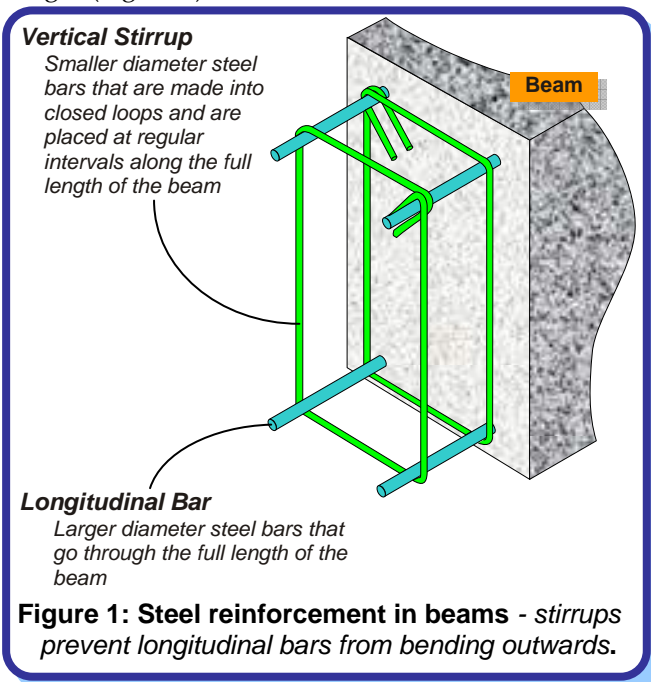


## How do Beams in RC Buildings resist Earthquakes?

### Reinforcement and Seismic Damage

In RC buildings, the vertical and horizontal members (*i.e.*, the *columns* and *beams*) are built integrally with each other. Thus, under the action of loads, they act together as a *frame* transferring forces from one to another. This Tip is meant for beams that are part of a building frame and carry earthquake-induced forces.

*Beams* in RC buildings have two sets of steel reinforcement, namely: (a) long straight bars (called *longitudinal bars*) placed along its length, and (b) closed loops of small diameter steel bars (called *stirrups*) placed vertically at regular intervals along its full length (Figure 1).



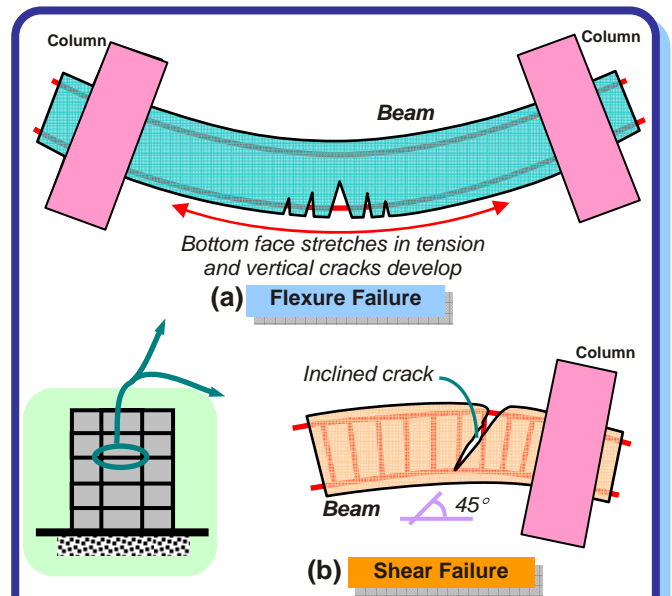
Beams sustain two basic types of failures, namely:

(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 (it *keeps elongating* but does not snap, as steel has ability to stretch large amounts before it snaps; see IITK-BMTPC Earthquake Tip 9) 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 (Figure 2a).

(b) **Shear Failure:** A beam may also fail due to shearing action. A shear crack is inclined at  $45^\circ$  to the horizontal; it develops at mid-depth near the support and grows towards the top and bottom faces (Figure 2b). Closed loop stirrups are provided to avoid such shearing action. Shear damage occurs when the area of these stirrups is *insufficient*. Shear failure is brittle, and therefore, shear failure must be avoided in the design of RC beams.

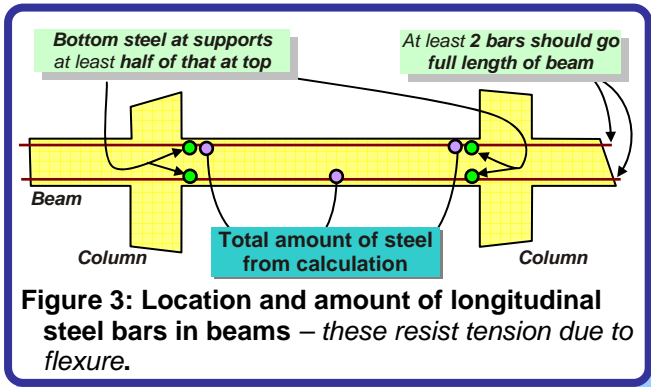
### Design Strategy

Designing a beam involves the selection of *its material properties* (*i.e.*, grades of steel bars and concrete) and *shape and size*; these are usually selected as a part of an overall design strategy of the whole building. And, the *amount and distribution of steel* to be provided in the beam must be determined by performing design calculations as per IS:456-2000 and IS13920-1993.



Longitudinal bars are provided to resist flexural cracking on the side of the beam that stretches. Since both top and bottom faces stretch during strong earthquake shaking (IITK-BMTPC Earthquake Tip 17), longitudinal steel bars are required on both faces at the ends and on the bottom face at mid-length (Figure 3). The Indian Ductile Detailing Code IS13920-1993 prescribes that:

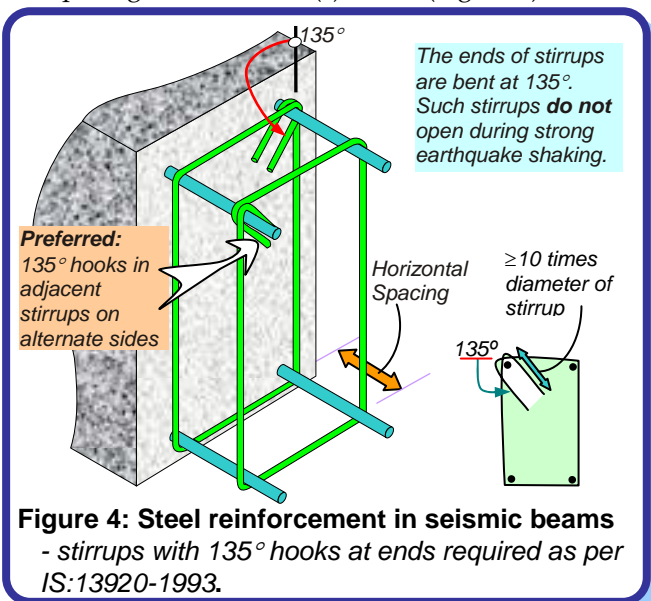
- (a) At least two bars go through the full length of the beam at the top as well as the bottom of the beam.
- (b) At the ends of beams, the amount of steel provided at the bottom is at least half that at top.



**Figure 3: Location and amount of longitudinal steel bars in beams – these resist tension due to flexure.**

Stirrups in RC beams help in three ways, namely (i) they carry the vertical shear force and thereby resist diagonal shear cracks (Figure 2b), (ii) they protect the concrete from bulging outwards due to flexure, and (iii) they prevent the buckling of the compressed longitudinal bars due to flexure. In moderate to severe seismic zones, the Indian Standard IS13920-1993 prescribes the following requirements related to stirrups in reinforced concrete beams:

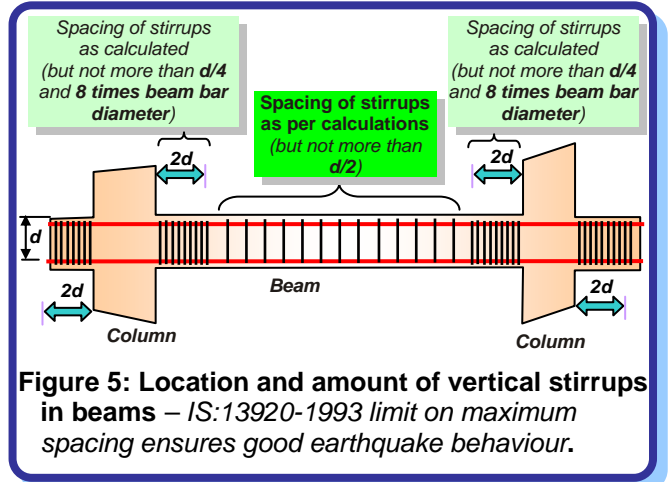
- (a) The diameter of stirrup must be at least 6mm; in beams more than 5m long, it must be at least 8mm.
- (b) Both ends of the vertical stirrups should be bent into a 135° hook (Figure 4) and extended sufficiently beyond this hook to ensure that the stirrup does not open out in an earthquake.
- (c) The spacing of vertical stirrups in any portion of the beam should be determined from calculations
- (d) For a length of twice the depth of the beam from the face of the column, an even more stringent spacing of stirrups is specified, namely half the spacing mentioned in (c) above (Figure 5).



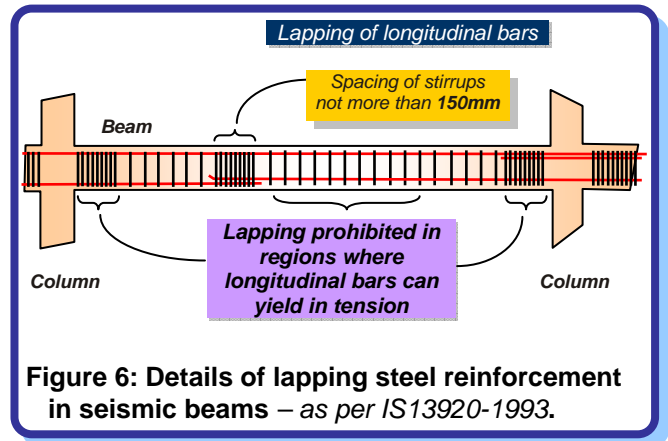
**Figure 4: Steel reinforcement in seismic beams - stirrups with 135° hooks at ends required as per IS:13920-1993.**

Steel reinforcement bars are available usually in lengths of 12-14m. Thus, it becomes necessary to overlap bars when beams of longer lengths are to be made. At the location of the lap, the bars transfer large forces from one to another. Thus, the Indian Standard IS:13920-1993 prescribes that such laps of longitudinal

bars are (a) made away from the face of the column, and (b) not made at locations where they are likely to stretch by large amounts and yield (e.g., bottom bars at mid-length of the beam). Moreover, at the locations of laps, vertical stirrups should be provided at a closer spacing (Figure 6).



**Figure 5: Location and amount of vertical stirrups in beams – IS:13920-1993 limit on maximum spacing ensures good earthquake behaviour.**



**Figure 6: Details of lapping steel reinforcement in seismic beams – as per IS13920-1993.**

**Related IITK - BMTPC Earthquake Tip**

Tip 9: How to Make Buildings Ductile for Good Seismic Performance?

Tip 17: How do Earthquakes Affect Reinforced Concrete Buildings?

**Reading Material**

IS 13920, (1993), "Indian Standard Code of Practice for Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces," Bureau of Indian Standards, New Delhi  
 Paulay, T., and Priestley, M.J.N., (1997), "Seismic Design of Masonry and Reinforced Concrete Buildings," John Wiley & Sons, USA  
 McGregor, J.M., (1997), "Reinforced Concrete Mechanics and Design," Third Edition, Prentice Hall, USA

Authored by:

C.V.R.Murty  
 Indian Institute of Technology Kanpur  
 Kanpur, India

Sponsored by:

Building Materials and Technology Promotion Council, New Delhi, India