Chapter - 1

Concepts of Prestress [2013-14, 2004-05]

1) First concept :

→ This concept visualizes prestressed concrete as concrete which is transformed from a brittle material to a elastic one by precompression given to it.

→ Concrete is weak in tension and strong in compression. It is generally precompressed by still under high tension so that it can withstand tensile stresses.

→ If there is no tensile stresses, there can be no cracks and the concrete is no longer a brittle material but becomes an elastic material

→ Concrete is visualized as being the subjec of two system of forces: internal prestress and external load, with the tensile stresses due to the external load counteracted by the compressive stresses due to prestress

For a beam eccentrically prestressed and loaded, stress distribution

$$f = \frac{F}{A} \pm \frac{Fey}{I} \pm \frac{My}{I}$$

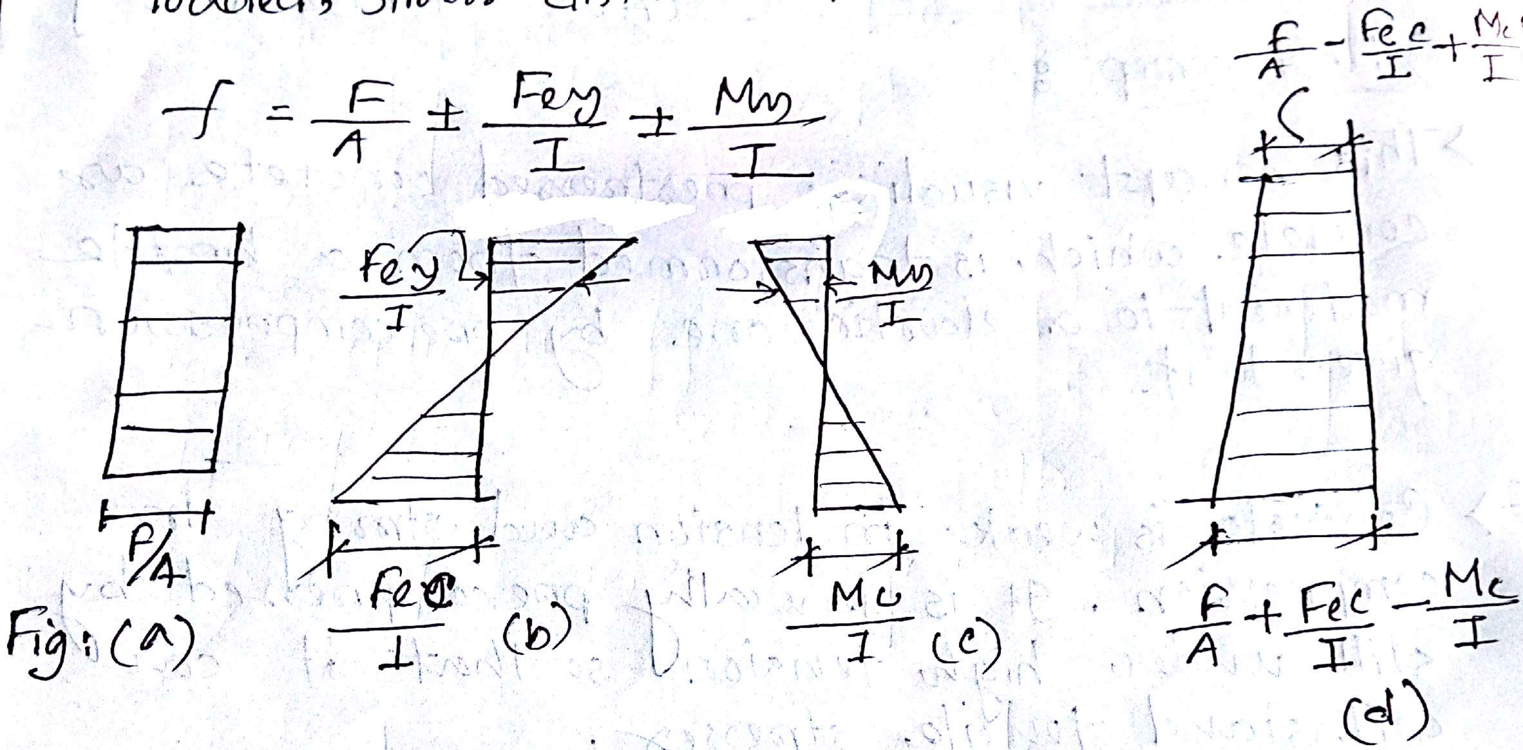


Fig : (a) Due to prestress direct load effect

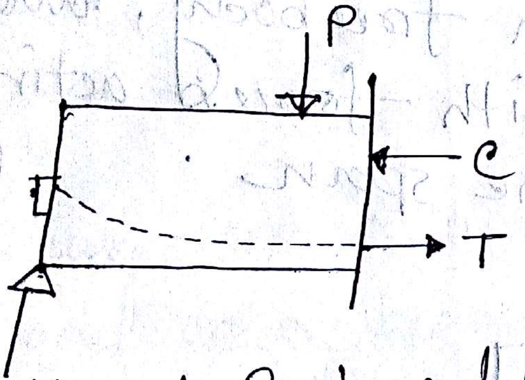
(b) Due to prestressed eccentricity

(c) Due to external Moment M

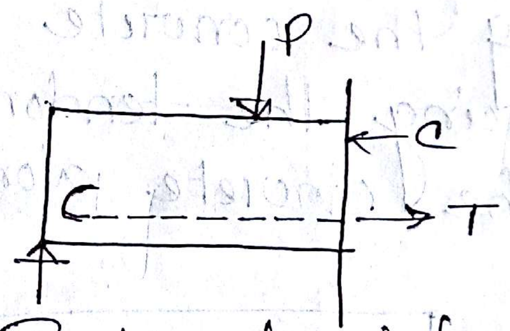
(d) Due to eccentric prestress and external M

(ii) Second Concept

This concept considers prestressed concrete as a combination of steel and concrete, similar to reinforced concrete with steel taking tension and concrete taking compression so that the two material form a resisting ~~moment~~ couple against external moment.



Portion of Prestressed beam



Portion of reinforced beam

According to second concept, for a eccentrically prestressed concrete beam, stress distribution

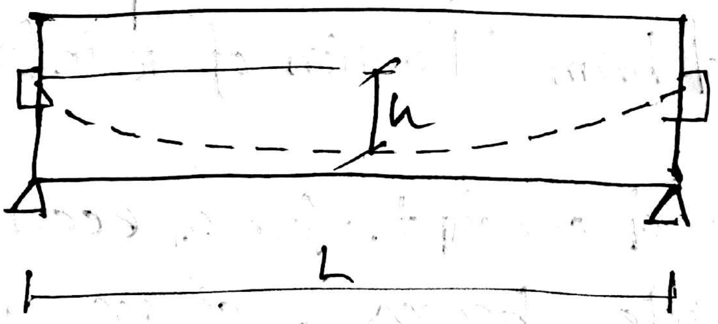
$$f = \frac{F}{A} \pm \frac{Mc}{I}$$

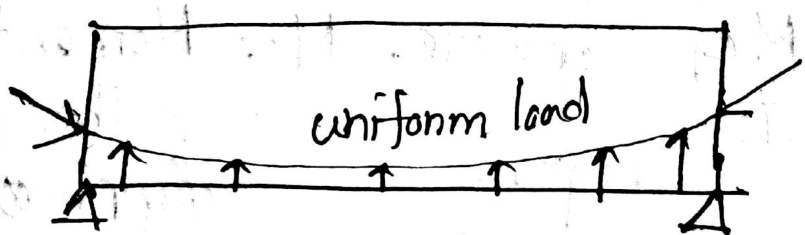
where M = Moment due to the prestressing compressive force, C

[1] Third Concept

This concept is to visualize prestressing primarily as an attempt to balance loads on a member.

The application of this concept requires taking the concrete as a free body, and replacing the tendons with forces acting on the concrete along the span.





concrete as free body

Fig: Prestressed concrete with parabolic tendon

For a simple beam prestressed with a parabolic tendon shown in the figure

F = Prestressing force

L = Length of span

h = Sag of parabola

The upward uniform load is given by

$$w_b = \frac{8Fh}{L^2}$$

Thus for a given load w, the transverse load on a beam is balanced and the beam is subjected to only ~~uniform load~~ axial force F, which produce uniform stress

$$f = \frac{F}{A}.$$

The change in stresses from this balanced condition can easily be computed as

$f = \frac{Mc}{I}$ where M being the unbalanced moment due to $(w - w_b)$.

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☐ Classification of Prestress

1) Externally or Internally Prestressed
2) Linear or Circular prestressed
3) Pre-tensioning and Post tensioning
4) End Anchored or Non end Anchored tendons
5) Bonded or unbonded tendon
6) Pre cast, cast in place or composit construction
7) Partial or full prestressing

☐ Partially prestressing [2013-14]

Partially prestressed member are those which are designed to allow significant tensile stresses to occur at service loads an such tensile regions are usually additionally reinforced with non prestressed reinforcement

[A] Stages of loading [2013-14, 2008-09]

1) Initial Stage:

The member or structure is under prestress but is not subjected to any superimposed external loads. This stage can be further subdevided into the following periods:

i) Before Prestressing

ii) During Prestressing

iii) At transfer of prestress

iv) Decentering and Retensioning

2) Intermediate Stage:

This is the stage during transportation and erection. It occurs only for precast members when they are transported to the sites and erected in position. It is highly important to ensure that the members are properly supported and handled all the time.

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3) Final stage:

This is the stage when actual working loads come on the structure. For prestressed concrete structure it is necessary to investigate their cracking and ~~working loads~~ ultimate loads, their behavior under the actual sustained load in addition to the working load.

~~4~~ "PC beam can be made with relatively thin web". Explain [2004-05]

Answer:

The use of curved tendons in pre-stressed concrete will help to carry some of the shear in a member.

In addition, pre compression in t concrete tends to reduce the principal tension, increasing shear strength. Thus it is possible to use a smaller section in prestressed concrete to carry the same amount of external shear in a beam. Hence, sections with thin web become desirable with prestressed concrete.

④ Comparision Prestressed Vs Reinforced concrete

	Prestressed	Re-inforced
1. Utilisation of high strength steel	Entire section of the concrete becomes effective	Only the portion section above neutral axis becomes effective
2. Shear capacity	Higher	Lower
3. Service-ability	Suitable for long span and heavy load, also for artistic treatment because of slenderness	Situations where weigh and mass are desired instead of strength, ~~RCC~~ RC section could serve just as well and at lower cost

Sub	Prestressed	RC
4. Safety	Overload capacity slightly higher than RC, gives warning before collapse. but complicated or delicate design feature	RC has simpler design but lower coverage
5. Economics	Economical when the same unit is repeated many times or heavy dead load on long span but stronger material have higher unit cost	Lower unit cost for less strong material

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Chapter 4

◻ Sources of losses in prestressed concrete
[2013-14, 2012-13, 2010-11, 2007-08, 2006-07, 2004-05]

1) Sources of short term or immediate losses
   a) Elastic shortening
   b) Friction
   c) Anchorage slip

2) Sources of time dependent losses
   a) Creep
   b) Relaxation
   c) Shrinkage

◻ Losses in Pre-tensioning Vs Post tensioning

SI	Type of loss	Pre tensioning	Post tensioning
1.	Elastic shortening	Yes	i) No if all cables are simultaneously tensioned ii) If wires are tensioned in stages loss will exist
2.	Anchorage slip	No.	Yes

Sl No.	Type	Pre tensioning	Post tensioning
3.	Friction loss	No	Yes
4.	Creep and shrinkage loss	Yes	Yes
5.	Relaxation of steel	Yes	Yes

[4] Elastic Shortening

→ For pre tensioned members when the tendons are cut and the prestressing force is transferred to the member concrete undergoes immediate shortening due to prestress.

→ Tendons also shortens by same amount which leads to loss in prestress

→ For post tensioned members if there is only one tendon there is no loss because applied prestress is recorded after the elastic shortening

→ For more than one tendon, if the tendons are stretched sequentially, there is a loss in a tendon during subsequent stretching of other tendons.

→ **Estimate of loss due to elastic shortening:**

$$ES = \Delta f_s = E_s \delta = \frac{E_s F_o}{A_c E_c} = \frac{n F_o}{A_c}$$

where,

ES = loss due to elastic shortening

E_s, E_c = Modulus of elasticity of steel and concrete

F_o = Total prestress after transfer

A_c = Area of concrete

δ = unit shortening = $\frac{F_o}{A_c E_c}$

[#] Anchorage slip:

→ In most post tensioning systems when the tendon force is transferred from the jack to the anchoring ends, the friction wedges slip over a small distance

→ Certain quantity of prestress is released due to this ~~stee~~ slip of wire through anchorage

→ Loss of prestressed due to slip can be calculated

$$\Delta f_s = \frac{E_s \Delta_a}{L}$$

where, E_s = Modular of elasticity of steel

Δ_a = anchorage deformation

L = Length of cable

Frictional Loss

→ Friction is generated due to curvature of tendon, and vertical component of the prestressing force

→ The magnitude of prestressing force, F_x at any distance, x from the tensioning end follows an exponential function type,

$$F_x = F_o e^{-\mu x - kx}$$

where, F_o = Prestressing force at jacking end

μ = Coefficient of friction between cable and the duct

α = Cumulative angle in radian through which the tangent to the cable profile has turned between any two point under consideration

k = frictional co-efficient

[H] Creep of concrete

→ Creep is assumed to occur with super-imposed permanent dead load added to the member after it has been pre-stressed.

→ Creep of concrete will occur over a long period of time under a sustained load

→ Loss of prestress due to creep is computed for the bonded members using following expression

$$CR = K_{cr} \frac{E_s}{E_c} (f_{cir} - f_{cds})$$

where,

$K_{cr} = 2$ for pre-tensioned members

$K_{cr} = 1.6$ for post tensioned members

f_{cds} = Stress in concrete at c.g.s of tendons due to all super imposed dead loads that are applied to the member after it is prestressed

E_s = Modulus of elasticity of prestressing tendons

E_c = Modulus of elasticity of concrete at 28 days

→ The losses in the unbonded tendon are related to the average member strain rather than strain at the point of maximum moment.

Thus, $CR = K_{cr} \frac{E_s}{E_c} f_{cpa}$

where f_{cpa} = average compressive stress in concrete along the member length at the c.g.s of tendons

(F) Loss due to shrinkage

→ Shrinkage of concrete is influenced by many factors, such as, creep, volume to surface ratio, relative humidity and time from end of moist curing to application of prestress.

→ Loss due to shrinkage can be estimated using following expression

$$SH = 8.2 \times 10^{-6} K_{sh} E_s \left(1 - 0.06 \frac{V}{S}\right)(100 - RH)$$

where, K_{sh} = 0.8 or only 80% of the shrinkage for a companion pretentioned beam

E_s = Elastic modulus of steel

$\frac{V}{S}$ = volume to surface ratio

RH = Relative humidity

[4] Loss due to steel Relaxation

→ Prestress force decreases gradually ~~with time~~. The amount of decrease depends on both time duration and the ratio of f_{pi}/f_{py}. The loss of prestress force is called relaxation.

→ The loss can be estimated using following equation

$$\frac{f_p}{f_{pi}} = 1 - \frac{\log t}{10}\left(\frac{f_{pi}}{f_{py}} - 0.55\right)$$

④ Measures of reducing friction

1) Overtensioning the tendons
2) Jacking from both end
3) Smoothing the surface with lubricant

④ Advantage of both end Prestress

→ Reduces frictional loss as friction gets devided in two parts.

④ Derivation of $FR = f_1\left(1 - e^{-\mu\alpha - KL}\right)$

⇒ Let's consider an infinitsimal length ~~arc~~ it dx of a prestressing tendon whose centroid follows the arc of a circle of radius R.

The change of angle of tendon as it goes around the length dx is

$$d\alpha = \frac{dx}{R}$$

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Normal component of pressure produced by the stress F bending around $d\alpha$

is, $N = F d\alpha = \frac{F dx}{R}$

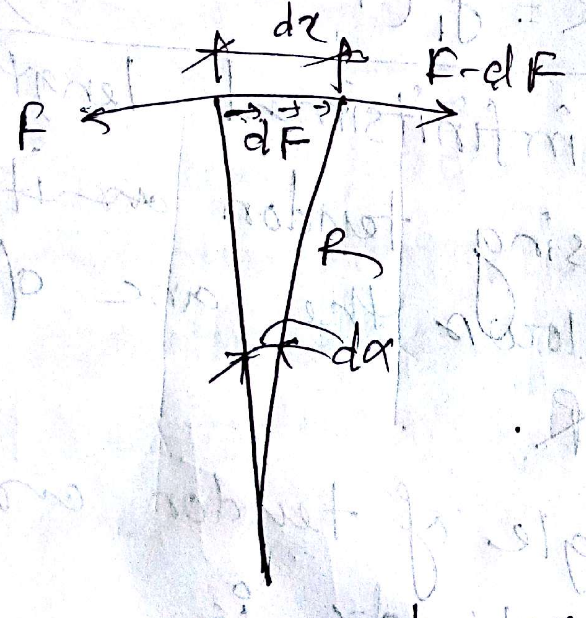
Now, Friction loss,

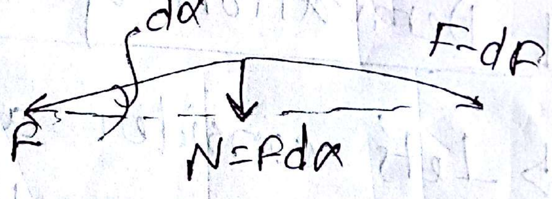
$dF = -\mu N$

$= -\mu \frac{F dx}{R} = -\mu F d\alpha$

$\therefore \int \frac{dF}{F} = \int \mu d\alpha$

$\Rightarrow \log_e F = -\mu \alpha$





This formula can also be applied ~~for~~ to compute loss due to length or wobble effect

$\therefore \log_e F = -KL$

Combining length and curvature effect:

$$\log_e F = -\mu\alpha - KL$$

For limit F_1 and F_2

$$\log_e F_2 - \log_e F_1 = -\mu\alpha - KL$$

$$\therefore \log_e \frac{F_2}{F_1} = -\mu\alpha - KL$$

$$\therefore F_2 = F_1 e^{-\mu\alpha - KL}$$

$$\Rightarrow f_2 = f_1 e^{-\mu\alpha - KL}$$

frictional loss $FR = f_2 - f_1$

$$\therefore FR = f_1 \left(1 - e^{-\mu\alpha - KL}\right)$$

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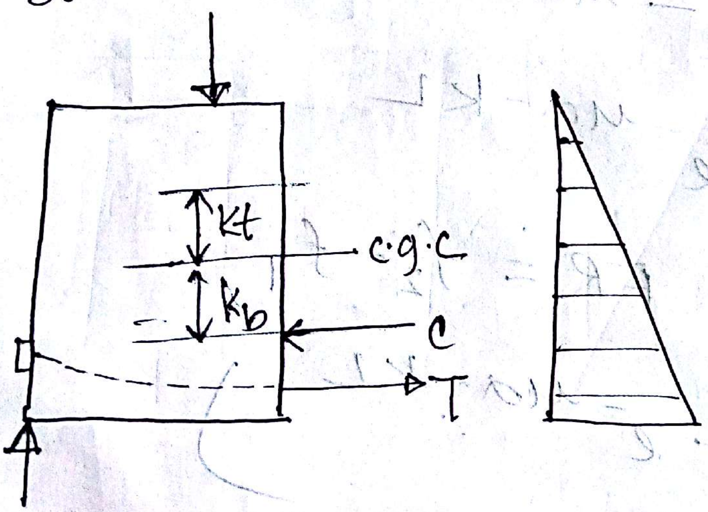
Chapter-6

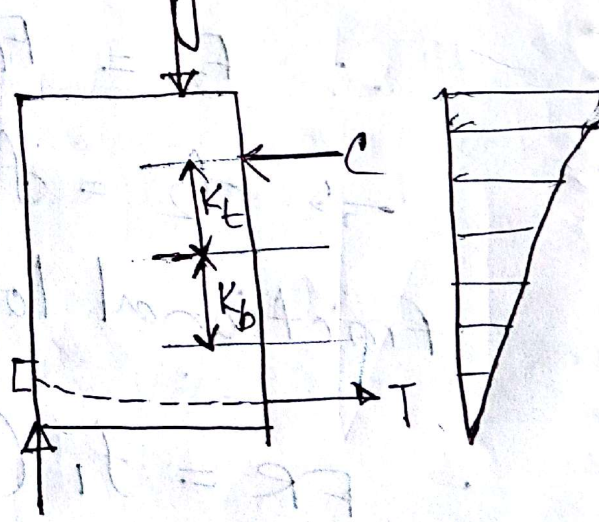
☐ Stress distribution of concrete by elastic theory :[2010-11, 2008-09, 2007-08, 2006-07, 2004-05]

→ Some of the simple relation between stress distribution and ~~elastic~~ theory location of c are described according to elastic theory

→ If c coinsides with the top or the bottom kern point, stress distribution will be triangular with zero stress at bottom or top fiber respectively

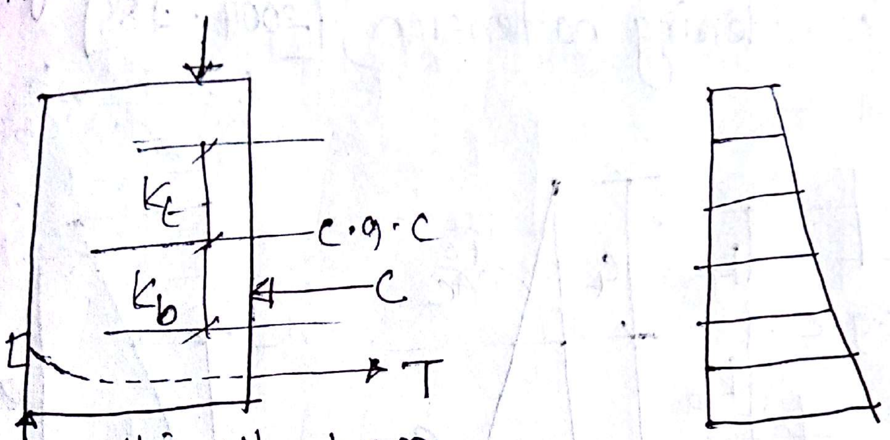


(a) C at bottom kern point



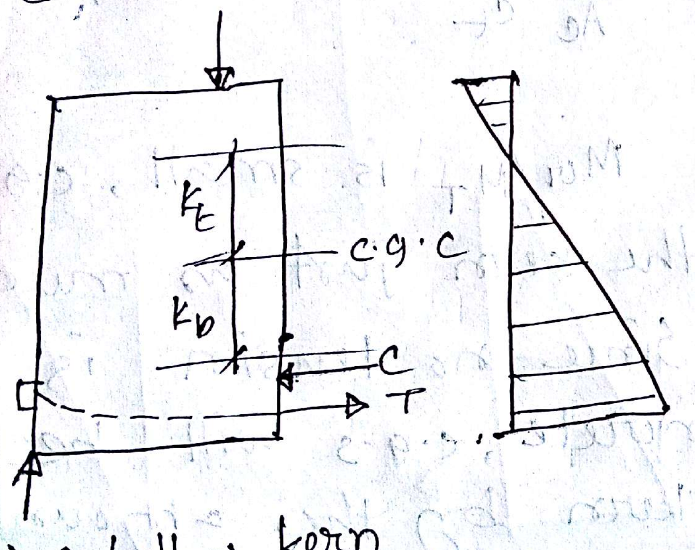
(b) C at top kern point

→ If C falls within the kern point, the entire section will be under compression.

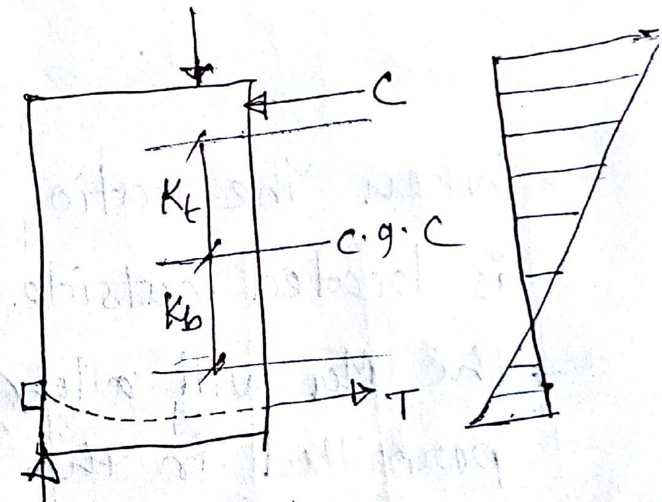


(c) C within the kern

→ If C is outside of the kern there will exist some tension

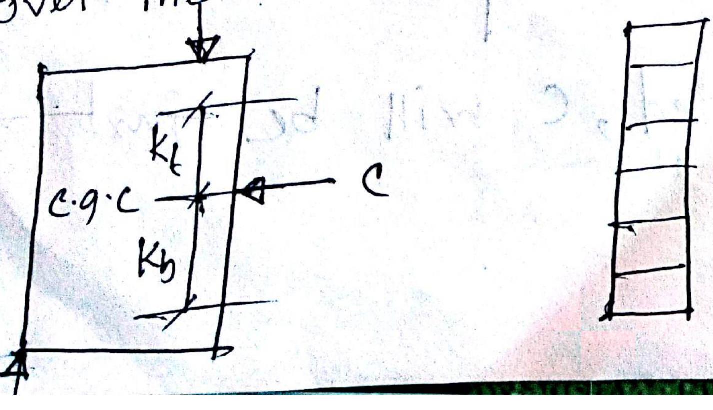


(d) C bellow kern



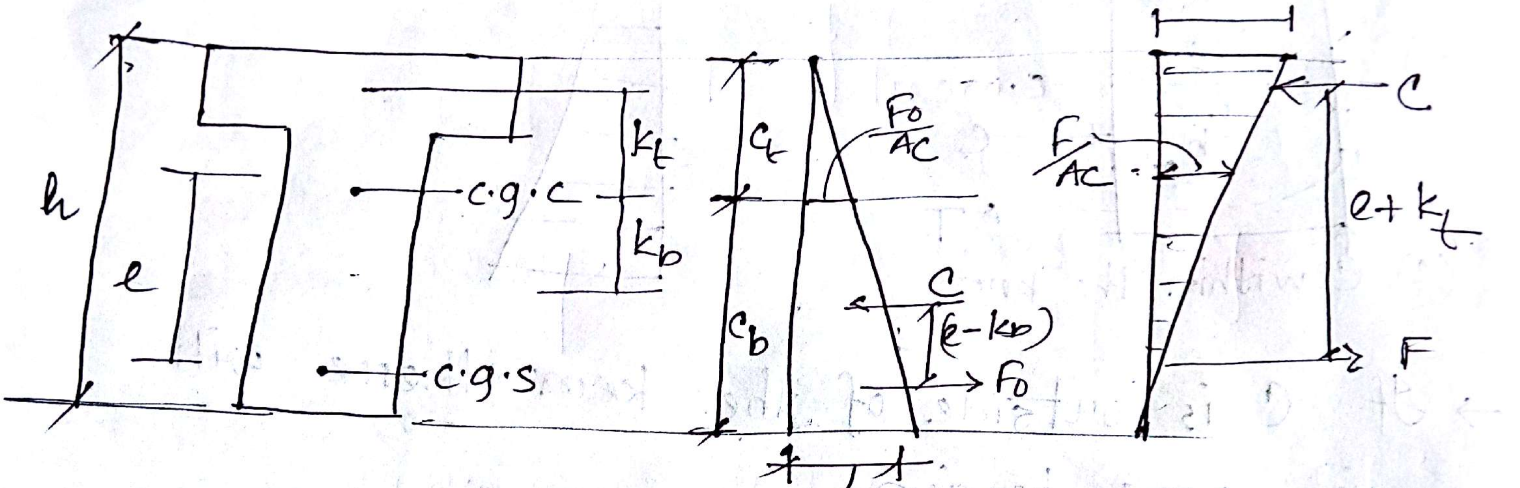
(e) C above top kern point

→ If C coincides with c.g.c stress will be uniform over the entire section



Expression for A_c for small ration of M_{cr}/M_T : (considering no tension) [2007-08]

$$f_t = \frac{F}{A_c} * \frac{h}{C_b}$$



$$f_b = \frac{F_o}{A_c} * \frac{h}{C_t}$$

→ When the ratio of M_{cr}/M_T is small, c.g.s is located outside the kern just as much the M_{cr} will allow. Since, no tension is permitted in the concrete, c.g.s will be located bellow the kern by the amount of,

$$e - k_b = \frac{M_{cr}}{F_o}$$

where, F_o = Prestress force acting at transf

If c.g.s is so located, C will be just →

at the bottom kern point for the given M_{cr} and the stress in top fiber,

$f_t = 0$

and stress in bottom fiber, $f_b = \frac{F_0}{A_c}\frac{h}{c_t} \leq 0.6 f_c'$

$\therefore \quad A_c = \frac{F_0 h}{f_b c_t}$

→ If c.g.s is located above, the available lever arm for resisting moment will be $e + k_t$ and the effective prestress F is given by,

$$F = \frac{M_T}{e + k_t}$$

→ Under the action of effective stress F and total moment M_T, C will be located at the top kern point

$\therefore f_b = 0$

$$f_t = \frac{F}{A_c}\frac{h}{c_b} \leq 0.45 f_c'$$

$$\therefore \quad A_c = \frac{F h}{f_t c_b}$$

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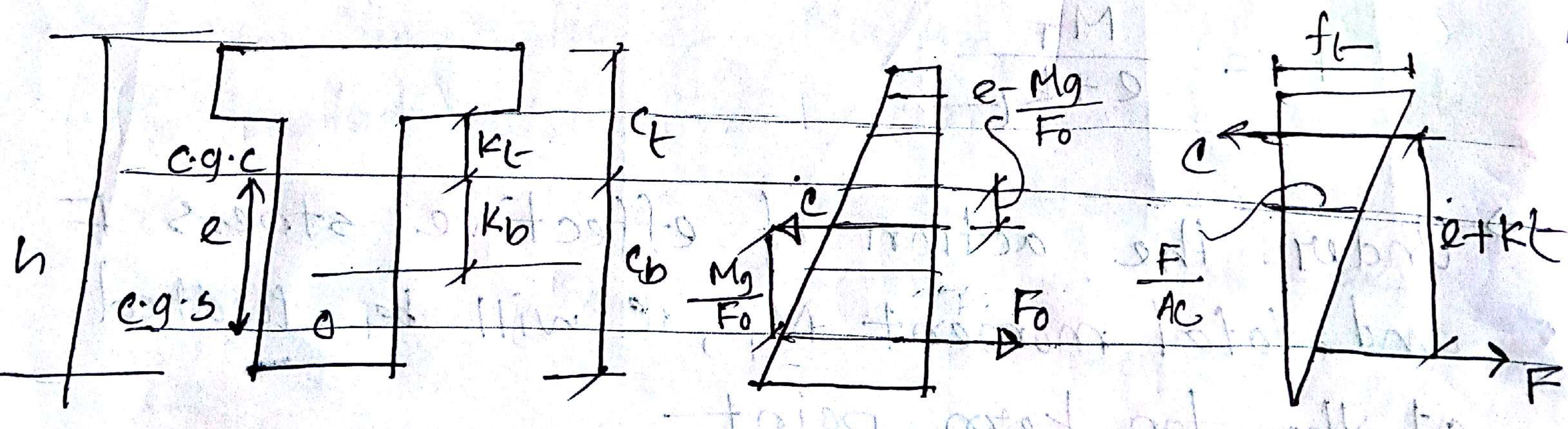
4 Large Ratio of M_G/M_T [2006-07]

When the ratio of M_G/M_T is large, the value of $e-k_b$ may place c.g.s outside of the practical limit, for example bellow the section of the beam. Then it is necessary to place c.g.s only as low as possible.

For such a condition, bottom fiber stress is critical.



(a) Section properties

(b) Just after Transfer, C above bottom kern point

(c) Under working load, C at top kern point

We see, stress condition ~~under the~~ just after transfer, the bottom fiber stress [Fig (b)] can be expressed by,

$$f_b = \frac{F_0}{A_c} + \frac{(F_0 e - M_G) c_b}{I}$$

$$= \frac{F_0}{A_c}\left(1 + \frac{e - \frac{M_G}{F_0}}{k_t}\right)$$

As, $k_t = \frac{r^2}{c_b} = \frac{I}{A c_b}$

$$\therefore A_c = \frac{F_0}{f_b}\left(1 + \frac{e - \frac{M_G}{F_0}}{k_t}\right) \quad (1)$$

For, ~~bo~~ calculating stress at top, f_t

From Fig (c) we observe, here, $f_b = 0$

and $f_t = \frac{F * h}{A_c * c_b} = \frac{Fh}{A_c * c_b}$

$$\therefore A_c = \frac{Fh}{f_t c_b} \quad (2)$$

Greater of two A_c's is selected as design criteria.

Chapter 7

[1] Evaluation of Vcw [2013-14]

The capacity of member is reached if

$$f_t^u = \sqrt{V_{cw}^2 + \left(\frac{f_{pc}}{2}\right)^2} - \frac{f_{pc}}{2}$$

$$\cancel{V_{cw} = f_t^u \sqrt{1 + \frac{f_{pc}}{f_t^u}}}$$

$$\cancel{f_t^{u2}} = \left[\cancel{V_{cw}^2 + \left(\frac{f_{pc}}{2}\right)^2}\right] \cancel{+ \left(\frac{f_{pc}}{2}\right)}$$

where

f_t^u = tensile strength of concrete

V_{cw} = shear stress

f_{pc} = compressive stress due to prestress

$$\left(f_t^u + \frac{f_{pc}}{2}\right)^2 = V_{cw}^2 + \left(\frac{f_{pc}}{2}\right)^2$$

$$\Rightarrow (f_t^u)^2 + 2 f_t^u * \frac{f_{pc}}{2} + \left(\frac{f_{pc}}{2}\right)^2 = V_{cw}^2 + \left(\frac{f_{pc}}{2}\right)^2$$

$$\Rightarrow f_t^{u2}\left(1 + \frac{f_{pc}}{f_t^u}\right) = V_{cw}$$

$$\therefore V_{cw} = f_t \sqrt{1 + \frac{f_{pc}}{f_t^u}}$$

Now, $f_t'' = 0.29\sqrt{f_c'}$ is used

$$\therefore \; v_{cw} = 0.29\sqrt{f_c'}\left(\sqrt{1 + \frac{f_{pc}}{0.29\sqrt{f_c'}}}\right)$$

This equation may be simplified to,

$$v_{cw} = 0.29\sqrt{f_c'} + 0.3 f_{pc}$$

Web shear strength,

$$V_{cw} = v_{cw}\, b_w d$$

$$= \left(0.29\sqrt{f_c'} + 0.3 f_{pc}\right) b_w d$$

For composite section,

$$V_{cw} = \left(0.29\sqrt{f_c'} + 0.3 f_{pc}\right) b_w d + V_p$$

where,

V_p = vertical component of effective prestress force

[ii] Evaluation of V_{ci} : [2013-14]

The total shear V_{ci} at inclined flexural cracking was correlated with formation of a flexural crack at a distance $d/2$ from the section under consideration plus a shear which is a function of the dimensions of cross section and the strength of concrete, expressed as follows:

$$V_{ci} = 0.05\, b_w d \sqrt{f_c'} + \frac{M_{cr}}{\frac{M}{V} - \frac{d}{2}} + V_d \qquad \text{—(1)}$$

where M_{cr} = the moment due to applied loads when flexural cracking occurs

The cracking moment can be correlated with $0.5\sqrt{f_c'}$ as modulus of rupture for concrete

$$M_{cr} = \frac{I}{y_t}\left(0.5\sqrt{f_c'} + f_{pe} - f_d\right)$$

where $f_{pe} - f_d$ = Net precompression at the extreme fiber.

The total shear V_{ci} due to applied loads and dead load, when flexural crack occurs is

$$V_{ci} = \frac{M_{cr}}{\frac{M}{V} - \frac{d}{2}} + V_d$$

where $\frac{M}{V}$ = a function of the distribution of loading

Equation (1) was simplified to drop the distance $d/2$. The resulting equation is

$$V_{ci} = 0.05\, b_w d \sqrt{f_c'} + V_d + \frac{V_i M_{cr}}{M_{max}}$$

For uniformly loaded non composite simple beams the equation becomes more simplified with

$$V_{ci} = 0.05\, b_w d \sqrt{f_c'} + \frac{V_i M_{cr}}{M_{max}}$$

[4] Why the shear capacity of a prestressed concrete beam is higher than the corresponding RC beam? [2012-13]

⇒ Prestressed concrete beams possess greater reliability in shear resistance than RC beams because prestressing will usually prevent the occurance of shrinkage cracks which could conceivably destroy the shear resistance RC beams, specially near the conflexture

[5] Transfer bond: [2013-14, 2012-13, 2010-11, 2008-09, 2007-08, 2006-07]

→ when the tendons are pretensioned their stress is often transferred to the concrete solely by bond between the two materials. Thus there is a length of transfer at each end of the tendons to perform the function of anchorage, when mechanical anchorages are not provided

→ At anchorage bond stress exists immediately after transfer. The stress in the tendons ~~vary~~ varies from zero at the exposed end to a full prestress at some distance inside the concrete. This distance is known as the length of transfer and such bond stress is termed as prestress transfer bond.

→ Along the length of transfer, there is an expansion of the wire diameter which produces radial pressure against the surrounding concrete. frictional force resulting from this pressure serves to transmit the stress between steel and concrete. A wedging action take place within the length of transfer

→ The length of transfer L_t is computed as,

$$L_t = \frac{d}{2\mu}(1+m_c)\left(\frac{n}{m_s} - \frac{f_i}{E_c}\right)\frac{f_e}{2f_i - f_e}$$

m_c = Poisson's ratio for concrete

m_s = Poisson's ratio for steel

$n = \frac{E_s}{E_c}$

E_c = modulus of elasticity for concrete

f_i = Initial prestress in steel

f_e = effective prestress in steel

μ = co-efficient of friction between steel and concrete

d = diameter of wire

4] Parameters affecting transfer length

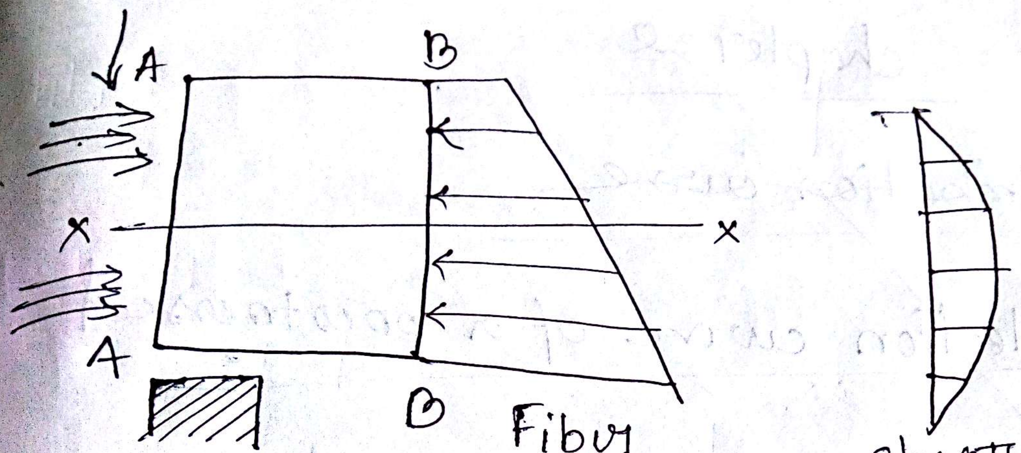
1) Type of steel
2) Steel size
3) Steel stress level
4) Surface condition of steel
5) Concrete strength
6) Type of loading
7) Type of release
8) Confining reinforcement around steel
9) Time dependent effect
10) Consolidation and consistency of concrete around steel
11) Amount of concrete coverage around steel

Syllabus
नाई

[2013-14, 2010-11, 2008-09]

Transverse tension at end block

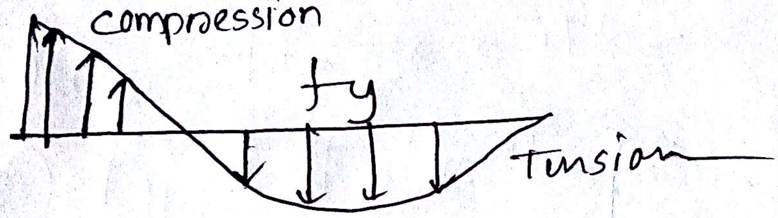
The portion of prestressed member surrounding the anchorages of the tendons is often termed as end block. Throughout the length of end block prestress is transferred from more or less concentrated areas and distributed through the entire beam section. The theoretical length of end block is distance through which this change takes place and is sometimes called lead length. It is known from theoretical and experimental investigations that this lead is not more than the height of the beam and often is much smaller except for pretension beams with long transfer length.



(a) end of a beam

Fiber stress at B-B

Shearing stress at B-B



(b) Variation of fy along X-X

Service
Beam

chapter-8

#1 Load deflection curve of a prestressed beam: [2012-13, 2010-11, 2008-09, 2007-08, 2004-05]

1) When beam is loaded beyond its working load, tensile stress will exist. As long as the beam has not cracked the elastic theory can be applied for the computation of deflections.

2) When cracks begin to occur in the beam, the nature of deflection will start to change. The effective section in resisting moment will be the ~~entire~~ cracked section instead of the entire section.

3) As the crack extend deeper and deeper the moment of inertia of the section will become smaller and smaller until the cracked section has a moment of inertia one-half or one-third of the uncracked section.

4) The concrete will be under high average stress and posses a lower

average value of Ec.

5) So, the deflection of the section will increase much faster than before cracking and will increase as more cracks develope.

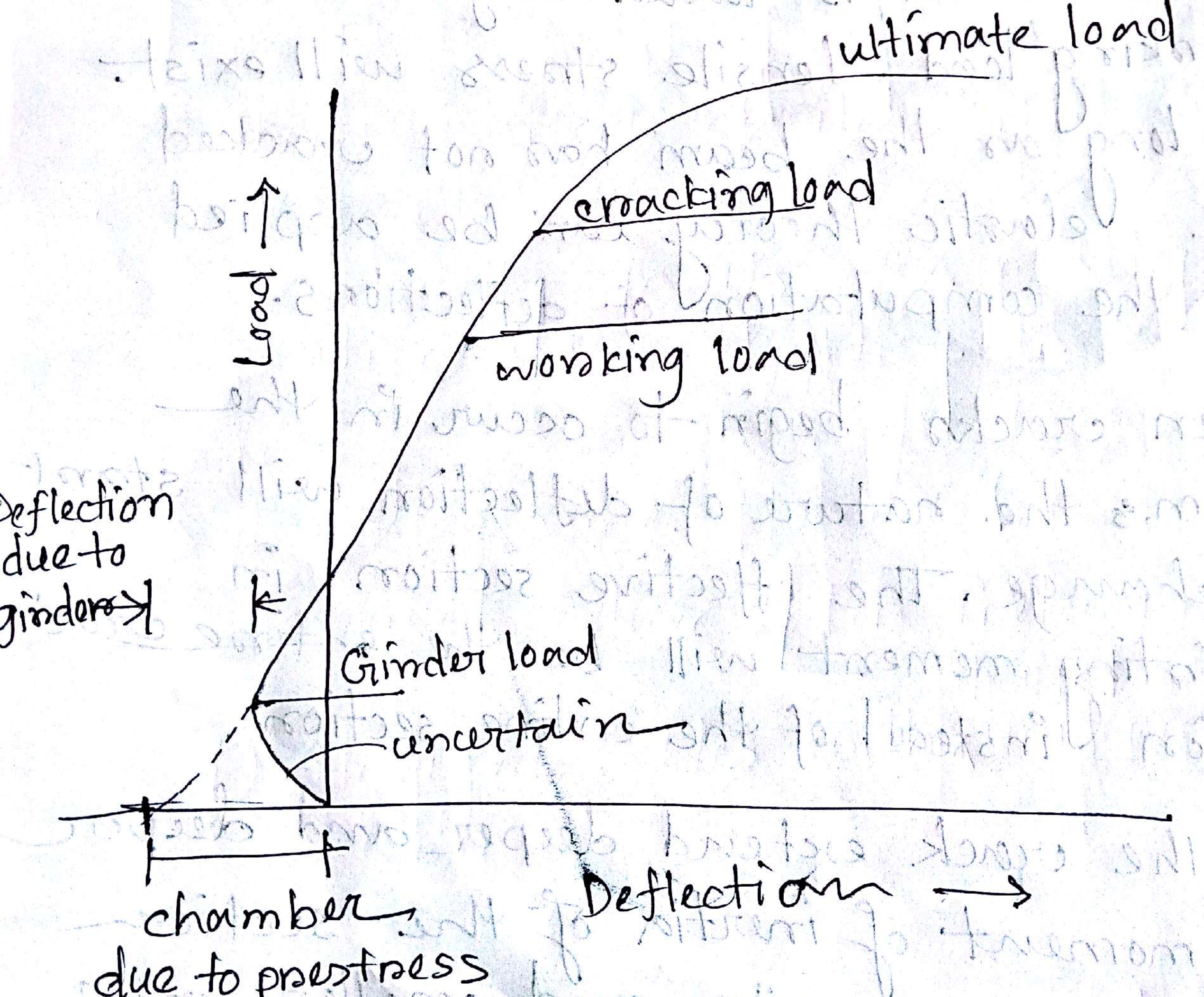


Fig: Load deflection curve of prestress beam

6) Upon the removal of the applied load the beam will return to its original position provided that prestress in the still has not suffered any loss due to overload

7) There will be some residual deflection left in the ~~left s~~ beam, depending on the degree and duration of loading.

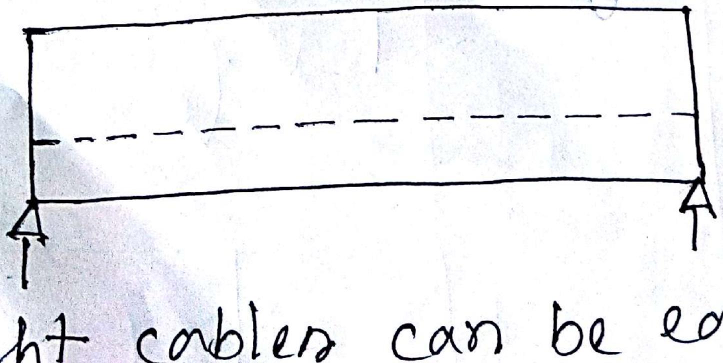
8) If the loading is sustained for some time, residual deflections will be produced as a result of creep but most of it can be recovered in the course of time after load is removed

9) Between the working load and the cracking load, the beam will deflect slightly more after it has been previously cracked

4] Simple beam layout [2006-07]

The layout of a beam can be adjusted by varying both concrete and the steel. The section of concrete can be varied as to it's height, width, shape and the curvature of it's softfit or extradots. The steel can be varied, occasionally in it's area, mostly in it's position. By adjusting these variables many combination of layouts are possible. Some standard cases are described bellow :- [For Pretensioned beams]

1) Straight Cables with straight uniform beam section :

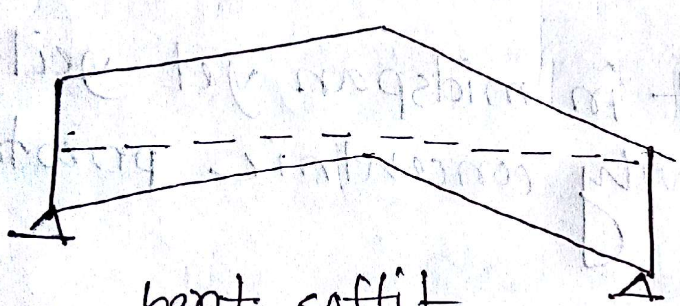


→ straight cables can be easily tensioned

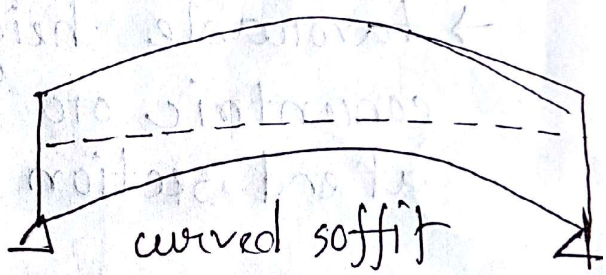
→ Simple in form and workmanship

→ can not be economically designed because of the conflicting requirement of the midspan and end section

2) Simply varying soffit of beam with straight cables and uniform beam section



bent soffit



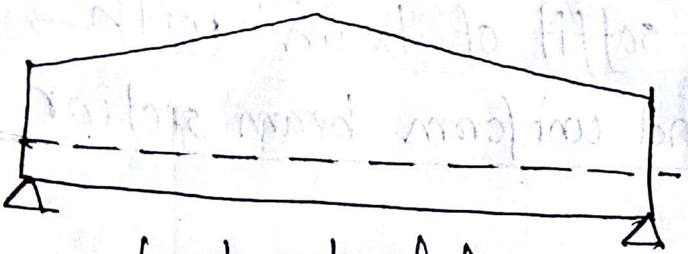
curved soffit

→ c.g.s can be depressed as low as desired in the midspan while the end can be kept near c.g.c

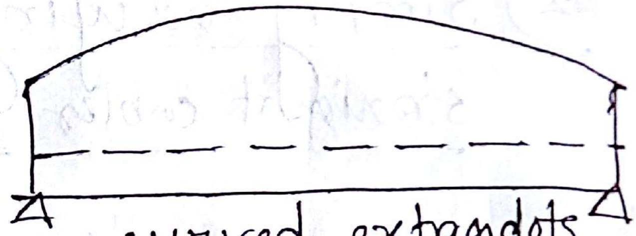
→ complicated formwork and sometimes impractical

→ can not be easily produced on a long line prestressing bed

3) Varying extradots of concrete with a straight cable



bent extradots



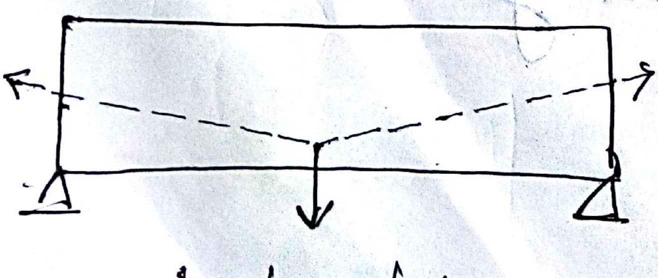
curved extradots

→ Favorable height in midspan yet yeild concentric or nearly concentric prestress at end section

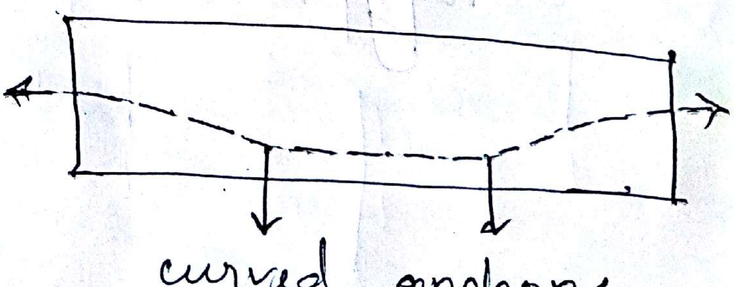
→ End section need to be checked for shear resistance for reduced depth

→ Critical section may not be in midspan

4) Beams with buried anchors along the stressing bed



bent anchors



curved anchors

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→ Tendons can be bent

→ Economical for i) straight and uniform section

ii) Mq causes additional bending

For, post tensioned beams it is not necessary to keep the tendons straight. The standard types are described bellow:

1) For a beam of straight and uniform section tendons are very often curved as figure(a). Curving the tendons will permit favorable position of c.g.s to be obtain at both end and midspan sections and others as well.

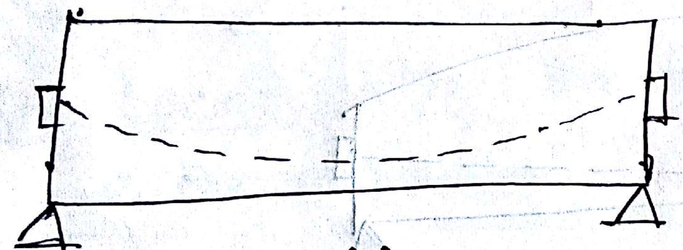

Fig: (a)

2) A combination of curved or bent tendons with curved or bent soffit is frequently used when straight soffits are not required as in Fig(b).

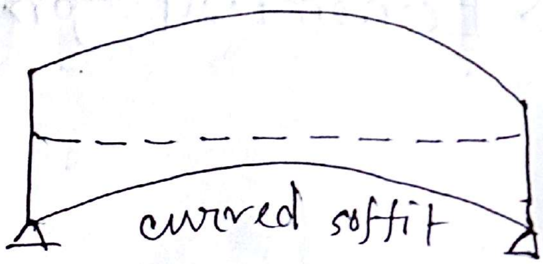

Fig: b_1 Fig: b_2

This will permit a smaller curvature in the tendons thus reducing the friction

3) Curved or bent cables are also combined with beams of variable depth as in Fig (c)

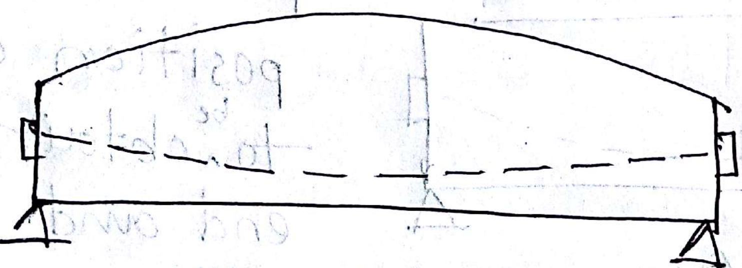

Fig: (c)

4) Combination of straight and curved tendons often found convinient as in Fig (d)

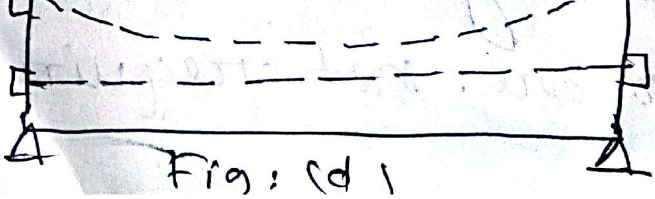

Fig: (d)

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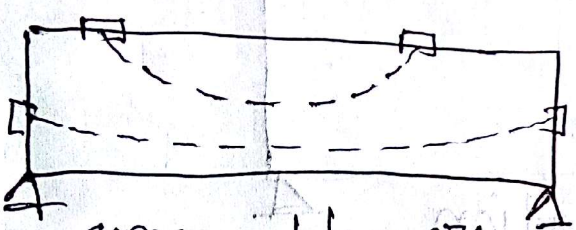
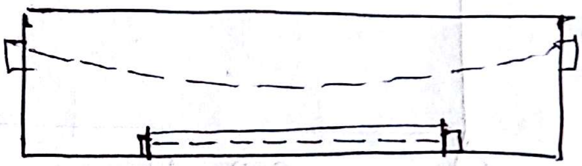
5) Variable steel area along the length of the beam is occasionally preferred. Special design and details may offset it's economy in weight of steel.



some cables are bent upward and anchored at top flange



some cables are stopped part way in the bottom flange

[2008-09]

Q. Location of limiting zone of c.g.s with a concentrated load on midspan :

The method is a graphical one, giving the limiting zone within which the c.g.s must pass in order that no tensile stresses will be produced.

Having determined the layout of

concrete sections, we proceed to compute their ~~co~~ kern points, thus yeilding two kern lines, one top and one bottom (c).

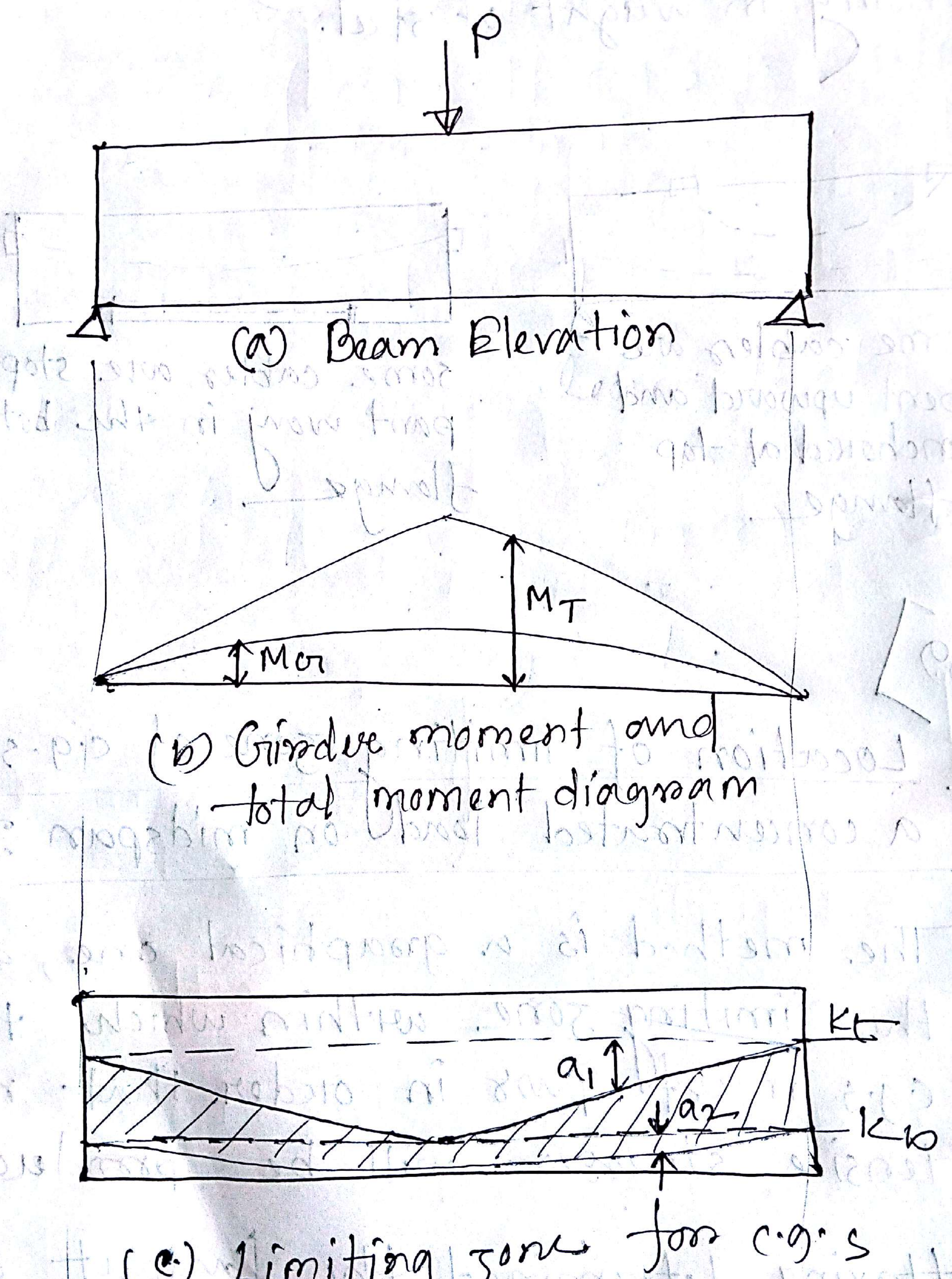


Fig: Location of limiting zone for c.g.s for a beam loaded as shown in (a), the minimum and maximum moment diagrams for girder load and for the total working load respectively are ~~the diagrams for~~ marked as M_G and M_T in (b).

In order that under the working load, the centre of pressure, the C line will not fall above the top kern ~~pt~~ line.

It is evident that the c.g.s must be located bellow the top kern at a distance of

$$a_1 = \frac{M_T}{F}$$

If the c.g.s falls above that upper limit at any point then the C line corresponding to M_T and F will fall above the top kern point resulting in tension in the bottom fiber.

Similarly, in order that the C line will not fall bellow the bottom kern line, the c.g.s line must not be positioned bellow the bottom kern by a distance greater than

$$a_2 = M_{GT}/F_0$$

which gives the lower limit for the location of c.g.s. If c.g.s is positioned above that lower limit, there will be no tention in the top fiber due to girder load and initial prestress F_0.

Thus it becomes clear that the limiting zone for c.g.s is given by the shaded area in Fig (c) in order that no tension will exist under the girder and working load.