4.6 Detailing Requirements for Flexure

This section covers the following topic.

- Tendon Profile
- Minimum Amount of Reinforcement
- Miscellaneous Requirements

Introduction

The detailing of the prestressing tendons and the reinforcing bars is important to satisfy the assumptions in the analysis, proper placement of concrete and durability. After the design calculations, drawings are prepared for construction. These drawings are referred to as the design drawings which become a part of the construction documents. The steel fabricator may prepare another set of drawings which are called shop drawings. These drawings are similar to the design drawings but they contain additional information such as the bar designations and bar bending schedule. It is essential to show the detailing in the design drawings so that there is no ambiguity during construction. It is also necessary to check the details in the shop drawings.

IS:1343 - 1980 specifies some minimum requirements. Here, these requirements are briefly mentioned. There are requirements for the non-prestressed reinforcement as per **IS:456 - 2000** which are not covered here. The detailing requirements for shear and torsion are covered in Section 5.3, Design for Shear (Part II) and Section 5.6, Design for Torsion (Part II), respectively. Of course the detailing is best learned by preparing drawings for construction projects.

4.6.1 Tendon Profile

For a simply supported post-tensioned beam with high uniformly distributed load, a parabolic profile is selected. The equation of the profile is given as follows.

$$y = \left(\frac{4y_m}{L^2}\right) \times (L - x) \qquad \textbf{(4-6.1)}$$

Here,

L = span of the beam

x = distance from one end

Y = vertical displacement of the tendon (from the level at the ends) at distance x

Y_m = vertical displacement of the tendon (from the level at the ends) at the middle of the beam

The following sketch shows the plot of the equation.

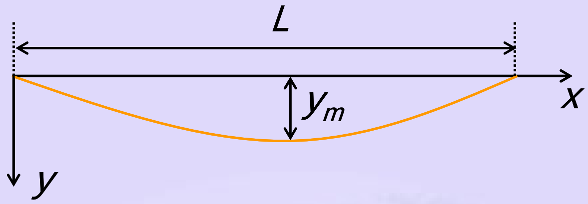

Figure 4-6.1 Profile of a parabolic tendon

Note that an individual tendon may be displaced from the CGS. Hence, the tendon need not pass through the CGC at the ends. The figure below shows the parabolic profiles of the ducts for placing tendon in a simply supported bridge girder.

Figure 4-6.2 Tendon profiles in a simply supported bridge girder
(Courtesy: Larsen & Toubro – Rambøll)

For continuous beams or slabs, parabolic profiles at the spans and at the supports are connected to get the continuous profile of a tendon. The following sketch shows the profile of the CGS in a continuous beam. The eccentricities of the CGS at the end span, first interior support and first interior span are represented as e_1, e_2 and e_3 respectively.

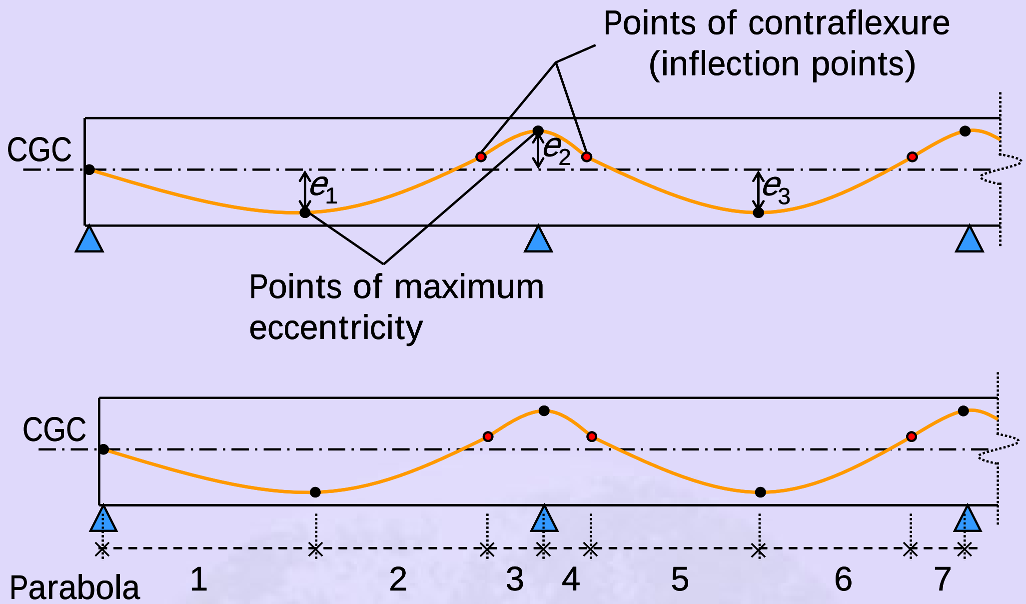

Figure 4-6.3 Profile of CGS in a continuous beam

A parabolic segment connects a point of maximum eccentricity with a point of contraflexure. A point of contraflexure is the location where the curvature of the profile reverses. It is also known as the inflection point. For varying spans and loading, the segments on two sides of a point of maximum eccentricity, may not be symmetric. In the second sketch of the above figure, the different parabolas between the points of maximum eccentricity and the points of contraflexure are numbered.

The convex segment over a support is required to avoid a kink in the tendon. The length of a convex segment is determined based on the minimum radius of curvature for the type of tendon.

A parabolic segment satisfies two conditions.

1) It has zero slope at the point of maximum eccentricity.
2) At a point of contraflexure, the slopes of the parabolic segments on both sides should match.

The equation of a parabolic segment is given below.

$$y = y_m \left(\frac{x}{l}\right)^2 \qquad \textbf{(4-6.2)}$$

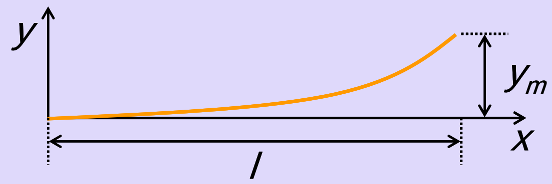

Figure 4-6.4 Plot of a parabolic segment

In the previous equation,

l = length of the parabolic segment

x = distance from the point of maximum eccentricity

y = vertical displacement of the profile at distance x

y_m = displacement of the point of contraflexure from the point of maximum eccentricity.

The origin is selected at the point of maximum eccentricity at a critical section. The equation satisfies the first boundary condition of zero slope at the point of maximum eccentricity. The length (l) is determined from the requirement of minimum radius of curvature at the support. The displacement y_m is determined from the boundary condition that at the point of contraflexure, the slopes of the segments on both sides should match.

The following photo shows the profiles of the tendons in a continuous bridge girder.

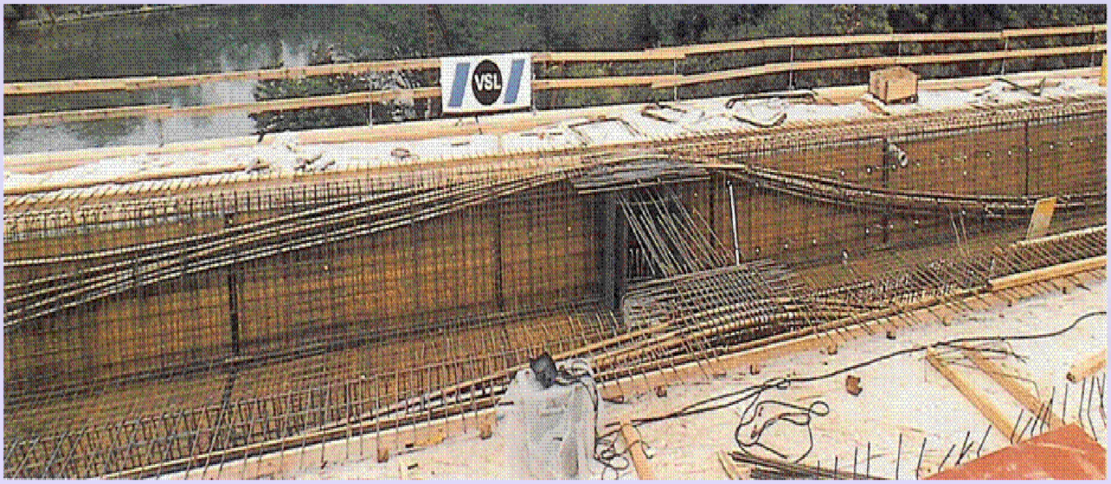

Figure 4-6.5 Tendon profiles in a continuous bridge girder

(Courtesy: VSL International Ltd.)

The profile is implemented by the use of hangers or cross bars or chairs of varying depth at regular intervals. In beams, the duct is supported by hangers from the top bars or by cross bars attached to the stirrups. The depth of the hanger or cross bar at a location can be calculated from the equation of the profile. In slabs, the duct is supported on chairs resting on the form work.

The CGS of the tendon shifts from the centre line of the duct after stretching. The following sketches show the shifts at the low and high points of the tendon. The shift in the CGS is available from the type of tendon used and can be accounted for in precise calculations.

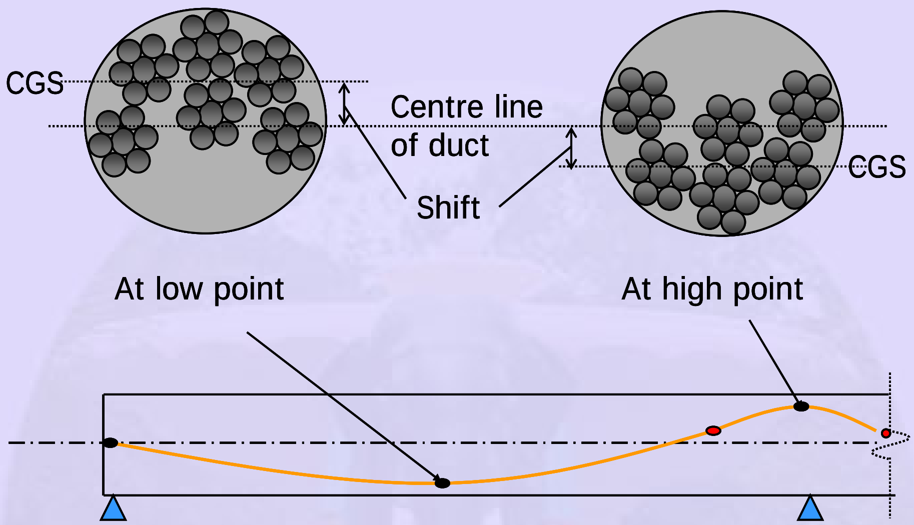

Figure 4-6.6 Shift in the CGS of a tendon from the centreline of duct

4.6.2 Minimum Amounts of Reinforcement

Minimum Longitudinal Reinforcement

A minimum amount of longitudinal reinforcement should be provided to have sufficient strength after the cracking of concrete.

According to **Section 18.6.3.3-a**, the minimum amount is as follows.

$$\text{Minimum } (A_s + A_P) = 0.2\% \, A \qquad \textbf{(4-6.3)}$$

Here,

A_s = area of steel without prestressing,

A_p = area of prestressing steel,

A = total area of cross-section.

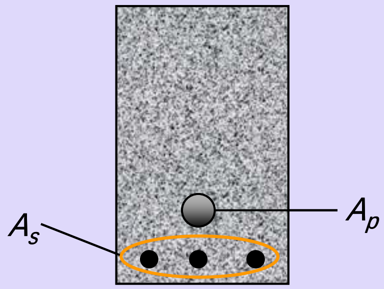

Figure 4-6.7 Cross-section of a beam showing longitudinal reinforcement

The minimum reinforcement can be reduced to 0.15% *A,* if high yield strength deformed bars are used.

Minimum Longitudinal Reinforcement with Unbonded Tendon

In a post-tensioned member when the ducts are not grouted, beyond the cracking load, the number of cracks is small and the crack width is large. To reduce the crack width, a minimum amount of non-prestressed reinforcement should be provided.

Since the non-prestressed reinforcement is bonded to the concrete, there are several cracks with small crack width.

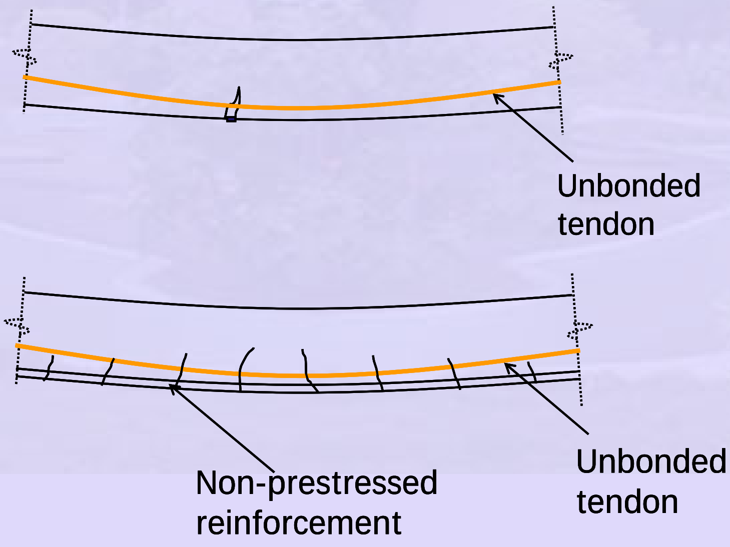

Figure 4-6.8 Crack pattern with and without non-prestressed reinforcement for beams with unbonded tendon

As per the code of the American Concrete Institute (**ACI 318**), the minimum amount of such reinforcement (A_s) is 0.4% A_t , where A_t is the area under tension between the centroid of the section (CGC) and the tension edge. The above reinforcement is not intended to provide flexural strength.

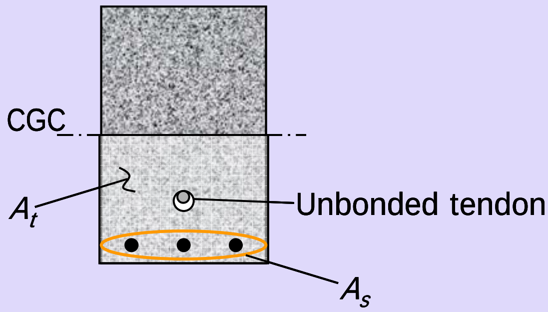

Figure 4-6.9 Cross-section of a beam showing longitudinal reinforcement and area under tension

Minimum Side Face Reinforcement

When the depth of the web exceeds 500 mm, a minimum amount of longitudinal reinforcement should be placed at each face (side face) of the web to check thermal and shrinkage cracks.

According to **Section 18.6.3.3-b**, the minimum amount of side face reinforcement ($A_{s,sf}$) is given as follows.

$$\text{Minimum } A_{s,sf} = 0.05\% \, A_w \qquad \textbf{(4-6.4)}$$

Here,

A_w = vertical area of the web.

The maximum spacing of the bars is 200 mm.

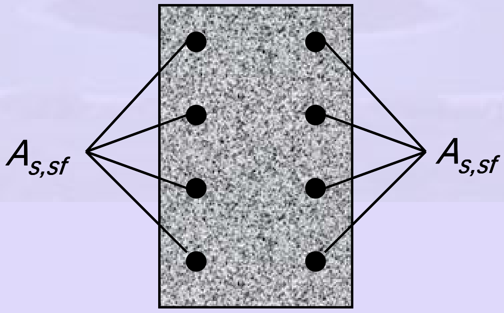

Figure 4-6.10 Cross-section of a beam showing side face reinforcement

4.6.3 Miscellaneous Requirements

Minimum Cover Requirements

A minimum clear cover of concrete is necessary to protect the steel against corrosion and to develop adequate bond between concrete and steel. The cover is implemented by chairs or blocks.

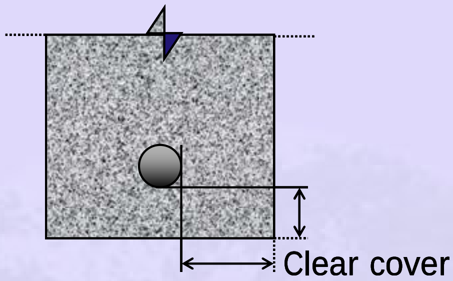

Figure 4-6.11 Cross-section of a beam showing cover

According to **Section 11.1.6**, the minimum cover requirements are as follows.

For pre-tensioned members, minimum cover for tendons is 20 mm. For post-tensioned members, minimum cover for sheathing (duct) is 30 mm or size of the tendon.

The minimum cover should be increased by 10 mm in aggressive environment.

Minimum Spacing Requirements

A minimum clear spacing of the tendons or reinforcing bars is necessary for the flow of concrete during casting and for the bond between concrete and steel.

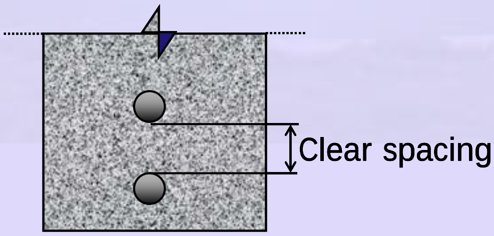

Figure 4-6.12 Cross-section of a beam showing spacing between tendons

According to **Section 11.1.7**, the minimum spacing requirements are as follows. For single wires in a pre-tensioned member,

Clear spacing $\geq$ 3 $\times$ wire diameter

$\geq$ 1⅓ $\times$ maximum aggregate size.

For large bars or tendons,

Clear spacing ≥ 40 mm
≥ maximum size of tendon / bar
≥ maximum aggregate size + 5 mm.

For grouped tendons (maximum four tendons per group), the requirement is for the spacing between the groups of tendons.

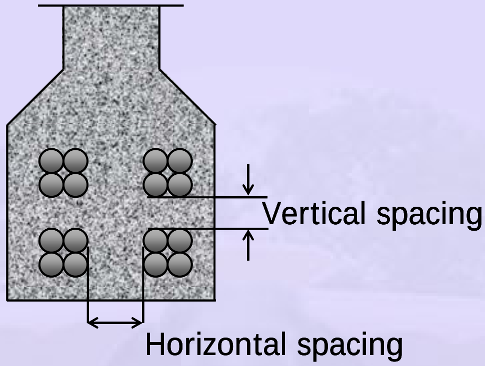

Figure 4-6.13 Cross-section of a beam showing spacing between groups of tendons

According to **Section 11.1.8**, for grouped tendons the spacing requirements are as follows.

Horizontal spacing ≥ 40 mm
≥ maximum aggregate size + 5 mm
Vertical spacing ≥ 50 mm.

Anchorage of Reinforcement

In a partially prestressed section, where the non-prestressed reinforcement contributes to flexural strength, the development length of the bars needs to be checked at the critical section. The bars should be anchored at the supports by hooks to avoid anchorage failure.

The following photo shows the fabrication of the reinforcement for a post-tensioned box-girder of a bridge.

Figure 4-6.14 Fabrication of reinforcement

(Courtesy: Cochin Port Trust, Kerala)