Chapter 8

# NON ENGINEERED REINFORCED CONCRETE BUILDINGS

## 8.1 INTRODUCTION

With the spread of reinforced concrete construction to semi-urban and rural area in various countries, often buildings are constructed using reinforced concrete columns and beams, without proper engineering design, based on the experience of local masons and petty contractors. Use of isolated columns in parallel with load bearing walls for supporting long internal beams or those in verandahs and porches is becoming quite common. In most cases, such constructions suffer from deficiencies from the seismic view point since no consideration is given for the effect of seismic lateral loads and the connection details are usually such that no moment carrying capacity can be relied upon. Beams simply rest on top of columns and mostly held in position through friction.

The other serious deficiency is in concrete quality in respect of mixing, compacting and curing. The aim of this chapter is to provide working guidelines for such low-rise, (upto three storeys) small buildings in RC frame constructions in which columns are supposed to resist vertical as well as horizontal seismic loads and the filler walls are assumed to be neither load bearing nor taking part in the lateral resistance of the building. Large halls for gymnasia, assembly halls, etc., having a floor area more than 60 $m^2$ or beam spans more than 7 m must be designed by an engineer.

## 8.2 TYPICAL DAMAGE AND COLLAPSE OF RC BUILDINGS

The following types of damage are quite common in reinforced concrete buildings:

### (a) Sliding of roofs off supports

Where the beams simply rest on walls or columns, they are bound to slide, when the earthquake intensity exceeds the frictional resistance and many times leave the support and fall down, particularly if the bearing length is small.

### (b) Falling of infill walls

The infill panel walls in between reinforced concrete columns overturn outside the framework if not held tight or connected with the frames.

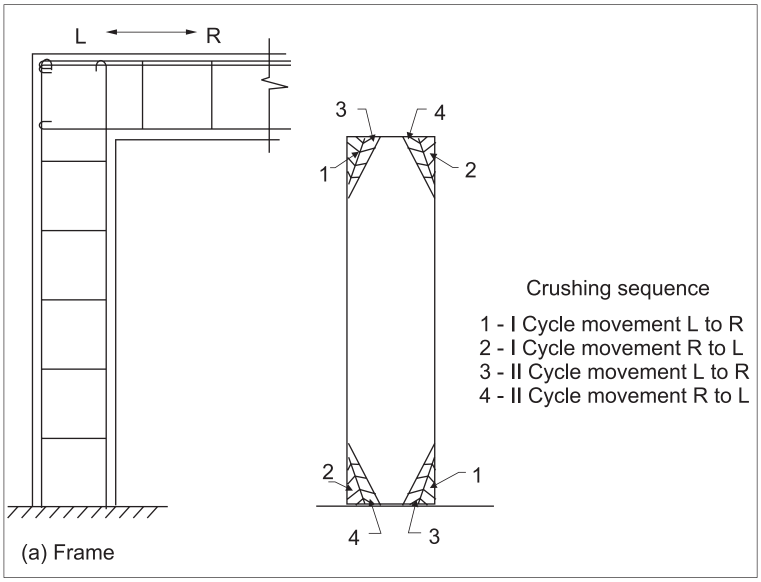



**Fig 8.1 Crushing of concrete at ends of column**

## (c) Crushing of column ends and virtual hinging

During severe shaking, the column ends are subjected to heavy eccentric compressive stresses under which the concrete gets crushed and spalled off from the outer surfaces. In repeated cycles the damage progresses inwards, thus effective section gets very much reduced, both column ends virtually start behaving as pins and the whole framework collapses like a mechanism, *Fig* 8.1.

## (d) Short column effect

When infill walls with wide openings are attached to the columns, the portions of the columns, that will deform under lateral seismic loads, become very short as compared to their normal height. Such short columns become much stiffer than other columns and attract much larger shear forces under which they get severe diagonal tension which may lead to failure of the column, *Fig* 8.2.

## (e) Diagonal cracking in columns

Columns are subjected to diagonal cracking due to large seismic shears caused under severe ground shaking. If twisting of the ‘building also occurs, the cracks may take spiral form reducing the load capacity of the columns severely.

## (f) Diagonal cracking of column-beam joint

Many times diagonal cracking occurs through the junction of the column with the beam which seriously impairs the strength of the frame.

## (g) Pulling out of reinforcing bars

Where the anchor length of column bars or

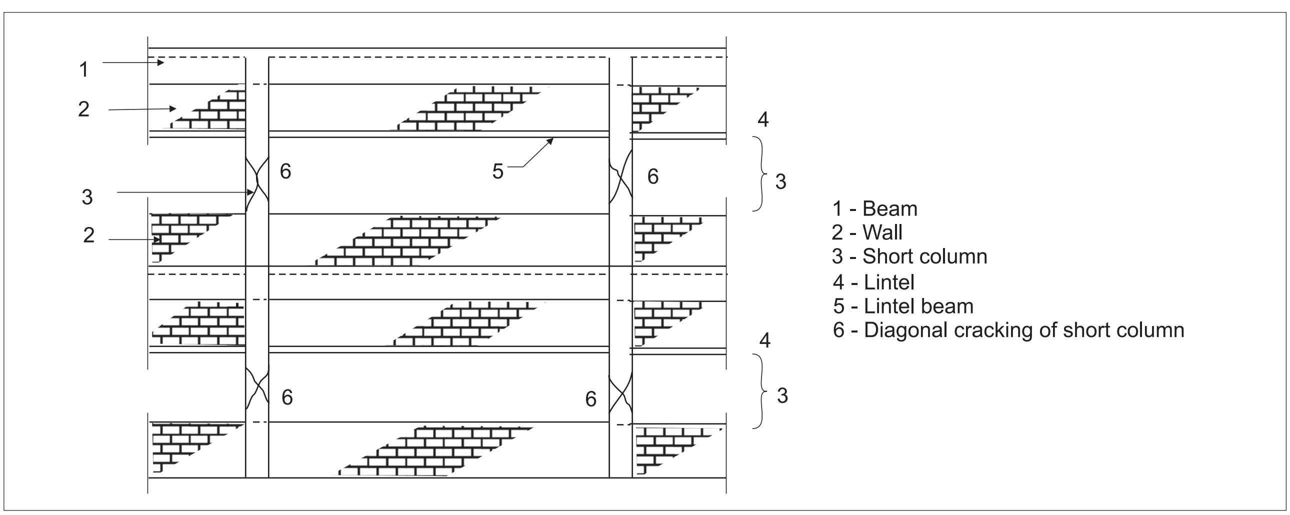



**Fig 8.2 Shear failure of short column**

overlaps between the longitudinal bars are not adequate for developing full tensile strength of the bar, they are often pulled out due to tensions caused in the column under severe reversal of stresses.

### (h) Collapse of gable frames

Reinforced concrete gable frames, often used for school workshops, gymnasia and assembly halls, or cinema halls, have a tendency of spreading out with no secondary resistance available once a joint fails. These are often found to fail and collapse (as was shown in *Fig* 6.6 for wooden gable frames), unless very carefully designed and detailed.

### (i) Foundation sinking and tilting

Sinking or tilting of foundations of columns due to seismic shaking occurs in loose soft soils and can lead to severe cracking of the superstructure and even collapse.

## 8.3 CARE IN CONCRETE CONSTRUCTION

In reinforced concrete work, the most important requirement for good behavior is good quality of concrete, which is not usually achieved in non-engineered construction. Here simple guidelines are given for making concrete of adequate strength.

### (a) Measuring materials

In non-engineered reinforced concrete constructions, the proportions of concrete mix are usually kept 1:2:4 by volume of cement:sand:aggregate. The aggregate may be in the form of river shingle, or crushed stone, of maximum 20-mm size. A 50 kg cement sack has a nominal volume of 0.0317 $m^3$. It will be best to make the concrete mixture using whole bags of cement. For measuring sand and aggregate, a wooden box with handles having a volume equal to one sack of cement will be most accurate as well as convenient to use. The measurements of such a box are shown in *Fig* 8.3. Such a box can also be made of steel sheets.

### (b) Mixing materials

Where mixing is done manually without using a power driven mixer, it should be done on an impervious platform, say, using iron sheets or cemented floor. For making a mix of 1:2:4, four boxes of aggregate should first be measured and flattened on the platform, then two boxes of sand should be spread on the aggregate and finally one full sack of cement opened on top. The material should first be mixed thoroughly in dry state so as to obtain uniform colour and then water added. The quantity of water should be enough to make a soft ball of the mixed concrete in hand. A little wetter mix is better for hand compaction and drier mix where vibrator is used for compaction.

### (c) Formwork

The quality of not only the concrete surface but also the strength of concrete depends on the surface of the formwork and its im-

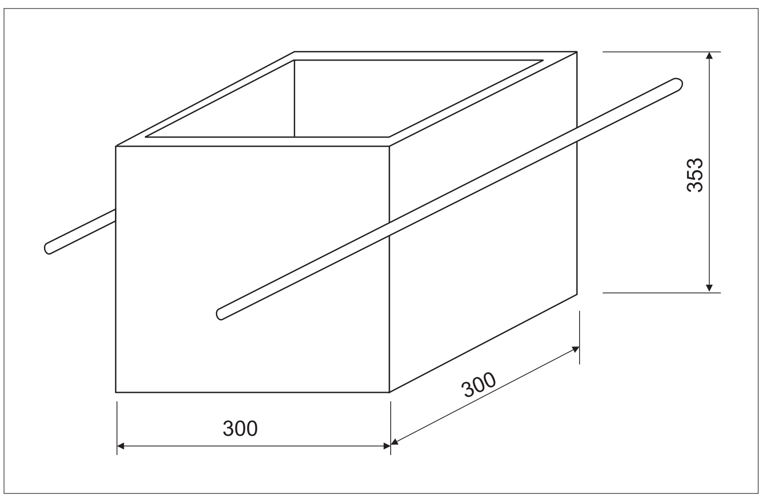



**Fig 8.3 Measuring box**

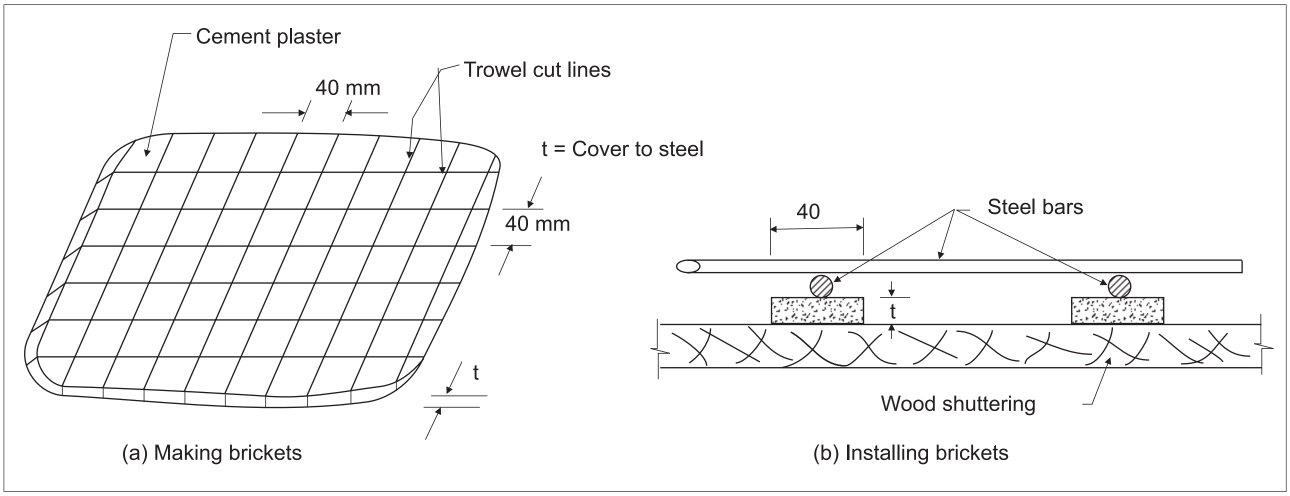



**Fig 8.4 Use of cement brickets for cover**

perviousness to the leakage or oozing out of the water and cement through the joints. Wooden formwork with well-formed surface and joints between planks should be used. Use of water resistant plywood for the skin of the formwork will give very good surface of the concrete.

### d. Placing of reinforcement

While placing reinforcing bars, the following points must be taken care of, otherwise the structure will get into undefined weaknesses:

- Minimum clear cover to the reinforcement: 15 mm to the bars in slabs, 25 mm to bars in beams and columns. In large columns, say 450 mm in thickness, the cover should be 40 mm. For achieving proper cover, a simple and effective method is to make cement mortar brickets of required size and install them between the bars and formwork. Tying with bars with thin binding wire will ensure the proper cover, see *Fig* 8.4.
- Tying of longitudinal bars with transverse bars and stirrups and links at each crossing with binding wire.
- Minimum overlap in bars: 45 times the diameter of the bar for plain mild steel and 60 times the diameter for high strength deformed bar. The overlapping portion should preferably be wound with binding wire.
- Shape of links and stirrups: The ends of bars should be hooked by bending through 180$^{o}$ in mild-steel bars and 135$^{o}$ in deformed bars, see *Fig* 8.5.

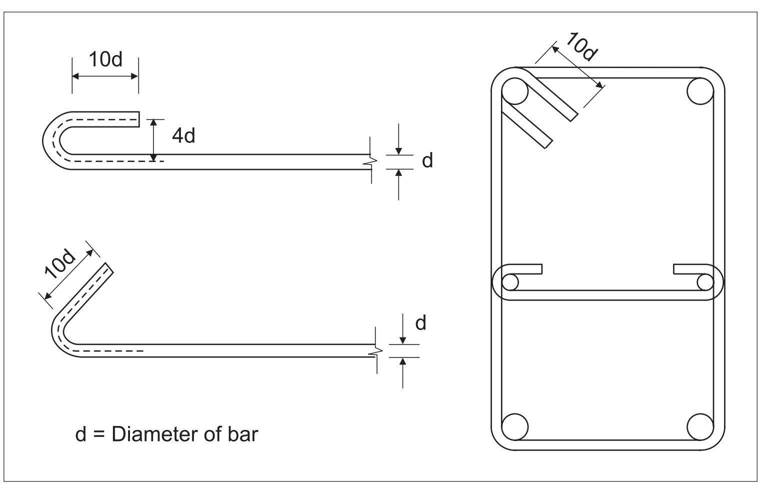



**Fig 8.5 Hooks at ends of bars**

### (e) Casting and compacting concrete

The concrete should normally be cast in

one continuous operation so as to avoid discontinuity of more than one hour. Mixed concrete should not be allowed to stay on the platform by more than 45 minutes and must be placed in the forms and compacted continually. Hand compaction must be done by rodding through the freshly placed concrete. Simply leveling the surface with trowels will leave voids in the mass. It may be mentioned that lack of compaction results in large reduction in concrete strength, hence utmost attention should be given to this factor. For rodding, good results will be obtained by using 16 mm diameter rods about 50 cm long.

**(f) Curing of concrete**

Concrete work requires water-curing for a minimum of 14 days so as to gain its strength, otherwise the gain of strength is low and concrete becomes brittle. Concrete slabs may be kept under water by ponding of water over it by making earthen barriers all around the edges. Columns should be kept covered with wet empty gunny bags. Keeping the side forms intact on the beam webs will prevent the evaporation of water from the concrete and help in curing. Covering any concrete surface with polythlene sheets after wetting the surface will help retain the moisture.

**(g) Construction joints**

Where a joint is to be made, the surface of the concrete shall be thoroughly cleaned and all laitance removed. The surface shall be thoroughly wetted, and covered with a coat of neat cement slurry immediately before placing of new concrete. Construction joints in floors shall be located near the middle of the spans of slabs, beams or girders, unless a beam intersects a girder at this point, in which case the joints in the girders shall be offset a distance equal to twice the width of the beam. Provision of keys should be made for transfer of shear through the construction joint.

## 8.4 TYPICAL MATERIAL PROPERTIES

Concrete is made to have the desired strength for the required use. The strength is defined on the basis of 28 days age, cube crushing strength or cylinder crushing strength. For use in buildings, the cube strength $F_c$ between 15 to 20 N/mm$^2$, will be adequate for RC work. The concrete mix is accordingly designed but ordinarily cement: sand:coarse aggregate mix proportion taken as 1:2:4 or 1:1½:3 by volume.

The mass density of RC is about 2400 kg/m$^3$ and modulus of elasticity is variously related with the concrete strength. Since the stress-strain characteristics are non-linear, the value of modulus of elasticity is ambiguous. Similarly the allowable stresses are differently specified by codes of practice in relation to $F_c$. Each country has its own standards for allowable stresses and load factors which may be referred to in this regard. A factor of safety of about 3 is used in determining the allowable stress in axial compression relative to the 28-day cube strength. Under seismic condition these allowable values may be increased by 33.33 percent and the load factors may be decreased by 25 percent unless specified otherwise in national standards.

It is important to know that the tensile strength of concrete is only about one-tenth of the compressive strength. The diagonal tension caused by seismic shear forces, if not throughly protected by well designed

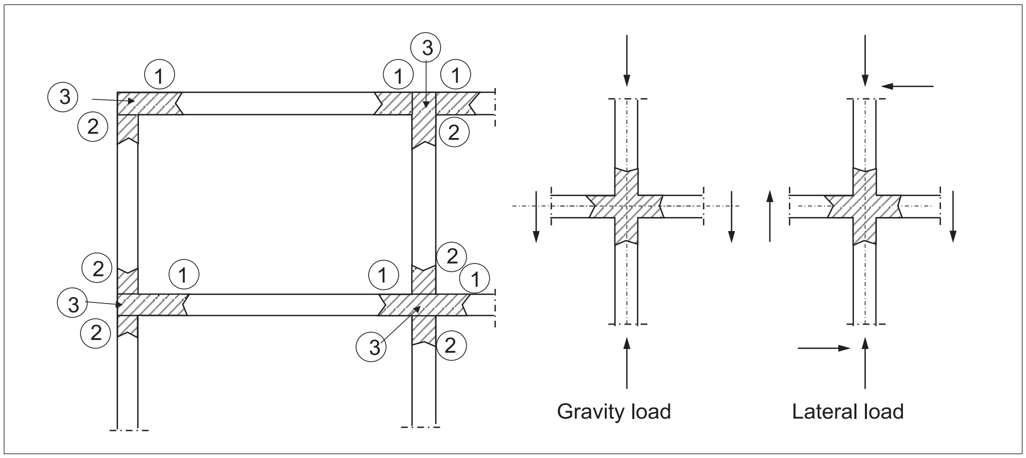



**Fig 8.6 Critical section in RC frame**

stirrups or ties, can lead to wide cracking and failure.

Concrete is a brittle material and weak against impact shock and vibrations. Ductility is imparted to it by the reinforcing steel only. The compressive strength as well as straining capacity can be greatly increased by using closely spaced lateral stirrup ties or spiral reinforcement. This is an important characteristic for improving the earthquake resistance of reinforced concrete columns and frames.

The critical zones in reinforced concrete frames where ductility of sections and confinement of concrete by closely spaced stirrups or spiral is required are shown shaded in *Fig* 8.6 and explained below:

1 Ends of beam upto a length of about twice the depth of the beam where large negative moments and shears develop are likely locations for plastic hinges. Here shear and moment reversal is possible under large seismic forces.

2 Ends of columns where maximum moments develop due to lateral forces. Values of maximum column moments closely approaching plastic moment capacity can be expected and these moments are likely to undergo full reversal. High lateral shears can be developed based on moments of opposite sign at the column ends and these shears can undergo full reversal. The length of such zones is about one-sixth of the clear height of the column between floors or the dimension of the column section in the plane of the frame

3 Joint regions between beams and columns undergo very high local shears, their full reversal is likely,

**Table 8.1 Recommended limits on steel area ratio in beam**

| *Concrete* | *Steel* | $P_{max}$ | $P_{min}$ |
|---|---|---|---|
| 1:2:4 ($F_c$= 15 MPa) | MS ($F_y$=250 MPa) | 0.011 | 0.0035 |
| | HSD ($F_y$=415 MPa) | 0.007 | 0.0022 |
| 1:1½:3 ($F_c$=20 MPa) | MS ($F_y$=250 MPa) | 0.015 | 0.0048 |
| | HSD ($F_y$=415 MPa) | 0.009 | 0.0029 |

*Notes:*

$F_c$ = 28-day crushing strength of 150-mm cubes

$F_y$ = Yield strength of reinforcement

MS = mild steel, HSD = high-strength deformed bars

$P = A_S / bh$

$A_{s_{max}} bh = P_{max} bh$

$A_{s_{min}} = P_{min}\, b\, h$

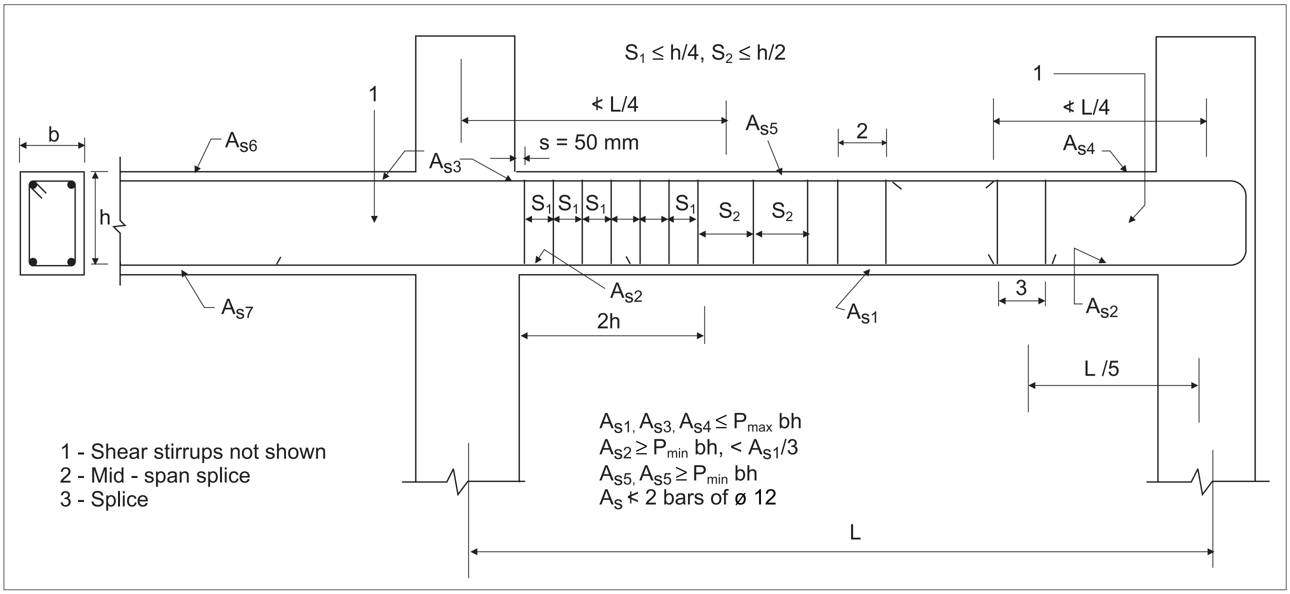



Fig 8.7 Detailing of beam reinforcement

shears, their full reversal is likely, diagonal cracking and local deformation may cause significant part of rotation at joint increasing the lateral displacement of frame.

## 8.5 DETAILING OF BEAMS

### (a) Longitudinal steel

Beams should be reinforced on both top and bottom face throughout. Where reinforcement is required by calculation, the percentage should correspond to ductile behavior. The recommended limits on steel area are shown in *Table* 8.1. Minimum steel should consist of two bars of 12 mm diameter in case of mild steel (MS) and 10 mm diameter

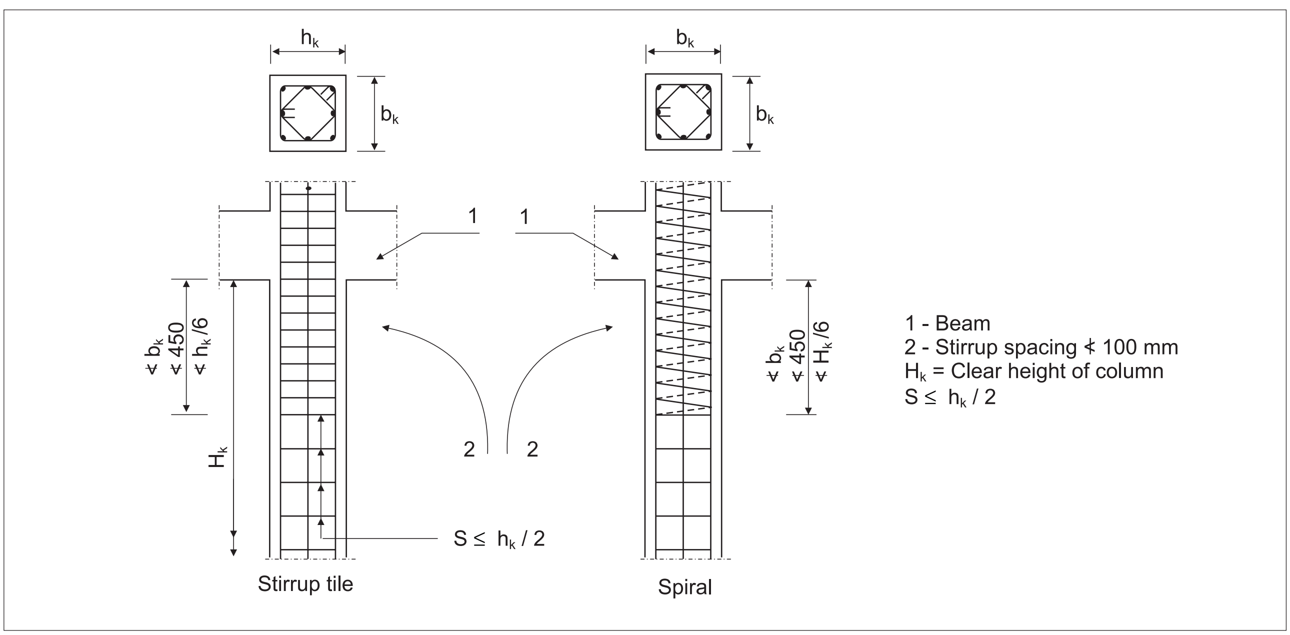



Fig 8.8 Column reinforcement

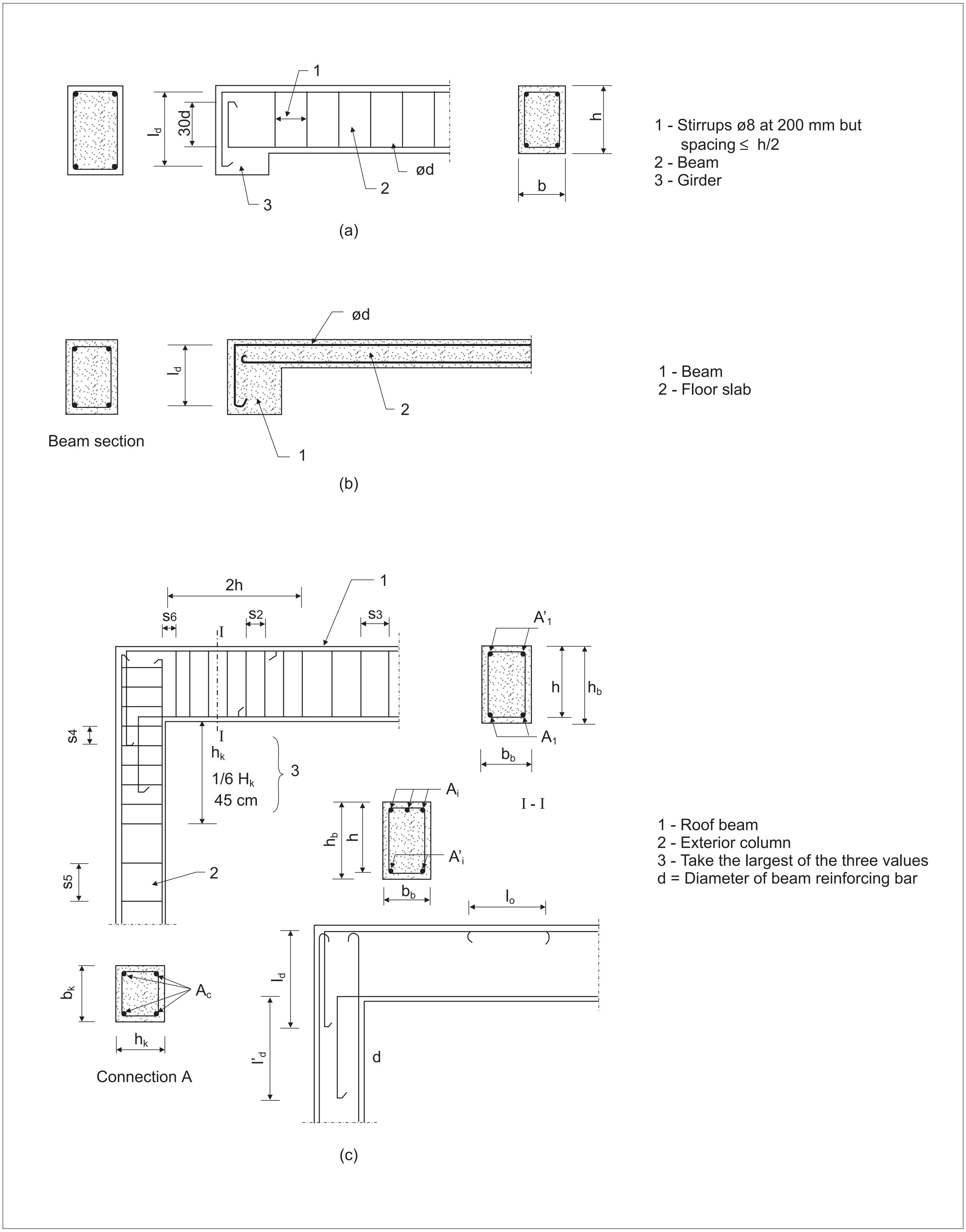



**Fig 8.9** ***(a)*** **Connection between beam and girder** ***(b)*** **Connection between floor slab and beam** ***(c)*** **Connection between roof beam and exterior column**

## (b) Splicing of steel

All longitudinal bars should be anchored or spliced for full strength development. All splices should be contained within at least two stirrups at each end of the splice so as to avoid spalling of cover concrete, *Fig* 8.7

## (c) Transverse steel stirrups

The ultimate shear strength of the beam should be designed to be more than its ultimate flexural strength, *Fig* 8.7. Vertical shear stirrups should be closely spaced at not more than one-fourth of effective depth in end 2*h*-length of spans of the beams. In

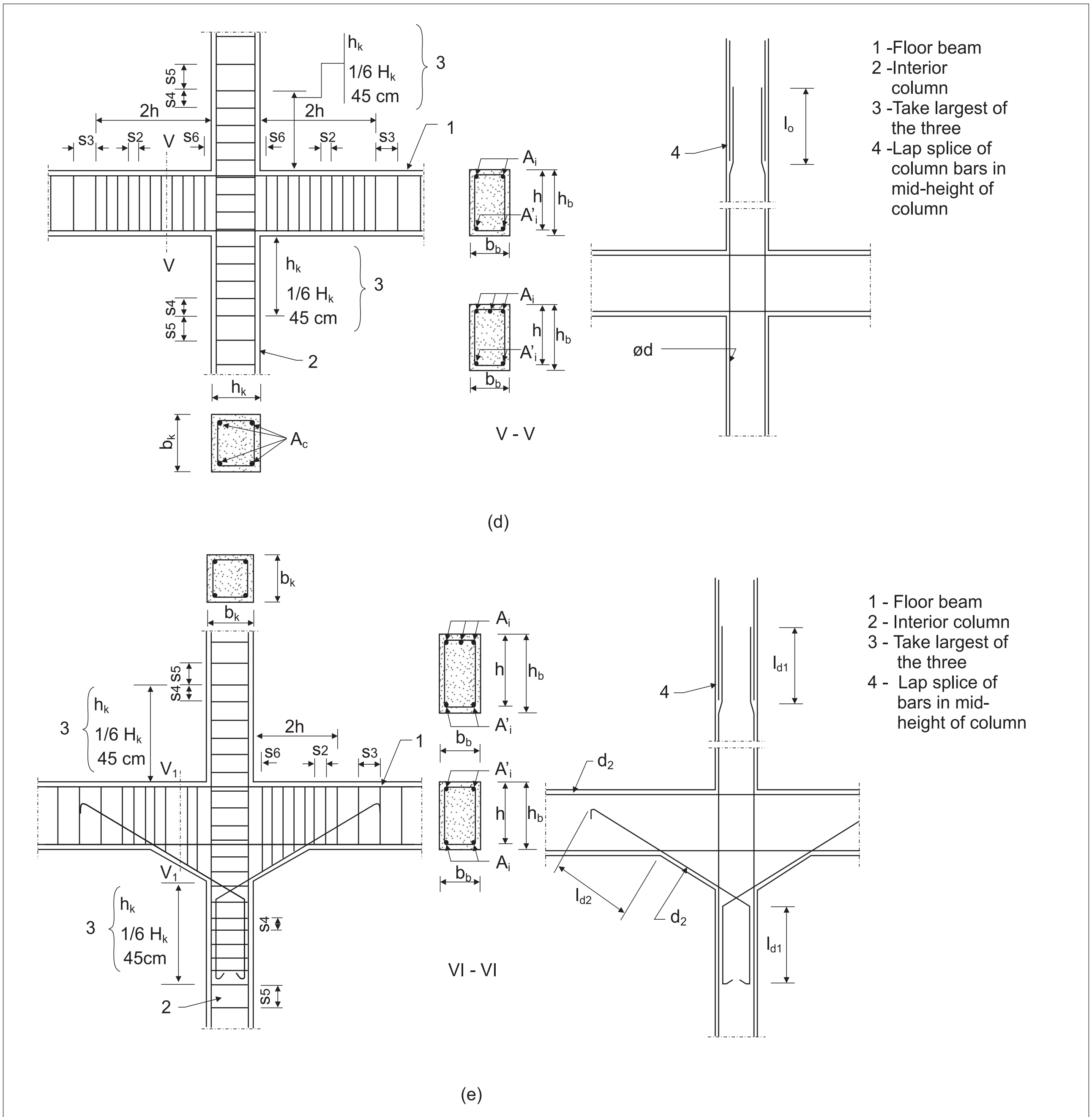
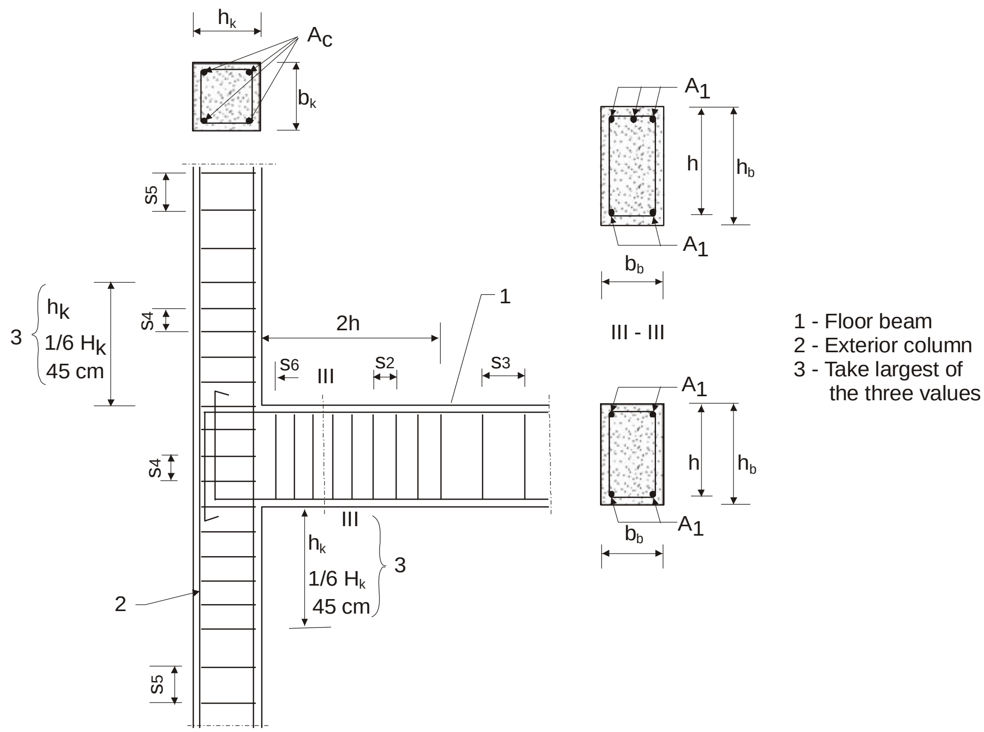
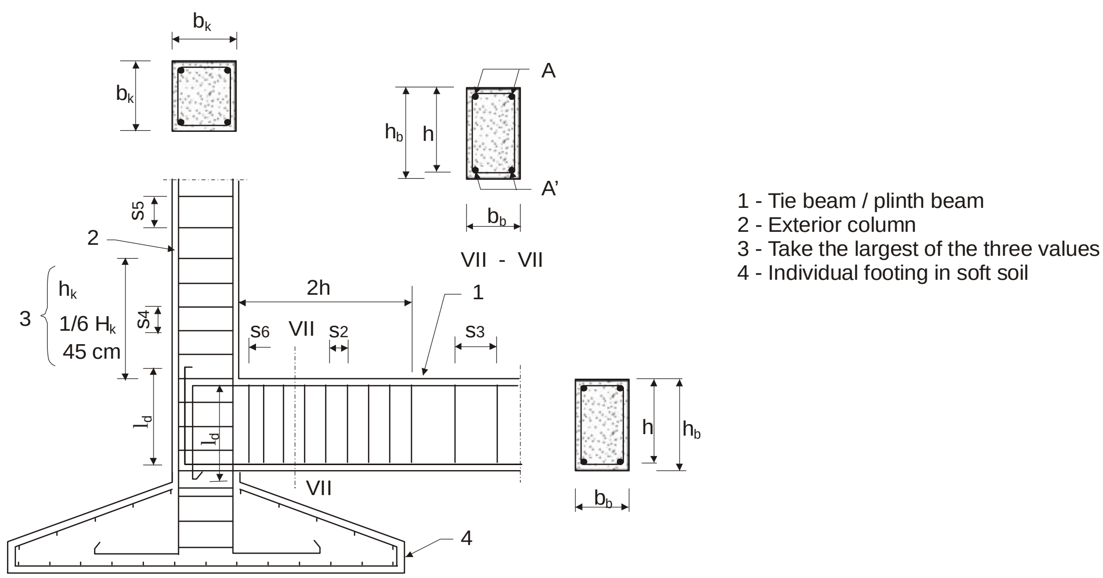



**Fig 8.9 *(d)* Connection between floor beam and interior column *(e)* Interior joint between haunched beam and column**




(f)




(g)

**Fig 8.9 *(f)* Connection between floor beam and exterior *(g)* Column footing and foundation/plinth beam**

the remaining length spacing should hot exceed $h/2$.

## 8.6 DETAILING OF COLUMNS

**(a) Column section**

In view of earthquake force acting in all directions, square section of columns is better than rectangular.

**(b) Longitudinal steel**

Vertical reinforcement should be distributed on all the faces of the columns. Use of 8 vertical bars is preferable to four bars of equal area; minimum diameter of bars, 12 mm.

**(c) Lateral reinforcement**

Concrete confined within the spirals is stronger as well as much more ductile as compared with plain concrete or that containing widely spaced stirrups.

The behavior of columns can be much improved by using the ties with adequate anchorage at ends in the form of suitable hooks as shown in *Fig* 8.5 and *Fig* 8.8 at close spacing.

In a length of about 450 mm near the ends of columns, a spacing not more than 100 mm may be adopted for achieving ductility there.

**(d) Corner column**

The corner columns of buildings are stressed more than any other column due to biaxial bending and must therefore have steel distributed on all faces and closely spaced lateral ties.

## 8.7 CONNECTION

The beam and column bars must be well anchored in the compression zone so as to achieve their full strength.

Where the joint is not confined by beams on all four sides, it will be necessary to place the closely spaced ties in the column throughout the height of the joint as well.

## 8.8 ILLUSTRATE SKETCHES

*Fig* 8.9 *(a)* to *(g)* give typical recommended details of connections in earthquake resistant frames in which the following dimensions are to be used (all in mm):

$s_2$: maximum value = $h/4$ or $16d$ whichever smaller where $d$ = bar diameter of beam reinforcement.

$s_3$: maximum value = $h/2$.

$s_4$: value 75 mm to 100 mm.

$s_5$: maximum value = $bk/2$ or 200 mm whichever smaller .

$s_6$: optimum value 50 mm.

$l_o$ : length of overlap to develop full tensile strength ~$55d$ including bends or hooks.

$l_d$ : anchorage length to develop full tensile strength ~ $55d$ including bends or hooks.

Use diameter of stirrup bar in beam and column:

Minimum = 6 mm,

preferable = 8 mm.

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