

GUIDELINES FOR
REPAIR, RESTORATION, CONDITION ASSESSMENT
AND
SEISMIC STRENGTHENING
OF
MASONRY BUILDINGS

by:-

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1 SCOPE

1.1 This standard covers the selection of materials and techniques to be used for repair and seismic strengthening of damaged buildings during earthquakes. It also covers the damageability assessment and retrofitting for upgrading of seismic resistance of existing masonry buildings.

1.2 The repair materials and techniques described herein may be used for all types of masonry buildings and construction.

1.3 The provisions of this standard are applicable for buildings in seismic Zones III to V of IS 1893 (Part – 1): 2002. These are based on damaging seismic intensities VII and more on M.S.K. Intensity scales. The scheme of strengthening should satisfy the requirements stipulated for the seismic zone of IS 1893: (Part – 1) 2002, building categories of IS 4326 and provisions made in this code and in IS 13828:1993 for low strength masonry building. No special seismic resistance features are considered necessary for buildings in seismic Zones II, but the important buildings in this Zone may also be considered for upgrading their seismic resistance.

1.4 The suggested reinforcing of horizontal and vertical seismic belts in this standard follow IS 4326 requirements of horizontal seismic bands and vertical bars at critical sections. For special buildings having larger span and heights beyond the dimensions considered in IS 4326 and in the standard, special analysis may be carried out at the responsibility of the specialist.

2 REFERENCES

The Indian Standards listed below are the necessary adjuncts to this standard:

<i>IS No.</i>	<i>Title</i>
456:2000	Code of practice for plain and reinforced concrete
1893 (Part – 1): 2002	Criteria for earthquake design of structures
4326:1993	Code of practice for earthquake resistant design and construction of buildings (third revision)
13827:1993	Guidelines for improving earthquake resistance earthen buildings
13828:1993	Guidelines for improving earthquake resistance of low strength masonry buildings

3 TERMINOLOGY

For the purpose of this guide, the definitions as given in IS: 1893 (Part – 1): 2002 shall apply besides which the following definitions shall also be applicable.

3.1 Box System

A bearing wall structure without a space frame, the horizontal forces being resisted by the walls acting as shear walls.

3.2 Centre of Rigidity

The point in a structure, where a lateral force shall be applied to produce equal deflections of its components, at any one level in any particular direction.

3.3 Design Seismic Coefficients

The value of horizontal seismic coefficient computed taking into account the soil system the importance factor and the response reduction factor as specified in IS 1893 (Part-1): 2002.

3.4 Seismic Band

A reinforced concrete, reinforced brick or wooden runner provided horizontally in the walls to tie them together and to impart horizontal bending strength in them.

3.5 Seismic Belt

A cast-in-place Ferro-cement plating installed post-construction on the masonry wall in lieu of the seismic bands or vertical reinforcing bars specified in IS 4326:1993 and IS 13828:1993

3.6 Seismic Zone, and Seismic Coefficient

Classification of seismic Zones II to V and the corresponding basic seismic coefficients shall be as specified in IS 1893.

3.7 Shear Wall

A wall designed to resist lateral force in its own plane. Braced frames, subjected primarily to axial stresses, shall be considered as shear walls for the purpose of this definition.

4 GENERAL PRINCIPLES AND CONCEPTS

4.1 Non-Structural/Architectural Repairs

4.1.1 The buildings affected by earthquake may suffer both non-structural and structural damages. Non-structural repairs may cover the damages to civil and electrical items including the services in the building. Repairs to non-structural components need to be taken up after the structural repairs and retrofitting work are carried out. Care should be taken about the connection details of architectural components to the main structural components to ensure their stability.

4.1.2 Non-structural and architectural components get easily affected/dislocated during the earthquake. These repairs involve one or more of the following:

- a) Patching up of defects such as cracks and fall of plaster;
- b) Repairing doors, windows, replacement of glass panes;
- c) Checking and repairing electric conduits/wiring;
- d) Checking and repairing gas pipes, water pipes and plumbing services;
- e) Re-building non-structural walls, smoke chimneys, parapet walls, etc;
- f) Replastering of walls as required;
- g) Rearranging disturbed roofing tiles;
- h) Relaying cracked flooring at ground level; and
- j) Redecoration - white washing, painting. Etc.

The architectural repairs as stated above do not restore the original structural strength of structural components in the building and any attempt to carry out only repairs to architectural/non-structural elements neglecting the required structural repairs may have serious implications on the safety of the building. The damage would be more severe in the event of the building being shaken by the similar shock because original energy absorption capacity of the building would have been reduced.

4.2 Structural Repairs/Restoration

4.2.1 Prior to taking up of the structural repairs for restoration of original strength and any strengthening measures, it is necessary to conduct detailed damage assessment to determine:

- a) The structural condition of the building to decide whether a structure is amendable for repair; whether continued occupation is permitted; to decide the structure as a whole or a part require demolition, if considered dangerous;
- b) If the structure is considered amendable for structural repair then detailed damage assessment of the individual structural components (mapping of the crack pattern, distress location; crushed concrete, reinforcement bending/yielding, etc). Non-destructive testing techniques could be employed if found necessary, to determine the residual strength of the members; and
- c) To work out the details of temporary supporting arrangement of the distressed members so that they do not undergo further distress due to gravity loads.

4.2.2 After the assessment of the damage of individual structural elements, appropriate repair methods are to be carried out component wise depending upon the extent of damage. The restoration work may consist of the following:

- a) Removal of portions of cracked masonry walls and piers and rebuilding them in richer mortar. Use of non-shrinking mortar will be preferable.
- b) Addition of reinforcing mesh on both faces of the cracked wall, holding it to the wall through spikes or bolts and then covering it, suitably, with cement mortar or micro-concrete i.e. Ferro-cement.
- c) Injecting cement, polymer-cement mixture or epoxy materials which are strong in tension, into the cracks in walls.
- d) The cracked reinforced concrete elements like slabs, beams and lintels may be repaired by epoxy grouting and could be strengthened by epoxy or polymer mortar application like shotcreting, jacketing, etc.

4.3 Seismic Strengthening

The main purpose of the seismic strengthening is to upgrade the seismic resistance of a damaged building while repairing so that it becomes safer under future earthquake occurrences. This work may involve some of the following actions:

- a) Increasing the lateral strength in one or both directions by increasing column and wall areas or the number of walls and columns.
- b) Giving unity to the structure, by providing a proper connection between its resisting elements, in such a way that inertia forces generated by the vibration of the building can be transmitted to the members that have the ability to resist them. Typical important aspects are the connections between roofs or floors and walls, between intersecting walls and between walls and foundations.
- c) Eliminating features that are sources of weakness or that produce concentration of stresses in some members. Asymmetrical plan distribution of resisting members, abrupt changes of stiffness from one floor to the other, concentration of large masses and large openings in walls without a proper peripheral reinforcement are examples of defects of this kind.
- d) Avoiding the possibility of brittle modes of failure by proper reinforcement and connection of resisting members.

4.4 Seismic Retrofitting

Many existing buildings do not meet the seismic strength requirements of present earthquake codes due to original structural inadequacies and material degradation over time or alterations carried out during use over

the years. Their earthquake resistance can be upgraded to the level of the present day codes by appropriate seismic retrofitting techniques, such as mentioned about seismic strengthening in 4.3.

4.5 Strengthening or Retrofitting vs Reconstruction

4.5.1 Replacement of damaged buildings or existing unsafe buildings by reconstruction is, generally, avoided due to a number of reasons, the main ones among them being:

- a) higher cost of re-building than that of strengthening or retrofitting,
- b) preservation of historical architecture, and
- c) Maintaining functional social and cultural environment.

In most instances, however, the relative cost of retrofitting to reconstruction cost determines the decision. As a thumb rule, if the cost of repair and seismic strengthening is less than about 30 percent of the reconstruction cost, the retrofitting is adopted. This may also require less working time and much less dislocation in the living style of the population. On the other hand reconstruction may offer the possibility of modernization of the habitat and may be preferred by well-to-do communities.

4.5.2 Cost wise the building construction *including* the seismic code provisions in the *initial instance*, works out the cheapest in terms of its own safety and that of the occupants. Retrofitting an existing inadequate building may involve as much as 2.5 to 3 times the initial extra expenditure required on seismic resisting features. Repair and seismic strengthening of a damaged building may even be 4 to 6 times as expensive as the initial cost of seismic measures. It is therefore very much safer as well as cost-effective to construct earthquake resistant buildings at the initial stage itself according to the relevant seismic IS codes.

5 SELECTION OF MATERIALS AND TECHNIQUES

5.1 General

The most common materials for repair and restoration works of various types of buildings are cement and steel. In many situations suitable admixture may be added to cement mortar/cement concrete to improve their properties, such as, non-shrinkage and bond strength. Steel may be required in many forms like bolts, rods, angles, beams, channels, expanded metal and welded wire fabric. Wood and bamboo are the most common material for providing temporary supports and scaffolding, etc, and will be required in the form of rounds, sleepers, planks, etc.

Besides the above, special materials and techniques are available for best results in the repair and strengthening operations. These should be selected appropriately depending on the nature and cost of the building to be repaired, materials availability and feasibility, and use of available skills, etc. Some special materials and techniques are described below.

5.2 Non-Shrink Grouts

Currently ready grout contents consisting of a polymer, non-shrink cement and special sands are available in the markets which are suitable to prepare the desired grout for the crack width observed in the masonry. The polymer improves the adhesion of the grout with the masonry as well imparts higher tensile strength.

5.3 Shotcrete

Shotcrete is cement mortar or cement concrete (with coarse aggregate size maximum 10 mm) conveyed through a hose and pneumatically placed under high velocity on to a prepared concrete or masonry surface. The force of the jet impingement on the surface compacts the shotcrete material and produces a dense

homogeneous mass. Basically there are two methods of shotcreting; wet mix process and dry mix process. In the wet mix process, all the ingredients, including water are mixed together before they enter the delivery hose. In the dry mix process, the mixture of damp sand and cement is passed through the delivery hose to the nozzle where the water is added. The dry mix process is generally used in the repair of concrete elements. The bond between the prepared concrete surface of the damaged member and the layer of shotcrete is ensured with the application of suitable epoxy adhesive formulation. The shear transfer between the existing and new layer of concrete may be ensured with the provision of shear keys.

5.4 Epoxy Resins

Epoxy resins are excellent binding agents with high tensile strength. These are chemical preparations the compositions of which can be changed as per requirements. The epoxy components are mixed just prior to application. Some products are of low viscosity and can be injected in fine cracks too. The higher viscosity epoxy resin can be used for surface coating or filling larger cracks or holes. The epoxy resins may also be used for gluing steel plates to the distressed members.

5.5 Epoxy Mortar

For larger void spaces, it is possible to combine the epoxy resins of either low viscosity or higher viscosity with sand aggregate to form epoxy mortar. Epoxy mortar mixture has higher compressive strength, higher tensile strength and a lower modulus of elasticity than cement concrete. The sand aggregate mixed to form the epoxy mortar increases its modulus of elasticity.

5.6 Quick-Setting Cement Mortar

This material is non-hydrous magnesium phosphate cement with two components, that is, a liquid and a dry powder, which can be mixed in a manner similar to cement concrete.

5.7 Mechanical Anchors

Mechanical types of anchors employ wedging action to provide anchorage. Some of the anchors provide both shear and tension resistance. Such anchors are manufactured to give sufficient strength.

Alternatively, chemical anchors bonded in drilled holes through polymer adhesives can be used.

5.8 Ferro cement – Fibre concrete

It is a building material composed of relatively thin layer of cement mortar, covering such reinforcing materials as 4.5 to 6 mm diameter mild steel rods spaced 75 mm intervals both ways covered with 19 gauge, 11 mm opening square mesh on each side. The building technique is simple enough to be done by masons and unskilled labor. In retrofitting application, the ferro-cement plating is applied in-situ on the wall face, fully attached and bonded to the masonry walls. The thickness may be kept as thin as 180 mm to as much as 30 mm.

5.8 Fibre Reinforced Plastics (FRP)

Fibre-reinforced polymer/plastic (FRP) is a recently developed material for strengthening of RC & masonry structure. This is an advanced material and most of the development in its application in structural retrofitting has taken place in the last few decades. It is used as a replacement of steel plate bonding. The main advantage of FRP is its high strength to weight ratio and high corrosion resistance. FRP plates can be 2 to 10 times stronger than steel plates, while their weight is just 20% of that of steel. These have to be glued to the walls or columns using epoxy mortars. Design of retrofitting using FRP has to be based on manufacturers specifications supported by tests.

6 TECHNIQUES TO RESTORE ORIGINAL STRENGTH

6.1 General

While considering restoration of structural strength, it is important to realize that even fine cracks in load bearing members which are unreinforced like masonry and plain concrete reduce their resistance in a large measure. Therefore, all cracks must be located and marked carefully and the critical ones fully repaired structurally either by injecting strong cement or chemical grout or by providing external bandage. The techniques are described below along with other restoration measures.

6.2 Structural Repair of Minor and Medium Cracks

For the repair of minor and medium cracks (0.50 mm to 5 mm), the technique to restore the lost tensile strength of the cracked element is by pressure injection of non-shrink cement polymer grout. The procedure is as follows (*see* Fig. 1A).

6.2.1 The external surfaces are cleaned of non-structural materials and plastic/aluminium injection ports are placed along the surface of the cracks on both sides of the member and are secured in place with polyester putty or 1:3 cement mortar. The center-to-centre spacing of these ports may be approximately equal to the thickness of the wall element. After the sealant has cured, cracks are cleared using compressed air, and/or water. Thereafter the grout 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 grout 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 injection port should be closed at this stage and injection equipment moved to the next port and so on.

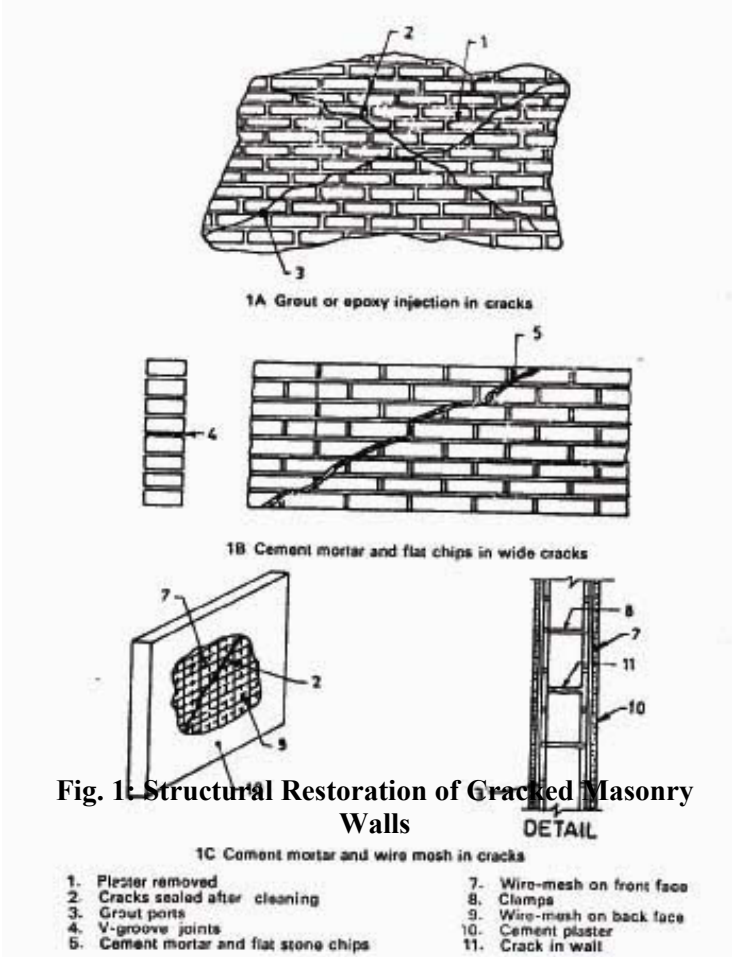
The finer the crack, higher is the pressure or more closely spaced should be the ports so as to obtain complete penetration of the appropriate grout material throughout the depth and width of member. Larger cracks will permit larger port spacing depending upon width of the member. This technique is appropriate for all types of structural elements - beams, columns, walls and floor units in masonry as well as concrete structures. In the case of loss of bond between reinforcing bar and concrete, if the concrete adjacent to the bar has been pulverized to a very fine powder (this powder will block the grout from penetrating the region). It should be cleaned properly by air or water pressure prior to injection of grout in the concrete.'

6.3 Repair 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.

The procedures may be adopted as follows:

- a) The loose material is removed and replaced with any of the materials mentioned earlier, that is, expansive cement mortar, quick setting cement (*see* Fig. 1B).
- b) 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 (*see* Fig. 1C).
- c) In areas of very severe damage, replacement of the member or portion of member can be carried out.
- d) 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 (*see* Fig. 1C).



6.4 Fractured Excessively Yielded and Buckled Reinforcement

In the case of severely damaged reinforced concrete member it is possible that the reinforcement would have buckled or elongated or excessive yielding may have occurred. This element can be repaired by replacing the old portion of steel with new steel using butt welding or lap welding.

Splicing by overlapping will be risky. If repair has to be made without removal of the existing steel, the best approach would depend upon the space available in the original member. Additional stirrup ties are to be added in the damaged portion before concreting so as to confine the concrete and enclose the longitudinal bars to prevent their buckling in future.

In some cases, it may be necessary to anchor additional steel into existing concrete. A common technique for providing the anchorage uses the following procedure:

6.4.1 A hole larger than the bar is drilled. The hole is filled with epoxy expanding cement or other high strength grouting material. The bar is pushed into place and held there until the grout has set.'

7. Damageability Assessment of Existing Masonry Buildings

The assessment of possible Grade of Damage in an existing masonry building under earthquake occurrences will mainly depend on:

- (i) The probable maximum intensity of the earthquake
- (ii) The building typology
- (iii) The building configuration
- (iv) The quality of construction and maintenance over time.

For initial quick assessment a Rapid Visual Screening of the building may be carried out as given in Appendix-A. Besides the above factors, consideration of Importance Factor of 1.5 as per IS 1893 (Part 1): 2002 has also been considered by raising the earthquake Intensity for assessment of damageability. Based on assessed damageability of the building the further actions can be planned [See Table 1 & 3(A)]:

Table 1: Damageability Grades & Pre-earthquake Actions

Damageability Grade	Action
G1	Retrofitting not needed
G2	Structural Retrofitting not needed, Unstable non structural elements to be stabilized
G3	(i) Structural and non-structural elements to be retrofitted (ii) Global as well as element deficiencies to be evaluated

	and retrofitting to be suitably designed
G4	(i) Structural and non-structural elements to be retrofitted (ii) Global as well as element deficiencies to be evaluated and retrofitting to be suitably designed
G5	(i) Structural and non-structural elements to be retrofitted (ii) Global as well as element deficiencies to be evaluated and retrofitting to be suitably designed (iii) Alternatively, replacement of the build with a new earthquake resistant building to be considered

- Note:**1 Detailed description of Grades G1 to G5 is given in Appendix A.
2. In case of G4 and G5, the option of replacing the existing building with a new one may also be explored, particularly for old buildings.
3. In case of G4 and G5, only *non-collapse performance level* may be aimed at. For example, in Seismic Zones IV and V, masonry buildings constructed using mud or weak lie mortar will fall in G4 and G5 categories and if they are retrofitted using the details of IS:13828:1993 as for new buildings, non-collapse performance will be achieved.

8. Assessment of Retrofitting Requirements

8.1 Categorisation of Buildings

In all cases of masonry buildings, Ordinary as well as Important (defined in IS 1893 with I=1.5), the retrofitting requirements can directly be assessed by comparing the data of the building under consideration with the specified safety requirements in the IS 4326:1993 and IS 13828:1993 as the case may be. Tables 3A, 3B & 3C illustrate this approach, in which the building categories B, C, D, and E are to be taken as given in – Table 2.

Table2: Building Categories (for use with IS 4326 &IS 13928)

Building Use	Building Category in Seismic Zone			
	II	III	IV	V
Ordinary	B	C	D	E
Important (I=1.5)	C	D	E	E

8.2 Special or Critically Important Buildings

Besides the Ordinary and Important buildings as defined in IS1893(Part 1)-2002, there are some *special buildings of monumental nature or of critical importance to the safety of the occupants*, e.g. the Qutab Minar and Taj Mahal on the one hand and Rashrapati Bhawan, residences and offices of the VVIPs on the other hand. Such buildings will need to be rationally analysed using the seismic actions as per IS 1893 (Part 1): 2002 taken appropriately while adopting if considered so, a higher importance factor. The strategy for retrofitting of such buildings will have to be chosen by the structural engineer concerned and proof checked by an expert appointed by the owner.

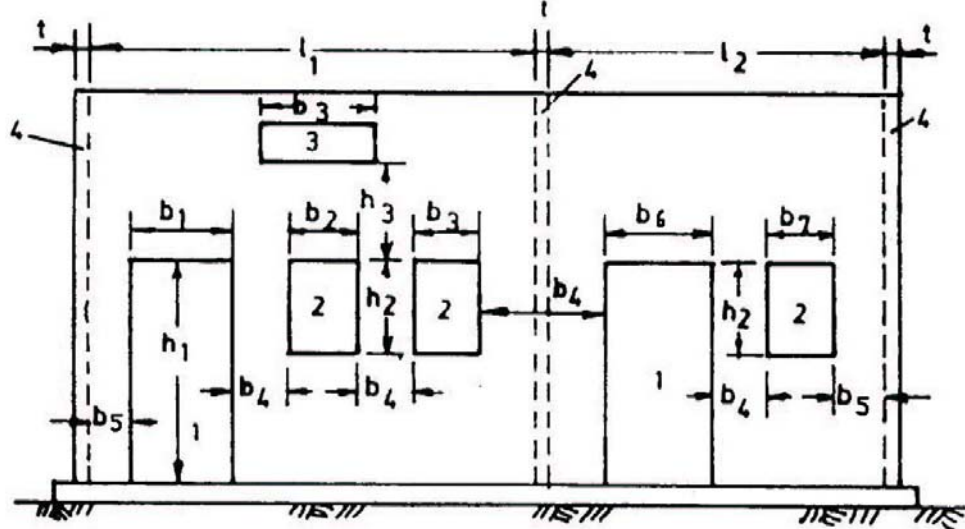
8.3 Old Masonry Buildings

For old buildings of more than 50 years of age, the building category in table 2 may be taken one category lower and the retrofitting requirements be determined accordingly.

8.4 Buildings Constructed in Weak Mortar

For masonry buildings constructed using weak mortars than the cement-sand or cement-lime-sand mortars such as the line or mud mortar, the requirements of retrofitting may be determined by raising the building category in table 2 by one category.

Table 3A Provisions in IS 4326:1993 and Actions for Retrofitting

S.N o	Item of Masonry	Requirement as per IS 4326:1993 for Building Category				Action for Retrofitting if Code Requirement not found satisfied.
		B	C	D	E	
1	Mortar	CLS-1:2:9 or CS-1:6		CLS-1:1:6 or CS-1:4		See cl.8.4. Alternatively, walls may be strengthened by ferro-cement plating
2	Door, Window openings – . b_5 minimum (See fig)	0.0	230 mm	450 mm	450 mm	Increase by building up or strengthening by ferro-cement plating.
	$(b_1+ b_2 +b_3)/l_1$ max. $(b_6+ b_7)/l_2$					Attain the limit by closing/ narrowing an opening <i>Or</i> reinforce the opening by seismic belting.
	one storey	0.6	0.55	0.50	0.5	
	two storey	0.50	0.46	0.42	0.42	
	three storey	0.42	0.37	0.33	0.33	
	four storey	0.42	0.37	0.33	Not allowed	
 1. Door 2. Window 3. Ventilator 4. Cross Wall						
	. b_4 minimum	340 mm	450 mm	560 mm	560 mm	Increase by build-up or reinforce with belt.
3	Length of wall between cross walls	---	Max length = 35 x thickness or 8 m whichever less			If length more, provide pilaster or buttress to reduce effective length.
4	Height of wall from floor to ceiling	---	Maximum = 15 times thickness or 4 m whichever less			If height more, add pilaster to increase effective thickness
5	Random-Rubble walls	• ‘Through’ or Header stones, one each in 0.72sq.m surface area of wall. • Long stones at corners of walls, in each wall in every alternate course.				If not provided, install RC Headers in holes made by removing stones.
6	Horizontal Seismic Bands-Plinth Lvl	Needed if soft (type III) soil at base				Provide seismic belt if plinth height ≥ 90 cm
	. Door window lintel level	Needed in all cases with varying reinforcement and thickness specified in each case				Provide seismic belt of equivalent strength on both sides of walls

S.No	Item of Masonry	Requirement as per IS 4326:1993 for Building Category				Action for Retrofitting if Code req. not found satisfied.
		B	C	D	E	
	. Ceiling or eave level	Needed in sloping roofs or floors and roofs of prefabricated elements.				-do-
	. Gable or ridge wall	Needed in case of pitched roofs				-do-
	. Window sill level or dowels	Not required	Not required	Required in 3 & 4 storeyed buildings only	Required in all buildings	-do-
7	Vertical bar at each corner and T-junction of wall	Needed in only 4 storey building	Needed in 3 and 4 storey building	Needed in all buildings	Needed in all buildings, (4 storeys not permitted)	Install equivalent bars or vertical belts at corners and T-junctions
8	Vertical bar at jambs of window & door	Not needed	-do-	-do-	-do-	Install equivalent seismic belts around the opening

Table 3B - Provisions for Roofs & Floors in IS 4326:1993 and Actions for Retrofitting

S. No.	Item of Roof/Floor	Requirement as per IS 4326:1993 for Building Category				Retrofitting Action if code provision not satisfied
		B	C	D	E	
1.	Roof/floor with prefabricated/ pre-cast elements	Tie beam all round		All round tie beam and RC screed		Provide RC screed and seismic belt or band around
2.	Roof/floor with wooden joists, various covering elements (brick, reeds etc) & earth fill	— —	All round seismic band and integration of units as a rigid horizontal diaphragm			Provide seismic belt around , inter-connect beam ends through wooden planks and diagonal x-ties
3.	Sloping roofs with sheeting or tile coverings	— —	(i) Horizontal x-bracing at level of ties of the trusses. (ii) X-bracing in the planes of the rafters and purlins			Install the x-bracings as per the code IS:4326. Anchor trusses into walls and rafters into seismic belt at eave level.
4.	Jack arch roof/floor	— —	Connect the steel joists by horizontal ties at intervals to prevent spreading and cracking of the arches. Provide seismic band all round			Install steel flats as ties by welding them to the steel joists and provide seismic belt

Table 3C - Improvements against Global Deficiencies

S.No	Item	B	C	D	E	Retrofitting Action if code provision not satisfied
1.	Sloping raftered roofs		Preferably use full trusses			Convert rafters into A-frames or full trusses to reduce thrust on walls
2.	Unsymmetrical Plans		Symmetrical plans are suggested			Inserting new walls to reduce dissymmetry
3.	Perpendicular Walls not connected at corners and T-junctions		Perpendicular walls should be integrally constructed			Stitch the perpendicular walls using tie rods in drilled holes fully grouted or box them with seismic belts

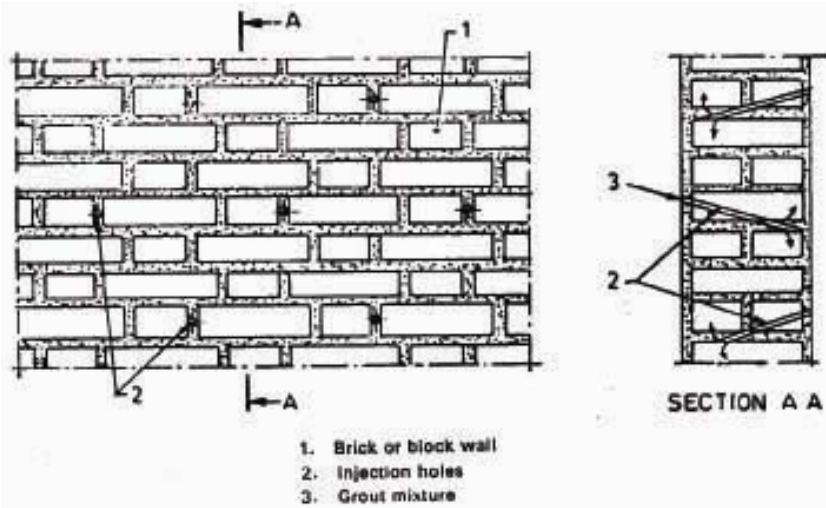
10 **Strengthening Existing Walls**

The lateral strength of buildings can be improved by increasing the strength and stiffness of existing individual walls, whether they are cracked or uncracked. This can be achieved:

- a) by grouting,
- b) by addition of vertical reinforced concrete coverings on the two sides of the wall, and
- c) by prestressing wall.

9.1 Grouting

A number of holes are drilled in the wall (2 to 4 in each square meter) (*see* Fig. 2). First water is injected in order to wash the wall inside, and to improve the cohesion between the grouting mixture and the wall elements. Secondly, a cement water mixture (1:1) is grouted at low pressure (0.1 to 0.25 Mpa) in the holes starting from the lower holes and going up.



Alternatively, polymeric mortars may be used for grouting. The increase of shear strength which can be achieved in this way is considerable. However, grouting can not be relied on as far as the improving or making a new connection between orthogonal walls is concerned.

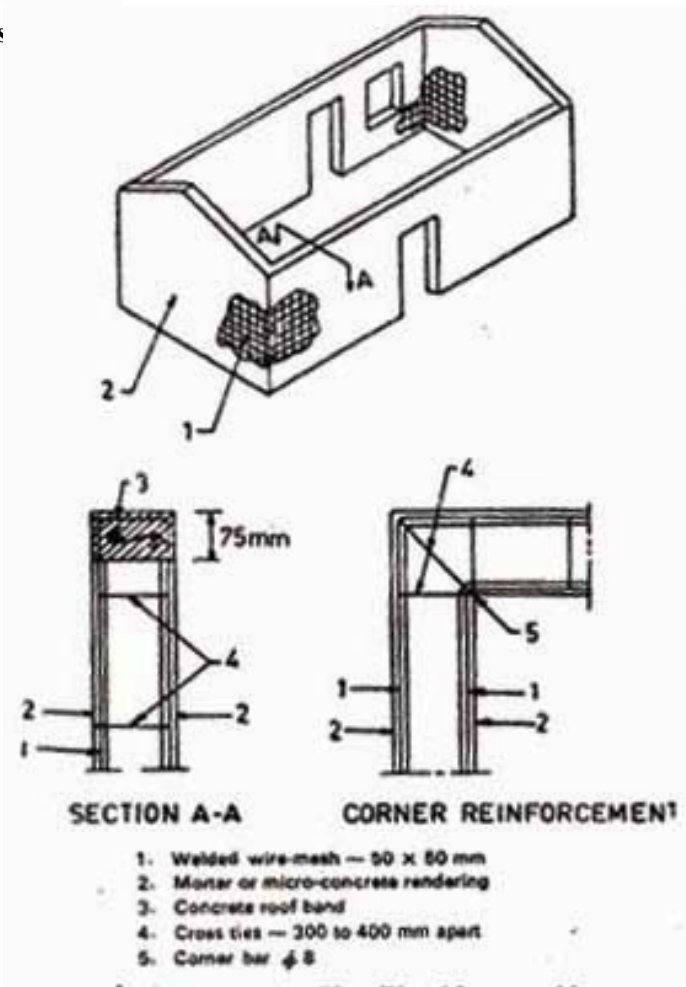
NOTE - The pressure needed for grouting can be obtained by gravity flow from super elevated containers.

Fig. 2: Grout or Epoxy Injection in Existing Weak Walls

9.2 Strengthening with Wire Mesh

Masonry walls with concentration of multiple cracks in the same portion and appearing on both sides on the wall or weal wall regions may be repaired with a layer of cement mortar or micro concrete layer 20 to 40 mm thick on both sides, reinforced with galvanized steel wire fabric (50 mm x 50 mm size) forming a vertical plate bonded to the wall. The two plates on either side of the wall should be connected by galvanized steel rods at a spacing of about 300 to 400 mm (*see* Fig. 3).

Fig. 3: Strengthening with Wire Mesh & Mortar



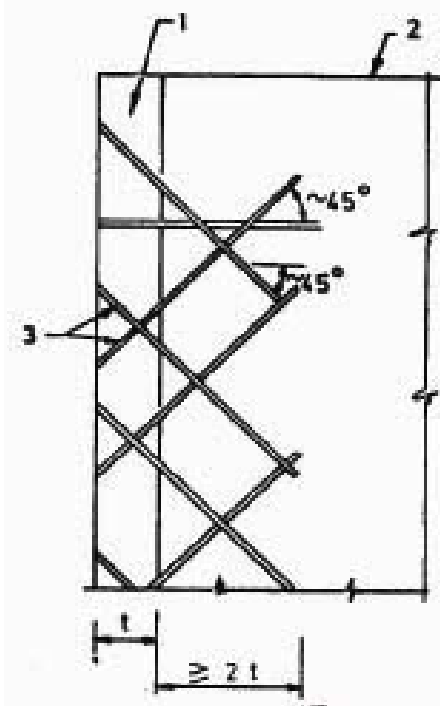


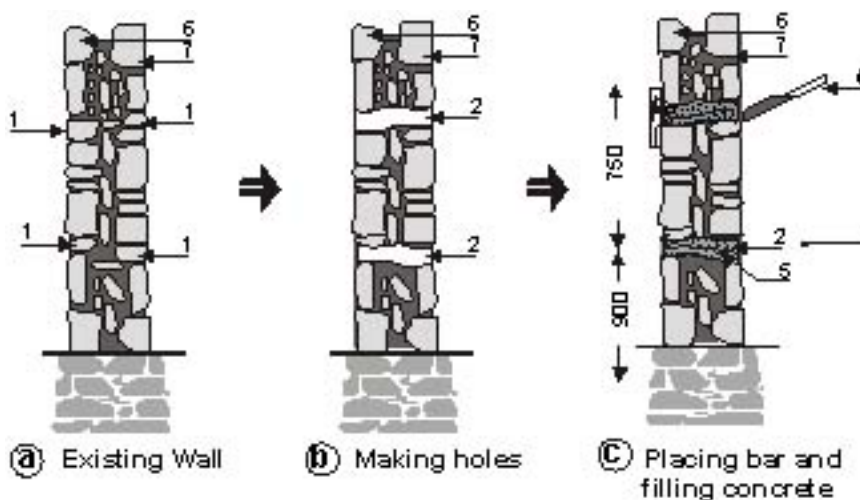
Fig.4: Sewing Transverse Walls with Inclined Bars

9.3 Connection between Existing Stone Walls

In stone buildings of historic importance, consisting of fully dressed stone masonry in good mortar, effective sewing of perpendicular walls may be done by drilling inclined holes through them inserting steel rods and injecting cement grout (*see Fig. 4*).

9.4 Making 'Through' Bond Elements in R.R. Stone Wall (Fig.5)

- Select points where 'through' stones will be installed at horizontal and vertical distance of about one meter apart, with 50cm horizontal stagger.
- Remove the plaster from the surface exposing the stones. Remove the mortar around the stone to sufficient depth gently, not violently, so as to expose the stone on all sides.
- Loosen the stone by means of gentle pushes side ways and up and down by means of a small crowbar, so that the other stones of the walls are not disturbed. Pull out the stone slowly, holding it by both hands.
- Remove inner material gradually so that a 75mm size hole can be made in the wall. Bigger hole is not needed.
- Locate position of the opposite stone on the other face of the wall by gentle tapping in the hole. Remove the identified stone slowly by same gentle process.
- The hole so made through the wall may be bigger in size on both faces and narrower inside resembling a dumbbell shape. This shape is good for holding the wythes together. It does not matter if the hole is inclined instead of being horizontal.



- 1 - Stones removed to make through holes
- 2 - Holes
- 3 - Hooked Bar
- 4 - Chute for pouring concrete
- 5 - Filled concrete
- 6 - Internal wythe
- 7 - External wythe

g) Place concrete of 1:2:4 or richer mix to fill half the depth of the hole from both sides and place 8mm dia. hooked steel bar in the hole and fill the hole completely.

h) Cure for minimum 10 days by sprinkling water on the exposed surfaces on both sides.

9.5 Masonry Arches

If the walls have large arched openings for doors & windows, it will be necessary to install tie rods across them at springing levels or slightly above it by drilling holes on both sides and grouting steel rods in them (*see Fig. 6 a*).

Fig.5: Providing R.C. through elements for Stitching Stone Wythe

Alternatively, a lintel consisting of steel channels or I-shapes could be inserted just above the arch to take the load and relieve the arch as shown at Fig. 6 b. In jack-arch roofs, flat iron bars or rods shall be provided to connect the bottom flanges of I-beams connected by bolting or welding (see Fig. 6 c).

10 SEISMIC BELTS AROUND DOOR/WINDOW OPENINGS

The jambs and piers between window and door openings require vertical reinforcement in the following situations:

- i) In category **D** and **E** buildings for resistance against earthquake forces.
- ii) For restoring the strength of the piers in any building category when badly damaged in an earthquake.

Where the above conditions specified in IS 4326 and IS: 13828 are not satisfied, action has to be taken to close an opening or reduce its size.

The following mesh reinforcement is recommended to be used for covering the jamb area on both sides of an opening or for covering the pier between the consecutive openings (See fig.7)

i) In Cat.D & E buildings

Mesh of gauge 10 with 8 wires in vertical direction spaced at 25 mm in a belt width of 200 mm or mesh of gauge 13 with wires @ 25 mm in a belt width of 250 mm may be used.

ii) In Cat. C buildings

Mesh of gauge 13 with 10 wires in vertical direction spaced at 25 mm in a belt width of 250 mm.

11 ACHIEVING INTEGRAL BOX ACTION

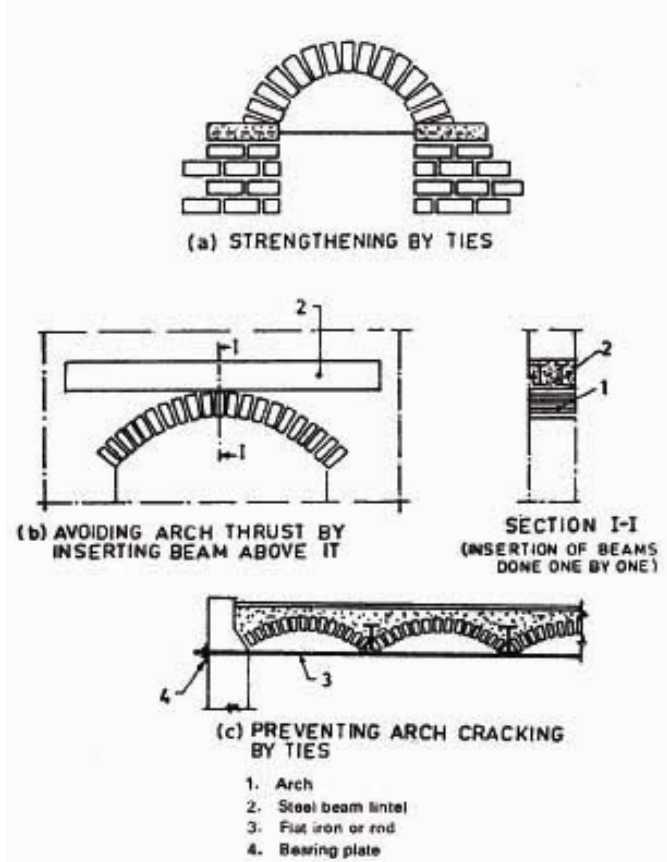


Fig.6: Strengthening an Arched Opening in masonry Wall

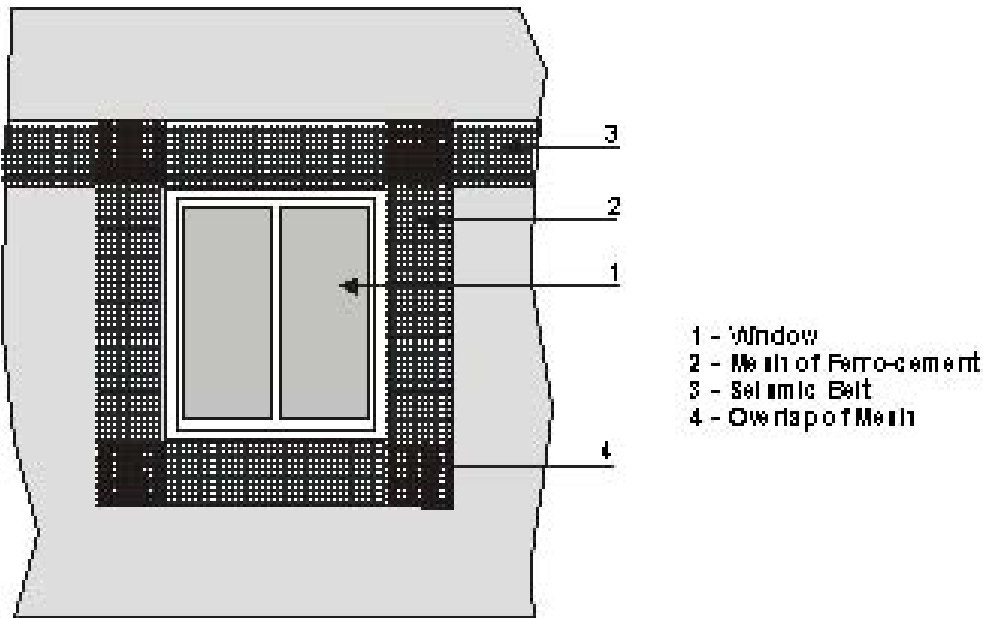


Fig.7: Reinforcing around Opening

The overall lateral strength and stability of bearing wall buildings is very much improved, if the integral box like action of room enclosures is ensured. This can be achieved by (a) use of pre-stressing (b) providing horizontal bands. Strength of shear walls is achieved by providing vertical steel at selected locations such as the corners and T-junction of walls.

11.1 Prestressing

A horizontal compression state induced by horizontal wires/bars can be used to increase the shear strength of walls. Moreover, this will also improve, considerably; the connections of orthogonal walls (*see* Fig. 8). The easiest way of affecting the pre-compression is to place two steel rods on the two sides of the wall and stretching them by turnbuckles. Note that, good effects can be obtained by slight horizontal pre-stressing (about 0.1 MPa) on the vertical section of the wall. Prestressing is also useful to strengthen spandrel beam between two rows of opening in the case no rigid slab exists. Opposite parallel walls can be held to internal cross walls by prestressing bars as illustrated above, the anchoring being done against horizontal steel channels instead of small steel plates. The steel channels running from one cross wall to the other will hold the walls together and improve the integral box like action of the walls.

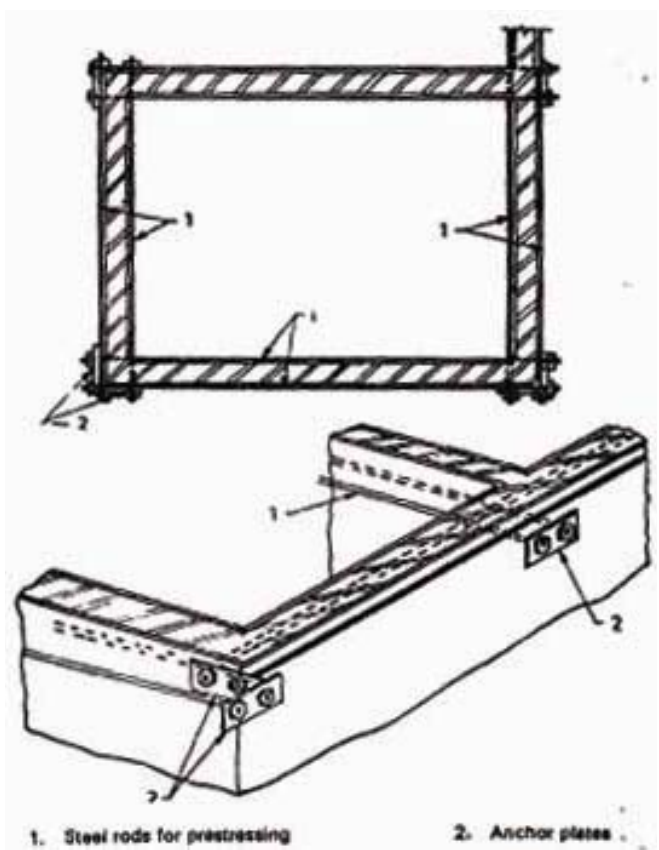


Fig.8: Strengthening of Walls by Prestressing

11.2 External Binding

The technique of covering the wall with steel mesh and mortar or micro concrete may be used only on the outside surface of external walls but maintaining continuity of steel at the corners. This would strengthen the walls as well as bind them together. As a variation and for economy in the use of materials, the covering may be in the form of vertical splints located between the openings and horizontal 'bandages' formed over spandrel walls at suitable number of points only (*see* Fig. 9).

11.3 Providing Horizontal Seismic Belts

11.3.1 Seismic Belt Locations

- i) Seismic belts are to be provided on all walls on both the faces just above lintels of door and window openings and below floor or roof.

Note: *On small wall lengths in a room (less than 5m) seismic band only on the outside face will suffice. In this case these should be connected by ties going across the rooms at about 2.5 m apart (see Fig.10).*

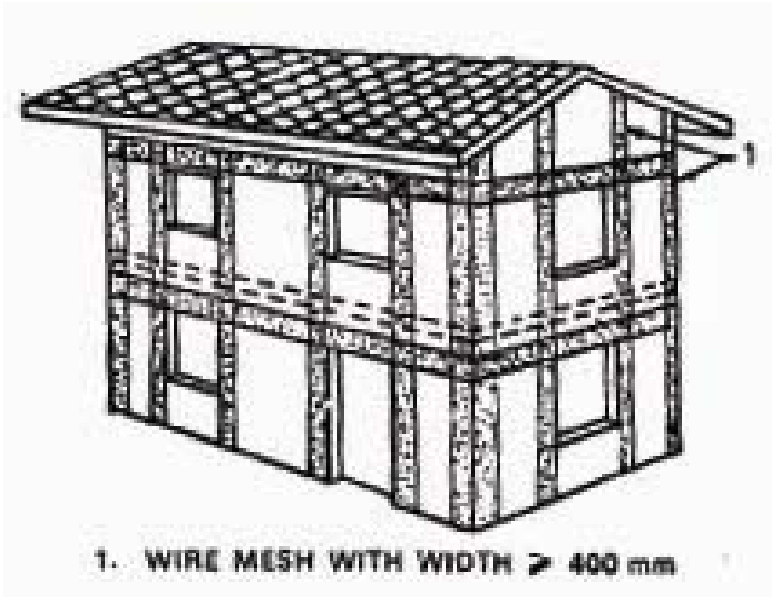


Fig.9: Splint and Bandage Strengthening Technique

ii) The roof belt may be omitted if the roof or floor is of RCC slab.

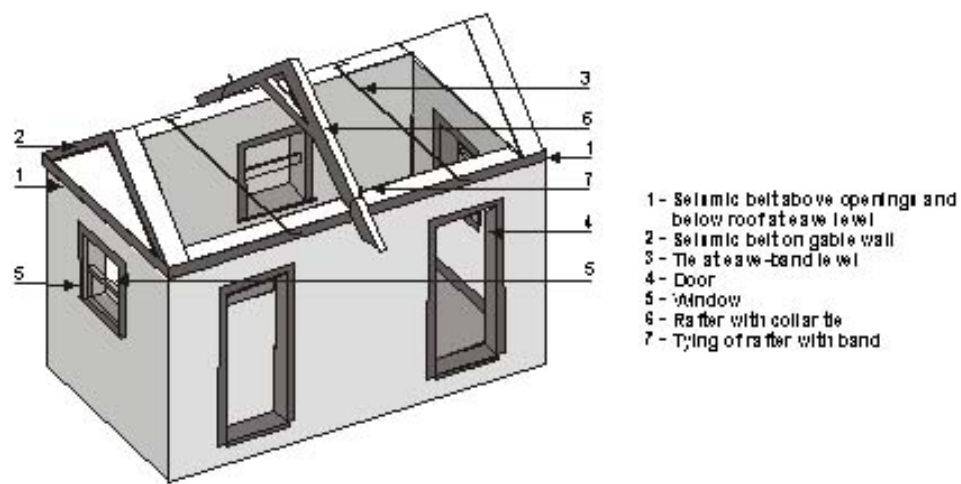


Fig.10: Overall arrangement of Seismic Belts

iii) Seismic belt is not necessary at plinth level, unless the plinth height is more than 900 mm.

iv) Install similar seismic belt at the eave level of sloping roof and near top of gable wall, below the roof.

Note: - If the height of eave level above the top of door is less than 900 mm, only the eave level belt may be provided and lintel level belt may be omitted.

11.3.2 Description of reinforcement in belt.

The reinforcement may be of mesh types as suggested in Table 4 or any other mesh of equivalent longitudinal wires. For example in Cat. D building with room length of 6 m, MW 21 weld mesh (with long wires 5 of 4.5 mm dia. spaced at 75 mm apart; cross wires of 3.15 mm dia. placed at 300 mm apart) can be used, the height of the belt being kept as 375 mm.

Note: Weld mesh has to be provided continuously. If splicing is required, there should be minimum overlap of 300mm.

Table 4- Mesh Reinforcement in Seismic Belts in Various Building Categories.

Length of wall m	Cat. B			Cat. C			Cat. D			Cat. E		
	Gauge	N	H	Gauge	N	H	Gauge	N	H	Gauge	N	H
≤ 5.0	g 14	9	250	g 13	9	250	g 12	9	250	g 10	10	280
6.0	g 13	9	250	g 12	9	250	g 10	10	280	g 10	14	380
7.0	g 12	9	250	g 10	10	280	g 10	14	380	g 10	18	460
8.0	g 10	9	250	g 10	14	380	g 10	18	460	g 10	23	580

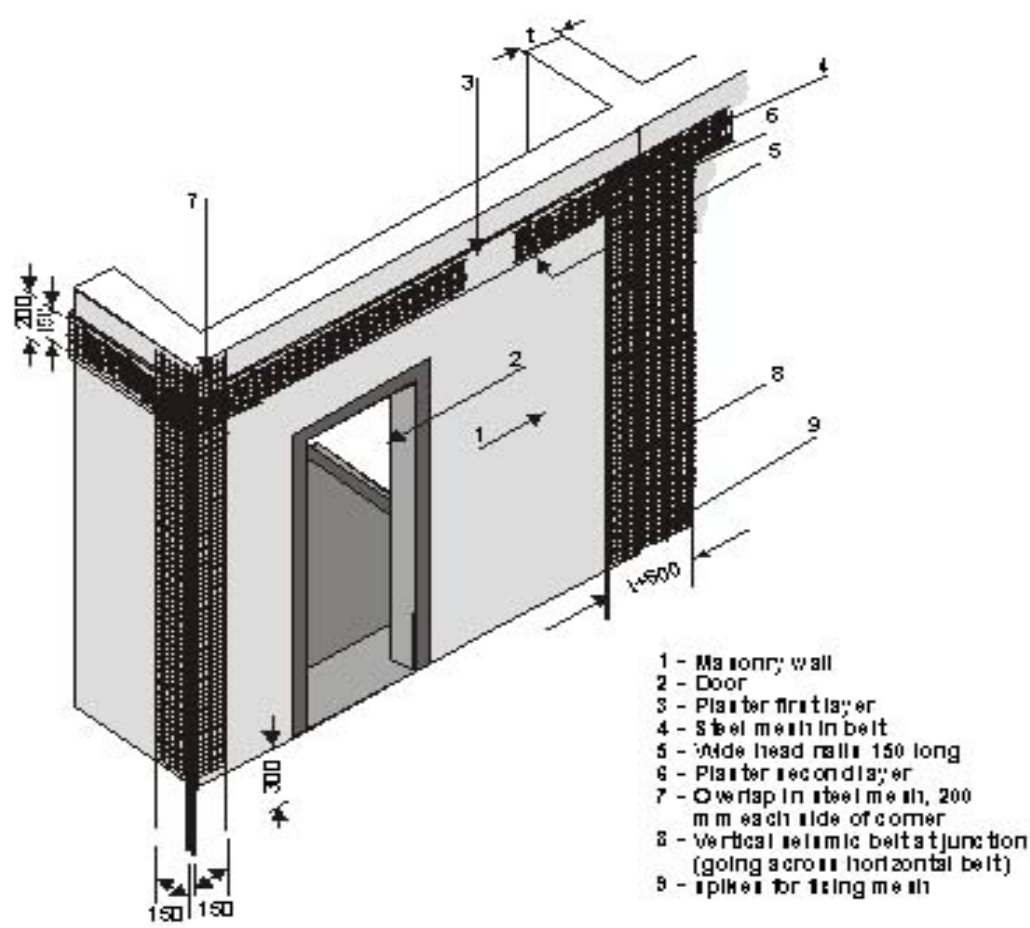
- 1. Gauges: g10=3.25 mm, g11=2.95 mm, g12=2.64 mm, g13=2.34 mm, g14=2.03 mm.
- 2. N = Number of longitudinal wires in the belt at spacing of 25 mm.
- 3. H = Height of belt on wall in micro-concrete, mm.
- 4. The transverse wires in the mesh could be spaced upto 150 mm.
- 5. The mesh should be galvanized to save from corrosion.

11.4 Vertical Seismic Belt at Corners

Vertical reinforcing is required at the corners of rooms and junctions of walls as per Table 5. The width of this belt on each side of the corner has to be kept 25mm extra to the width of the mesh. This reinforcement should be started 300mm below the plinth level and continued into the roof/eave level horizontal belt. (See Fig.11).

Table 5-Vertical Bar or Mesh Reinforcement in Vertical Belt at Corners of rooms

No. of Storeys	Storeys	Cat.B			Cat.C			Cat.D			Cat. E		
		Single Bar, mm	Mesh(g10)		Single Bar, mm	Mesh(g10)		Single Bar, mm	Mesh (g10)		Single Bar, mm	Mesh (g10)	
			N	B		N	B		N	B		N	B
One	One	-	-	-	-	-	-	10	10	300	12	14	400
Two	Top	-	-	-	-	-	-	10	10	300	12	14	400
	Bottom	-	-	-	-	-	-	12	14	400	16		
Three	Top	-	-	-	10	10	300	10	10	300	12	14	400
	Middle	-	-	-	10	10	300	12	14	400	16	25	650
	Bottom	-	-	-	12	14	400	12	14	400	16	25	650



- 1. Gauge 10 (3.25 mm dia) galvanized mesh with 25 mm spacing of wires shall be used.
- 2. Single bar, if used, shall be HSD or TOR type. If two bars are used at a T-junction, the diameter can be taken as follows. For one of 10 or 12 mm take 2 of 8 mm, and for one of 16 mm take 2 of 12 mm.
- 3. N = Number of longitudinal wires in the mesh.
- 4. B = Width of the micro concrete belt, half on each wall meeting at the corner or T-junction.
- 5. The transverse wires in the mesh could be at spacing up to 150 mm.

Fig.11: Vertical Seismic Band at Corner & Junction

11.5 Providing Vertical Reinforcement At Corners, Junctions Of Walls.

The vertical reinforcement consisting of TOR bar as per Table 6 or equivalent shall be provided on the inside corner of room starting from 750 mm below the ground floor going upto the roof slab, passing through each middle floor through holes made in the slabs. (See Fig.12) The reinforcement will be connected to the walls by using L shape dowels of 8 mm TOR bar, the vertical leg of 400 mm length firmly tied to the vertical reinforcement bars and the horizontal leg of minimum 150 mm length embedded in the walls through 75 mm dia. holes drilled in the wall into which the 8 mm dia. leg of the dowel will be grouted using non- shrink cement cum polymer grout. Such dowels will be provided, first one just above plinth level and then at about

every 1 m distance apart. The corner reinforcement will be covered with 1:3 cement mortar or 1:1 1/2:3 micro concrete fully bonded with the walls giving a minimum cover of 15 mm on the bar.

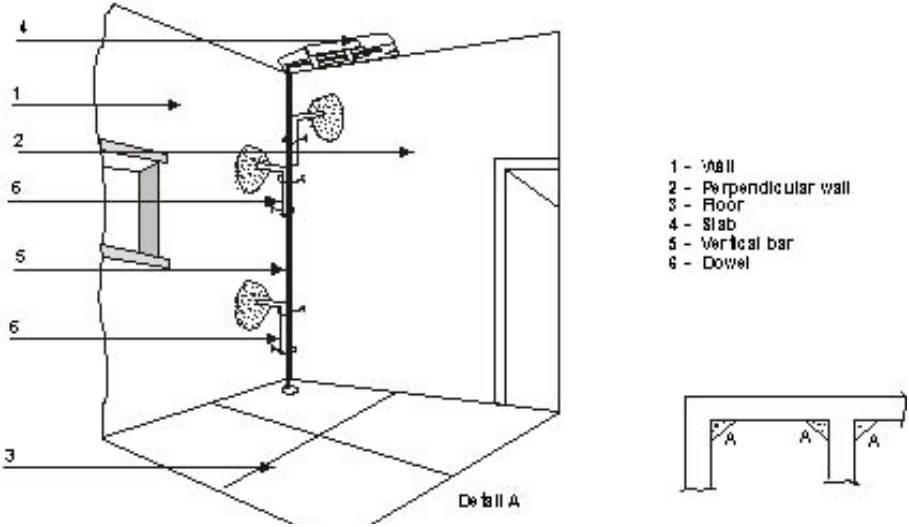


Fig.12: Vertical Bar at inside corner

12.3 Roof truss frames should be braced by welding or clamping suitable diagonal bracing members in the vertical as well as horizontal planes.

12.4 Anchors of roof trusses to supporting walls should be improved and the roof thrust on walls should be eliminated.

Figures 13 and 14 illustrate one of the methods for pitched roofs without trusses.

12 Modification of Roofs or Floors

12.1 Slates and roofing tiles are brittle and easily dislodged. Where possible, they should be replaced with corrugated iron or asbestos sheeting.

12.2 False ceilings of brittle material are dangerous. Non-brittle material, like Hessian cloth, bamboo matting or light ones of foam substances, may be substituted.

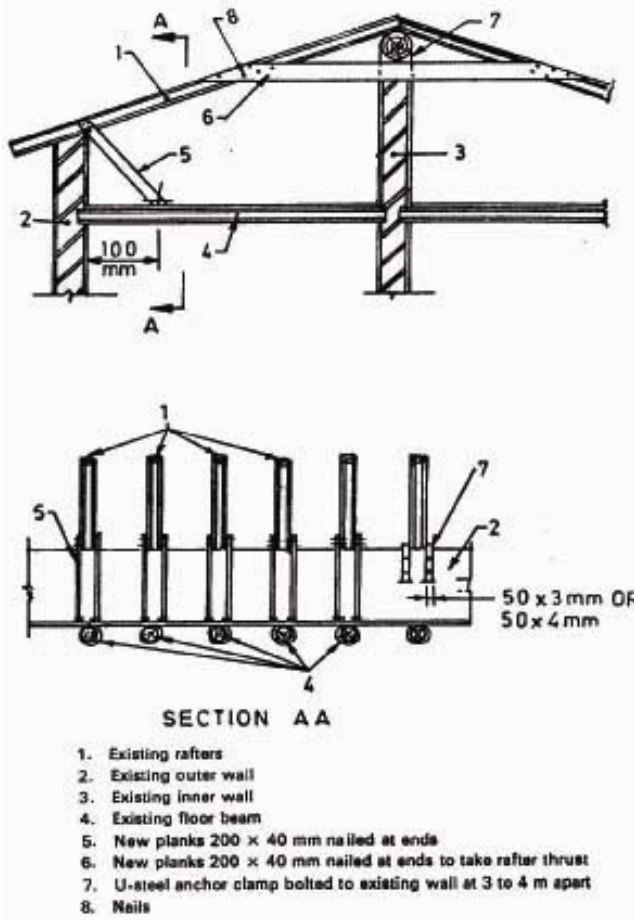


Fig.13: Roof Modification to Reduce Thrust of Walls

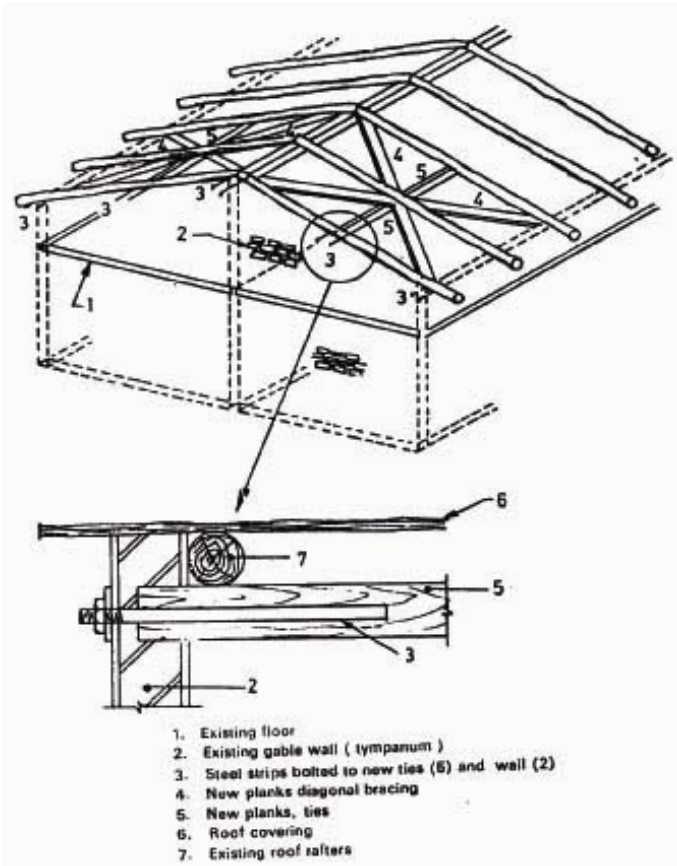


Fig.14: details of New Roof Bracing

12.5 Where the roof or floor consists of prefabricated units like RC rectangular T or channel units or wooden poles and joists carrying brick tiles, integration of such units is necessary. Timber elements could be connected to diagonal planks nailed to them and spiked to an all round wooden frame at the ends. Reinforced concrete elements may either have 40 mm cast-in-situ concrete topping with 6 mm dia. bars 150 mm c/c both ways or bounded by a horizontal cast-in-situ reinforced concrete ring beam all round into which the ends of reinforced concrete elements are embedded. Fig. 15 shows one such detail.

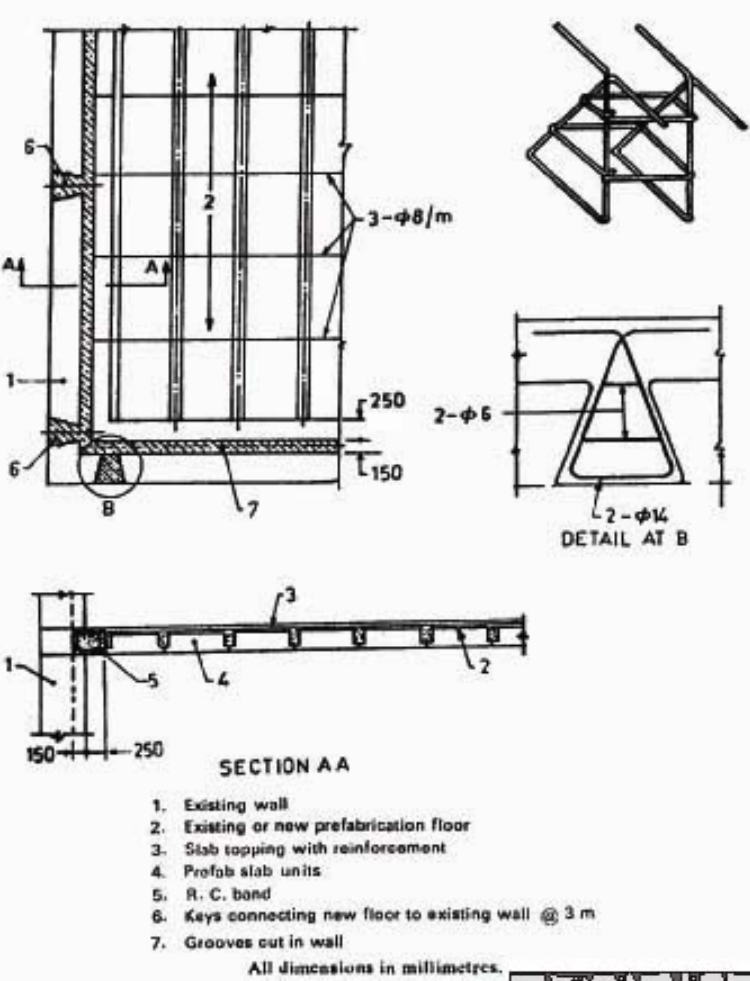
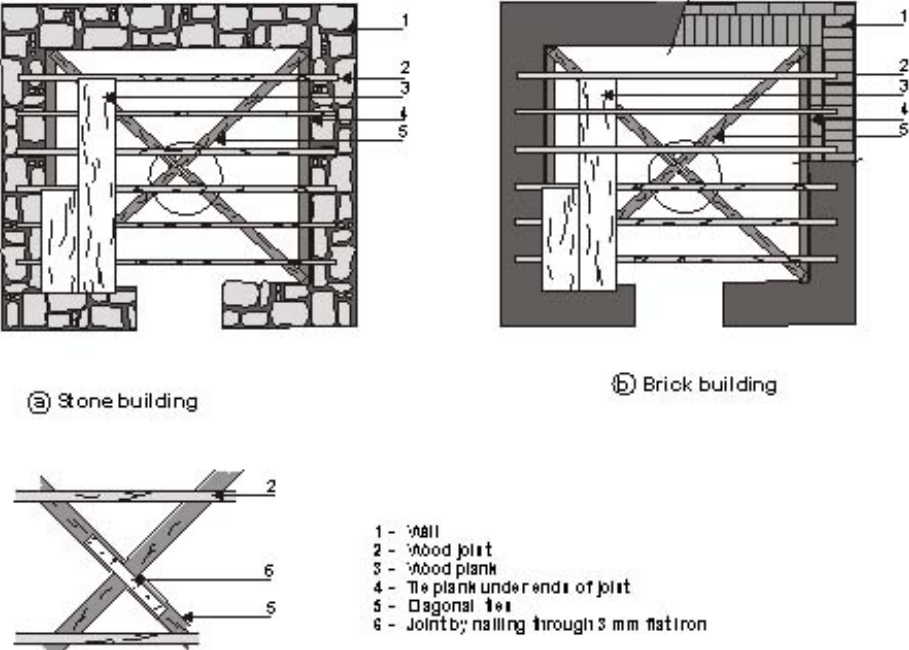


Fig.15: Integration and Stiffening of an Existing Floor

use of ties. Such roofs push the walls outward during earthquakes.

For stiffening such roofs, the rafters should be tied with the seismic belt as in the Note under 11.3.1. Also the opposite rafters, on both sides of the ridge need to be connected near about mid-height of the roof through cross ties nailed to the rafters (see Fig.17).

Fig.16: Stiffening Flat Wooden Floor/Roof



12.6 Roofs or floors consisting of steel joists flat or segmental arches must have horizontal ties holding the joists horizontally in each arch span so as to prevent the spreading of joists. If such ties do not exist, these should be installed by welding or clamping.

12.7 Stiffening the flat wooden floor/roof

Many of the houses have flat floor or roof made of wood joists covered with wooden planks and earth. For making such roof/floor rigid, long planks 100mm wide and 25 mm thick should be nailed at both ends of the joists from below. Additionally, similar planks or galvanized metal strips 1.5 mm thick 50 mm wide should be nailed diagonally also. See Fig. 16.

12.8 Stiffening the Sloping Roof Structure

Most of the sloping roofs are made of rafters, purlins, and burnt clay tiles on top. Similarly AC or CGI sheet roofs are made using wooden purlins resting on gable walls or main rafters. But trusses were not formed which require the

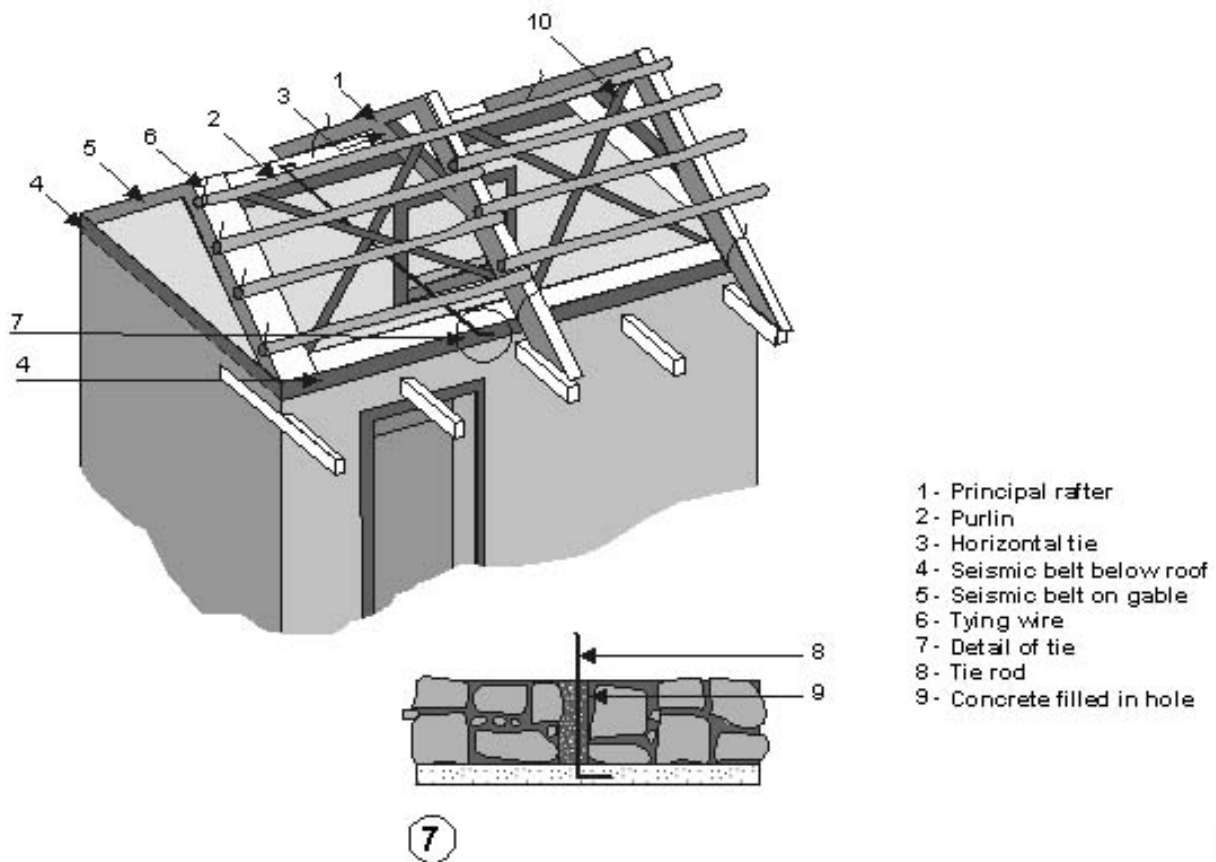


Fig.17: Stiffening of Sloping Roof Structure

13. Inserting New Walls

13.1 Unsymmetrical buildings which may produce dangerous torsional effects during earthquakes the center of masses can be made coincident with the center of stiff nesses by separating parts of buildings thus achieving individual symmetric units and/or inserting new vertical resisting elements such as new masonry or reinforced concrete walls either internally as shear walls or externally as buttresses. Insertion of cross wall will be necessary for providing transverse supports to longitudinal walls of long barrack-type buildings used for various purposes such as schools and dormitories.

13.2 The main problem in such modifications is the connection of new walls with old walls. Figs. 18, 19 and 20 show three examples of connection of new walls to existing ones. The first two cases refer to a T-junction whereas the third to a corner junction. In all cases the link to the old walls is performed by means of a number of keys made in the old walls. Steel is inserted in them and local concrete infilling is made. In the second case, however, connection can be achieved by a number of steel bars inserted in small length drilled holes filled with fresh cement-grout which substitute keys.

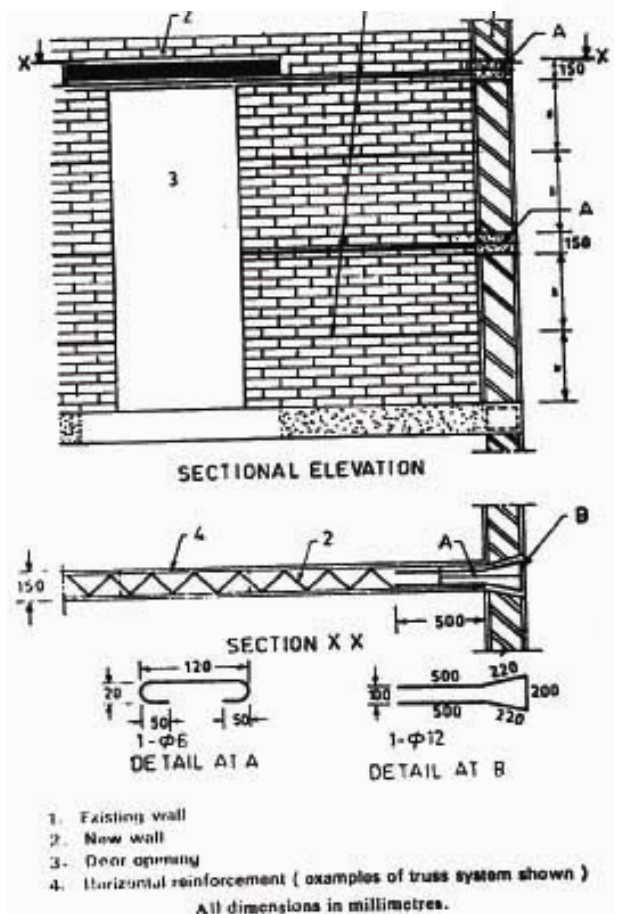


Fig.18: Connection of new & Old Brick Walls

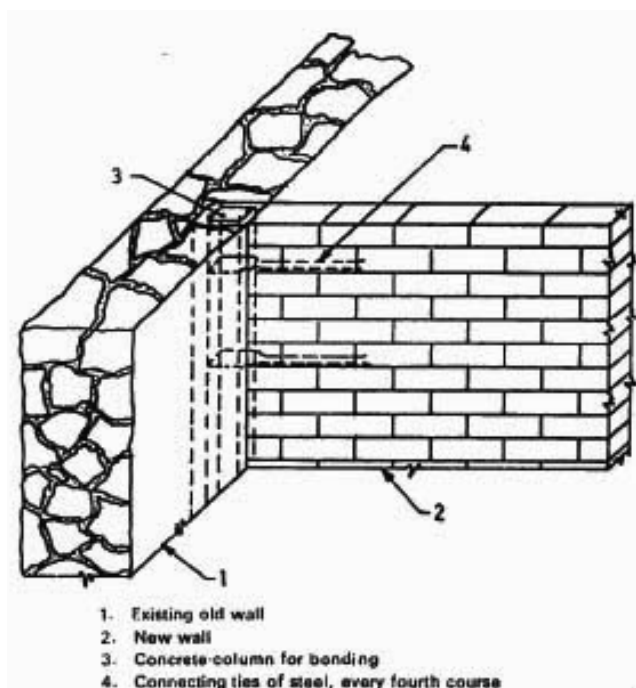


Fig.19: Connection of New Brick Wall with Existing Stone Walls

14. Strengthening of Foundations

Strengthening of foundations before or after the earthquake is the most involved task since it may require careful underpinning operations. Some alternatives are given below for preliminary consideration of the strengthening scheme:

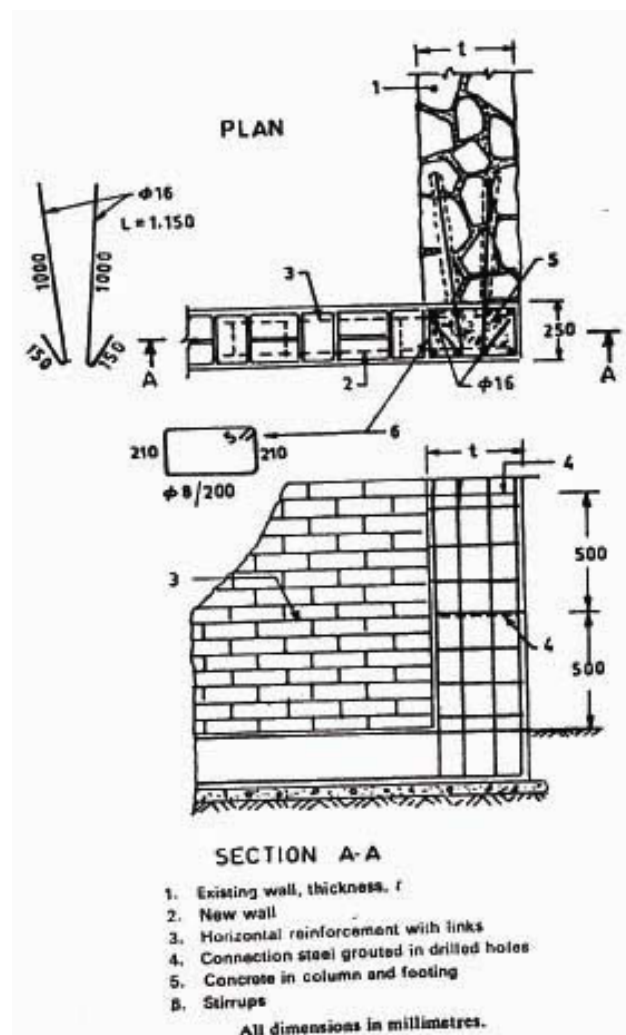
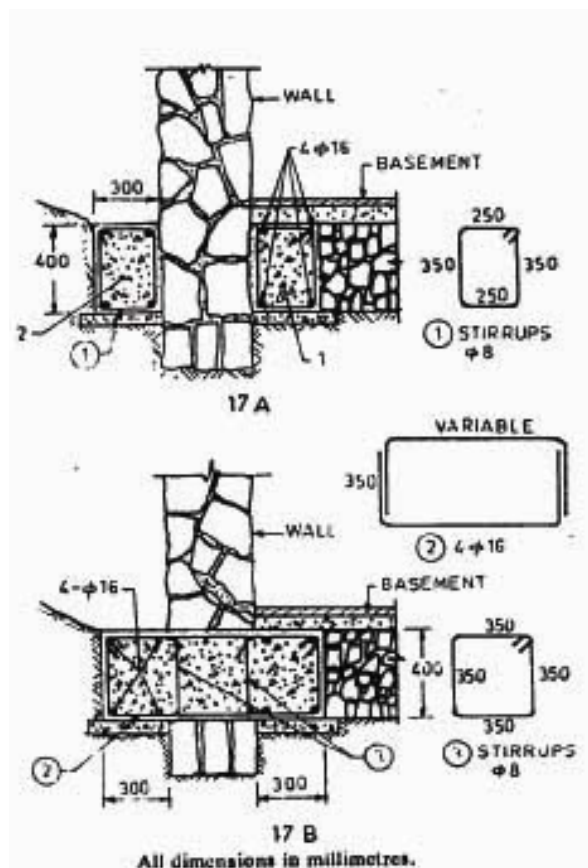


Fig.20: Connection of New & Old Walls (Corner Junctions)



- Introducing new load bearing members including foundations to relieve the already loaded members. Jacking operations may be needed in this process.
- Improving the drainage of the area to prevent saturation of foundation soil to obviate any problems of liquefaction which may occur because of poor drainage.
- Providing apron around the building to prevent soaking of foundation directly and draining off the water.
- Adding strong elements in the form of reinforced concrete strips attached to the existing foundation part of the building. These will also bind the various wall footings and may be provided on both sides of the wall (*see* Fig. 21) or only one side of it. In any case, the reinforced concrete strips and the wall have to be linked by a number of keys inserted into the existing footing.

Fig.21: Strengthening Existing Foundation (R.C.Strip on Both Sides)

NOTE - To avoid disturbance to the integrity of the existing wall during the foundation strengthening process proper investigation and design is called for.

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