06CV834 – EARTHQUAKE RESISTANT DESIGN OF STRUCTURES

UNIT 7 – EARTHQUAKE RESISTANT DESIGN OF RC BUILDINGS

DUCTILE DETAILING CONSIDERATIONS AS PER IS 13920: 1993

Introduction

The lateral loads used in seismic design are highly unpredictable. Actual forces that act on structures during earthquakes are much higher than the design forces. It is recognized that neither the complete protection against earthquakes of all sizes is economically feasible nor design alone based on strength criteria is justified. The basic approach of earthquake resistant design should be based on lateral strength as well as deformability and ductility capacity of structure with limited damage but no collapse. Thus, the design philosophy shall include provisions to provide minimum standards to maintain public safety in an extreme earthquake and safeguard against major failures and loss of life. The design assumes significant amount of inelastic behaviour to occur in the structure during earthquake.

The collapse of RCC buildings is generally preventable if the following principles of earthquake resistant design are observed

- Failure should be ductile rather than brittle – ductility with large energy dissipation capacity with less deterioration in stiffness must be ensured.
- Flexure failure should precede shear failure
- Beams should fail before columns
- Connections should be stronger than the members which fit into them

The code IS 13920; 1993 entitled "Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces-Code of Practice" is based on this approach. This standard covers the requirements of lateral strength designing and detailing of monolithic reinforced concrete buildings so as to give them adequate toughness and ductility to resist severe earthquake shock without collapse. Thus, the ductility of a structure is in fact one of the most important factors affecting its seismic performance and it has been clearly observed that the well-designed and detailed reinforced structures behave well during earthquakes and the gap between the actual and design lateral force is narrowed down by providing ductility in the structure.

Advantages of Ductility

The following are the advantages of a reinforced concrete structure having sufficient ductility:

- A ductile reinforced concrete structure may take care of overloading, load reversals, impact and secondary stresses due to differential settlement of foundation.

- A ductile reinforced concrete structure gives the occupant sufficient time to vacate the structure by showing large deformation before its final collapse. Accordingly, the loss of life is minimized with the provision of sufficient ductility.
- Properly designed ductile joints are capable of resisting forces and deformations at the yielding of steel reinforcement. Therefore, these sections can reach their respective moment capacities, which is one of the assumptions in the design of reinforced concrete structures by limit state method.

Ductile Detailing Considerations as per IS 13920: 1993

General Specifications

- The design and construction of reinforced concrete buildings should be governed by the provision of IS 456: 2000, except as modified by the provisions of IS 13920: 1993.

- **Concrete:** For all buildings which are more than 3 storeys in height, the minimum grade of concrete shall be M20 (fck= 20 MPa). However, for all buildings more than 4 storeys or more than 15m in height and situated in Zones IV and V, the minimum grade of concrete should be M25 (fck= 25 MPa). Most of the codes worldwide specify higher grade of concrete for seismic regions than that for non-seismic constructions. Higher grade of concrete facilitates ductile behaviour and the concrete strength below M 20 may not have the requisite strength in bond or shear.

- **Steel:** Steel reinforcements of grade Fe 415 or less shall be used. However, high strength deformed steel bars, produced by the thermo-mechanical treatment process, of grades Fe 500 and Fe 550, having elongation more than 14.5 percent and conforming to other requirements of IS 1786 : 1985 may also be used for the reinforcement.

  Based on a tensile test of steel, $(\sigma_{y,actual} - \sigma_{y,specified}) \ngtr 120$MPa. If the difference is more, shear or bond failure may precede the flexural hinge formation. Further, in order to develop inelastic rotation capacity, a structural member needs an adequate length of yield region along the axis of the member. Thus, $(\sigma_{u,actual}/\sigma_{y,actual}) \geq 1.25$.

  Strong steel is not preferable to low strength steel in earthquake prone region because typical stress strain curve of low steel shows the following advantages:
  - a long yield plateau
  - a greater breaking strain
  - less strength gain after first yield

- **Cover:** To develop the required bond strength and to protect the reinforcement against corrosion, cover to reinforcement is provided. Minimum cover for reinforcement should comply with Tables 16 and 16A of IS 456 : 2000.

Flexural Members

Beams sustain two basic types of failures namely flexure and shear as shown in Figure 1.

(a) **Flexural (or Bending) Failure:** As the beam sags under increased loading, it can fail in two possible ways. If relatively more steel is present on the tension face, concrete crushes in compression; this is a brittle failure and is therefore undesirable. If relatively less steel is present on the tension face, the steel yields first and redistribution occurs in the beam until eventually the concrete crushes in compression; this is a ductile failure and hence is desirable. Thus, more steel on tension face is not necessarily desirable! The ductile failure is characterized with many vertical cracks starting from the stretched beam face, and going towards its mid-depth.

(b) **Shear Failure:** A beam may also fail due to shearing action. A shear crack is inclined at 45°to the horizontal; it develops at mid-depth near the support and grows towards the top and bottom faces. Closed loop stirrups are provided to avoid such shearing action. Shear damage occurs when the area of these stirrups is insufficient.

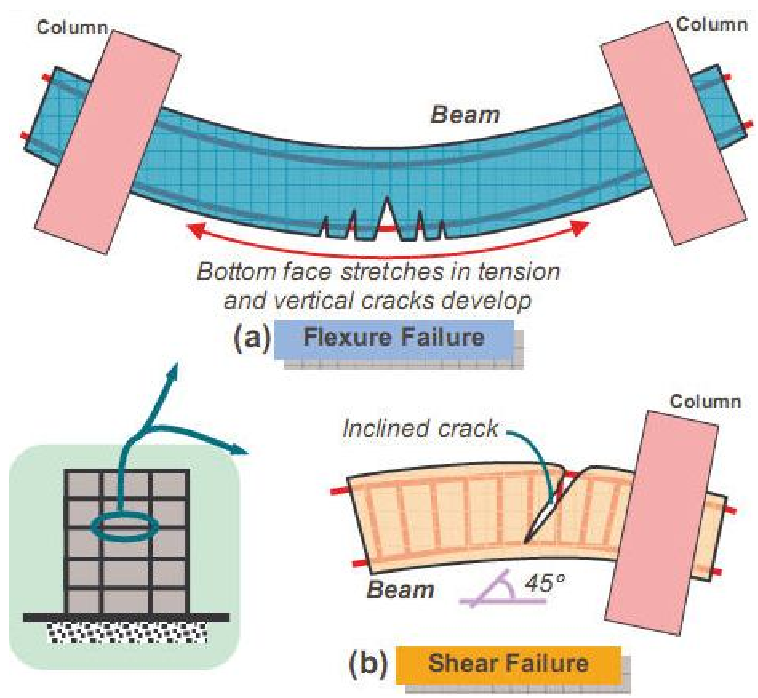


Figure 1: Two types of damage in a beam: flexure and shear

Shear failure is brittle, and therefore, shear failure must be avoided in the design of RC beams.

General

- These requirements apply to frame members resisting earthquake induced forces and designed to resist flexure.

- Axial Stress
  - Factored axial stress under earthquake loading ≤ 0.1 fck
  - Generally, axial force in a flexural member is relatively very less
  - If exceeds, design the member for bending and axial load
- Dimensions
  - Preferably b/D ratio > 0.3
  - b ≥ 200 mm

  To avoid difficulties in confining concrete through stirrups in narrow beams
  - Depth, D ≤ ¼ of clear span

  To avoid deep beam behaviour under cyclic inelastic deformations

Longitudinal Reinforcement

- To ensure adequate ductility, the amount of longitudinal reinforcement must be limited in relation to
  - Dimensions of the beam
  - The quality of concrete
  - Yield stress of reinforcement

  Under earthquake loading the critical sections for the longitudinal reinforcement in frames occur at the face of the beam-column and girder-column connection and at the beam-girder connection immediately adjacent to the columns. Since the distribution of bending moment along the beams/girders framing into columns may be quite different in severe earthquake from that under gravity loads, the cut-off points of the bars require special consideration. It is desirable that only straight bars are used, however bent bars may be used in beams that do not frame into columns.

- The minimum bar diameter permissible is 12 mm. There must be at least two bars both the top and bottom face (Figure 2).
  - To ensure integrity of the member under reversed loading
  - A construction requirement rather than behavioral requirement

- The positive steel at a joint face must be at least equal to half of the negative steel at that face (Figure 2).
  - Compression reinforcement increases ductility and hence this provision ensures adequate ductility at potential yielding regions
  - The seismic moments are reversible and design seismic loads may be exceeded by a considerable margin during strong shaking resulting in development of substantial sagging moments at beam ends

- Maximum steel ratio on any face at any section shall not exceed $\rho_{max} = 0.025$
  - To avoid congestion of reinforcement which may cause insufficient compaction or poor bond between concrete and reinforcement

- Tension steel ratio on any face at any section, shall not be less than $\rho_{min} = 0.24 \sqrt{f_{ck}}/f_y$
  - To provide necessary ductility or to avoid brittle failure upon cracking

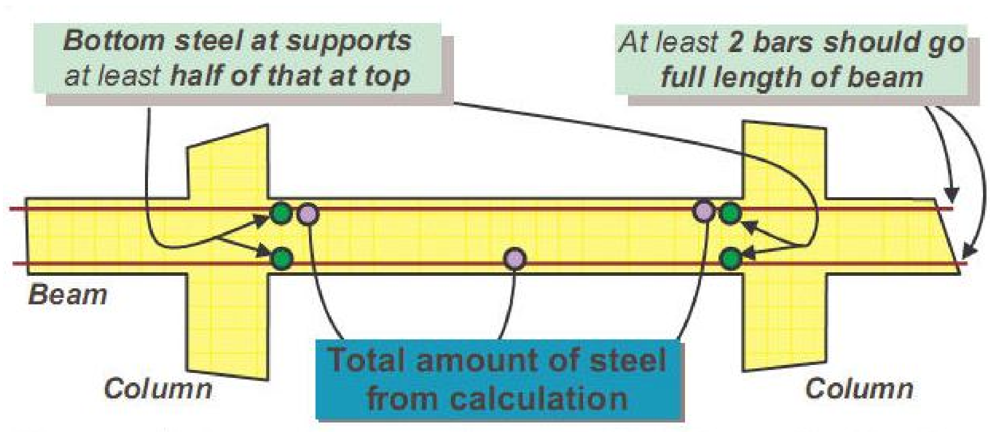


Figure 2: Location and amount of longitudinal steel bars in beams

- Steel provided at each of top and bottom face of member at any section along its length ≥ 1/4 of maximum negative steel provided at the face of either joint
  - To ensure some positive and negative moment capacity throughout the beam in order to allow unexpected deformations and moment distribution from severe earthquake action

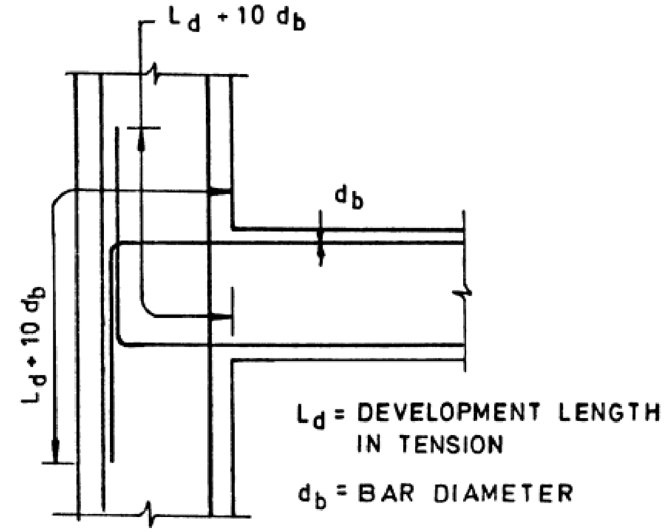
- In an external joint, Anchorage length = Ld + 10 dia - allowance for 90 degree bends for both the top and bottom bars (Figure 3)
  - Such an arrangement will make a ductile junction and provide adequate anchorage of beam reinforcement into columns

- In an internal joint, for both faces of beam, bars shall be taken continuously through the column (Figure 4)

- Splicing of longitudinal bars (Figure 5)
  - Hoops to be provided over the entire splice length, at a spacing not exceeding 150 mm
  - Lap length shall not be less than the bar development in tension
  - Lap splices shall not be provided with in a joint and within a distance of 2d from joint face
  - Lap splices shall not be provided within a quarter length of the member where flexural yielding may generally occur under the effect of earthquake forces
  - Not more than 50 percent of the bars shall be spliced at one section

Web Reinforcement

- To ensure that beam capacity will be governed by flexure and not by shear
  Web reinforcement
  - Carry the vertical shear force and prevent the diagonal shear cracks
  - Protect the concrete from bulging outwards due to flexure
  - Prevent buckling of compression bars



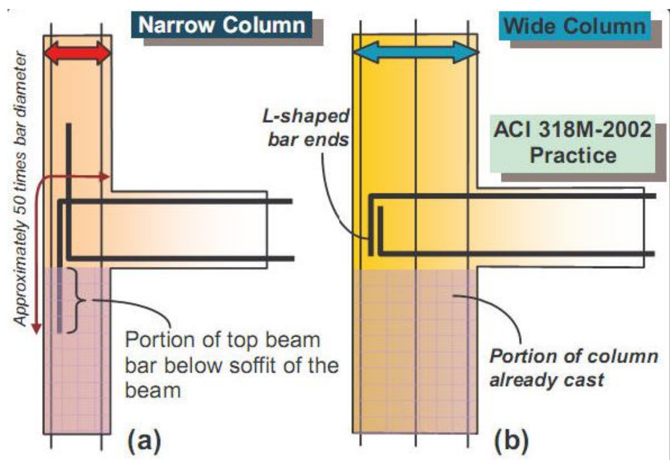


Figure 3: Anchorage of beam bars in an external joint

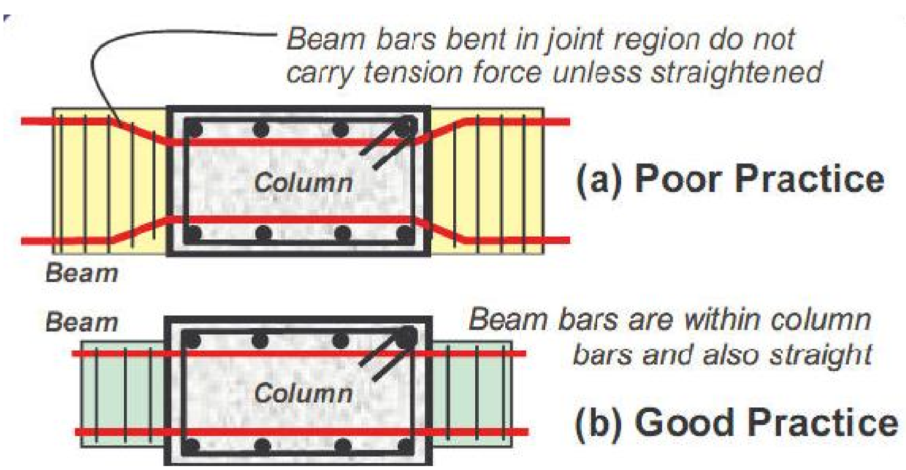


Figure 4: Anchorage of beam bars in an external joint

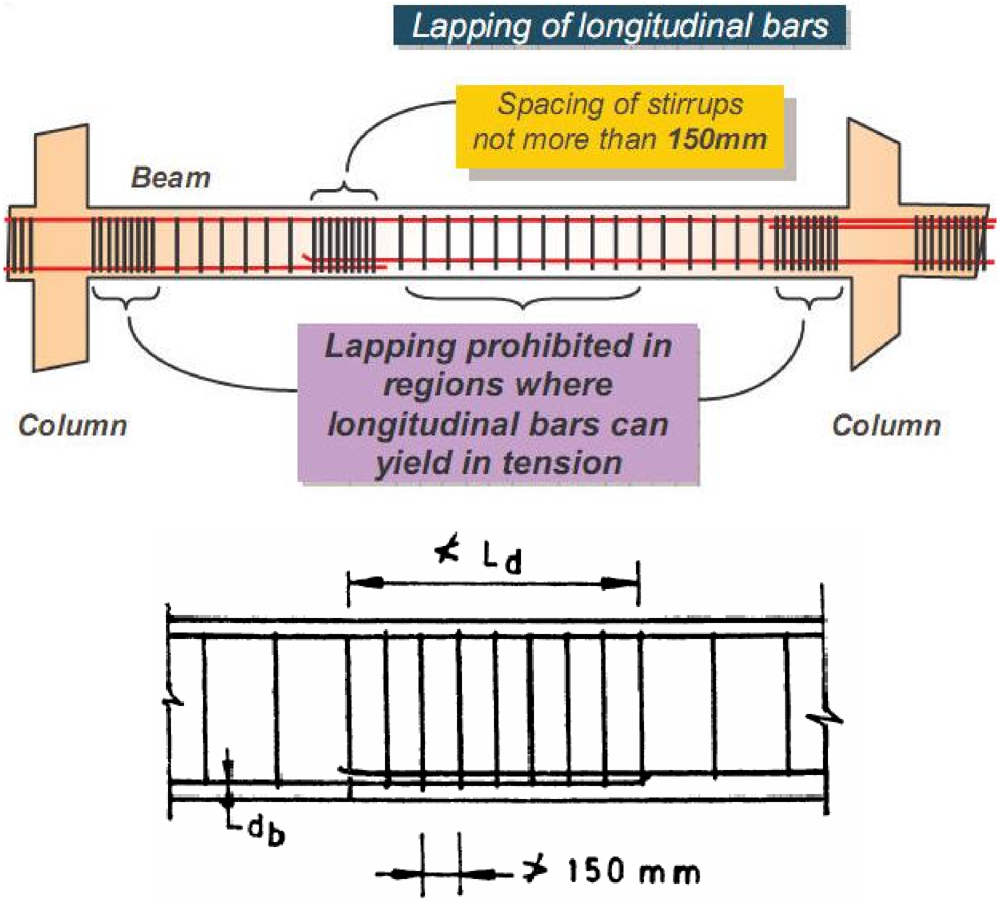


Figure 5: Splicing of longitudinal bars

- Web reinforcement shall consists of vertical hoops and the details of requirements are shown in (Figure 6, Figure 7 and Figure 8)

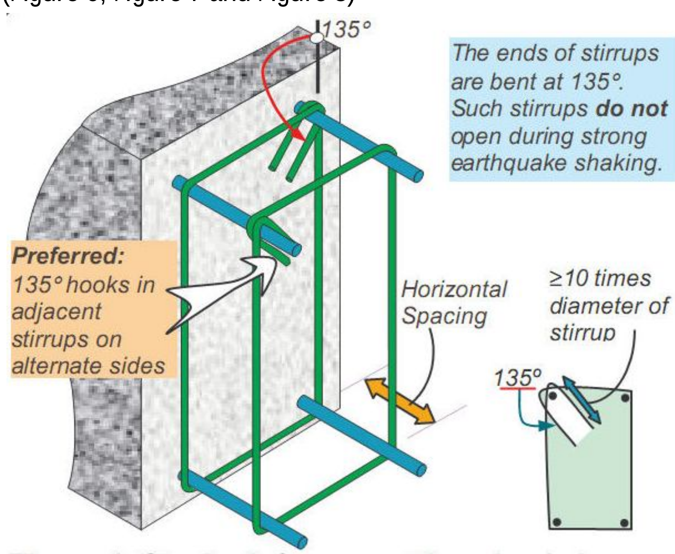


Figure 6: Web reinforcement details in a seismic beam

- In compelling circumstances, web reinforcement may also be made of TWO pieces of reinforcement (Figure 7)
  - a U – stirrup with a 135^0 hook and a 10 dia extension (min of 75 mm), and
  - a crosstie with hooks at ends similar to U – stirrup

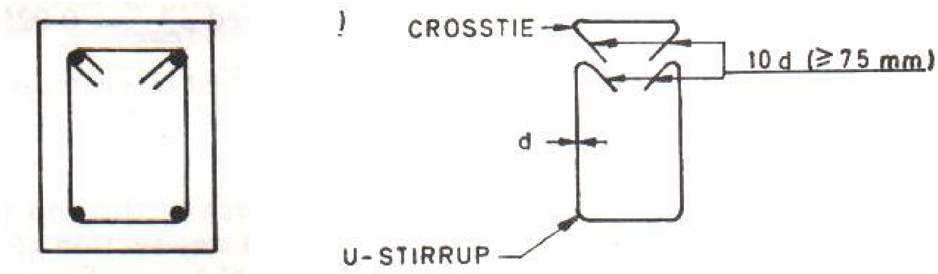


Figure 7: Beam web reinforcement

- Minimum bar diameter 6 mm for Spans ≤ 5 m and 8 mm for Spans > 5 m

- First stirrup not less than 50 mm of column face

- Minimum spacing is 100 mm

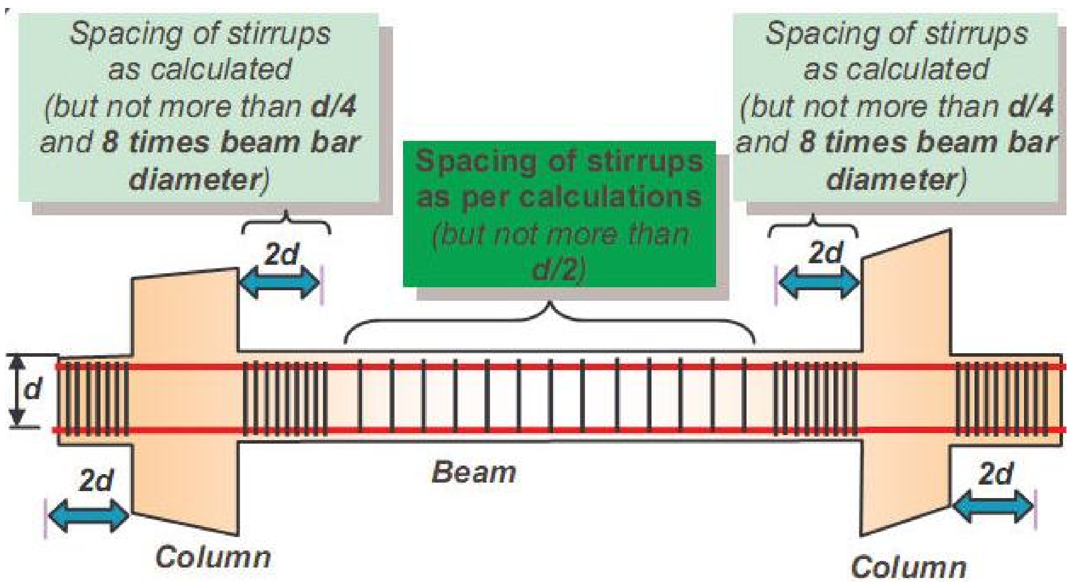


Figure 8: Location and amount of vertical stirrups in beams

- Shear Force to be resisted by vertical hoops – Maximum of
  - The calculated factored shear force as per analysis
  - Shear force due to formation of plastic hinges at both ends of beam plus factored gravity load on the span

Columns and Frame Members Subjected to Bending and Axial Load

General

- These requirements apply to frame members which have axial stress in excess of $0.1f_{ck}$ under the effect of earthquake forces

- Minimum Dimensions

In General	**≮ 200 mm**
In frames which have beams of span > 5m	**≮ 300 mm**
columns having unsupported length > 4m	**≮ 300 mm**

  To avoid
  - very slender columns
  - Column failure before beams

- Dimensions: Preferably b/D ratio ≥ 0.4
  - Since confinement of concrete is better in a relatively square column than in a column with large width-to-depth ratio

Longitudinal Reinforcement

- Lap Splicing
  - Shall be provided only in the central half of the member length
  - Length = Tension splice
  - Hoops to be provided over the entire splice length
  - Spacing of hoops ≯150 mm
  - Not more than 50 percent of the bars shall be spliced at one section. If more than 50% of the bars are spliced at one section, the lap length should be $1.3L_d$

Transverse Reinforcement

- Transverse reinforcement (Figure 9)
  - Provides shear resistance to the member
  - Confines the concrete core and thereby increases ductility
  - Provides lateral resistance against buckling to the compression reinforcement
  - Prevents loss of bond strength within column vertical bar splices

- Closed Ties 135^0 hook with a 10 dia extension (min of 75 mm) that is embedded in the confined core

- Spacing of hoops shall not exceed B/2, where B is the least lateral dimension of column

- Spacing of parallel legs of rectangular hoops ≤ 300 mm

- Provide cross-tie if the length of any side of the hoop is > 300 mm

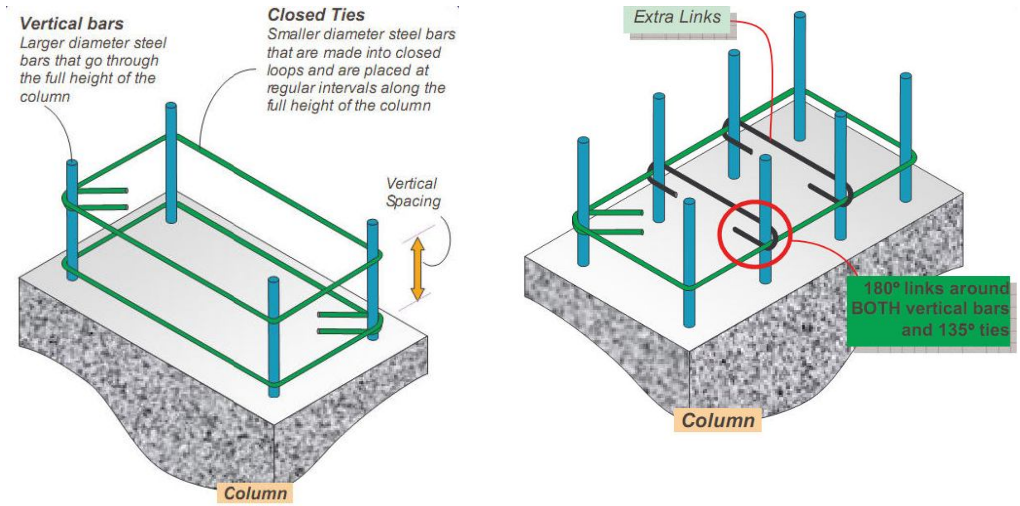


Figure 9: Steel reinforcement in columns

Special Confining Reinforcement

- Provided over a length of
  - l_0 from each joint face towards mid-span
  - l_0 on either side of any section where flexural yielding may occur under the effect of earthquake forces

- The length of l_0 shall not be less than
  - Larger lateral dimension of the member
  - 1/6 of clear span of the member, and
  - 450 mm

- Spacing of ties used as special confining reinforcement
  - 1/4 of minimum member dimension.
  - minimum 75 mm
  - shall not be more than 100 mm

- Area of cross section, A_{sh}, of the bar forming circular hoops or spiral is

$$A_{sh} = 0.09\ S\ D_k \frac{f_{ck}}{f_y}\left[\frac{A_g}{A_k} - 1.0\right]$$

- Area of cross section, A_{sh}, of the bar forming rectangular hoops is

$$A_{sh} = 0.18\ S\,h\ \frac{f_{ck}}{f_y}\left[\frac{A_g}{A_k} - 1.0\right]$$

S = Spacing of ties

h = Longer dimension of the rectangular confining hoop measured to its outer face, which shall not exceed 300 mm.

A_g = Gross area of the column cross section

A_k = Area of the concrete core

D_k = Diameter of core measured to the outside of the spiral or hoop

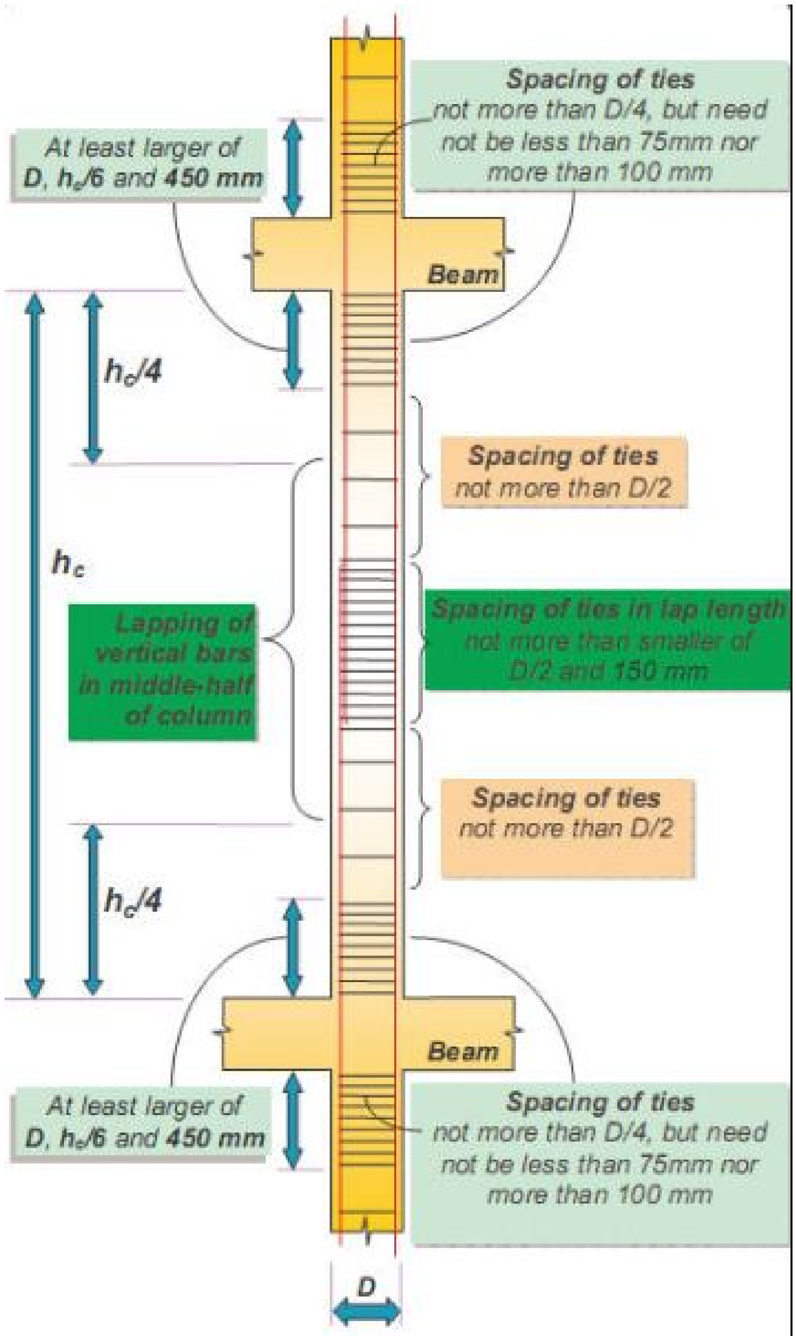


Figure 10: Placing vertical bars and closed ties in columns