CHAPTER

6

CONSTRUCTION OF EARTHQUAKE RESISTANT BUILDINGS

6.1 INTRODUCTION :

- The masonry buildings are the most common type of traditional construction used for housing purposes, all around the world. The masonry buildings are constructed in rural, urban and hilly regions; which have very low seismic resistance.
- The recent earthquakes have shown that the collapse of these construction is the main cause of destruction. Hence, it is necessary to increase the seismic resistance of these buildings or constructions.
- In most cases, the resistance can be improved by following simple, inexpensive principles of good building construction.
- Thus, the retrofitting of already constructed buildings is also
12. essential for improving their seismic resistance.

6.2 FUNDAMENTALS OF EARTHQUAKE

6.2.1 DEFINITION EARTHQUAKE

- "The sudden shaking or movement of the earth's crust caused due to disturbances occurring inside the earth is known as the earthquake."
- Whenever the earth is disturbed, vibrations are produced. These vibrations set out in all directions from the place of their origin. Wherever these vibrations travel, an earthquake is said to have taken place. These vibrations are more intense near their source. As the distance increases, these become feeble and slowly die out.

6.2.2 STRUCTURE OF EARTH

→ The interior of the earth is divided into various zones, such as :
(i) Crust (ii) Mantle (iii) Core

(i) Crust :

- The uppermost part of the earth is called as crust. It is solid and extends upto 60 km. inside the earth. It mainly consists of rocks like granite, basalt, etc. The density of the crust varies from 2.5 to 3.0.

(ii) Mantle :

- Below the crust is mantle, which is divided into two parts, outer and inner.
- The outer mantle extend upto 660 km. and inner mantle upto 2900 km.
- The density of mantle varies from 3.4 to 5.5. This part is in semi-solid state and the approximate temperature inside the mantle is 3000°C.

(iii) Core :

- The innermost part of the earth is called as core. It is divided into two parts, outer and inner. It mainly consists of liquid zone. In composition, it has Nickel and Iron.
- The outer core extend upto 5200 km. and inner core from 5200 to 6370 km.
- The density of core varies from 11.0 to 16.0 and the temperature at the inner core is 6000°C.

The boundary between crust and Mantle is called as MOHO.

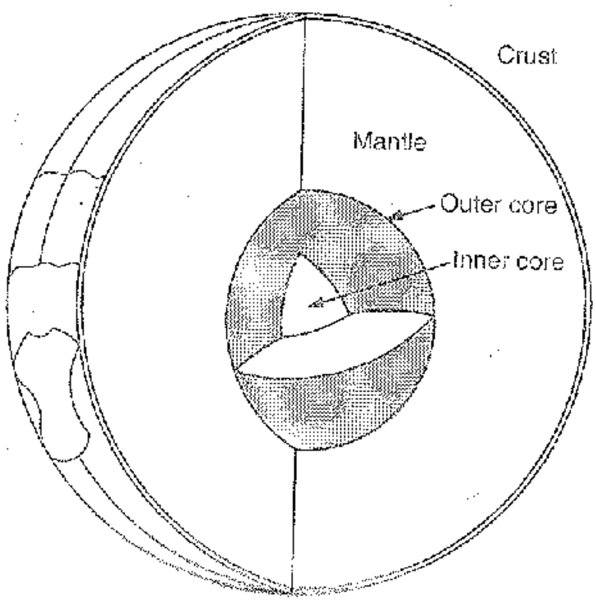

Fig. 6.1 Structure of the Earth

6.2.3 PLATE TECTONICS :

→ The high temperature and pressure difference between the crust and the core results in the convection currents (like flow of water molecules when heated up). These currents result in circulation of the earth's mass from crust to core and vice versa.

→ The hot molten lava comes out and cold rock mass goes into the earth. The flow of material cause the crust and some part of the Mantle to slide on the outer core. This sliding of earth's mass takes place in different parts of the earth, called as Tectonic plates.

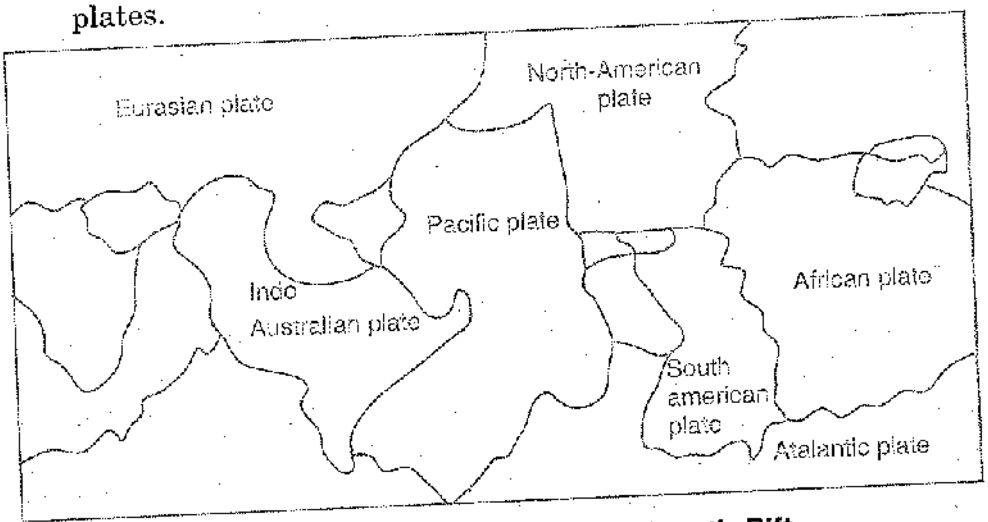

Fig. 6.2 Major Tectonic Plates of earth Rift

→ The surface of earth consists of seven major tectonic plates (Fig. 6.2) and many small plates. These plates move in different directions and at different speeds. Thus, resulting in rising and sinking of the continents.

12. → In India, the raised batches along the eastern and western coasts and the submerged forests of Bombay are typical examples of plate movements. Some movements of these plates also occur tangential to the earth's surface and are very slow. These movements result in the formation of mountains (like Alps and Himalayas). (Fig. 6.3)

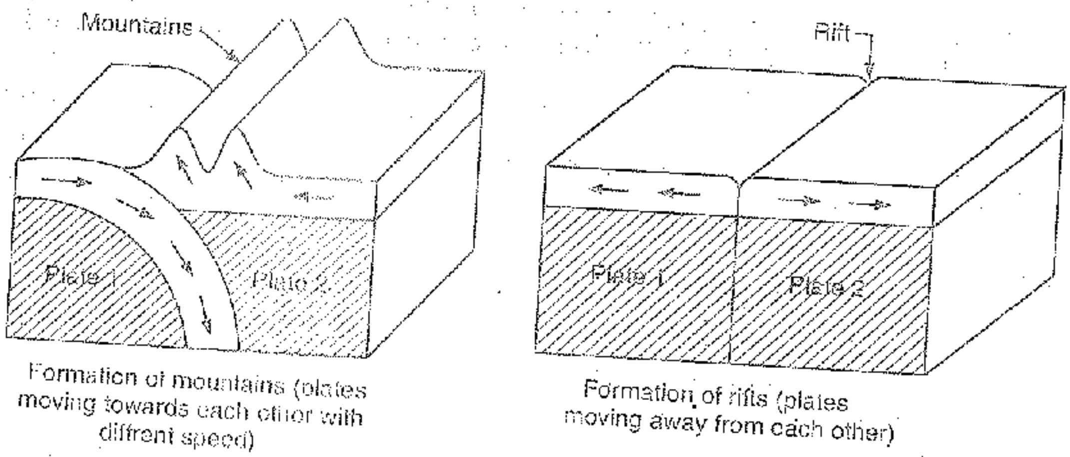

Fig. 6.3 Plate movements

6.3 EARTHQUAKE RESISTANT CONSTRUCTION :

[G.T.U., May 2011, Nov./Dec. 2011]

An earthquake resistant construction should have following properties for better seismic performance :

(i) Good structural configuration

(ii) Lateral strength

(iii) Ductility

(iv) Deformability

(v) Damageability

(i) Good structural configuration :

→ The size, shape and structural system of building should be such that inertia forces transferred to the ground safely.

→ An important property of good structural configuration is its integral action. An integral action means the structure acts as one unit and is able to resist the earthquake forces in a better and safer way.

(ii) Lateral strength :

→ The earthquake result in large inertia forces. Thus, a good earthquake resistant building should have enough lateral strength, so that it can resist the inertia forces without collapse.

(iii) Ductility :

→ The ductility is the property of a material, which enable it to undergo large elongation before breaking.

- The materials generally used for the construction are masonry, concrete and steel. The masonry and concrete are brittle, while steel is ductile.
- A good earthquake resistant building should have enough ductility. This can be done by the addition of ductile material, such as wood in earthen construction and steel bars in masonry and concrete construction.

(iv) Deformability :

- The deformability refers to the ability of a structure to undergo large deformations without collapse. The ductility is the inherent property of a material, while the deformability pertains to the structure.
- The deformability of a structure can be increased by making regular, well proportioned structure; which is tied properly.
- Good deformability of a structure is also necessarily to make it earthquake resistant. For example, Even when ductile material is present in the building components, such as beams and walls, the building may fail if the components are not well proportioned and tied together properly.

(v) Damageability :

- The damageability refers to the ability of a structure to undergo substantial damage without partial or total collapse. This will result in sufficient warning to the people before collapse; thus resulting in less loss of lives.
- The good damageability can be achieved by providing several supports to important structural components, such as beams etc. and avoiding central columns or walls supporting large portions of building.

6.4 INDIAN STANDARD CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURES :

→ The following Indian Standards may be used for guidance of earthquake resistant construction of building :

Sr. No.	I.S. Code No.	Title of code
01	1983 (Part-1 to 5)	Earthquake Resistant Design of Structures (5th Revision)
02	4326 – 1993	Earthquake resistant design and construction of buildings – code of practice' [2nd Revision]
03	13287 – 1993	Improving earthquake resistance of earthen buildings – Guidelines
04	13828 – 1993	Improving earthquake resistance of low strength masonry buildings – Guidelines
05	13920 – 1993	Ductile detailing of Reinforced concrete structures subjected to seismic forces [Code of practice]
06	13985 – 1993	Repair and seismic strengthening of buildings [Guidelines]

6.5 ZONING OF EARTHQUAKE AS PER INDIAN STANDARDS :

→ Seismic Department of India has divided entire country in five zones according to possibility of earthquake.

→ According to that "ZONE NO.", the possibility of earthquake can be identified easily.

Sr. No.	Zone No.	Possibility of earthquake
1	Zone-1	No Risk
2	Zone-2	Very Low Risk
3	Zone-3	Moderate Risk
4	Zone-4	High Risk
5	Zone-5	Very High Risk

6.6 (A) EFFECT OF EARTHQUAKE FORCES ON BUILDINGS :

[G.T.U., May 2011]

→ Earthquake causes shaking of the ground. The structures or building resting on the ground will be subjected to motion on base.
Thus, the base of the structure or building moves but the building or structure has a tendency to stay in its original position due to inertia.

→ The structure can be supposed to be acted upon by a force, called inertia force (which resists the change of the state of the structure).
For example, in a building whose roof is supported on columns, Fig. 6.4(a) and the columns are fixed to the foundation (base), when the ground moves the foundation alongwith the columns tries to move the roof. But roof has a tendency to stay back, hence inertia force equal to mass of the roof times acceleration acts on the roof in the direction opposite to the ground motion, Fig. 6.4(a).

→ During earthquake motion, the columns of the building are subjected to displacement. But, they also have a tendency to come back to the straight position (original position). Thus, restoring forces, which depends upon the stiffness of the columns and the displacement(x) are developed ($F_p = K \cdot x$). These act also opposite to the direction of motion. It is clear that if the columns are stiffer than the restoring forces are more.
Every structure possess some damping, which depends upon its materials connections and components, etc.
Thus, the damping forces equal to $C\dot{x}$ (C = damping coefficient and $\dot{x}$ is the velocity of ground motion) are developed which also act opposite to the direction of motion.
Thus, the summation of forces acting on the building is

$$F_{(t)} = m\ddot{x} + C\dot{x} + Kx$$

which is same as equation for dynamic equilibrium. Thus, the equation of motion (dynamic equilbrium) is applicable to buildings under earthquake motion also. Here, $F_{(t)}$ is the dynamic force due to earthquake inertia force motion.

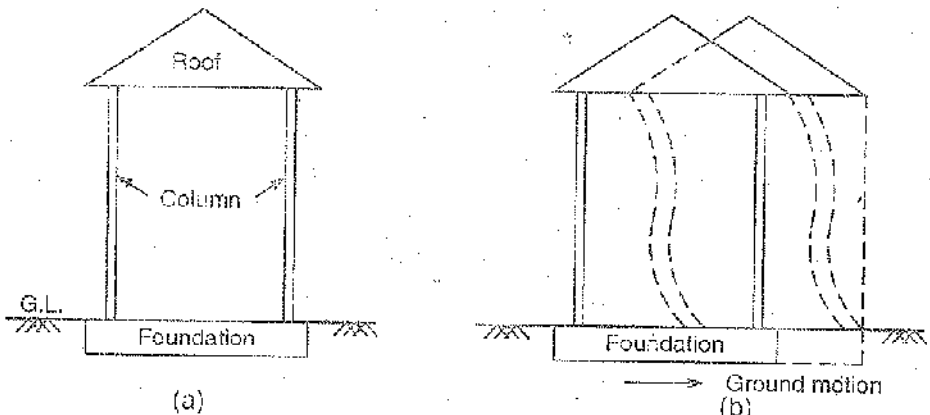

Fig. 6.4 Inertia Force

6.6 (B) GENERAL PRINCIPLES FOR EARTHQUAKE RESISTANT BUILDINGS : [G.T.U., May 2011, Nov./Dec. 2011, May/June 2012, Jan.2013]

The earthquake resistance of buildings can be improved by following simple principles of design and good building construction practices.

The various points/principles considered, while planning earthquake-resistant buildings :

6.6.1 Lightness : [G.T.U., May/June 2012]

→ The earthquake force depends on mass of the structure. Heavier structure means large inertia force and collapse of these structure results in heavier damage and loss of lives.

→ Thus, a building should be as light as possible, especially the roofs and upper storeys.

6.6.2 Plan of building : [G.T.U., May/June 2012]

→ The behaviour of a building during earthquake depends on its shape, size and geometry.

→ A good building plan can result in less damage during earthquake.

(a) Symmetry :

→ The building as a whole or its various blocks should be kept symmetrical about both the axis.

→ The asymmetrical buildings are subjected to twist or torsion during earthquakes. This twist make different portions at the same floor level to move horizontally by different amounts.

→ This causes more damage. This damage can be minimized by planning symmetrical buildings as shown in fig. 6.5.

(b) Simplicity and Regularity :

→ The building should have a simple rectangular plan.

→ It is seen that simple shapes behave better during the earthquake than complex shapes like L, T, E, U and T, etc. (Fig. 6.6)

→ Also, separation of a large building into smaller blocks can lead to symmetry and regularity. (Fig. 6.7)

(c) Size of the building :

→ The Length of the building should not be more than three times its width.

→ If longer lengths are needed, two separate blocks with separation should be provided. (Fig. 6.7)

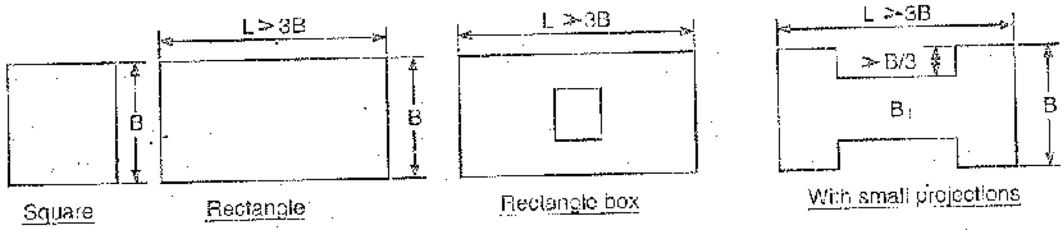

Fig. 6.5 Symmetrical desirable plans

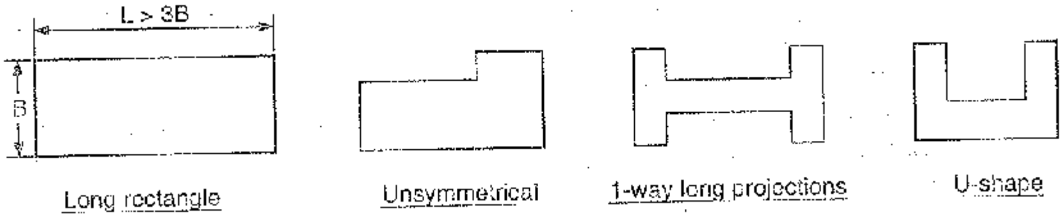

Fig. 6.6 Long or Unsymmetrical undesirable plans

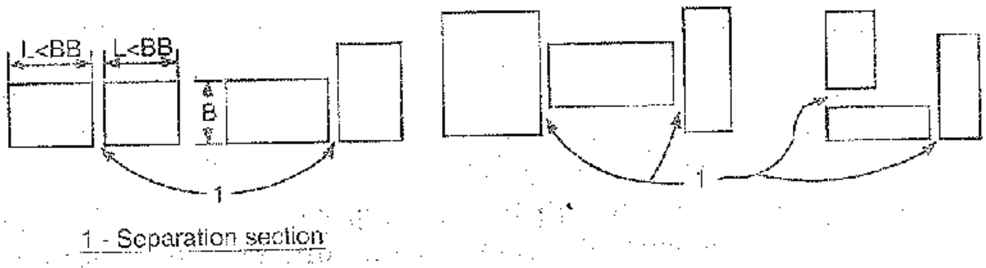

Fig. 6.7 Use of separation section for improving plans

6.6.3 Openings in Walls :

The following are the guidelines on the size and position of openings in walls :

(i) The distance of an opening from the inside corner of the adjacent perpendicular edge wall (b_5) is limited.

(ii) The total length of openings should not exceed a certain percentage of the span of the wall (distance between consecutive cross walls).

There are limits on the ratio of total length of openings to the length of the wall $[(b_1 + b_2 + b_3) / l_1$ or $(b_6 + b_7) / l_2]$

(iii) The width of the pier between two adjacent openings (b_4) should not be less than a minimum value.

(iv) The vertical distance between two openings one above the other (h_3) should not be less than a minimum value.

(v) The width of the ventilator opening (b_8) is limited. The specific limits are available in Table below :

Size and Position of openings in bearing walls

Sr. No.	Position of Opening	Details of openings for Building category		
		A and B	C	D and E
1.	Distance b_5 from the inside corner of outside wall, Minimum	zero mm	230 mm	450 mm
2.	For total length of openings, the ratio $\frac{(b_1+b_2+b_3)}{l_1}$ or $\frac{(b_6+b_7)}{l_2}$ shall not exceed			
	(a) one-storeyed building	0.60	0.50	0.50
	(b) two-storeyed building	0.50	0.46	0.42
	(c) 3 or 4 storeyed building	0.42	0.37	0.33
3.	Pier width between consecutive opening b_4, minimum	340 mm	450 mm	560 mm
4.	Vertical distance between two openings one above the other h_3, minimum	600 mm	600 mm	600 mm

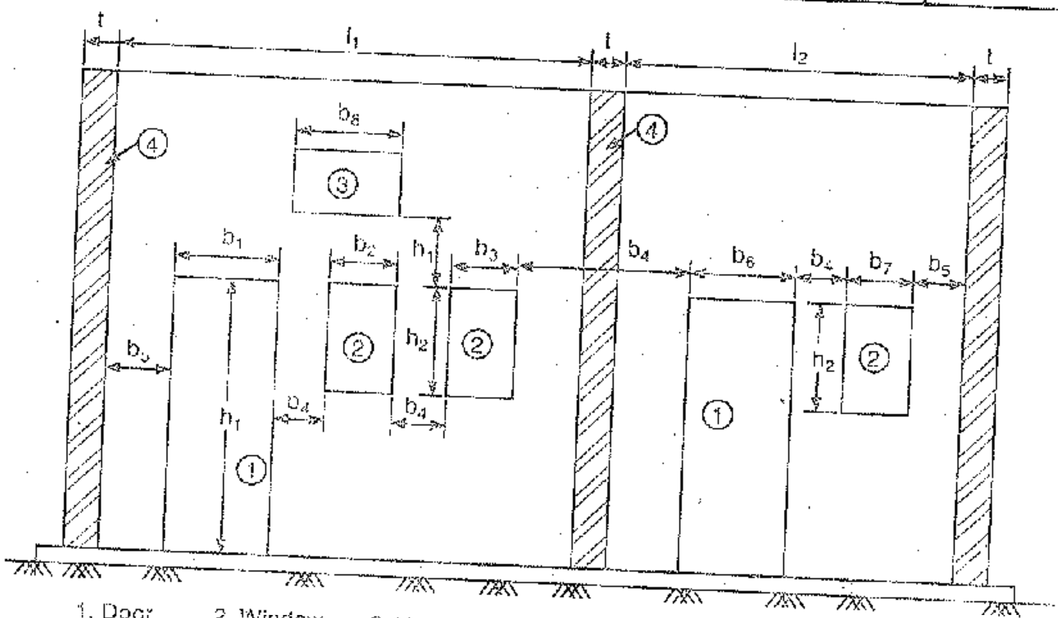

Fig. 6.8 Dimensions of Openings

→ These bars must be laid in CM (1:3) with a minimum cover of 10 mm. Fig. 6.10.

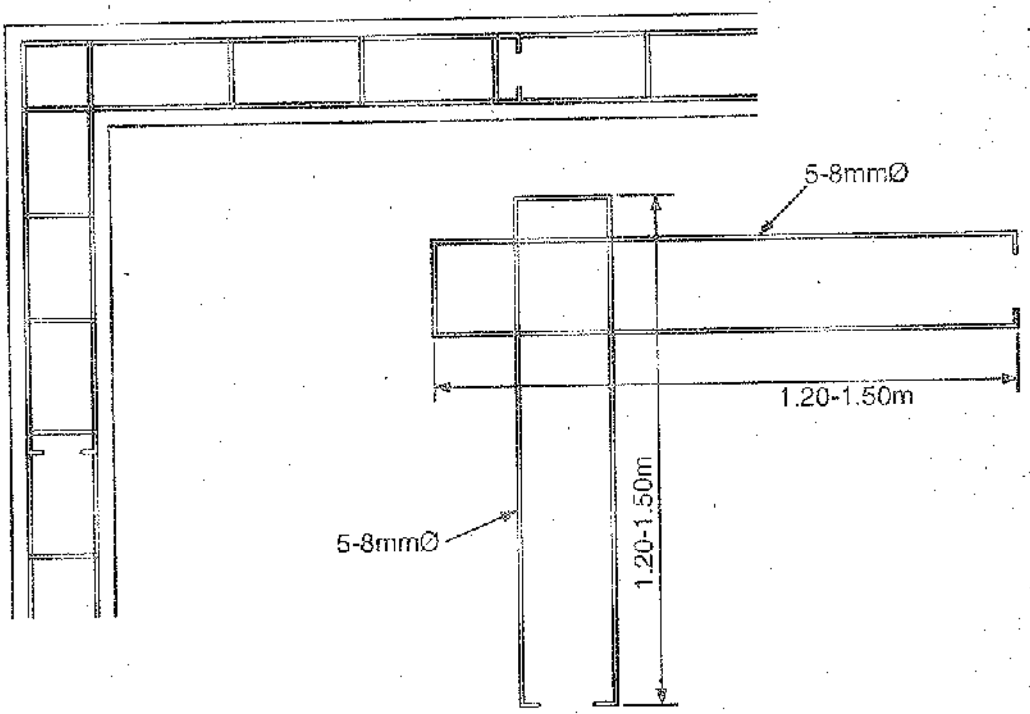

Fig. 6.10 Dowel bars at corners and T-junction all sill level of windows

6.6.4.2 Vertical reinforcement

The vertical reinforcement is also provided in walls to improve the seismic resistance of buildings.

Various points to be considered are as follows :

(i) Vertical steel at corners and junctions of walls, which are upto 345 mm (1½ brick) thick shall be provided.

(ii) For walls thicker than 345 mm, the area of bars can be increased proportionately. The amount of vertical steel depends upon number of storeys and category of building.

(iii) The vertical reinforcement should be properly embedded in the plinth masonry and roof slab or roof band.

(iv) The vertical reinforcement should pass through the lintel bands and floor level in all storeys.

(v) Vertical reinforcement for window and door openings should start from foundation of floor and upto lintel band.

(vi) The typical details of providing steel in brick masonry buildings are shown in fig. 6.11.

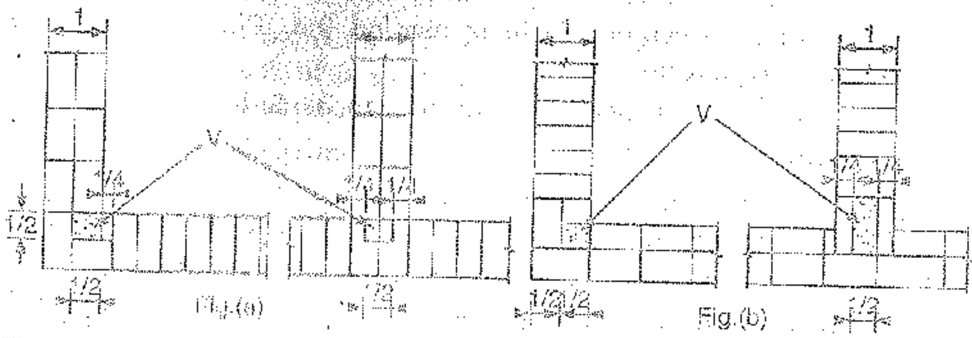

Fig. (a) and (b) : Alternate courses in 1 brick wall at corner and T-junction

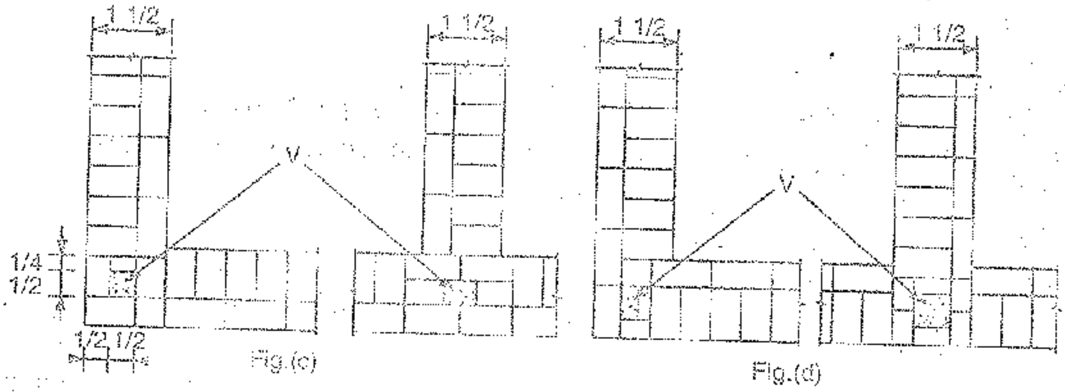

Fig. (c) and (d) : Alternate courses in 1½ brick wall at corner and T-junction

Fig. 6.11 Vertical bars in Masonry Walls

6.7 SELECTION OF MATERIALS AND PROPORTION OF MORTAR FOR EARTHQUAKE PRONE STRUCTURES :

REPAIR MATERIALS :

- The traditional materials used for repair are mud, lime, cement, sand, brick, stone and steel.
- Wood, bamboo, casuarina posts are used for supports and braces.
- Cement or lime is combined with sand and water to prepare the mortar.
- Various types of cement with properties such as shrinkage compensation, low heat evolution and sulphate resistance are preferred for specific repair applications.
- Steel is used in the form of bolts, threaded rods, angles, channels and prestressing strands.

(i) *Grout* :

- Grout is a mixture of water, cement and optional materials like sand, water reducing admixtures, expansion agents and pozzolans.

→ The water to cement ratio is around 0.5. Fine sand is used to avoid segregation.

→ The desirable properties of grout are as follows :

- Fluidity
- Minimum segregation
- Low shrinkage
- Adequate strength after hardening
- Good bond with the substrate
- No detrimental compound
- Durable

(ii) Epoxy Resins :

→ Epoxy resins are used for the following purposes :

- To bond plastic concrete to a hardened concrete surface.
- To bond two rigid materials
- For patch work
- For applying a coating over concrete surface to give colour, resistance to penetration of water and chemicals and resistance to abrasion.

→ Epoxy resigns are excellent binding agents. The low viscosity resins can be injected into small cracks. The higher viscosity resins are used as coating and for filling larger openings or holes.

(iii) Epoxy Mortar :

→ The epoxy mortar is made using epoxy resin, sand, cement and water.

→ The resin is added as an additional binder. It has high compressive strength, high tensile strength and low modulus of elasticity.

→ The polymer particles join and form chain link reinforcement, increasing the tensile strength of the mortar.

→ There is greater plasticity and reduction in shrinkage stress.

(iv) Quick Setting Cement Mortars :

→ There are patented mortars generally having two components and are sold in a pre-packed state.

→ They are classified as follows :

- Unmodified cementitious
- Polymer or Epoxy resin based
- Polymer modified
- Cement / pozzolanic modified

→ Cementitious mortars such as gypsum cement mortar have limited use for structural purposes and are intended for architectural hand/trowel applications.

→ The use of various types of mortars is given in Table below :

Applications of mortars

Sr. No.	Defect	Type of mortar	Properties
1.	Minor surface defect	Polymer modified cementitious mortar	• Gives a fair surface • Good water proofing • Resists acids and gases
2.	Surface cavities and honey-combed concrete	Highly adhesive thixotropic mortar	• Water proof and anti-carbonation finish • Good resistance to pollution
3.	Powdery surface	A two component surface stabilizer	• Binds powdery surface • Evens out absorption characteristics
4.	Non-structural cracks	Non-shrinking polymer filler	• Easily applied elastic compound • Eases at low temperatures
5.	Minor voids of approximate size 100 mm × 100 mm × 50 mm	Rapid curing polymer modified cementitious mortar	• High strength • Can be compacted in layers
6.	Major voids of approximate size 200 mm × 20 mm × 150 mm	Heavy duty thixotropic fiber reinforced polymer modified cementations mortar	• Can be applied upto 100 m thick without sag • Easy to mould
7.	**Other uses :** Surface protection	Resin rich water based co-polymer.	• Hihgly resistant to diffusion • Self cleaning

8.	Surface barrier	Water based co-polymer.	• Resistant to fungal attack
9.	Bonding agent	Polymer modified cementations surface impregnate	• High penetration into porous concrete creating enhanced adhesion
10.	Protection of steel reinforcement	Two component system of cementations powder and polymer.	• High penetration • React chemically to generate passivity of steel

(v) Shotcrete :

→ Shotcrete is a method in which compressed air forces mortar or concrete through a nozzle to be sprayed on a surface of building component such as a wall, at a high velocity. The materials used in shotcrete are generally same as those used for conventional concrete. The reinforcement provided is welded wire fabric or deformed bars tacked on the existing surface.

→ Shotcrete is applied using either wet or dry process. The wet mix consists of cement and aggregate premixed with water and pump pushes the mixture through the hose and a nozzle. Compressed air is used at the nozzle to increase the velocity of application.

In the dry mix process, compressed air propels premixed mortar and damp aggregate and at the nozzle end, water is added through a separate hose. The dry mix and water are projected on to the surface through a second hose.

In most cases, shotcrete can be applied in a single application for the required thickness. It is a versatile technique as it can also be applied to curved or irregular surfaces. Its strength after application and its good physical characteristics make it ideal for strengthening weak members.

(vi) Micro-concrete :

→ Based on hydraulic binders, these ready-made formulations are tailored to produce concrete, which is flowable and free of shrinkage. They are applied in complicated locations and in thin sections such as concrete jackets.

(vii) Fibre-reinforced concrete :

→ Fibre-reinforced concrete has better tensile strength as compared to conventional concrete. They also have improved ductility (energy absorption capacity) and durability. They are being increasingly used for structural strengthening.

(viii) Fibre Reinforced Polymers :

- The fibre reinforced polymer (FRP) composites are made up of a polymer matrix and fibres.
- The fibres can be of glass, carbon or aramid. They possess high strength to weight ratios, high fatigue strength, high wear resistance, vibration absorption capacity, dimensional stability, high thermal and chemical stability and corrosion resistance.
- They are manufactured in long lengths by the pultrusion process. FRP wraps can be used to strengthen structural members.

(ix) Ferro - Cement :

- Ferro-cement is constructed of cement mortar reinforced with closely spaced layers of small diameter wire mesh.
- The mesh may be made of steel or other suitable material.
- The mortar should be compatible with the opening size and weight of the mesh.
- The mortar may contain discontinuous fibres.
- The use of ferro-cement can be economical even for non-engineered buildings.

6.8 REPAIR, RESTORATION AND RETROFITTING :

1. Repair :

- The repairs are carried out for patching up superficial defects and doing finishes, so that the functioning of building is resumed quickly.
- Repair does not mean to improve the structural strength of the building.
- The repair work consists of following measures :
  (i) Patching up the defects in plaster.
  (ii) Replastering of wall.
  (iii) Repairing doors and windows, replacement of glass panes.
  (iv) Repairing electric connection, gas connection.
  (v) Repairing plumbing, heating connection.
  (vi) Rebuilding non-structural walls, chimneys, boundry walls, etc.
  (vii) Relaying damaged flooring.
  (viii) Repairing roofing sheets or tiles, etc.
  (ix) Redecorating work, i.e. white washing, colour washing, pointing, etc.

2. **Restoration :**

→ The purpose of the restoration is to carryout structural repairs for restoring the lost strength of structural elements.

→ The restoration work consist of following measures :

(i) Removal of portion of cracked masonry walls, piers, etc.

(ii) Rebuilding of removed portion with rich non-shrinking mortar.

(iii) Providing reinforcing wire mesh on both faces of cracked wall.

(iv) Injecting neat cement slurry or epoxy material in cracks in walls, columns, beams, etc.

3. **Retrofitting :**

→ Retrofitting is the seismic strengthening carried out to upgrade the seismic resistance of a damaged building.

→ The retrofitting work consist following measures :

(i) Upgrading seismic resistance of existing building

(ii) Modification of existing roof

(iii) Strengthening of floor

(iv) Modification of plan

(v) Strengthening of wall with provision of horizontal and vertical seismic band as per IS 4326.

(vi) Adding section of beam or column using jacketing or casing.

(vii) Adding shear walls, adding diagonal bracings.

(viii) Strengthening of foundation, if possible.

6.9 METHODS OF REPAIRING AND RETROFICATION OF EARTHQUAKE DAMAGED STRUCTURE :

1. **Repairs of Minor and medium cracks :**

→ For the repair of minor and medium cracks (0.50 mm to 5 mm) the technique to restore the original tensile strength of the cracked element is by pressure injection by epoxy. (Fig. 6.12(b))

Procedure :

→ The external surfaces are cleaned of non-structural materials and plastic injection ports are placed along the surface of the cracks on both the sides of the member and are secured in place with an epoxy sealant. The centre to centre spacing of these ports may be approximately equal to the thickness of the element. (wall or beam).

- → After the sealant has cured, a low viscosity epoxy resin is injected into one port at a time beginning at the lowest part of the crack, in case it is vertical, or at one end of the crack, in case it is horizontal.
- → The resin is injected till it is seen flowing from the opposite sides of the member at the corresponding port or from the next higher port on the same side of member.
- → The smaller the crack, higher is the pressure or more closely spaced should be the ports so as to obtain complete penetration of the epoxy material, throughout the depth and width of the member.
- → This technique is appropriate for all types of structural elements like beams, columns, walls and floor units in masonry as well as concrete structures.

2. **Repairs of Major cracks and crushed concrete :**

- → For cracks wider than about 5 mm or for regions in which the concrete or masonry has crushed, a treatment other than injection is indicated.

Procedure :

(i) The loose material is removed and replaced with any of the materials, such as cement mortar, quick setting cement, expansive cement mortar, etc. (Fig. 6.12(c))

(ii) Where found necessary, additional shear or flexural reinforcement is provided in the region of repairs. This reinforcement could be covered by mortar to give further strength as well as protection to the reinforcement. (Fig. 6.12(d))

(iii) In areas of very severe damage, replacement of the member or portion of member can be carried out.

(iv) In the case of damage to walls and floor diaphragms, steel mesh could be provided on the outside of the surface and nailed or bolted to the wall. Then it may be covered with plaster or micro-concrete. (Fig. 6.12(e))

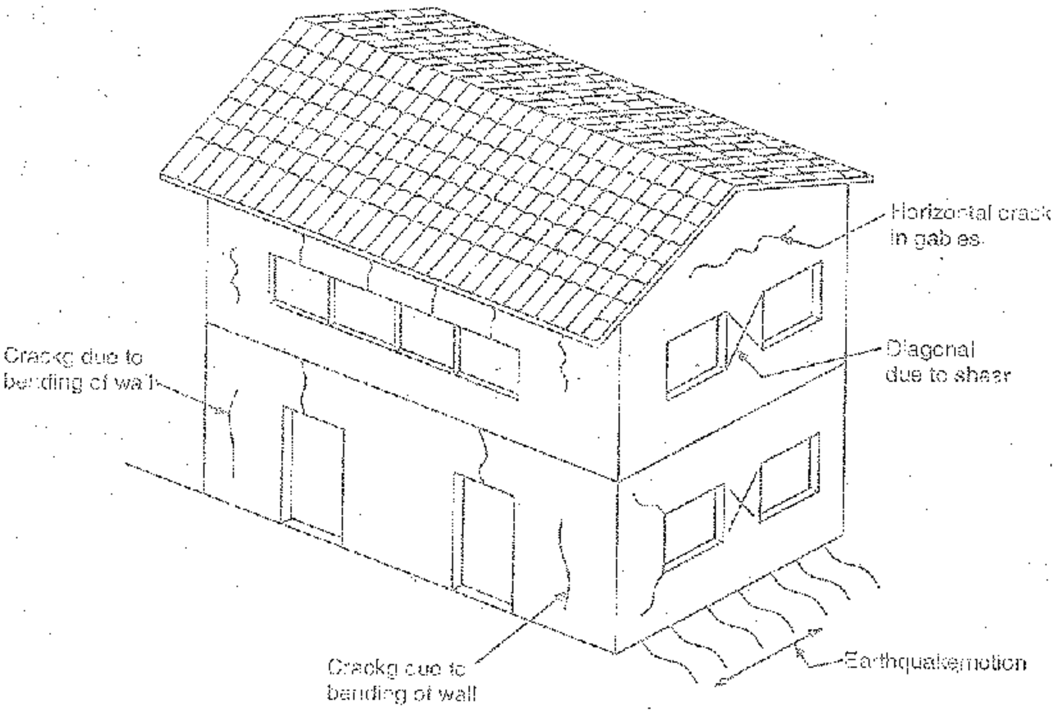

Fig. 6.12(a) Cracking in bearing walls due to bending and shear

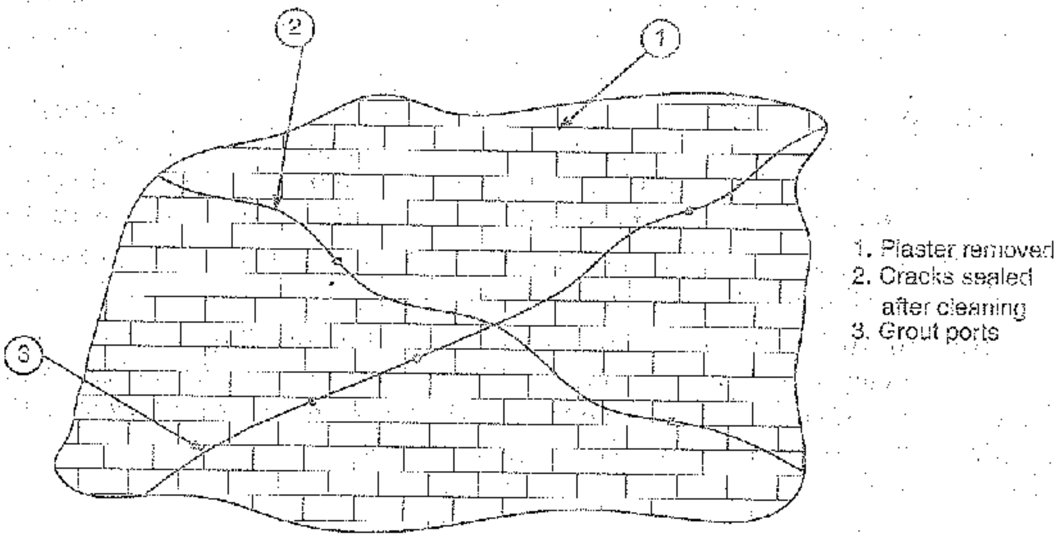

Fig. 6.12(b) Grout or Epoxy injection in cracks

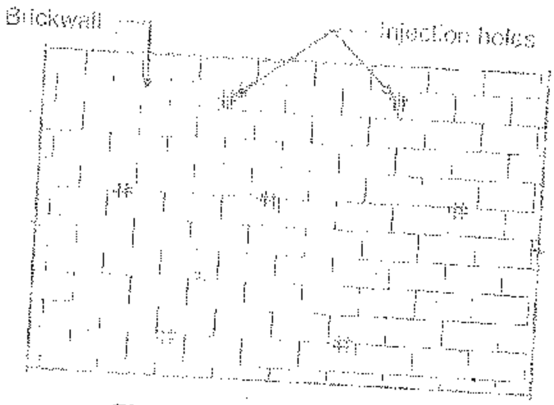

Fig. 6.12(c) Strengthening of Existing masonry

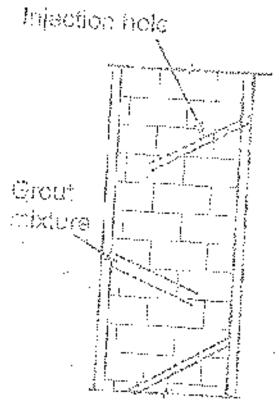

Fig. Grout or epoxy injection in cracks

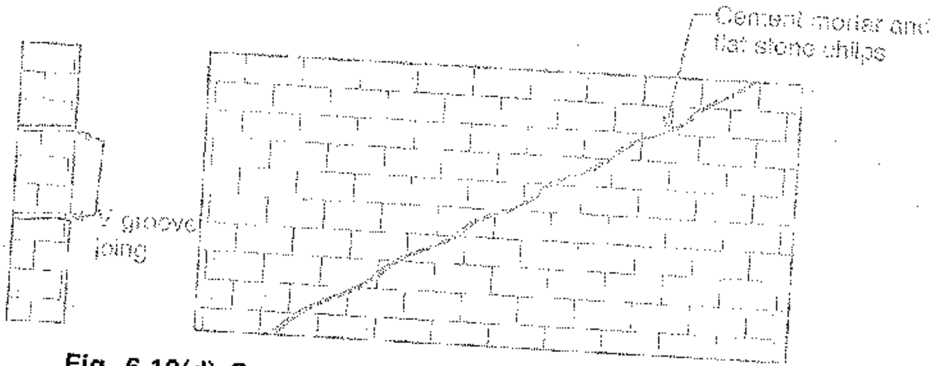

Fig. 6.12(d) Cement mortar and flat chips in wide cracks

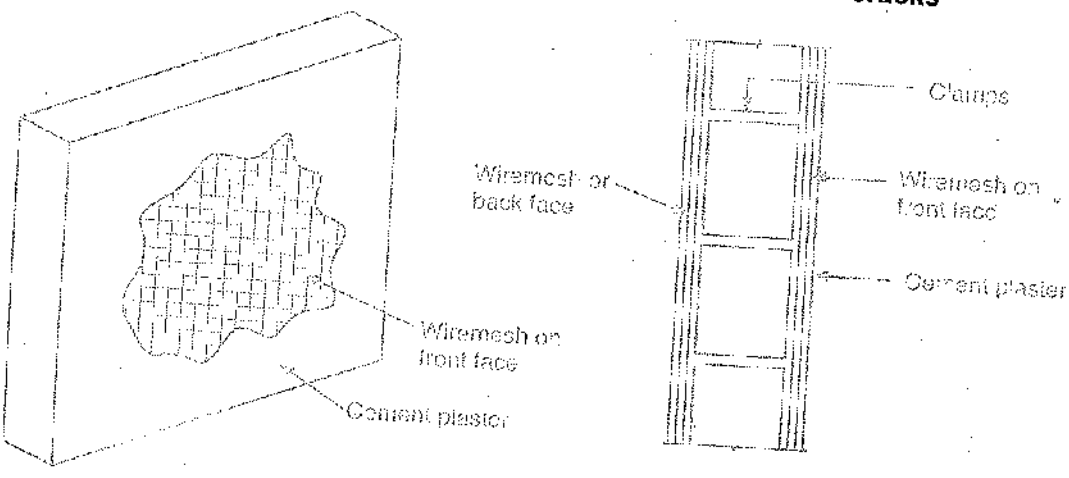

Fig. 6.12(e) Cement mortar and Wire mesh in cracks

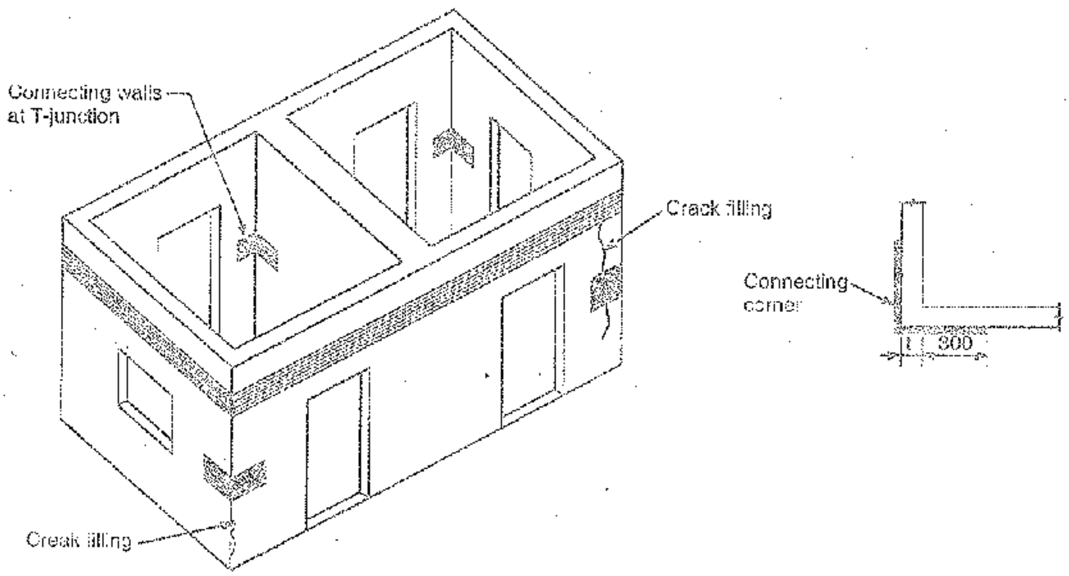

Fig. 6.12(f) Connection of cracked walls at Corners and Junctions

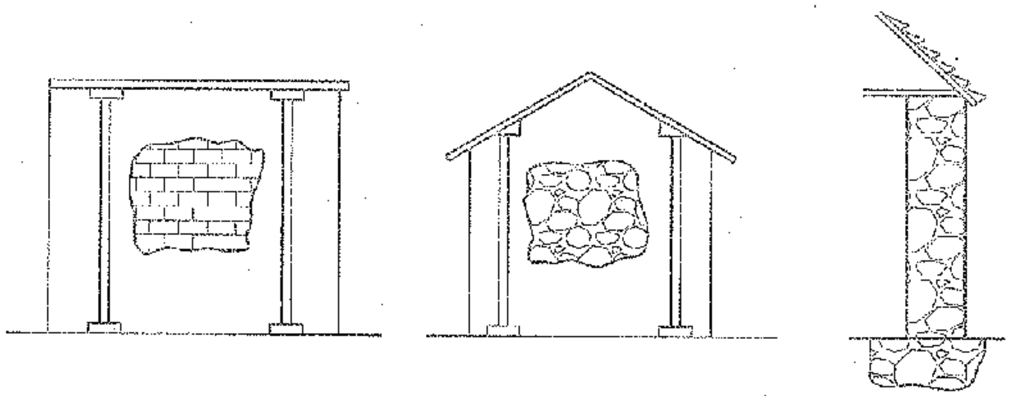

Fig. 6.12(g) Rebuilding part of wall

3. **Installing Ferro-cement plate at corners :**

→ When the cracks may appear at the corners or T-junctions and separation of cross-wall may occur, the following steps must be taken to restore the building :

Procedure : (Fig. 6.12(f))

→ The plaster from and around the crack is removed and the cracked masonry is exposed.

→ The V-shape groove is cut along the cracks on both the sides of the wall.

→ Then the grouting nipple of plastic or aluminium of 12 mm diameter and 30 to 40 mm long are fixed in the V-shaped groove at 150 to 200 mm spacing.

- The cracks are then cleaned by means of compressed air through nipples.
- Then the cracks are sealed with the polyster sand mortar of proportion 1:3 on both the faces of the wall.
- The water is then injected from upper level nipples. The water must pass freely towards bottom level nipple.
- then the cement slurry consisting proportion 1:1 (1 part non shrink cement, 1 part water) is injected from lowest level nipple till slurry comes out from next higher level nipple.
- The galvanised weld mesh of 14 gauge (2.03 mm dia) and 25 mm × 25 mm mesh is provided over a length of 500 to 600 mm on each side of crack both inside and outside of room in a depth of 300 mm at window sill and 900 mm height from floor level.
- The mesh is fixed with wall using clamp.
- Then the meshed area is plastered with Ferrocement – sand mortar of 1:3, covering mesh by minimum 12 mm thickness.

4. **Rebuilding portion of wall :**

- If some portion of Random rubble stone masonry walls has been damaged during an earthquake and the walls get separated and get bulged; then this portion of wall is dismantled and new masonry wall is constructed. (Fig. 6.12(g))
- When any portion of wall require rebuilding, the roof resting on such wall should be properly supported first.
- The new portion of wall must be constructed using rich cement sand mortar (1:4).

5. **Strengthening (Retrofication) of Reinforced concrete members :**

(1) Columns : **[G.T.U., May 2011]**

- The retrofitting of deficient column is essential to avoid collapse of storey.
- The columns are retrofitted to increase their flexural and shear strengths, to increase the deformation capacity near the beam-column joints and to strengthen the regions of faulty spacing of longitudinal bars.
- The concrete jacketing involves additional layer of concrete, longitudinal bars and closely spaced ties.

→ The longitudinal bars of 12 mm diameter as specified by the engineer and the ties of 8 mm diameter at 20 mm centre to centre spacing may be provided and thickness of jacket may be 100 mm on all the four sides, as shown in fig. 6.12(h).

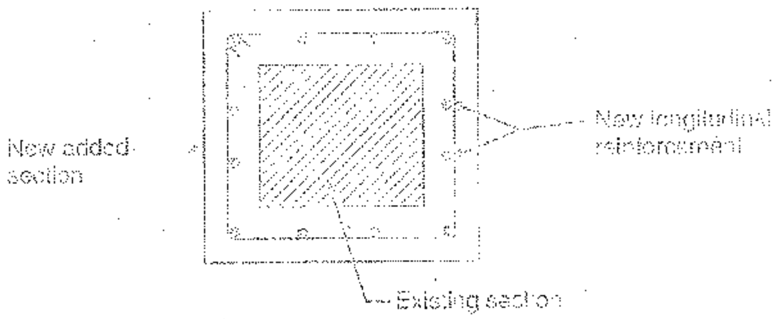

Fig. 6.12(h) Casing of concrete column

(2) Beams : **[G.T.U., May 2011]**

→ The beams are retrofitted to increase their positive flexural strength, shear strength and the deformation capacity near the beam-column joints. (Fig. 6.12(i))

→ The strengthening involves the placement of longitudinal bars and closely spaced stirrups.

→ A reinforced concrete beam can be encased as shown in fig. 6.12(i)(a). For holding the stirrups, the holes are drilled through the slab.

→ Alternatively, it can be jacketed as shown in fig. 6.12(i) (b) and fig. 6.12(i)(c), where in holes will need to be drilled through web of existing beam for the new stirrups. Desired quantity of longitudinal and transverse steel bars may be added in each case, as specified by the engineer.

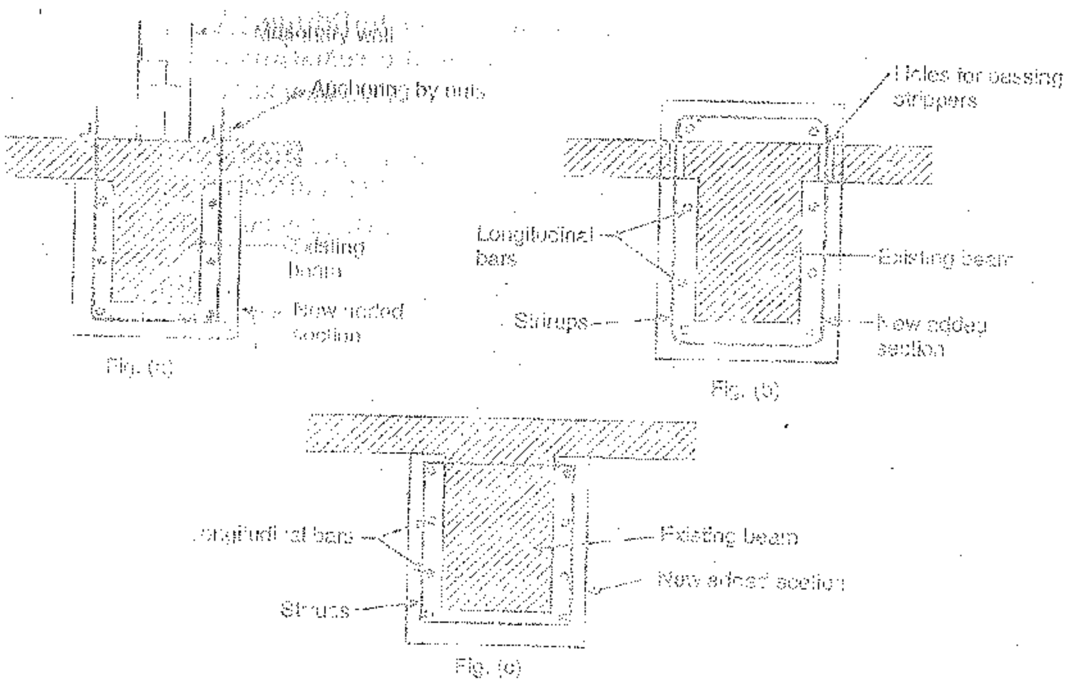

Fig. 6.12(i) Concrete jacketing for beams

QUESTIONS

1. Explain the general principles for earthquake resistant buildings with drawings and latest bye-laws. **[G.T.U., May 2011]**
2. Describe the guidelines for the size and position of openings in walls, for various categories of building, giving sketch; as per IS : 4326-1993, IS : 13828-1993.
3. Explain the provision of horizontal rain forcement (canals) in masonry structures, as per IS : 4326, giving detailed sketch.
4. Explain the provision of vertical reinforcement in measonry structures, as per IS 4326, giving detailed sketch.
5. Explain the selection of materials and proportion of mortar for earthquake prone structures.
6. Explain the difference between Repair, Restoration and Retrofitting.
7. Describe the methods of repairing and retrofication of earthquake damaged structures.
8. Describe various properties of earthquake resistant construction for better seismic performance. **[G.T.U., Nov./Dec. 20**

9. What are the effects of seismic forces on buildings? What points do you consider while planning of earthquake resistant buildings?
[G.T.U., May 2011, Nov./Dec. 2011]

10. What are the suggestive construction methods/measures for improvement of (i) Masonry walls (ii) R.C.C. columns and beams of buildings against the earthquake? **[G.T.U., May 2011, Nov./Dec. 2011]**

11. Discuss planning (shape) of earthquake resistant building.
[G.T.U., May/June 2012]

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