

7.2 Transmission of Prestress (Part II)

This section covers the following topic.

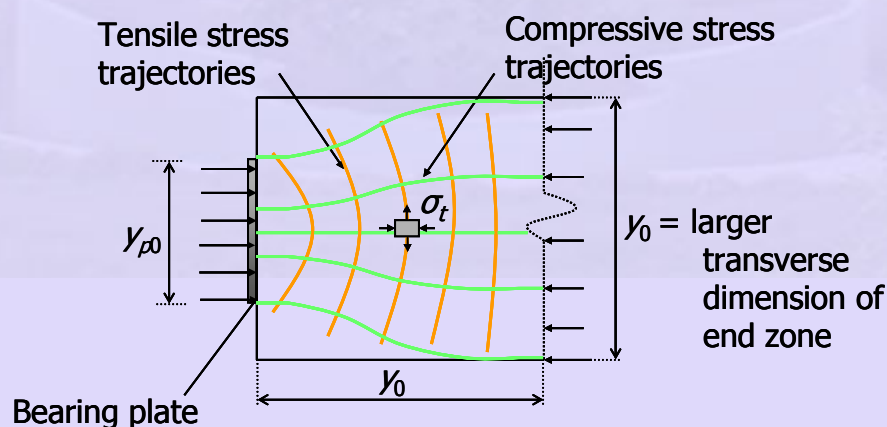
- Post-tensioned Members

7.2.1 Post-tensioned Members

Unlike in a pre-tensioned member without anchorage, the stress in the tendon of a post-tensioned member attains the prestress at the anchorage block. There is no requirement of transmission length or development length.

The end zone (or end block) of a post-tensioned member is a flared region which is subjected to high stress from the bearing plate next to the anchorage block. It needs special design of transverse reinforcement. The design considerations are bursting force and bearing stress.

The stress field in the end zone of a post-tensioned member is complicated. The compressive stress trajectories are not parallel at the ends. The trajectories diverge from the anchorage block till they become parallel. Based on **Saint Venant's principle**, it is assumed that the trajectories become parallel after a length equal to the larger transverse dimension of the end zone. The following figure shows the external forces and the trajectories of tensile and compressive stresses in the end zone.



Stress trajectories in the end zone

Figure 7-2.1 Stress trajectories in the end zone of a post-tensioned beam

The larger transverse dimension of the end zone is represented as y_0 . The corresponding dimension of the bearing plate is represented as y_{p0} . For analysis, the

end zone is divided into a **local zone** and a **general zone** as shown in the following sketch.

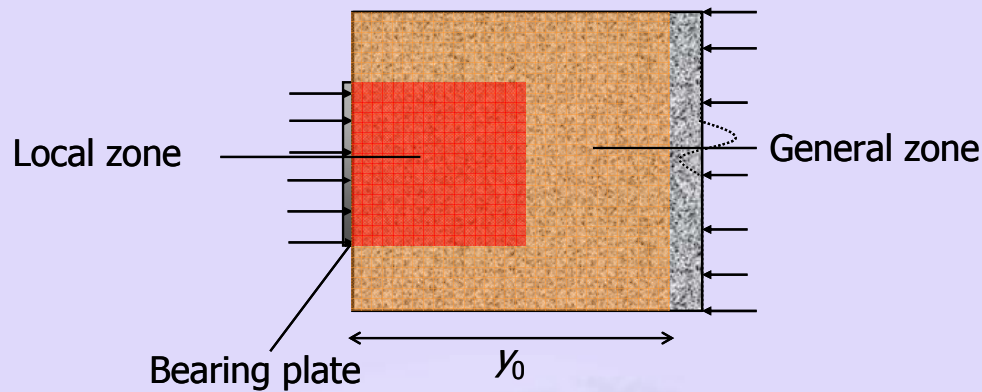


Figure 7-2.2 Local and general zones in the end zone

The local zone is the region behind the bearing plate and is subjected to high bearing stress and internal stresses. The behaviour of the local zone is influenced by the anchorage device and the additional confining spiral reinforcement. The general zone is the end zone region which is subjected to spalling of concrete. The zone is strengthened by end zone reinforcement.

The variation of the transverse stress (σ_t) at the CGC along the length of the end zone is shown in the next figure. The stress is compressive for a distance $0.1y_0$ from the end. Beyond that it is tensile. The tensile stress increases and then drops down to zero within a distance y_0 from the end.

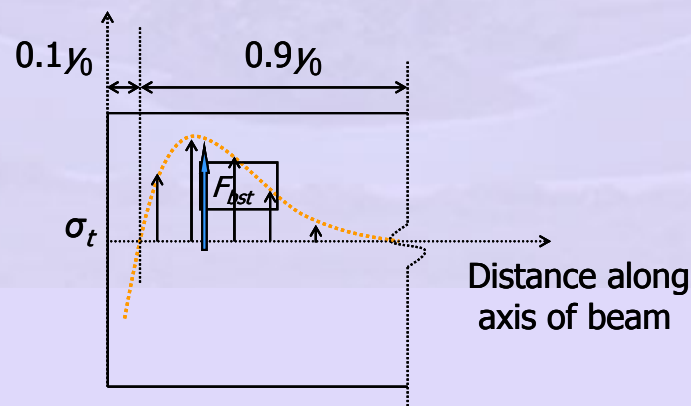


Figure 7-2.3 Transverse stress in the end zone

The transverse tensile stress is known as **splitting tensile stress**. The resultant of the tensile stress in a transverse direction is known as the **bursting force** (F_{bst}). Compared

to pre-tensioned members, the transverse tensile stress in post-tensioned members is much higher.

Besides the bursting force there is spalling forces in the general zone.

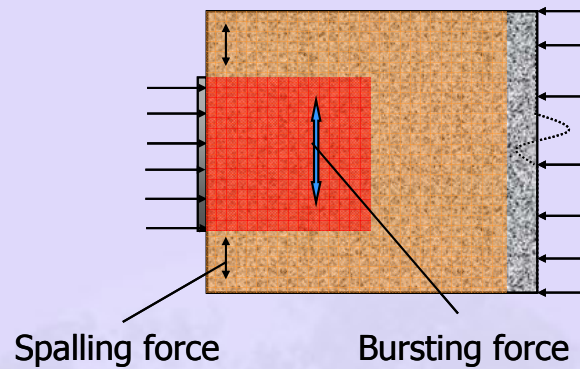


Figure 7-2.4 Spalling and bursting forces in the end zone

IS:1343 - 1980, Clause 18.6.2.2, provides an expression of the bursting force (F_{bst}) for an individual square end zone loaded by a symmetrically placed square bearing plate.

$$F_{bst} = P_k \left[0.32 - 0.3 \frac{y_{p0}}{y_0} \right] \tag{7-2.1}$$

Here,

- P_k = prestress in the tendon
- y_{p0} = length of a side of bearing plate
- y_0 = transverse dimension of the end zone.

The following sketch shows the variation of the bursting force with the parameter y_{p0} / y_0 . The parameter represents the fraction of the transverse dimension covered by the bearing plate.

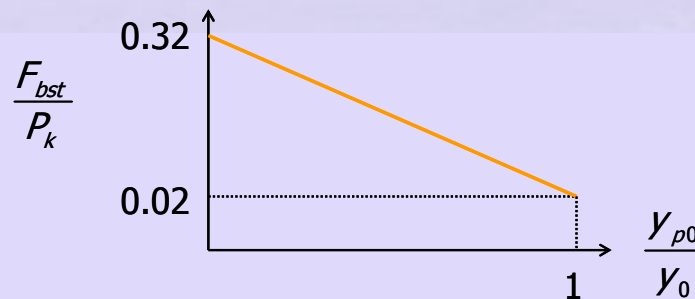


Figure 7-2.5 Variation of bursting force with size of bearing plate

It can be observed that with the increase in size of the bearing plate the bursting force (F_{bst}) reduces. The following sketch explains the relative size of the bearing plate with respect to the end zone.

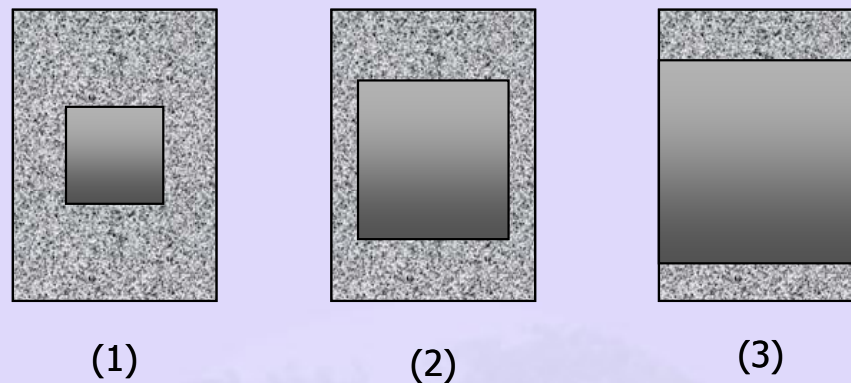


Figure 7-2.6 End views of end zones with varying size of the bearing plate

In the above end views of end zones, the bursting force (F_{bst}) will be largest for Case (1) and least for Case (3). For a rectangular end zone, F_{bst} is calculated from the previous equation for each principle direction. For a circular bearing plate, an equivalent square loaded area is considered in the calculation of F_{bst} . For more than one bearing plate, the end zone is divided into symmetrically loaded prisms. Each prism is analysed by the previous equation.

End Zone Reinforcement

Transverse reinforcement is provided in each principle direction based on the value of F_{bst} . This reinforcement is called end zone reinforcement or anchorage zone reinforcement or bursting links. The reinforcement is distributed within a length from $0.1y_0$ to y_0 from an end of the member.

The amount of end zone reinforcement in each direction (A_{st}) can be calculated from the following equation.

$$A_{st} = \frac{F_{bst}}{f_s} \quad (7-2.2)$$

The stress in the transverse reinforcement (f_s) is limited to $0.87f_y$. When the cover is less than 50 mm, f_s is limited to a value corresponding to a strain of 0.001.

The end zone reinforcement is provided in several forms, some of which are proprietary

of the construction firms. The forms are closed stirrups, mats or links with loops. A few types of end zone reinforcement is shown in the following sketches.

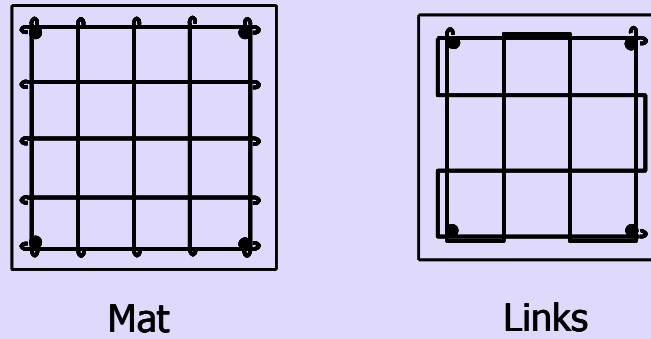


Figure 7-2.7 Types of end zone reinforcement

The local zone is further strengthened by confining the concrete with spiral reinforcement. The performance of the reinforcement is determined by testing end block specimens. The following photo shows the spiral reinforcement around the guide of the tendons.

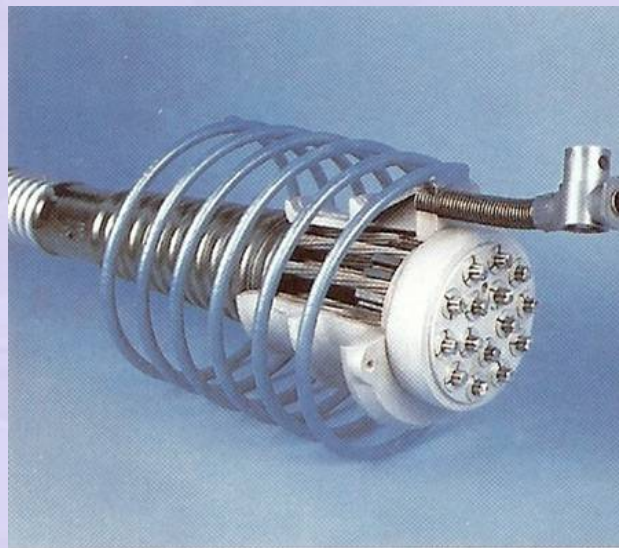


Figure 7-2.8 Spiral reinforcement in the end zone
(Reference: Dywidag Systems International)

The end zone may be made of high strength concrete. The use of dispersed steel fibres in the concrete (fibre reinforced concrete) reduces the cracking due to the bursting force. Proper compaction of concrete is required at the end zone. Any honey-comb of the concrete leads to settlement of the anchorage device. If the concrete in the end zone is different from the rest of the member, then the end zone is cast separately.

Bearing Plate

High bearing stress is generated in the local zone behind the bearing plate. The bearing stress (f_{br}) is calculated as follows.

$$f_{br} = \frac{P_k}{A_{pun}} \quad (7-2.3)$$

Here,

P_k = prestress in the tendon with one bearing plate

A_{pun} = Punching area

= Area of contact of bearing plate.

As per **Clause 18.6.2.1, IS:1343 - 1980**, the bearing stress in the local zone should be limited to the following allowable bearing stress ($f_{br,all}$).

$$\begin{aligned} f_{br,all} &= 0.48f_{ci} \sqrt{\frac{A_{br}}{A_{pun}}} \\ &\leq 0.8f_{ci} \end{aligned} \quad (7-2.4)$$

In the above equation,

A_{pun} = Punching area

= Area of contact of bearing plate

A_{br} = Bearing area

= Maximum transverse area of end block that is geometrically similar and concentric with punching area

f_{ci} = cube strength at transfer.

The expression of allowable bearing stress takes advantage of the dispersion of the bearing stress in the concrete. The following sketch illustrates the dispersion of bearing stress in concrete.

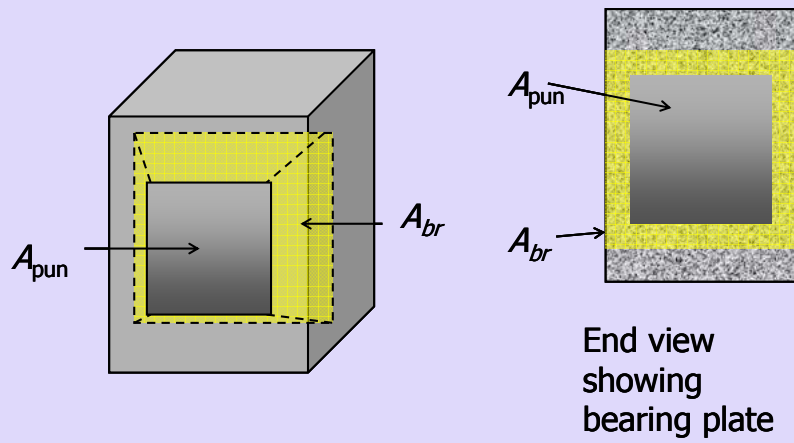


Figure 7-2.9 End and isometric views of end zone

The performance of anchorage blocks and end zone reinforcement is critical during the post-tensioning operation. The performance can be evaluated by testing end block specimens under compression. The strength of an end block specimen should exceed the design strength of the prestressing tendons.

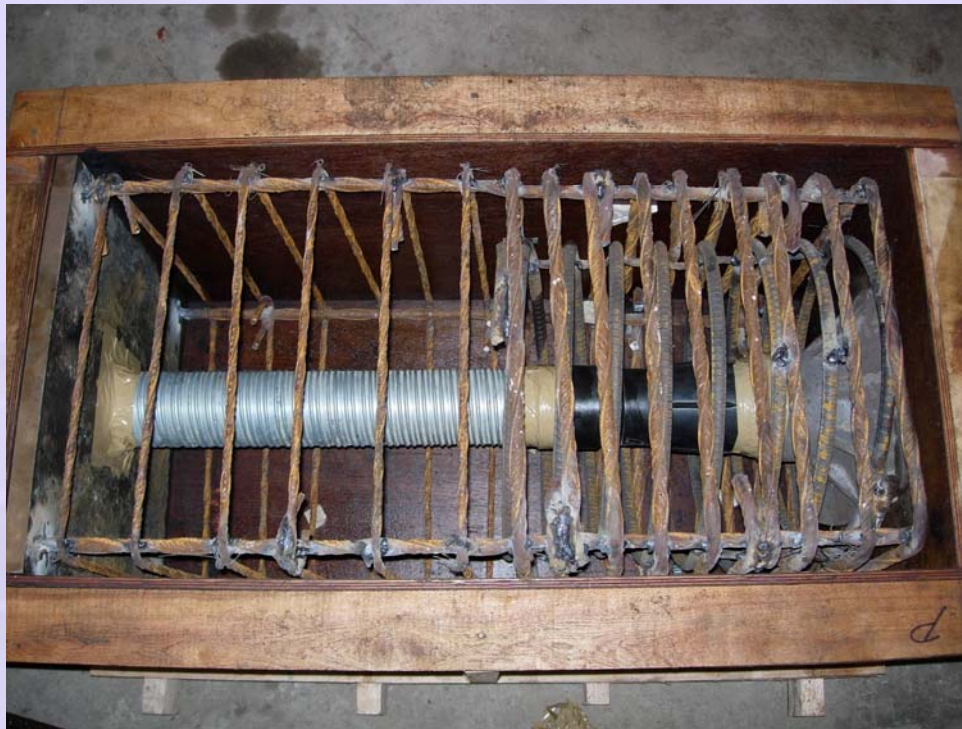
The following photos show the manufacturing of an end block specimen.



(a) Fabrication of end zone reinforcement



(b) Anchorage block and guide



(c) End zone reinforcement with guide and duct



(d) End block after casting

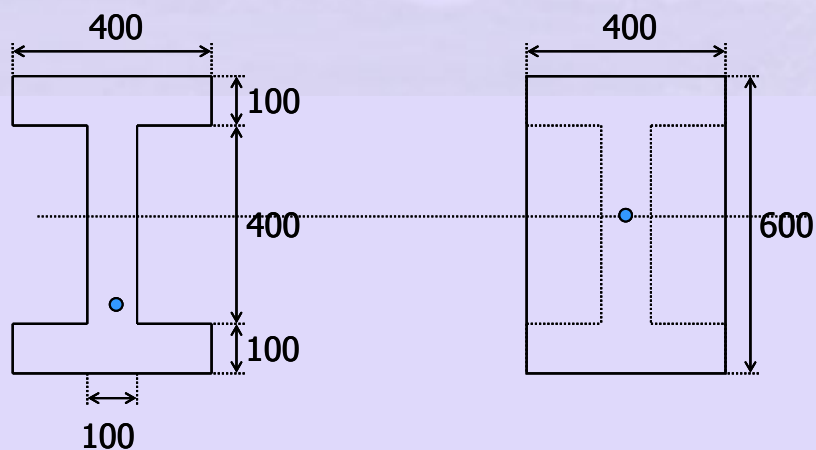
Figure 7-2.10 Manufacturing of an end block specimen

Example 7-2.1

Design the bearing plate and the end zone reinforcement for the following bonded post-tensioned beam.

The strength of concrete at transfer is 50 N/mm^2 .

A prestressing force of 1055 kN is applied by a single tendon. There is no eccentricity of the tendon at the ends.



Section beyond end zone

Section at end zone

Solution

1) Let the bearing plate be 200 mm × 300 mm. The bearing stress is calculated below.

$$\begin{aligned} f_{br} &= \frac{P_k}{A_{pun}} \\ &= \frac{1055 \times 10^3}{200 \times 300} \\ &= 17.5 \text{ N/mm}^2 \end{aligned}$$

The allowable bearing stress is calculated.

$$\begin{aligned} f_{br,all} &= 0.48 f_{ci} \sqrt{\frac{A_{br}}{A_{pun}}} \\ &= 0.48 \times 50 \sqrt{\frac{400 \times 600}{200 \times 300}} \\ &= 48 \text{ N/mm}^2 \end{aligned}$$

Limit $f_{br,all}$ to $0.8 f_{ci} = 0.8 \times 50 = 40 \text{ N/mm}^2$. Bearing stress is less than $f_{br,all}$. Hence OK.

2) Calculate bursting force.

In the vertical direction

$$\begin{aligned} F_{bst} &= P_k \left[0.32 - 0.3 \frac{y_{p0}}{y_0} \right] \\ &= 1055 \left[0.32 - 0.3 \frac{300}{600} \right] \\ &= 179.3 \text{ kN} \end{aligned}$$

In the horizontal direction

$$\begin{aligned} F_{bst} &= P_k \left[0.32 - 0.3 \frac{y_{p0}}{y_0} \right] \\ &= 1055 \left[0.32 - 0.3 \frac{200}{400} \right] \\ &= 179.3 \text{ kN} \end{aligned}$$

3) Calculate end zone reinforcement.

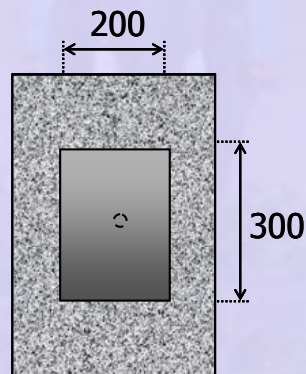
$$\begin{aligned}
 A_{st} &= \frac{F_{bst}}{0.87f_y} \\
 &= \frac{179.3 \times 10^3}{0.87 \times 250} \\
 &= 824.6 \text{ mm}^2
 \end{aligned}$$

Provide $\frac{2}{3} A_{st} = \frac{2}{3} \times 824.6 = 550 \text{ mm}^2$ within $0.1 y_0 = 60 \text{ mm}$ and $0.5 y_0 = 300 \text{ mm}$ from the end.

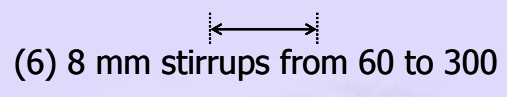
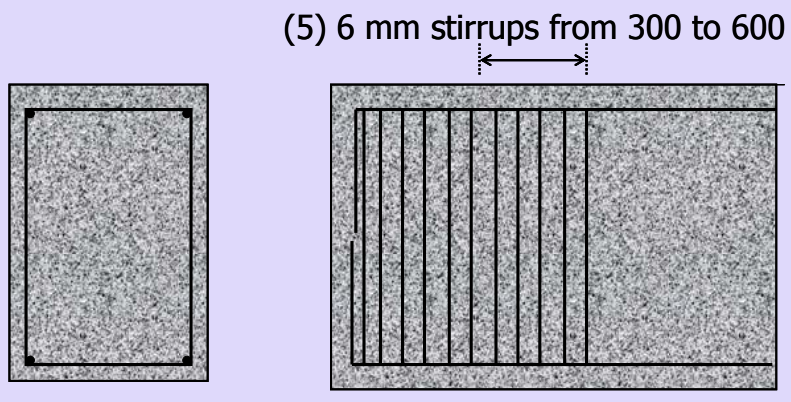
Select (6) 2 legged 8 mm diameter stirrups.

Provide $\frac{1}{3} A_{st} = \frac{1}{3} \times 824.6 = 275 \text{ mm}^2$ within $0.5 y_0 = 300 \text{ mm}$ and $y_0 = 600 \text{ mm}$ from the end.

Select (5) 2 legged 6 mm diameter stirrups.



End view



End zone reinforcement

