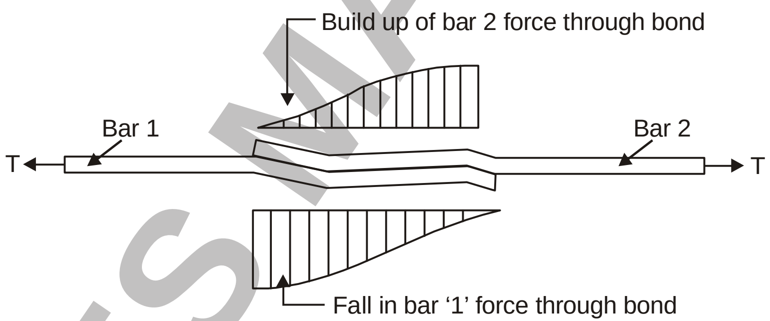
1. Splicing of Reinforcement

- Splices are provided for the following reasons :
  (i) Bars placed short of their required length due to non-availability of longer bars
  (ii) When the bar diameter has to be changed along the length.
- Purpose of Splicing is to transfer effectively the axial force from the terminating bar to the connecting bar with the same line of action at the junction.
- Splices shall be
  (i) AS far as possible be away from the sections of maximum stress and be staggered.
  (ii) Splices in flexural member should not be at sections where the bending moment (due to load) is more than 50 percent of the moment of resistance (MOR).
  (iii) Not more than half the bars are spliced at a section in general. When more than one half of the bars are spliced at a section or where splices are made at a points of maximum stress, special precautions shall be taken.
- **Types of Splices :**
  (i) Lap splice (lapping of bars)
  (ii) Welded splice (Welding of bars)
  (iii) Mechanical splice (mechanical coupler)

(i) Lap Splice :

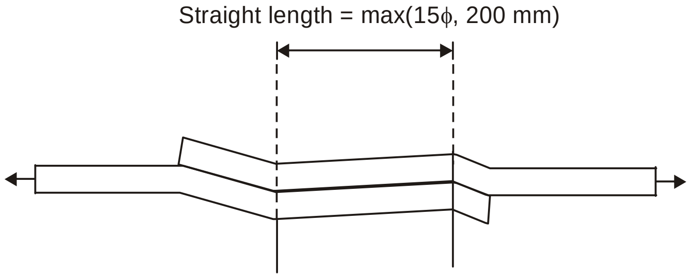
- By overlapping the bars over a certain length. The axial force is transferred from the terminating bar to the connecting bar through the mechanism of the bond with the surrounding concrete.
- Lap splice is not used for bars dia larger than 32 mm (welding or mechancial splicing shall be used).



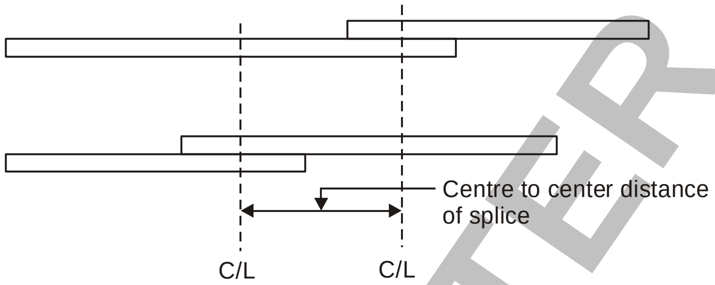
Sl.No.	Type of Force	Lap Length
(a)	For bars in flexural tension	Max. (L_d, 30ϕ) [L_d calculated for tension bars]
(b)	For direct tension	Max. (2L_d, 30ϕ) [L_d calculated for tension bars]
(c)	For compresion bars	Max. (L_d, 24ϕ) [L_d calculated for compression bars]

ϕ = Diameter of **smaller bars**

- When bars of two different diameters are spliced lap length shall be calculated on the basis of diameter of smaller bar.
- The straight length of the lap shall not be less than 15ϕ or 200 mm.



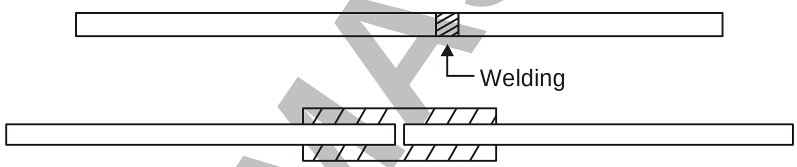
- Lap splices shall be considered as staggered if the center to center distance of splices is not less than 1.3 time the lap length calculated for the particular case.



(PLAN OF REINFORCEMENT)

- In case of bundled bars, lapped splices of bundled bars shall be made by splicing one bra at a time; such individual splices within a bundled shall be staggered.

(ii) Welded Splice and Mechanical Splice :



(Mechanical Coupler)

- Suitable for larger diameter bars because of reduced consumption of reinforcing steel compared to lap splice.
- Butt welding of bars is generally used.
- The code recommends that the design strength of a welded splice should in general be limited to 80 percent of the design strength of the bar for tension splice and 100 percent of the design strength of the bar for splice in compression bars.
- For mechanical connection 100 percent of the strength of bars for both tension bars and compression bars (no reduction in strength).
- Sometime, end bearing splices shall be used only for bars in compression.

- When splicing of welded wire fabric is to be carried out, lap splices of wires shall be made so that overlap measured between the extreme cross wires shall be not less than the spacing of cross wires plus 100 mm.

2. Bundled Bars

- When bars are bundled, specific surface area decreases and we require higher development length to hold the bar.

- As per IS code, the development length of each bar of bundled bars shall be that for the individual bar, increased by **10% for 2 bars in contact, 20% for 3 bars in contact** and **33% for four bars in contact.**

3. Minimum Reinforcement in Walls

(a) The **minimum ratio of vertical reinforcement** to gross concrete area shall be

(i) 0.0012 for deformed bars (so percentage wise 0.12%) not larger than 16 mm in diameter and with a characteristic strength of 415 MPa or greater.

(ii) 0.0015 for other types of bars.

(iii) 0.0012 for welded wire fabric not larger than 16 mm in diameter.

(b) Vertical reinforcement shall be spaced not farther apart than 3 × thickness or 450 mm, whichever is less.

(c) The **minimum ratio of horizontal reinforcement** to gross concrete area shall be ;

(i) 0.0020 for deformed bars not larger than 16 mm in diameter and with a characteristic strength of 415 MPa or greater.

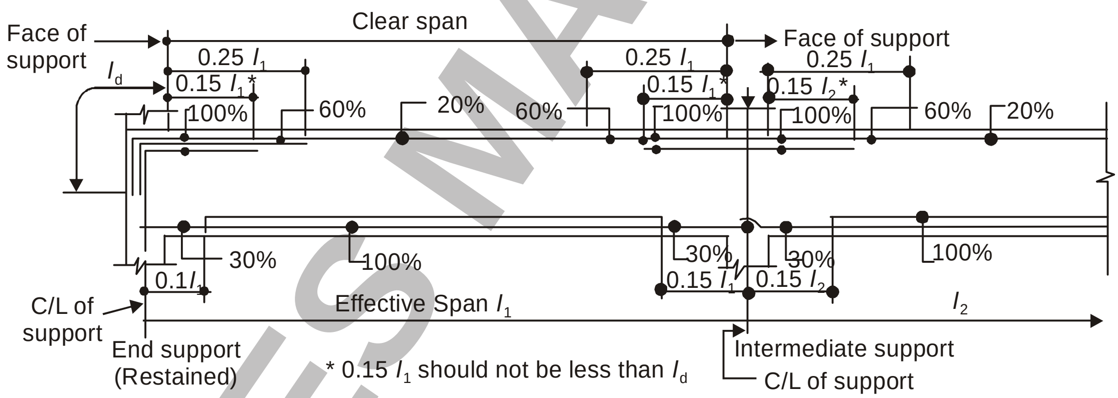
(ii) 0.0025 for other types of bars.

(iii) 0.0020 for welded wire fabric not larger than 16 mm in diameter.

(d) Horizontal reinforcement shall be spaced not farther than 3 × wall thickness or 450 mm, whichever is less.

4. Typical Detailing of R/F

In subjective question, when we are asked to draw the typical detailing of reinforcement, the following reinforcement detail shall be drawn :



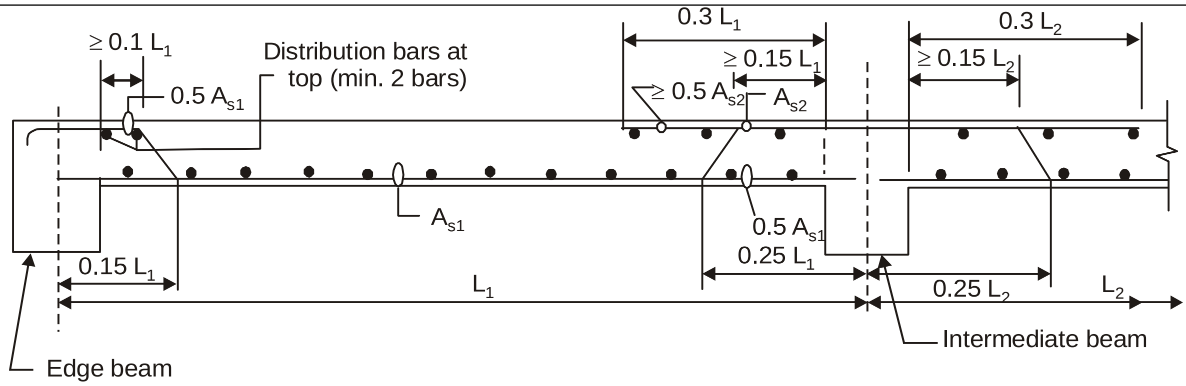
Note: Applicable to continuous beams with approximately equal spans (not differing more than 15 percent) and subjected to predominately UDL and designed without compression steel.

Simplified curtailment rules for continuous beams (Typical detailing)

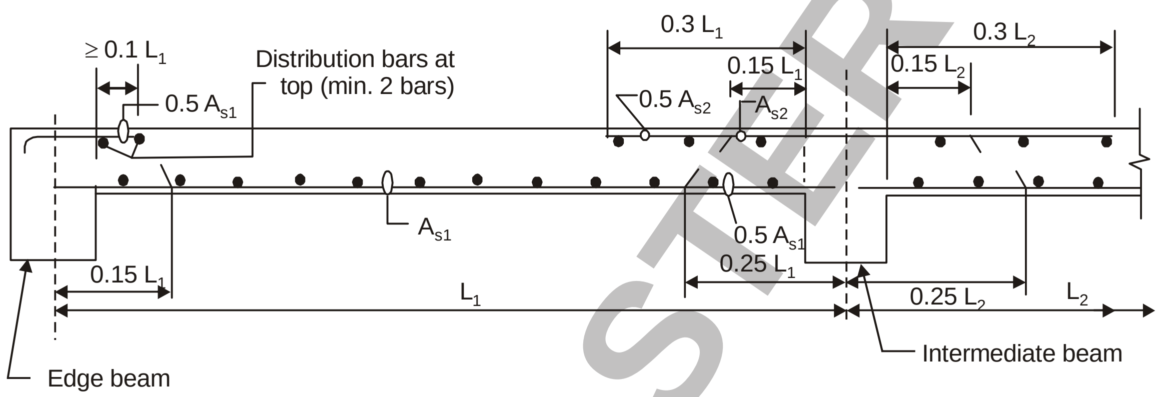
Note: On the top side from face of support

100% $A_{st} \rightarrow 0.15\, l$

60% $A_{st} \rightarrow 0.25\, l$

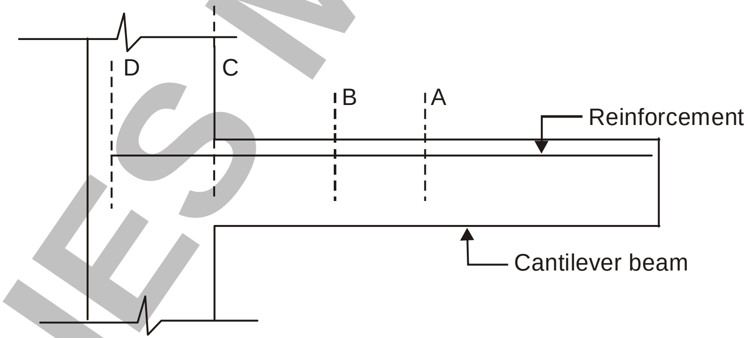


Simplified curtailment rules for continuous slab using bent up bars (Typical detailing)

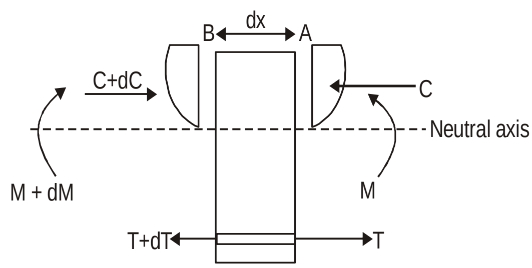


Simplified curtailment rules for continuous slab using straight bars (Typical detailing)

5. Flexural bond and Anchorage Bond (Development Bond) :



<u>Flexural bond (local bond)</u>- Which arise in flexural members due to change in bending moment i.e. due to shear. Variation in tension along the length of a reinforcing bar due to varying bending moment is made possible through flexural bond.



AB $\rightarrow$ Flexural bond

$(T + dT)Z = M + dM$ and $TZ = M$ [Z = lever arm]

$$\Rightarrow \quad dT\,Z = dM$$

$$\Rightarrow \quad dT = \frac{dM}{Z}$$

$$dT = \tau_{bd} \times \text{perimeter} \times \text{length}$$

$$= \tau_{bd} \times \sum 0 \times dx$$ [τ_{bd} =bond stress due to applied load]

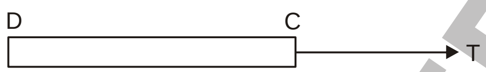
$$\Rightarrow \qquad \tau_{bd} \sum 0 \times dx = \frac{dM}{Z} \qquad [\Sigma 0 = \text{perimeter}]$$

$$\Rightarrow \qquad \tau_{bd} = \frac{dM}{\sum 0 \times dx\ Z} = \frac{dM/dx}{\sum 0 \times Z}$$

Note : Flexural bond stress is high at locations of high shear and can be effectively reduced by increasing $\sum 0$ (Perimeter) i.e. by providing higher number of smaller diameter bars instead of smaller numbers of larger dia. bars.

Anchorage Bond (Development Bond) :

Which arises over the length of anchorage provided for a bar or near the end (or cut off point) of a reinforcing bar; this bond resist the pulling out of the bar if it is in tension or conversely the pushing in of the bar if it is in compression.



$$L_d = \frac{0.87 f_y \phi}{4\tau_{bd}} \quad \text{[As discussed in class]}$$

6. Masonry Wall :

Code of practice for structural use of unreinforced masonry (IS 1905-1987)

(a) Effective Height of Walls

Effective height of a wall shall be taken as shown in Table below

Sl.No.	Condition of Support	Effective Height
1.	**Lateral as well as rotational restraint (that is, full restraint) at top and bottom.** For example, when the floor/roof spans on the walls so that reaction to load of floor/roof is provided by the walls, or when an RCC floor/roof has bearing on the wall (minimum 9cm), irrespective of the direction of the span (foundation footings of a wall give lateral as well as rotational restraint).	0.75 H
2.	**Lateral as well as rotational restraint (that is, full restraint) at one end and only lateral restraint (that is, partial restraint) at the other.** For example, RCC floor/roof at one end spanning or adequately bearing on the wall and timber floor/roof not spanning on wall, but adequately anchored to it, on the other end.	0.85 H
3.	**Lateral restraint, without rotational restraint (that is, partial restraint) on both ends.** For example, timber floor/roof, not spanning on the wall but adequately anchored to it on both ends of the wall, that is, top and bottom	1.00 H
4.	**Lateral restraint as well as rotational restraint (that is, full restraint) at bottom but have no restraint at the top.** For example, parapet walls with RCC roof having adequate bearing on the lower wall, or a compound wall with proper foundation on the soil.	1.50 H

H = height of wall between centres of supports.

(b) Effective Length : Effective length of a wall shall be as given in table below

Sl.No.	Condition of Support	Effective length
1.	Where a wall is continuous and is supported by cross wall, and there is no opening within a distance of H/8 from the face of cross wall or where a wall is continuous and is supported by piers/buttresses	0.8 L
2.	Where a wall is supported by a cross wall at one end and continuous with cross wall at other end or Where a wall is supported by a pier/buttress at one end and continuous with pier/buttress at other end.	0.9 L
3.	Where a wall is supported at each end by cross wall or Where a wall is supported at each end by a pier/buttress	1.0 L
4.	Where a wall is free at one end and continuous with a cross wall at the other end. or Where a wall is free at one end and continuous with a pier/buttress at the other end	1.5 L
5.	Where a wall is free at one end and supported at the other end by a pier/buttress, where H : actual height of wall between centres of adequate lateral support; and L : Length of wall from or between centres of cross wall, piers or buttresses.	2.0 L
In case there is an opening taller than 0.5H in a wall, ends of the wall at the opening shall be considered as free.		

(c) Slenderness Ratio :

For a wall, slenderness ratio shall be effective height divided by effective thickness or effective length divided by the effective thickness, whichever is less. In case of a load bearing wall, slenderness ratio shall not exceed that given in Table below

Maximum Slenderness Ratio for a Load Bearing Wall

No. of Storeys	Maximum Slenderness Ratio	
	Using Portland Cement or Portland Pozzolana Cement in Mortar	Using Lime Mortar
Not exceeding 2	27	20
Exceeding 2	27	13

7. Reinforced Masonry Wall :

In the cast of round bars used as reinforcement, the diameter shall not exceed 8 mm. Flat bars and similar reinforcement shall not have a thickness exceeding 8 mm.

8. Prestressed

(a) **Kern points :** When the resultant compression (C) is located within a specific zone of a section of a beam, tensile stresses are not generated. This zone is called the kern zone of a section.

(b) In the post-cracking stage, a prestressed concrete beam behaves in a manner similar to that of a reinforced concrete beam.

(c) The recommendations of the Indian standard code (IS: 1343 – 1980) with regard to the limit state of deflection are as follows:

1. The final deflection, due to all loads including the effects of temperature, creep and shrinkage should normally not exceed span/250.
2. The deflection, including the effects of temperature, creep and shrinkage occuring after the erection of partitions and the application of finishes, should not normally exceed span/350 or 20 mm, whichever is less.
3. If finishes are to be applied to the prestressed concrete members, the total **upward deflection** should not exceed span/300, unless uniformty of camber between adjacent units can be ensured.

(d) In general, there are three ways of improving the shear resistance of structural concrete members by prestressing techniques:

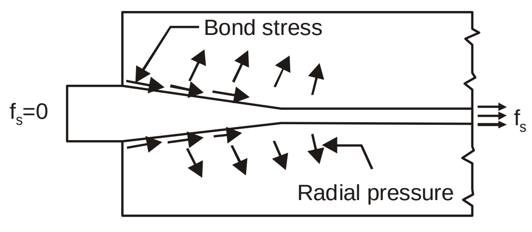
1. Horizontal or axis prestressing;
2. Prestressing by inclined or sloping cables; and
3. Vertical or transverse prestressing.

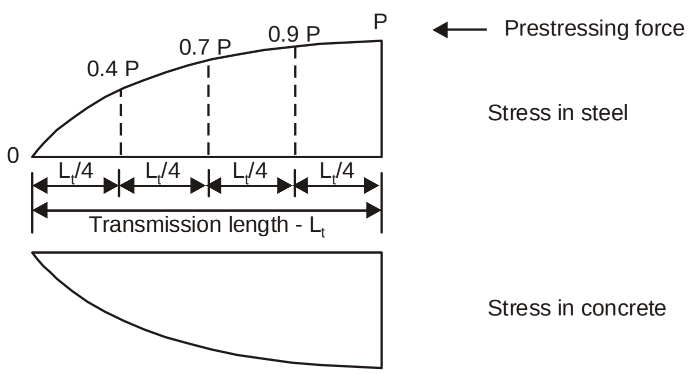
(e) Shear design for a prestressed concrete beam is based on elastic theory.

(f) Pretensioned members

(i) Transmission on Prestressing forces by bond

- In a pre-tensioned system, when a wire is released from its temporary anchorage on the prestressing bed, the end of the wire swells as a result of the recovery of the lateral contraction and develops a wedge effect.
- The swelling of the wire is only a few thoudsands of a millimeter, but it nevertheless produces considerable radial pressures on the concrete, giving rise to large frictional froces.
- The transmission of prestressing force from steel to concrete is generally through a bond comprising of (i) adhesion, (ii), friction, and (iii) shearing resistance (dilatancy).
- At intermediate points along the length of a beam, the bond stress is resisted by adhesion, while in a transfer zone the tendons invariably slip and sink into the concrete, destroying most of the adhesion.
- The bond stress, stress in steel and concrete in the transmission zone are showns in Fig. below.
- When the bond stress is zero, the stress in steel and concrete reach their maximum values, and uniform stress distribution is prevalent from this section. The length needed for achieving this is **termed transmission length.**
- The transimission length depends mainly on the diameter and surface characteristic of the wire, the elastic properties of steel and concrete, and the coefficient of friction between steel and concrete.
- The transmission length prevailing at the time of transfer does not remain constant, but increases at a decreasing rate with time due to the effect of creep and shrinkage of concrete.





(ii) Transverse Tensile stresses

- Transverse tensile stresses of considerable magnitude develop in the transfer zone due to concentration of tendons at the ends.
- If the tensile stresses exceed the tensile strength of concrete, horizontal cracking occurs.
- It has been found that the method of distributing tendons at the ends has a greater influence on the end-zone cracking.

(iii) End zone reinforcement

- In the transfer zone of pre-tensioned beams, transverse reinforcements are necessary to prevent the failure of the end-zones due to the cracking of concrete as a consequence of large transverse tensile stresses, which often exceed the tensile strength of concrete.
- Proper compaction of concrete in the end zones by vibration is essential to achieve dense concrete associated with high strength.

(iv) Code Previsions for bond and transmission length

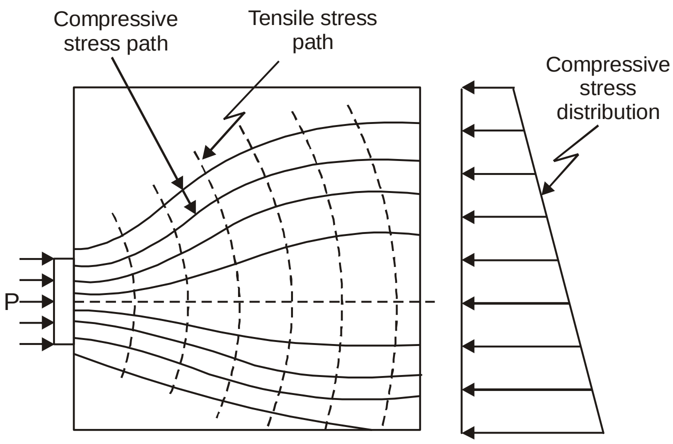
- In the absence of values based on actual test-results, the following values are recommended for the transmission length, provided the concrete is well compacted and its strength at transfer is not less than 35 N/mm^2 and the tendons are released gradually;

1.	Plain and indented wires	100 ϕ
2.	crimped wires	65 ϕ
3.	Strands	30 ϕ

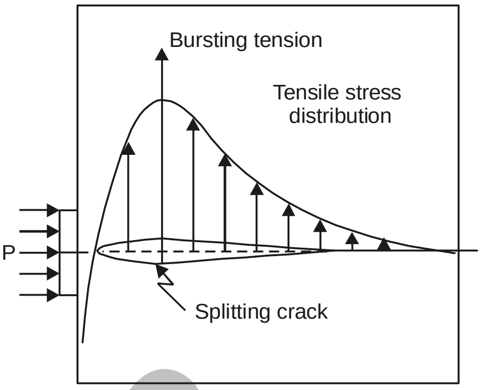
- ϕ is the diameter of the tendon
- The recommended values of transmission length apply to wires of diameter not exceeding 5 mm and strands of diameter not exceeding 18 mm
- It is recommended that one half of the transmission length shall overhang the support in simly supported beams and the whole of the transmission length should extend beyond the supports in the case of fixed ends.

(g) Anchorage zone stresses in post tensioned member

- In the anchorage zone or the end blocks of a post-tensioned prestressed concrete element, the state of stress-distribution is complex and three-dimensional in nature.
- In most post-tensioned members, the prestressing wires are introduced in cable holes or ducts, pre-formed in the members, and then stressed and anchored at the end faces.
- As a result of this, large forces, (concentrated over relatively small areas) are applied on the end blocks. These forces which are applied at the end develop transverse and shear stresses.
- The transverse stresses developed in the anchorage zone are tensile in nature over a large length. If large tendon forces are concentrated over the anchorage zone high tensile stresses are induced in the concrete and concrete starts spalling around the tendon and at anchorage zone.
- The zone between the end of the beam and the section where only longitudinal stress exists is generally referred to as the **anchorage zone or end block** .
- The transverse stresses developed in the anchorage zone are tensile in nature over a large length and since concrete is weak in tension, adequate reinforcement should be provided to resist this tension.
- The idealised stress distribution in an end block with the compressive and tensile stress paths is shown in Fig. below
- The effect of transverse tensile stress is to develop a zone of bursting tension in a direction perpendicular to the anchorage force, resulting in horizontal cracking a shown in Fig. Since concrete is weak in tension, suitable reinforcement are generally provided in the transverse direction to resist the bursting tension.



(a) idealized stress paths



(b) Bursting tension and splitting cracks

End blocks of post-tensioned beams

(h) Concordant Cable Profile

- If the profile of the cable is properly selected called concordant cable profile, the profile does not produce reactions at the supports or secondary moments in the spans.
- Concordant cable profile is not unique for all type of loading and support conditions but depends upon degree of indeterminancy of the structure, thus profile satisfies a set of geometrical conditions and located in a narrow zone.

The advantage of a concordant cable profile

(1) The calcualtions become simpler.

(2) There is no secondary moment in the spans due to the prestress.