

Design of Sections for Flexure

The design problem is taken in two steps.

- Preliminary Design
- Final Design for Type 1 Members

Before moving to preliminary design the followings are needed.

- **Calculation of Moment Demand**

- For simply supported prestressed beams, the maximum moment at the span is given by the beam theory. For continuous prestressed beams, the analysis can be done by moment distribution method. The moment coefficients in **Table 12** of **IS:456 - 2000** can be used under conditions of uniform cross-section of the beams, uniform loads and similar lengths of span.
- The design is done for the critical section. For a simply supported beam under uniform loads, the critical section is at the mid span. For a continuous beam, there are critical sections at the supports and at the spans.
- For design under service loads, the following quantities are known.
- $M_{DL} = M_d$ = moment due to dead load (excluding self-weight)
- M_{LL} = moment due to live load.
- The material properties are selected before the design.
- The following quantities are unknown.
- The member cross-section and its geometric properties,
- M_{SW} = moment due to self-weight,
- A_p = amount of prestressing steel,
- P_e = the effective prestress,
- e = the eccentricity.

- There are two stages of design.
- **1) Preliminary:** In this stage the cross-section is defined and P_e and A_p are estimated.
- **2) Final:** The values of e (at the critical section), P_e , A_p and the stresses in concrete at transfer and under service loads are calculated. The stresses are checked with the allowable values. The section is modified if required

- **Preliminary Design**
- The steps of preliminary design are as follows.
- 1) Select the material properties f_{ck} and f_{pk} .
- 2) Determine the total depth of beam (h).
- The total depth can be based on architectural requirement or, the following empirical equation can be used.
- $h = 0.03 \sqrt{M}$ to $0.04 \sqrt{M}$
- Here, h is in meters and M is in kNm.
- M is the total moment excluding self-weight.
- 3) Select the type of section. For a rectangular section, assume the breadth
- $b = h/2$.

Preliminary Design

- 4) Calculate the self-weight or, estimate the self-weight to be 10% to 20% of the load carried.
- 5) Calculate the total moment M_T including self-weight. The moment due to self-weight is denoted as $M_d = M_{sw}$.
- 6) Estimate the lever arm (z).
- $z \approx 0.65h$, if M_{sw} is large ($M_{sw} > 0.3M_T$).
- $z \approx 0.5h$, if M_{sw} is small.
- 7) Estimate the effective prestress (P_e)
- $P_e = M_T / z$, if M_{sw} is large.
- $P_e = M_{IL} / z$, if M_{sw} is small.
- If M_{sw} is small, the design is governed by the moment due to imposed load ($M_{IL} = M_T - M_{sw}$).
- 8) Considering $f_{pe} = 0.7f_{pk}$, calculate area of prestressing steel $A_p = P_e / f_{pe}$.
- 9) Check the area of the cross-section (A).
- The average stress in concrete at service $C/A (= P_e / A)$ should not be too high as compared to 50% of the allowable compressive stress $f_{cc,all}$. If it is so, increase the area of the section to $A = P_e / (0.5f_{cc,all})$.

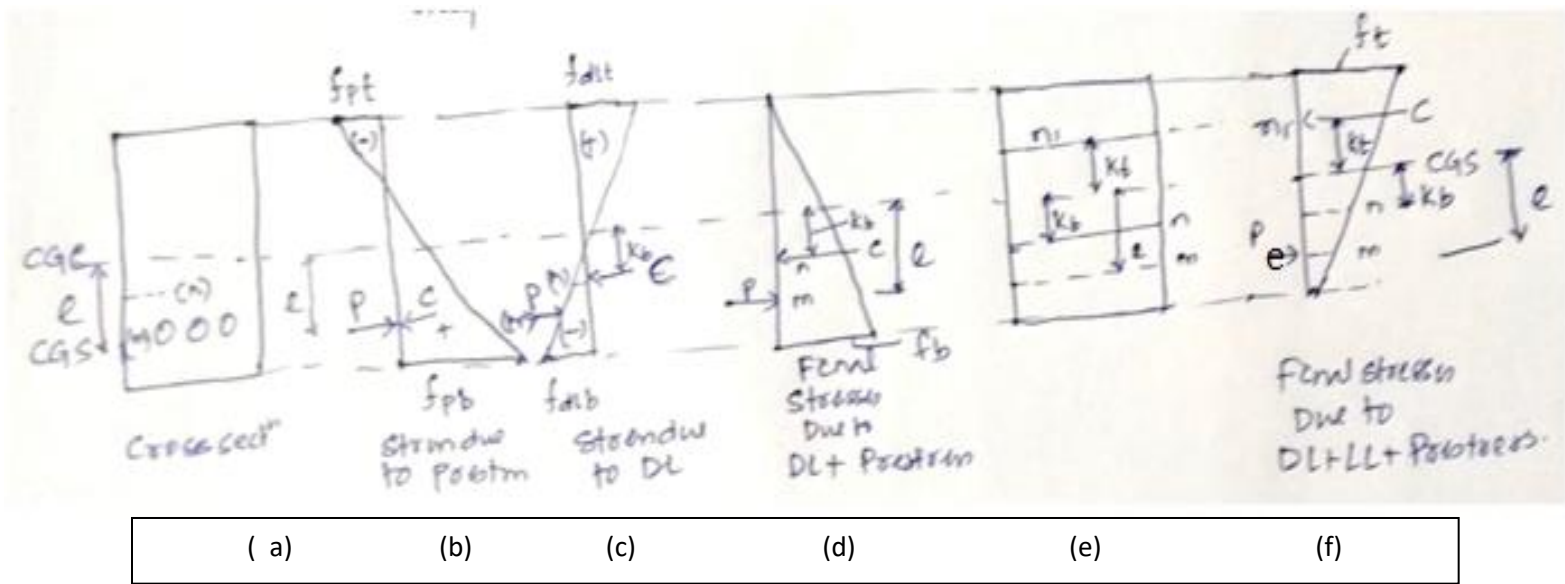
Final Design for Type 1 Members

- **Type 1:** In this type of members, no tensile stress is allowed in concrete at transfer or under service loads.

1) Calculate eccentricity e to locate the centroid of the prestressing steel (CGS).

- With increasing load, the compression (C) moves upward from the location of the Prestress (P) at CGS. At transfer, under the self-weight, C should lie within the kern zone to avoid tensile stress at the top. *restressing steel (CGS).*

The following sketch explains the lowest permissible location of C due to self-weight moment (M_{sw}) at transfer.



- In the above sketch,
- A = gross area of cross section
- f_b = maximum compressive stress in concrete at bottom edge
- h = total height of the section
- k_t, k_b = distances of upper and lower kern points, respectively, from CGC
- c_t, c_b = distances of upper and lower edges, respectively, from CGC
- P_0 = prestress at transfer after initial losses = P

- The stresses induced due to prestress are shown in figure (b). In that figure the prestress force P and the compressive force C will be in the same line. But when the moment due to moment ($M_d = M_{sw}$) is acting in the beam figure (c), C shifts to towards top to point n resist moment M_d where as the prestressing force is acting at same place m .
- Figure (d) shows the combined effect of stresses due to prestress and dead load. Final stresses are shown. Final stress at top will be zero to avoid tension in the member.
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- The lowest permissible location of C due to self-weight is at the bottom kern point (at a depth k_b below CGC) to avoid tensile stress at the top. The design procedure based on the extreme location of C gives an economical section.

- $$\frac{P}{A} - \frac{Pe}{Z} + \frac{M_d}{Z} = 0$$

- If k_b is the lower kern point then

- $$\frac{P}{A} - \frac{Pk_b}{Z} = 0$$

- From these two Equations

- $$e = k_b + M_d/P$$

- Here, the magnitude of C or T is equal to P_0 . The value of P_0 can be estimated as follows.

- a) 90% of the initial applied prestress (P_i) for pre-tensioned members.

- b) Equal to P_i for post-tensioned members.

- The value of P_i can be estimated from the amount of prestressing steel determined in the preliminary design.

- $$P_i = A_p(0.8f_{pk})$$

The permissible prestress in the steel is $0.8f_{pk}$, where f_{pk} is the characteristic tensile strength.

- 2) Recompute the effective prestress P_e and the area of prestressing steel A_p .
- At service condition, stresses at bottom point will be the critical point as there is chance tension to be developed. There is loss of prestress. Let it be P_e .
- Taking no tension to be developed at bottom.
- $$\frac{P}{A} + \frac{Pe}{Z} - \frac{M_T}{Z} = 0$$
- If k_t is the upper kern point then
- $$\frac{P}{A} - \frac{Pk_t}{Z} = 0$$
- Taking $P = P_e$, From these two Equations we get
- $P_e = M_T / (e + k_t)$
- Considering $f_{pe} = 0.7f_{pk}$, the area of prestressing steel is recomputed as follows.
- $A_p = P_e / f_{pe}$

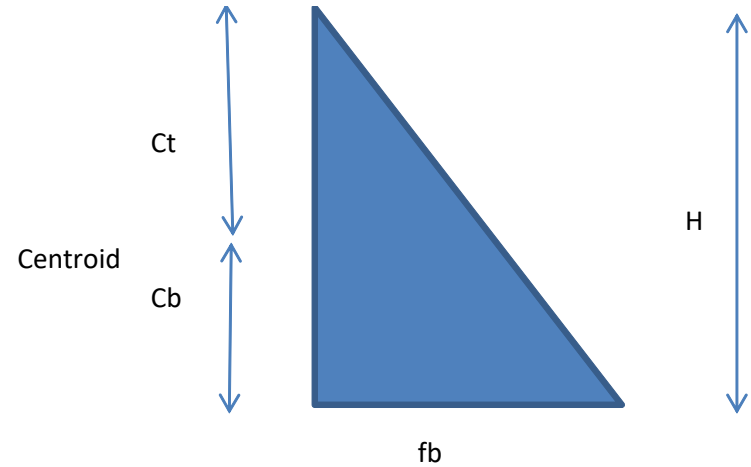
- 3) Recompute eccentricity e
- First the value of P_0 is updated. The eccentricity e is recomputed with the updated value of P_0 .
- If the variation of e from the previous value is large, another cycle of computation of the prestressing variables can be undertaken.
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- 4. Check the compressive stresses in concrete.
- The maximum compressive stress in concrete should be limited to the allowable values. At transfer, the stress at the bottom should be limited to $f_{cc,all}$, where $f_{cc,all}$ is the allowable compressive stress in concrete at transfer (available from **Figure 8** of **IS:1343-- 1980**). At service, the stress at the top should be limited to $f_{cc,all}$, where $f_{cc,all}$ is the allowable compressive stress in concrete under service loads (available from **Figure 7** of **IS:1343 - 1980**).

- a) At Transfer
- The stress at the bottom can be calculated from the average stress P_0/A .

$$f_b = -\frac{P_0 h}{A C_t}$$

- To satisfy the area of the section should be
- $A \geq \frac{P_0 h}{f_{cc.all} C_t}$
- If A is not sufficient redesign the section.



At Centroid Average stress is P_0/A

At Bottom= $F_b=(P_0/A)*C_t/H$

F_b Should be less than or equal to $f_{cc.all}$

$A \geq P_0 h / (f_{cc.all} * c_b)$

b) Design at Service

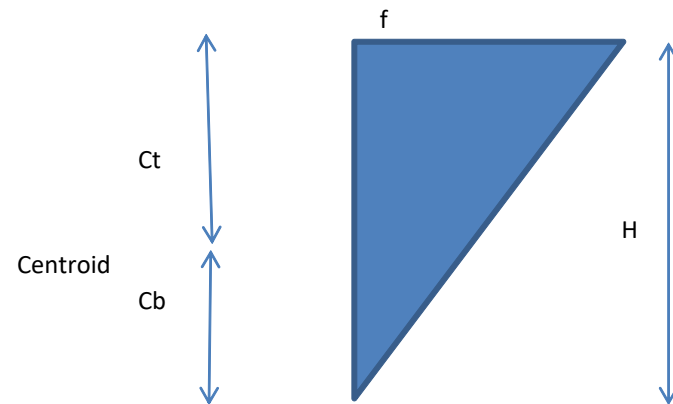
- The stresses at top can be calculated from average stress P_e/A

$$f_t = -\frac{P_e h}{A C_t}$$

- To satisfy the area of the section A should be

$$A \geq \frac{P_e h}{f_{cc,all} C_b}$$

- If A is not adequate then the section has to be redesigned.



At service maximum compressive stress will occur at top