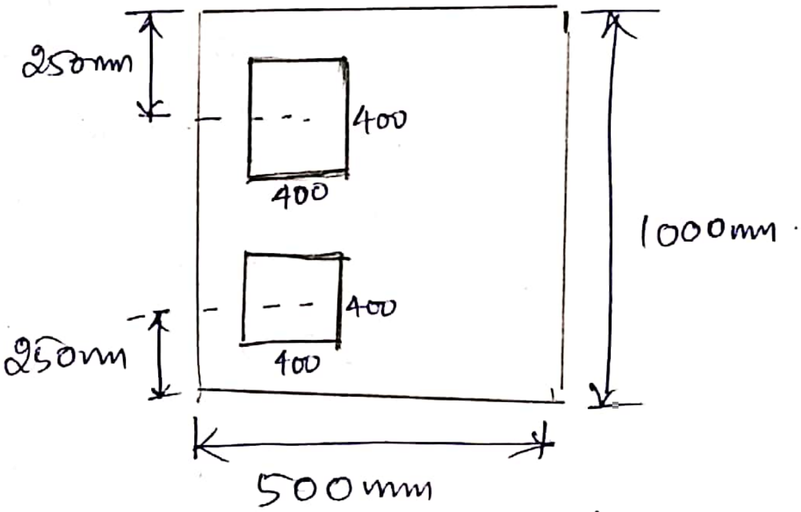
$$f_{max,min} = \left(\frac{f_v + f_h}{2}\right) \pm \frac{1}{2}\sqrt{(f_h - f_v)^2 + 4\tau^2}$$

Q9b Explain End zone Reinforcement. (05 Marks)

Sol: The main reinforcement in the anchorage zone should be designed ~~by~~ to withstand the bursting tension which is determined by the transverse stress distribution on the Critical Axis, usually coinciding with the line of action of the largest individual force. Mats, helics, loops or links are generally provided in perpendicular directions. Tests by Zielinski and Rowe has shown that helical reinforcement is more efficient than Mat reinforcement. In view of the short available bond lengths loops, hooks or right angle bends are necessary, even with deformed bars.

In case where spalling or secondary tension develops at the Corner, suitable steel in the form of hairpin bars should be provided to prevent the failure of corner zones. Suitable pockets are generally provided behind the anchorage so that the secondary reinforcement can be bent and the pocket filled with Mortar after prestressing operations. In case of end Blocks where bearing plate are positioned close to the edge of block, steel Cage should be arranged so that the bearing plate donot overlap with it.

Q9c The end block of a Post tensioned beam 500mm x 1000mm prestressed 2 cables each comprising (6 Marks) of 5 Wires of 7mm dia. The Cable is anchored by square anchorplates ~~beam~~ 400mm x 400mm with their Centre located at 250mm from the top and bottom edges of the beam. The Jacking force in the Cable is 3000KN. Design a suitable anchorage zone reinforcement as per IS 1343, ~~Assuing~~ Assuming Fe 415



2 Cables of 5 Wires of 7mm dia

y_o Depth of equivalent prism = 500 mm

y_{po} Depth of anchor plate = 400 mm.

P_K = 3000KN.

$$\text{Ratio} = \frac{y_{po}}{y_o} = \frac{400}{500} = 0.8$$

$$\text{Bursting Tension} = F_{bst} = P_K\left(0.32 - 0.3\frac{y_{po}}{y_o}\right)$$

$$= 3000 \times (0.32 - 0.3 \times 0.8) = 240\text{KN}$$

$$A_{st} = \frac{F_{bst}}{0.87 f_y} = \frac{240 \times 10^3}{0.87 \times 415} = 664.72\ mm^2$$

By using 7mm dia

By providing 2 Cables of 5 Wires of having 7mm diameter bars both ways at 150mm Centre over a length of 1000mm.

Q10. A ~~Post~~ Pre tensioned Rectangular beam of 120mm x 240mm is simply supported over a Span of 6m. The beam is prestressed by Tendons carrying an intial prestressing force 225 KN at a Constant eccentricity of 40mm. The loss of Prestress is assumed to be 15%. The beam is incorporated in a composite T beam by casting a top flange of 450mm Wide and 40mm thick. live load on composite beam is 8 KN/m^2 Calculate the resultant stress developed in the beam assuming the pre tensioned beam is unpropped during casting of top flange if the Modulus of Elasticity of the flange position and pre-tensioned Beam are 28 KN/mm^2 and 35 KN/mm^2 Also check the composite T-Beam for limit state of deflection (16 Marks)

Sol:- Properties of Pre cast Prestressed beam

$A = (120 \times 240) = 28.8 \times 10^3 \text{ mm}^2$

$g = 0.12 \times 0.24 \times 24 = 0.69 \text{ kN/m}$.

$I = \dfrac{120 \times 240^3}{12} = 138.24 \times 10^6 \text{ mm}^4$

$P = 225 \text{ KN}$.

$e = 40 \text{mm}$.

$L = 6\,m$

$g = 0.85$

$E_c = 35\ kN/m^2$

Properties of Composite Beam (Section)

$A = 450 \times 40 = 18 \times 10^3\ mm^2$

$g = 0.45 \times 0.4 \times 24 = 4.32\ kN/m$

$E_c = 28\ kN/m^2$

Ratio of Modulus of Elasticity $\frac{35}{28} = 1.25$

The Centroid of the Composite section consisting of two different units is determined by Taking moments about an axis passing through the soffit of the beam

y_b = distance of Centroid from the soffit

$$(18 \times 1.25 \times 28.8) \times 10^3 y_b = (18 \times 10^3 \times 240) + (1.25 \times 28.8 \times 10^3 \times 120)$$

Solving $y_b = 13.33\ mm$.

$$I_e = \frac{450 \times 40^3}{12} + (18 \times 10^3 \times 246.67^2) + 1.25 \left[\left(\frac{120 \times 240^3}{12} \right) + 28.8 \times 10^3 \times 106.67^2 \right]$$

$$= 2.4 \times 10^6 + 1.09 \times 10^9 + 1.25 [138.24 \times 10^6 + 327.7 \times 10^6]$$

$$\Rightarrow 2.4 \times 10^6 + 1.09 \times 10^9 + 1.25 [465.94 \times 10^6]$$

$I_e = 1.82 \times 10^9$

Deflection of the Prestressed Beam is Computed as.

$$a_p = \frac{PeL^2}{8EI} = \frac{225 \times 40 \times 6000^2}{8 \times 138 \cdot 24 \times 10^6 \times 35}$$

$\therefore a_p = 8.37$ mm (Upward)

Deflection of the Composite Beam due to self weight of Prestressed Beam, Selfweight of Cast in situ slab and liveload is computed as

$$a_{g+q} = \frac{5wL^4}{384EI}$$

$\therefore g = 0.69 + 4.32 = 5.01$ KN/m

$q = 8$ KN/m

$\therefore w = 5.01 + 8.0 = 13.01$ KN/m $= 0.01301$ KN/mm

$\phi = 1.6 \quad \eta = 0.85$

$$a_{g+q} = \frac{5 \times 0.01301 \times 6000^4}{384 \times 35 \times 1.82 \times 10^9} = 0.344 \text{ mm}$$

long term deflection is found as –

$$a = (1+\phi)\left[\eta a_p + a_{g+q}\right]$$

$$= (1+1.6)\left[0.85 \times 8.37 + 0.344\right]$$

19.39 mm.

According to IS 1343:1980 Max. Permissible for long term deflection is limited to

$\left(\frac{Span}{250}\right)$

$$\therefore \frac{Span}{250} = \frac{6000}{250} = 24 \text{ mm}$$

24 > 19.39

Hence Actual deflection is Well within the Maximum permissible deflection.

Hence Design is safe.

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