

END ZONE REINFORCEMENT PRE-TENSIONED MEMBER

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PRETENSIONED MEMBERS

- The stressed tendons transfer the prestress to the concrete in prestressed members.
- The pre-tensioned and post-tensioned members have different way of the transfer mechanism.
- Pre-tensioned member have no anchorage device at the ends.



No anchorage

TRANSFER OF PRESTRESS

- For a pre-tensioned member without any anchorage at the ends, the prestress is transferred by the bond between the concrete and the tendons.

FACTORS AFFECTING BOND

- 1) Adhesion between concrete and steel
- 2) Mechanical bond at the concrete and steel interface
- 3) Friction in presence of transverse compression.

Out of three the main is the mechanical bond is the primary mechanism in the bond for indented wires, twisted strands and deformed bars.

- The transfer of prestress to concrete takes over a certain length from each which is called the **transmission length** or **transfer length** (L_t).
- The stress in the tendon is zero at the ends of the members.
- It increases over the transmission length to the effective prestress (f_{pe}) under service loads and remains practically constant beyond it.
- The following figure shows the variation of prestress in the tendon

TRANSFER OF PRESTRESS

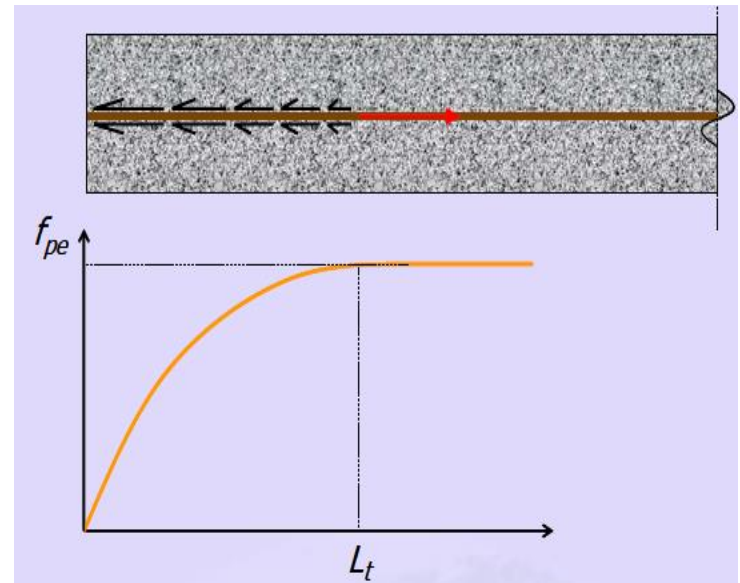
- **Hoyer Effect**

Due to stretching of tendon diameter reduces .

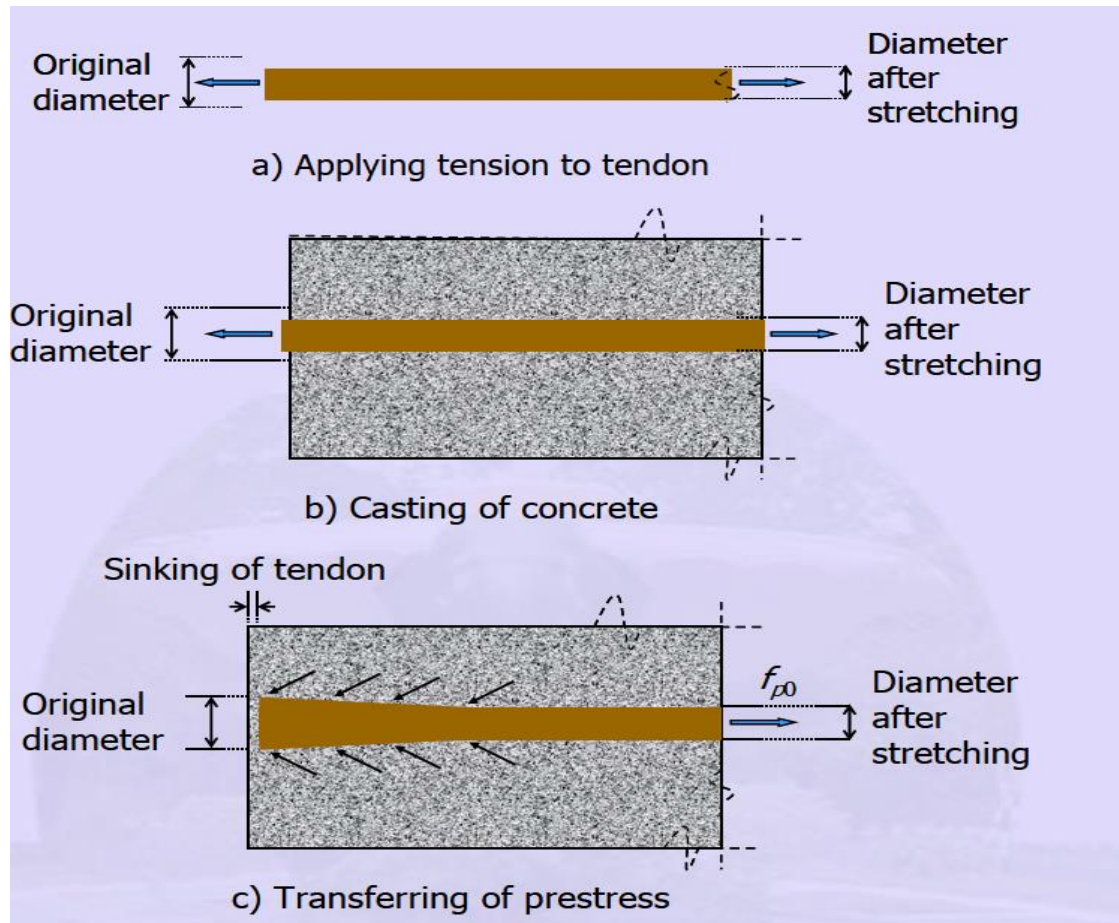
When the prestress is transferred after the hardening of concrete, the ends of the tendon sink in concrete.

The prestress at the ends of the tendon is zero. The diameter of the tendon regains its original value towards the end over the transmission length. The change of diameter from the original value (at the end) to the reduced value (after the transmission length), creates a wedge effect in concrete.

This helps in the transfer of prestress from the tendon to the concrete. This is known as the Hoyer effect. The following figure shows the sequence of the development of Hoyer effect.



Hoyer effect



Transmission Length

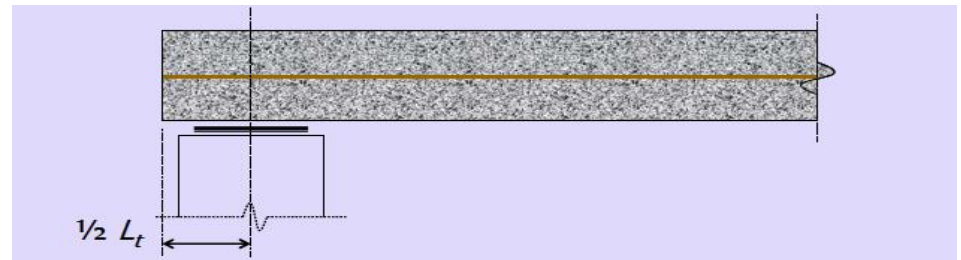
- 1) Type of tendon : wire, strand or bar
- 2) Size of tendon
- 3) Stress in tendon
- 4) Surface deformations of the tendon: Plain, indented, twisted or deformed
- 5) Strength of concrete at transfer
- 6) Pace of cutting of tendons: Abrupt flame cutting or slow release of jack
- 7) Presence of confining reinforcement
- 8) Effect of creep
- 9) Compaction of concrete
- 10) Amount of concrete cover.

- **According to IS:1343 – 1980** transmission length are as follows and concrete should be of minimum M35 grade, ϕ is do of tendons

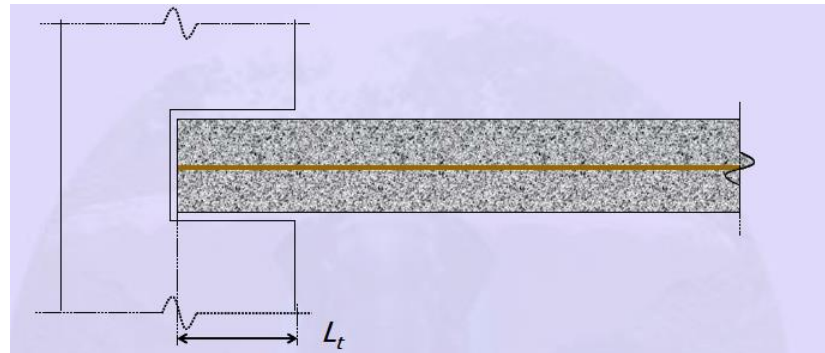
For Plain and intended wires	$L_t=100 \phi$	For Plain and intended wires
For Crimped wires	$L_t=65 \phi$	For Crimped wires
For strands	$L_t=30 \phi$	For strands

To avoid the transmission length in the clear span of a beam, **IS:1343 - 1980** recommends the following.

- 1) To have an overhang of a simply supported member beyond the support by a distance of at least $\frac{1}{2} L_t$.



- 2) If the ends have fixity, then the length of fixity should be at least L_t .



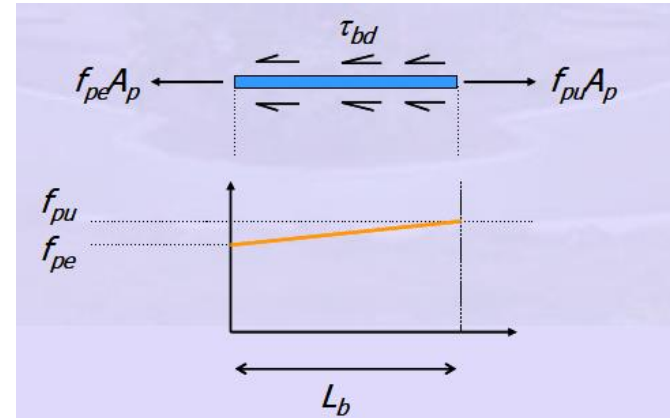
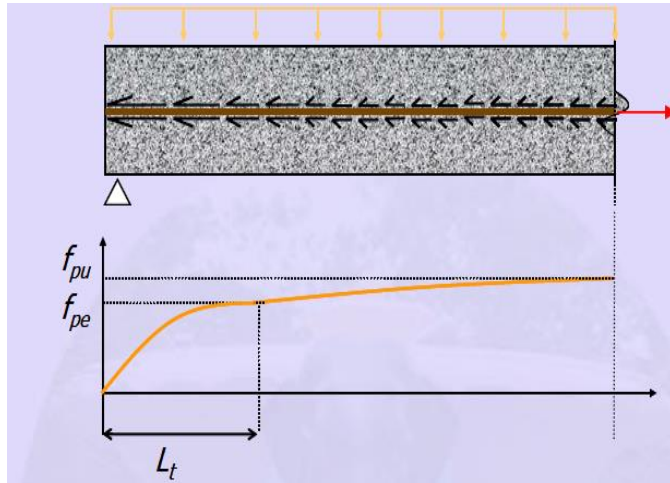
Development Length

- The development length needs to be provided at the critical section, the location of maximum moment.
- The length is required to develop the ultimate flexural strength of the member.
- The development length is the minimum length over which the stress in tendon can increase from zero to the ultimate prestress (f_{pu}). The development length is significant to achieve ultimate capacity.
- The development length (L_d) is the sum of the transmission length (L_t) and the bond length (L_b).

$$L_d = L_t + L_b$$

- The bond length is the minimum length over which, the stress in the tendon can increase from the effective prestress (f_{pe}) to the ultimate prestress (f_{pu}) at the critical location.

Development Length



The above figure shows the variation of prestress in the tendon over the length of a simply supported beam at ultimate capacity

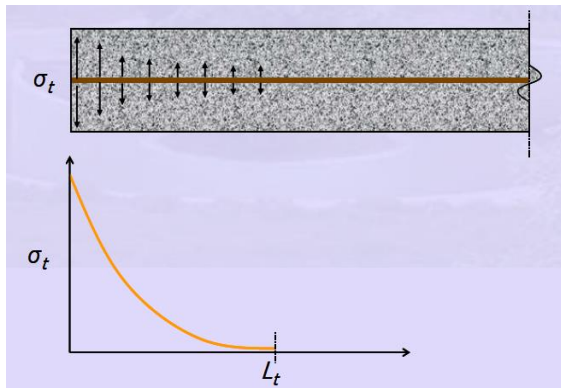
$$L_b = \frac{(f_{pu} - f_{pe})\phi}{4\tau_{bd}}$$

ϕ is the nominal diameter of the tendon and

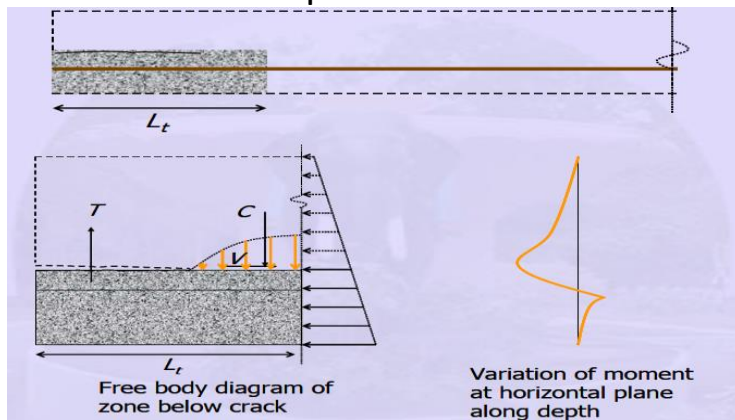
τ_{bd} is the design bond strength

End Zone Reinforcement

- The prestress and the Hoyer effect cause transverse tensile stress (σ_t).



Transverse stress in the end zone of a pre-tensioned beam



Forces in End zone

To restrict the splitting of concrete, transverse reinforcement (in addition to the reinforcement for shear) needs to be provided at each end of a member along the transmission length. This reinforcement is known as **end zone reinforcement**. The generation of the transverse tensile stress can be explained by the free body diagram of the following zone below crack, for a beam with an eccentric tendon. Tension (T), compression (C) and shear (V) are generated due to the moment acting on the horizontal plane at the level of the crack. The internal forces along the horizontal plane are shown in (a) of the following figure. The variation of moment (due to the couple of the normal forces) at horizontal plane along the depth is shown in (b).

End Zone Reinforcement

- The end zone reinforcement is provided to carry the tension (T) which is generated due to the moment (M). The value of M is calculated for the horizontal plane at the level of CGC due to the compressive stress block from the normal stresses in a vertical plane above CGC. The minimum amount of end zone reinforcement (A_{st}) is given in terms of the moment (M) as follows.

$$A_{st} = 2.5 M / f_s \cdot h$$

- h = total depth of the section , M = moment at the horizontal plane at the level of CGC due to the compressive stress block above CGC
- f_s = allowable stress in end zone reinforcement.
 - The lever arm for the internal moment is $h/2.5$.
 - The value of f_s is selected based on a maximum strain.

End Zone Reinforcement

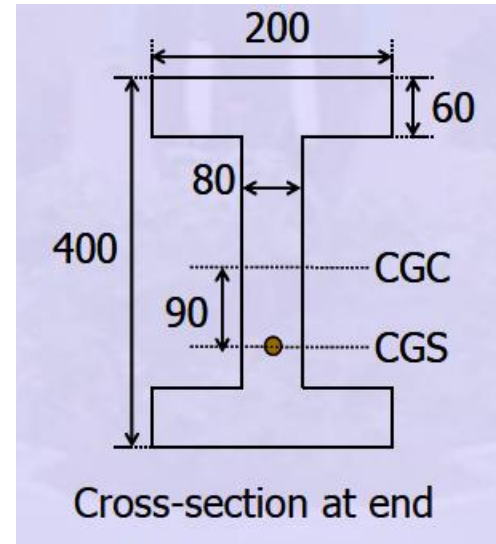
- The end zone reinforcement is provided in the form of closed stirrups enclosing all the tendons, to confine the concrete.
- The first stirrup should be placed as close as possible to the end face, satisfying the cover requirements.
- About half the reinforcement can be provided within a length equal to $\frac{1}{3}L_t$ from the end. The rest of the reinforcement can be distributed in the remaining $\frac{2}{3}L_t$.

PROBLEM

Design the end zone reinforcement for the pre-tensioned beam shown in the following figure.

The sectional properties of the beam are as follows.

- $A = 46,400 \text{ mm}^2$
- $I = 8.47 \times 10^8 \text{ mm}^4$
- $Z = 4.23 \times 10^5 \text{ mm}^3$
- There are 8 prestressing wires of 5 mm diameter.
- $A_p = 8 \times 19.6 = 157 \text{ mm}^2$
- The initial prestressing is as follows.
- $f_{p0} = 1280 \text{ N/mm}^2$.
- Limit the stress in end zone reinforcement (f_s) to 140 N/mm^2 .



SOLUTION

- 1) Determination of stress block above CGC
- Initial prestressing force
- $P_0 = A_p \cdot f_{po}$
- $= 157 \times 1280 \text{ N}$
- $= 201 \text{ kN}$

$$f_t = \frac{P_0}{A} - \frac{P_0 e}{Z} = \frac{201 \cdot 10^3}{46400} - \frac{201 \cdot 10^3 \cdot 90}{4.23 \cdot 10^5} = 0$$

$$f_b = \frac{P_0}{A} + \frac{P_0 e}{Z} = \frac{201 \cdot 10^3}{46400} + \frac{201 \cdot 10^3 \cdot 90}{4.23 \cdot 10^5} = 8.60 \text{ N/mm}^2$$

- 2) Determination of components of compression block

$$C_1 = \frac{1}{2} \times 1.29 \times 200 \times 60 = 7.74 \text{ kN}$$

$$y_1 = 140 + \frac{1}{3} 60 = 160 \text{ mm}$$

$$C_2 = \frac{1}{2} \times 1.29 \times 140 \times 80 = 7.22 \text{ kN}$$

$$y_2 = \frac{2}{3} 140 = 93.3 \text{ mm}$$

$$C_3 = \frac{1}{2} \times 4.3 \times 140 \times 80 = 24.08 \text{ kN}$$

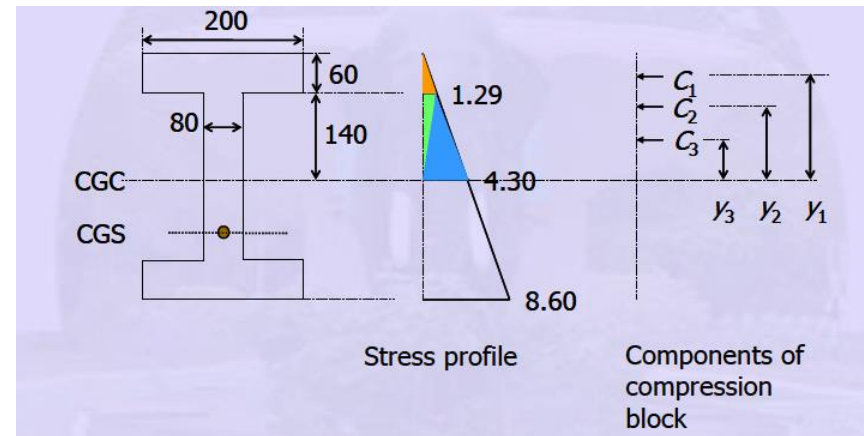
$$y_3 = \frac{1}{3} 140 = 46.7 \text{ mm}$$

- 3) Determination of moment

$$M = \sum C_i \cdot y_i$$

$$= C_1 \cdot y_1 + C_2 \cdot y_2 + C_3 \cdot y_3$$

$$= (7.74 \times 160) + (7.22 \times 93.3) + (24.08 \times 46.7) = 3036.6 \text{ kN-mm}$$



- 4) Determination of amount of end zone reinforcement

$$A_{st} = \frac{2.5 M}{f_s h}$$

$$A_{st} = \frac{2.5 * 3036.6 * 1000}{140 * 400} = 135.6 \text{ mm}^2$$

With 6 mm diameter bars, required number of 2 legged closed stirrups = $135.6 / (2 \times 28.3) \Rightarrow 3$.

For plain wires, transmission length

$$L_t = 100 \phi$$

$$= 600 \text{ mm.}$$

Provide 2 stirrups within distance 200 mm

($L_t/3$) from the end. The third stirrup is in the next 400 mm.

Designed end zone reinforcement

