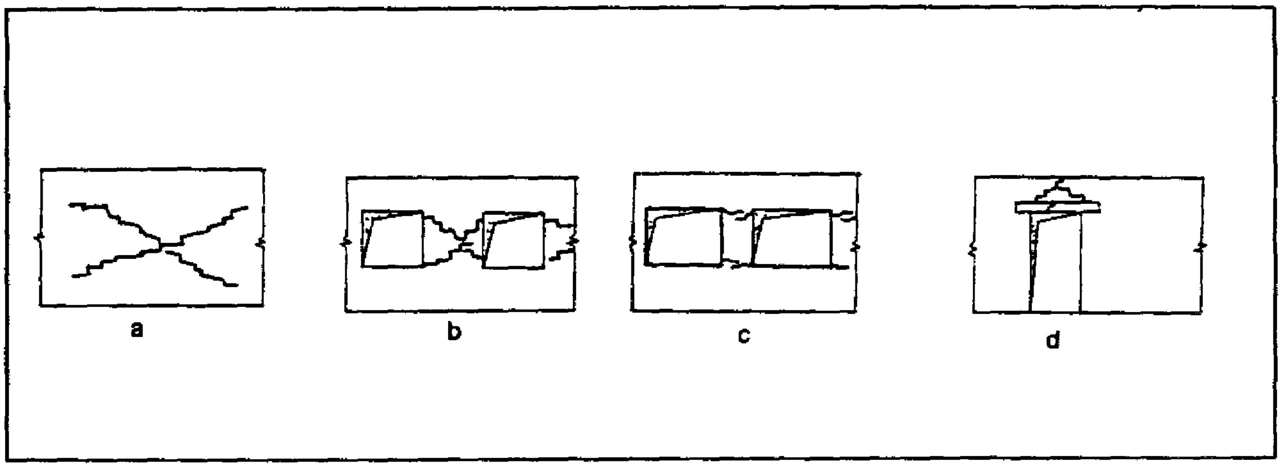

Figure 13.1-11 Crack Patterns in Masonry Walls [3]

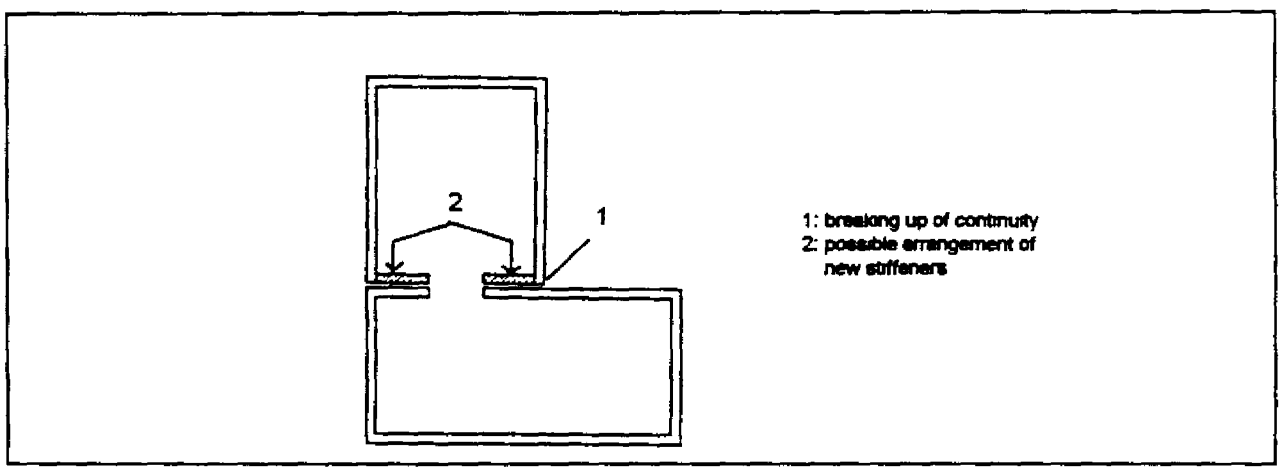

Figure 13.1-12 Adding Externally Buttresses [3]

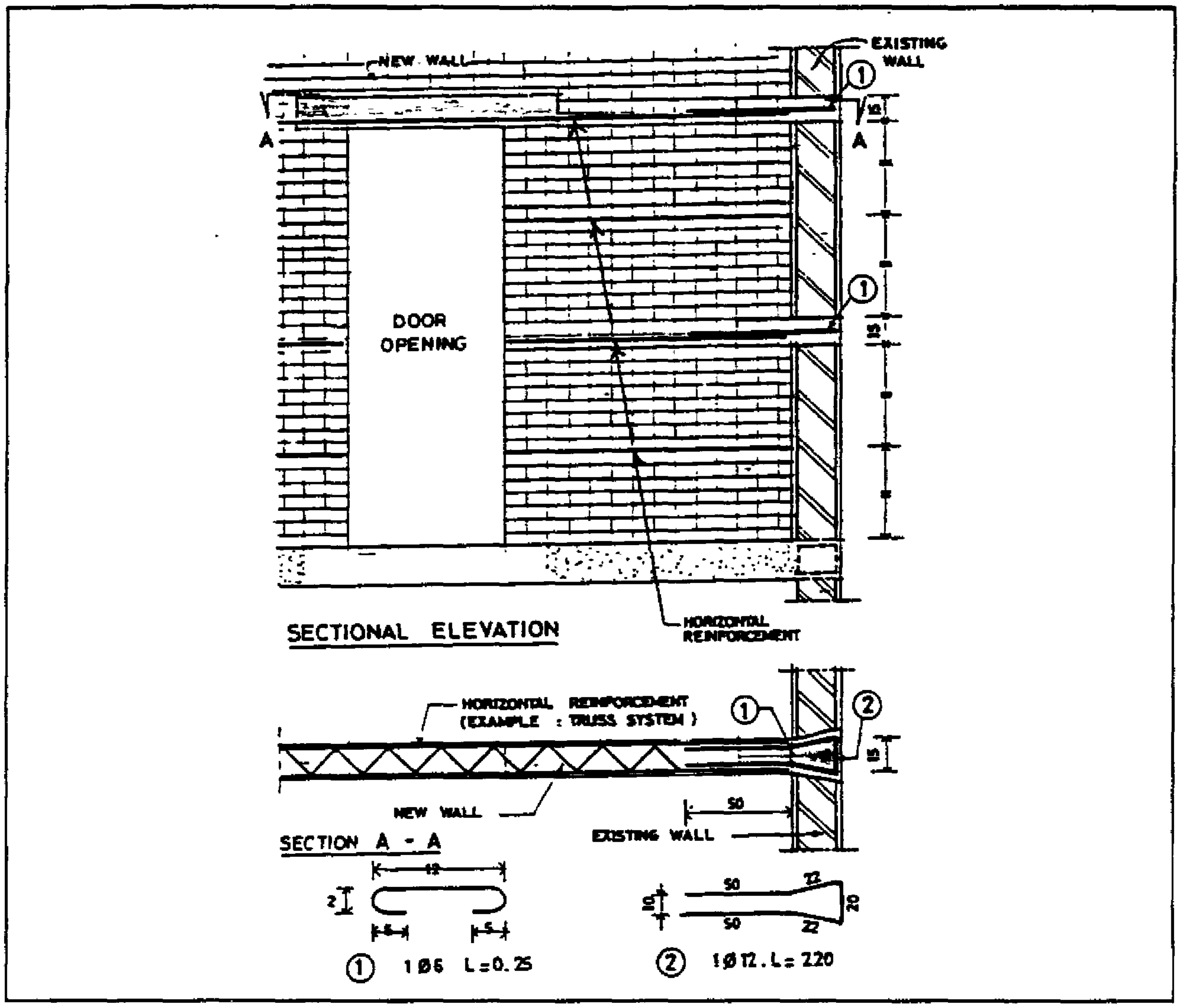

Figure 13.1-13 Connection of New and Old Walls (Tjunction). [1]

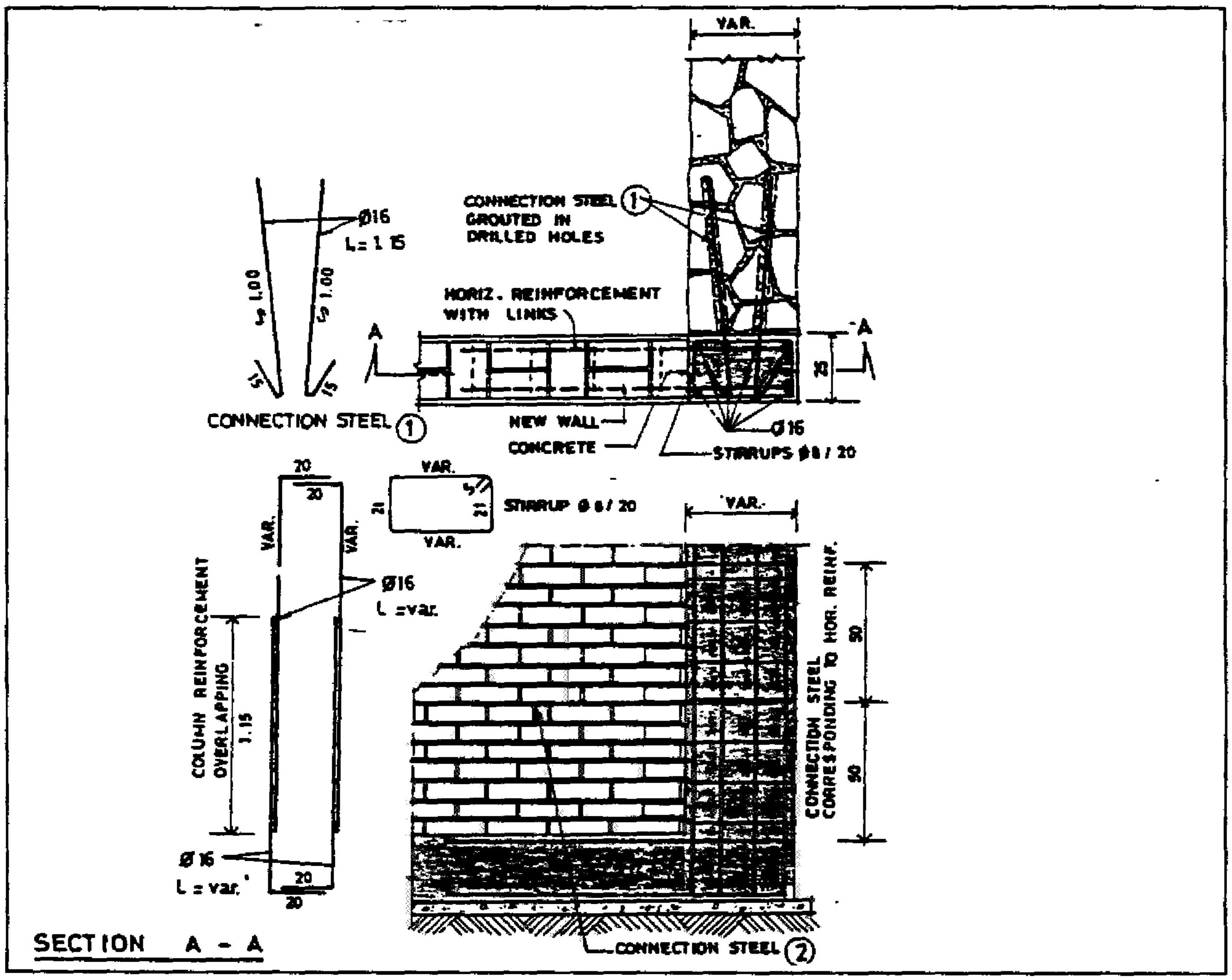

Figure 13.1-14 Connection of New and Old Walls (Corner Junction). [1]

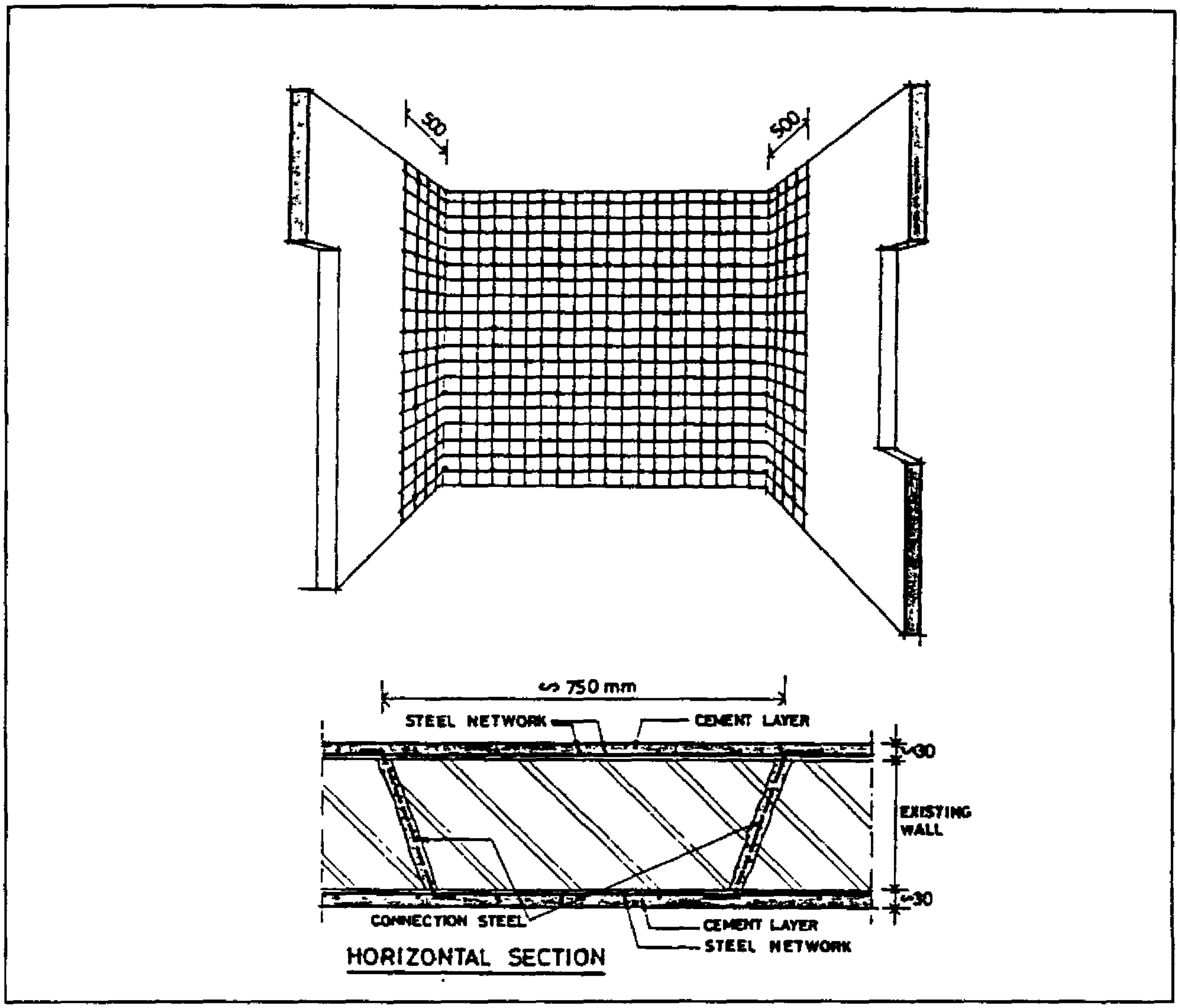

Figure 13.1-15a Vertical Reinforced Concrete Covering Plates (Jackets). [1]

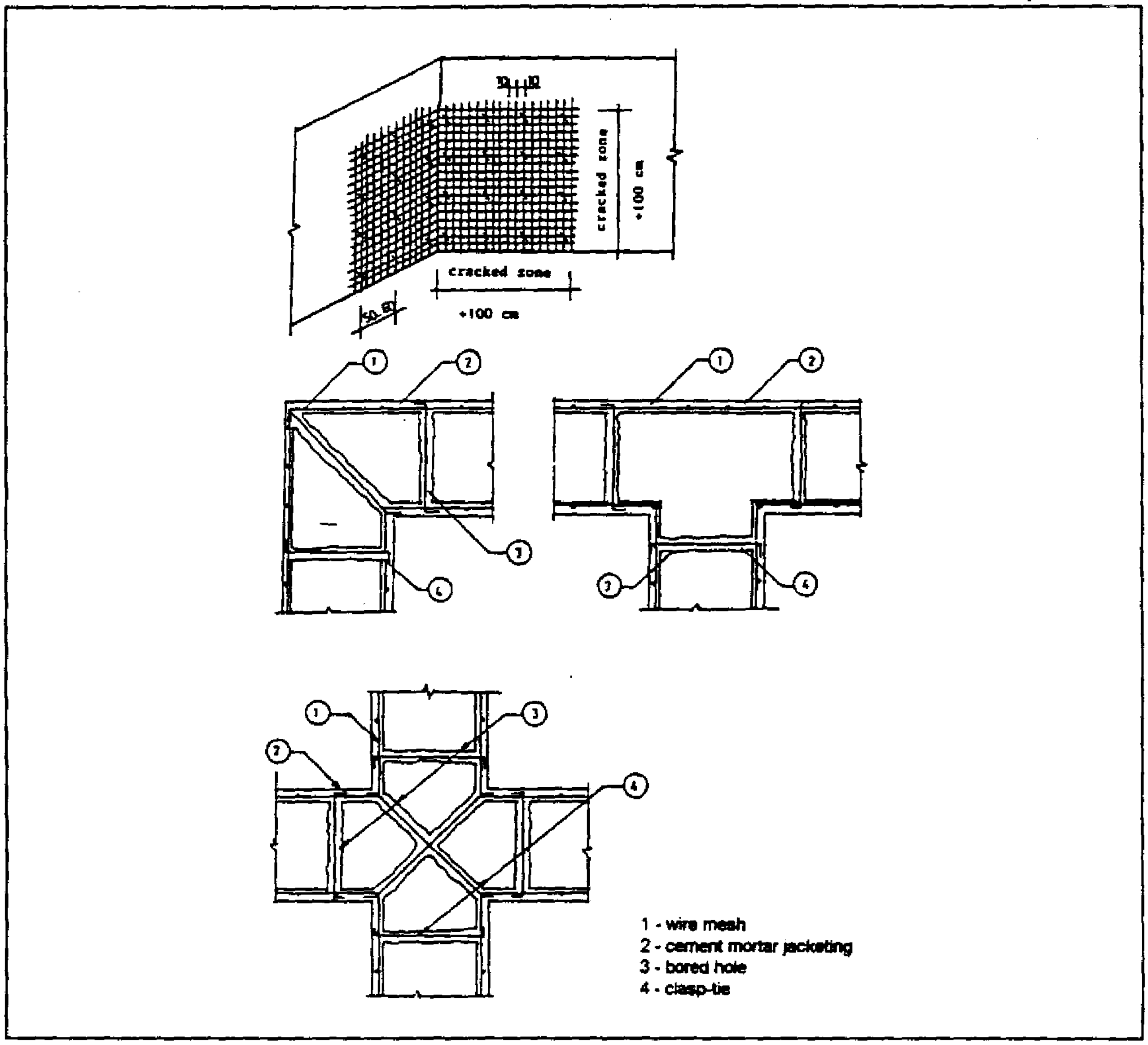

Figure 13.1-15b Jacketing. [3]

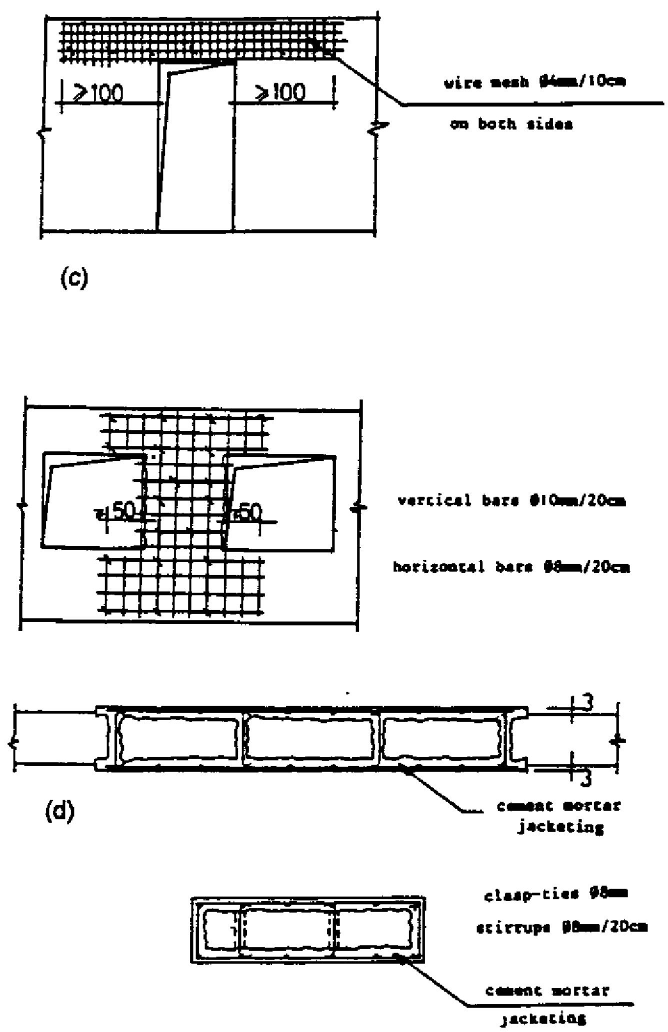

Figure 13.1-15 c-d Jacketing. [3]

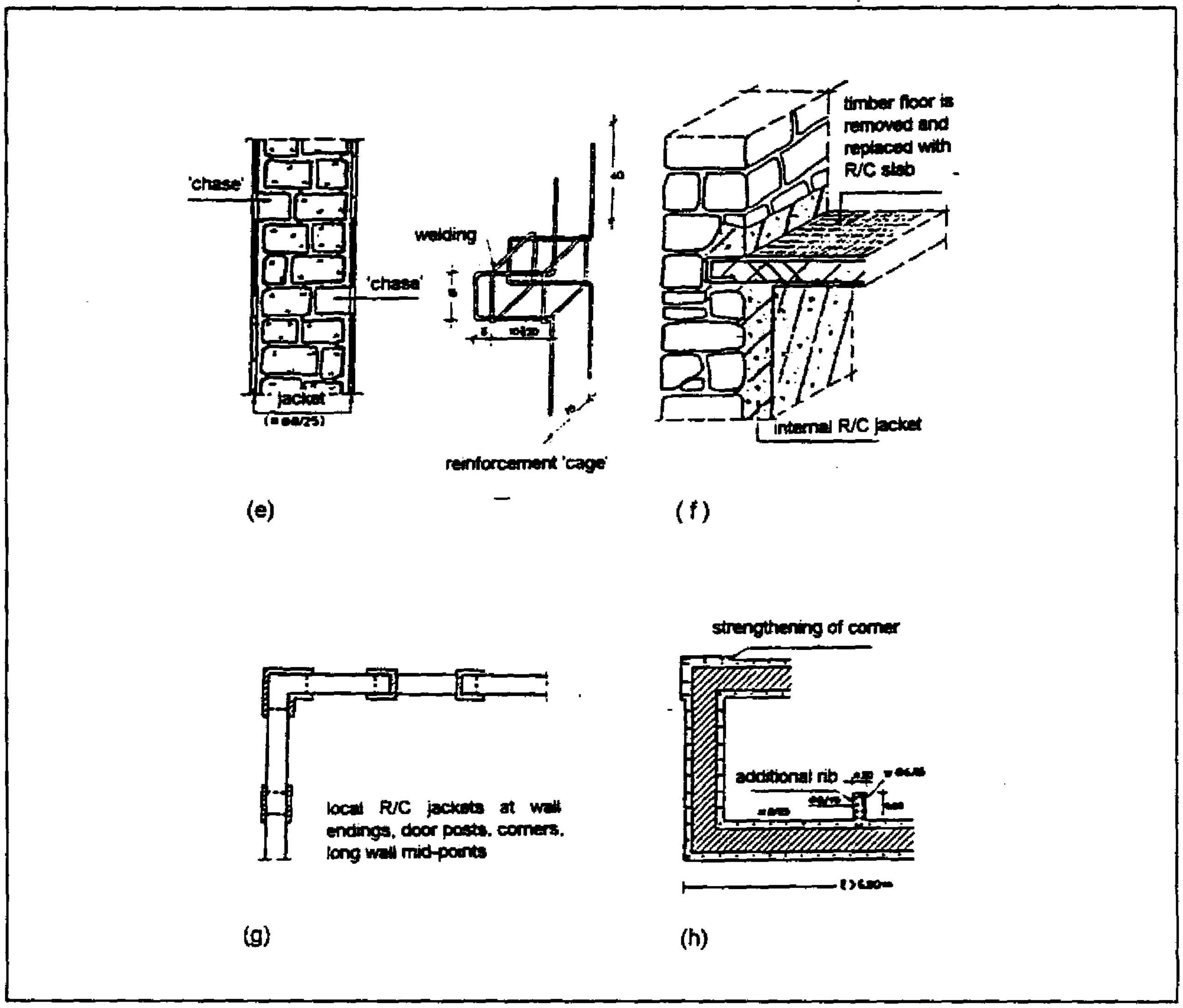

Figure 13.1-15 e-h Jacketing. [3]

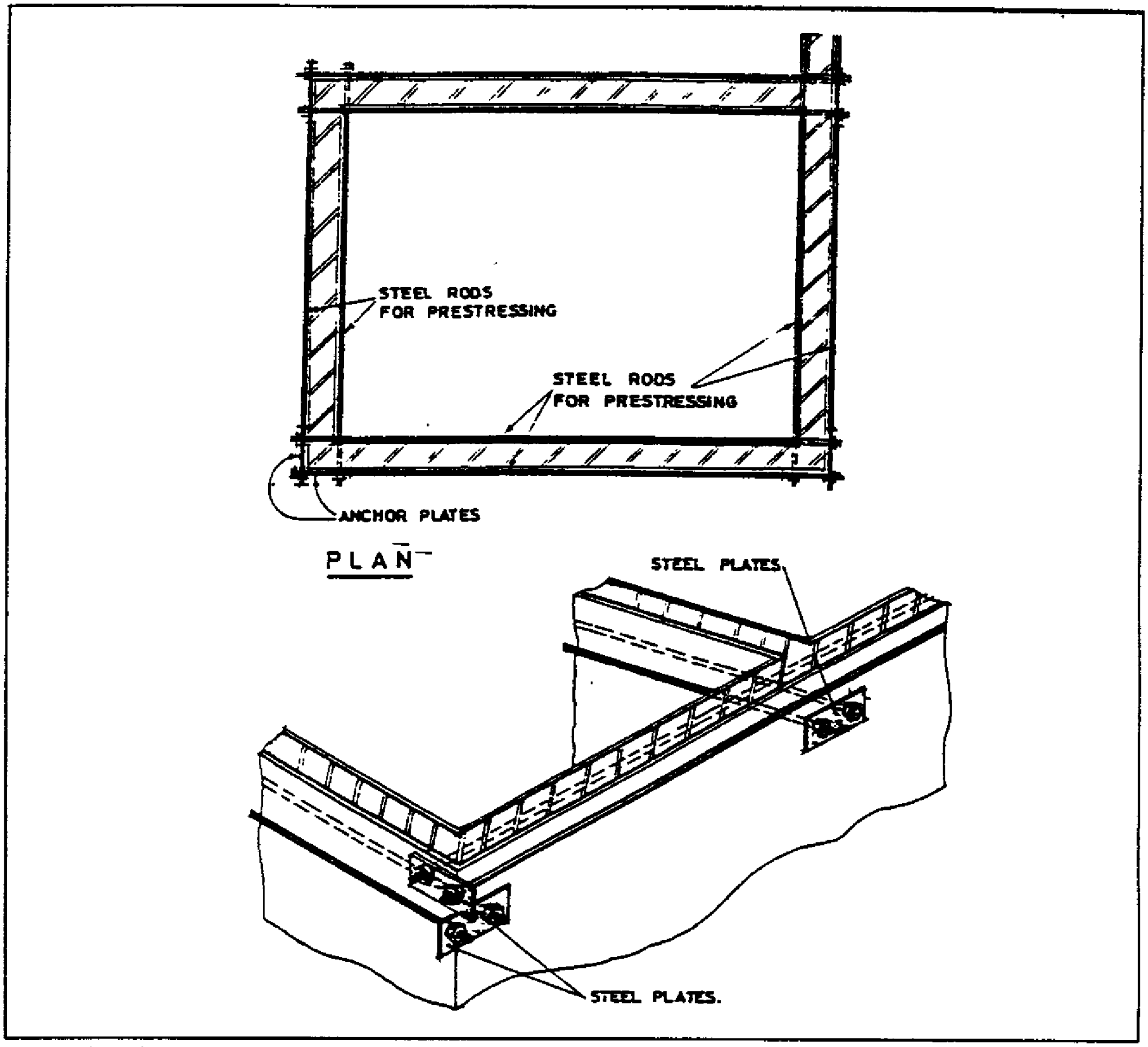

Figure 13.1-16 Strenghtening of Walls [1]

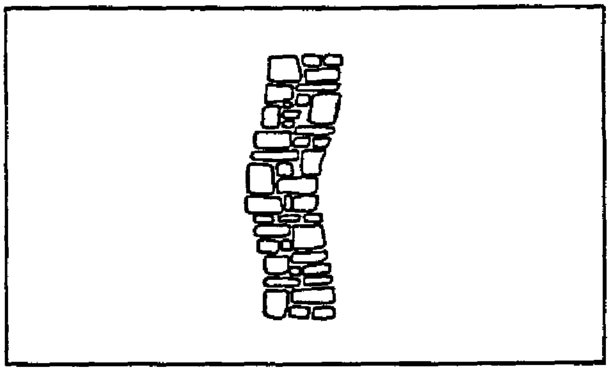

Figure 13.1-17 Lateral Distortion on Both Sides of Masonry Wall. [3]

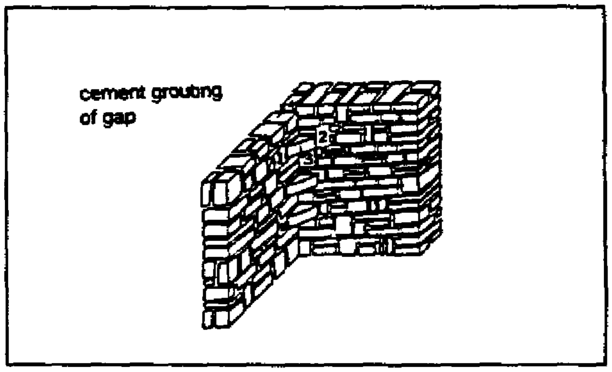

Figure 13.1-19 Stitching across the Crack. [3]

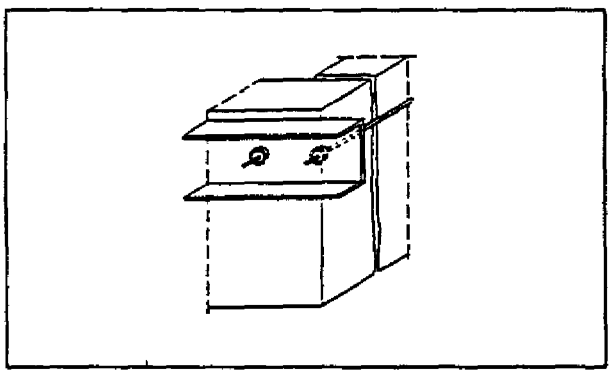

Figure 13.1-21 Reducing Separation prior to Repair. [3]

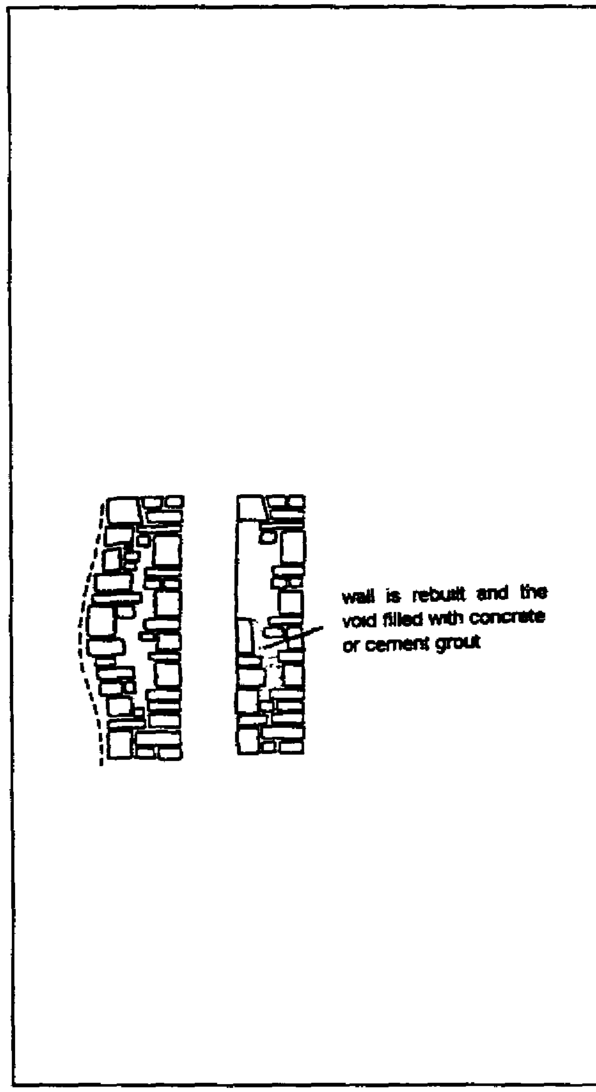

Figure 13.1-18 Placing Headers in Rebuilt Wall [3]

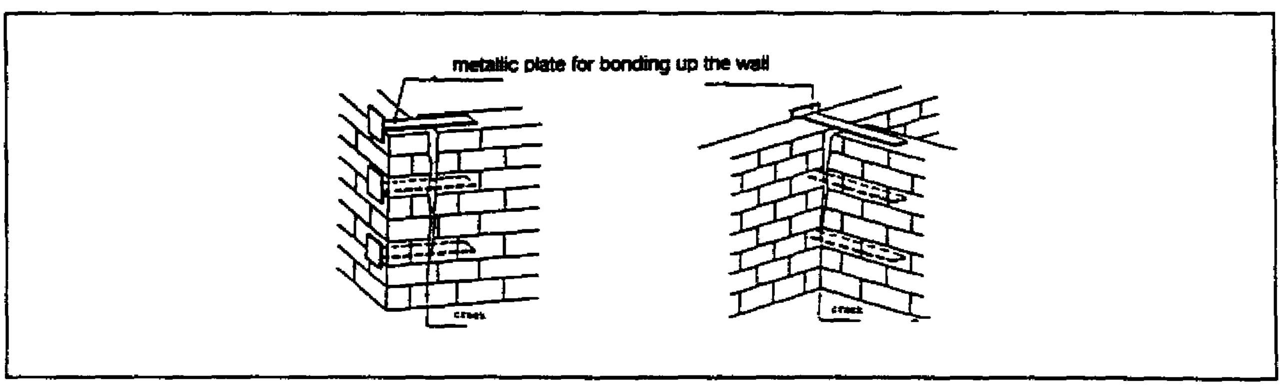

Figure 13.1-20 Tying Separated Walls Together. [3]

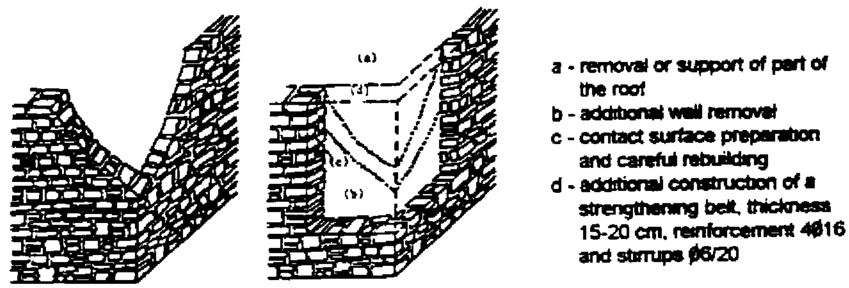

Figure 13.1-22 Repairing Collapsed Corners in Stone Masonry. [3]

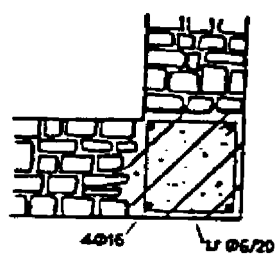

Figure 13.1-23 Adding a Concrete Column. [3]

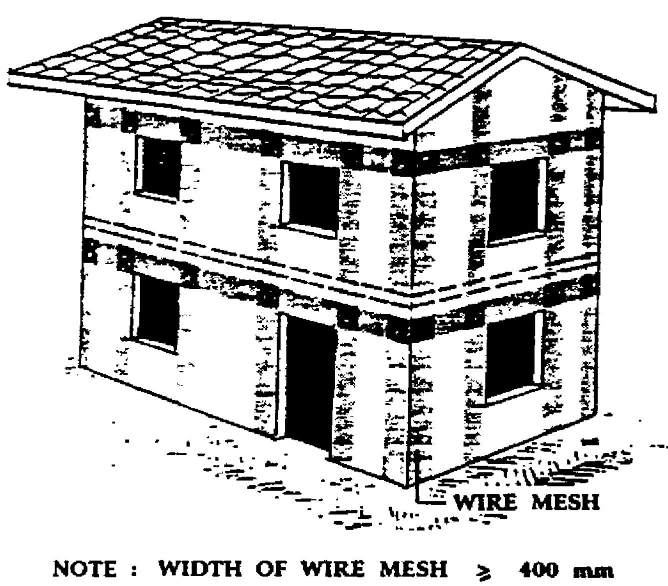

Figure 13.1-24 Splint and Bandage Strengthening Technique. [1]

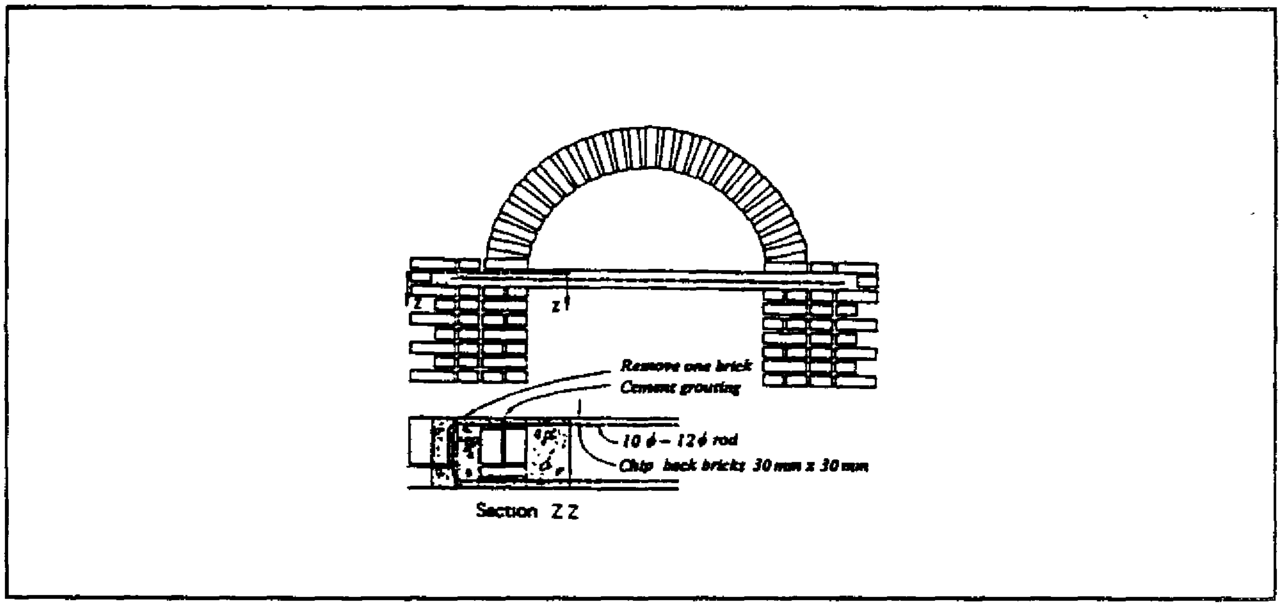

Figure 13.1-25 Strengthening of Arched Opening. [2]

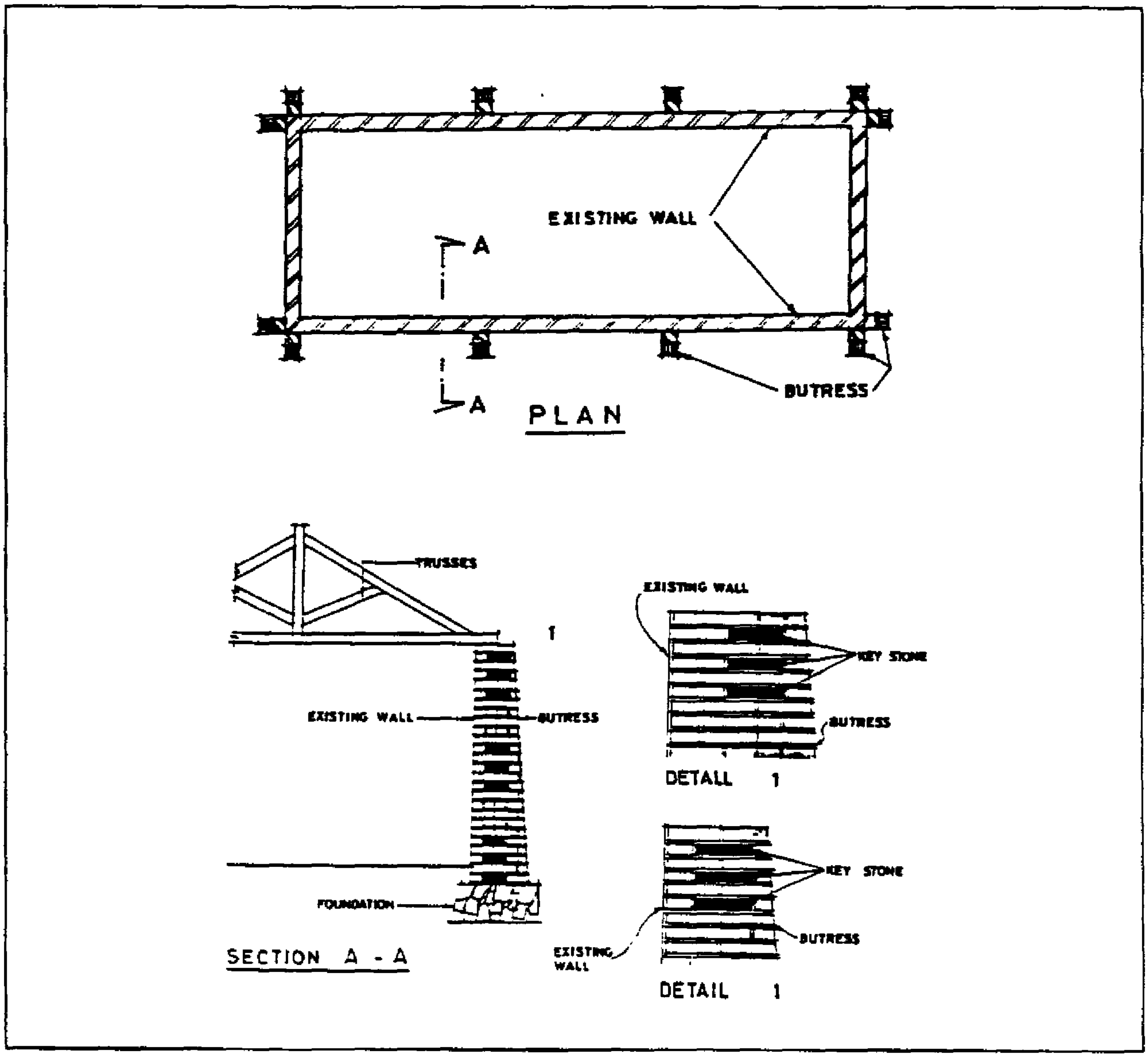

Figure 13.1-26 Strengthening of Long Walls by Buttresses. [1]

Topic 13.2 : Strengthening of Masonry Structures

Strengthening of Masonry Walls

Masonry walls may show cracks due to shear and tensile forces in the wall and near wall intersections or openings. The fol lowing crack-patterns can be observed:

Diagonal cracks, partially or completely through the masonry wall (diagonal tensile stresses Figure 13.1-11(a)).

Diagonal cracks in masonry piers between window openings, due to alternating bending moments (Figure 13.1-11(c))

Diagonal cracks above the wall openings, due to shearing and arch-type load-carrying mechanism, together with possible cracks in reinforced concrete lintels (Figure 13 1-11(d))

Insufficient interlocking between connecting walls results in vertical cracks. Such cracks may occur in an interior wall that is linked with a heavier exterior wall or in the corner connec tion of two exterior walls.

Depending on the size of cracks, different repair methods can be used, namely:

1. injection repair,
2. removal and replacement of bricks and stones along the length of the crack,
3. the replacement of entire wall sections.

Inserting New Walls

Asymmetrical buildings are subject to torsional effects during earthquakes. The center of masses can be made to coincide with the center of stiffness, by separating parts of buildings. This is to achieve individual symmetric units by inserting new walls (masonry or reinforced concrete) or by adding external buttresses (Figure 13.1-12). Inserting cross walls also provides transverse supports to longitudinal walls of long, barrack-type buildings (schools and dormitories)

The main problem in such modifications is the connection of new walls with old walls Figures 13.1-13 and 13.1-14 show two examples of connection of new walls to existing ones The first case refers to a T-junction, the second to a corner junction. In both cases the link is performed by a number of keys made in the old walls Steel and cement infilling is inserted here. In the second case a number of steel bars are inserted in small drilled holes filled with epoxy or other bonding material, to substitute the keys.

Strengthening existing walls

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

1. grouting,
2. addition of vertical reinforced concrete coverings (jackets) on both sides of the wall,
3. using steel tie bars to hold the walls together (prestressing the walls).

1. *Grouting*

   A number of holes are drilled in the wall (2 to 4 per square meter). First water is injected in order to wash the wall inside and to improve the adhesion between the grouted mixture and the wall elements. Secondly a cement water mixture (1:1) is grouted at low pressure (1 to kg/cm2) 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 the solution as far as the improving of connections between orthogonal walls is required.

   Note: In most cases the pressure needed for grouting can be obtained by gravity flow from elevated tanks.

2. *Vertical R.C. Covering Plates (Jackets).*

   Two steel meshes (welded wire fabric with spacing of 15x15) are placed on both sides of the wall connected by steel bars, 50 to 75 cm apart. A 3 to 4 cm thick cement mortar layer is then applied on mesh which become two interconnected plates. This system can also be use to improve connection of orthogonal walls or other weak parts of walls (Figure 13 1-15).

3. *Prestressing (Tie Bars)*

   A horizontal compression by horizontal tendons can increase the shear strength of walls. This also improves the connections of orthogonal walls (Figure 13.1-16). The easiest pre-compression is achieved by placing two steel rods on the two sides of the wall and stretching them with turnbuckles. Note that good effects can be obtained by slight horizontal prestressing (about 1 kg/cm2) of the wall. Prestressing also strengthens the spandrel beam between two rows of openings.

Replacement of Damaged Walls.

Extensive damage may occur to masonry walls which requires reconstruction of a portion of the wall. It is important to install temporary shoring promptly to support the floors and walls above the heavily damaged wall.

When portions of masonry walls have permanent lateral distortion or humping at both sides of the wall (Figure 13.1-17), that portion of the wall must be completely removed and reconstructed.

If the wall has spread or humped on one side only complete reconstruction can be avoided if the vertical face is stable enough to be used as formwork after the bulging side is taken down. Headers are placed in the rebuilt wall using concrete or cement grout to fill all voids (Figure 13.1-18).

Strengthening of Intersections.
Wall intersections are particularly vulnerable to earthquake damage, resulting in vertical cracks when the walls are insufficiently interconnected to allow proper interaction. Various methods may be considered. Repairs of masonry construction are often combined with a local strengthening of the wall intersection.

In case of small vertical cracks, repair can be achieved by using techniques, with or without some stitching procedures across the crack.

Stitching or adding stones across the crack is one method which can be used (Figure 13.1-19). Adjacent bricks or stones are removed as denoted by "1" and "2" and installing a new brick or stone common to both walls denoted by "3". This new stitching stone should be embedded in rich cement grout, at about 70 cm spacing. The gap formed between the two walls is then filled with a rich cement grout. A wire trellis is fastened to both the internal and the external surfaces, and plastered with cement plaster. Reinforced concrete tie beams or belts which are damaged need to be repaired. If missing tie beams should be considered to strengthen the structure.

In order to tie the separated wall sections together, steel plates (i.e. 40x4 in cross-section) embedded in rich cement grout in between two brick or stone layers can be used (Figure 13.1-20). Such plates can be effective for reinforcing a corner but cannot bring the walls back into a vertical position. The gap is then sealed and the surfaces covered with wire trellis and plaster. An alternative is drilling horizontal holes in the masonry through the vertical crack for grouting or epoxing steel rods in the holes. In both methods the remaining crack should be filled with cement mortar. To reduce the separation prior to repair, tie rods from both sides can be used (Figure 13 1-21). Tightening is carried out with bolts and wrench, providing a controlled restoration of the walls and tying of the corners. If aesthetically permissible, the tie rods can remain in place and typical crack repair would complete this.

In stone masonry, a total collapse of a corner is common. Strengthening requires temporary support for the structure above, removal of additional masonry around the damaged area, preparation and cleaning of the contact surface and rebuilding (Figure 13 1-22). Attention should be paid to bonding the rebuilt part onto the contact surface. Damaged belts should be repaired or should be added. A reinforced concrete corner column tied into the intersecting walls could be added. Such columns should have minimum reinforcement of 4 ~ 16 and stirrups of ~ 8 at 20 cm (Figure 13 1-23). Alternatively the use of horizontal reinforcing bars, well extended into the intersecting walls, can strengthen the corner.

External Binding
Opposite parallel walls can be held to cross walls by prestressing bars as illustrated in Figure 13.1-16, with anchoring in horizontal steel channels. The steel channels running from one cross wall to the other will hold the walls together and improve the box effect of the walls.

The technique of covering the wall with steel mesh and mortar or microconcrete can be used on the external walls while maintaining continuity of steel at the corners. This strengthens the walls and binds them together. The covering may also be with vertical splints between openings and horizontal bandages over spandrel walls (Figure 13.1-24).

Other Cases

1. If the walls have large arched openings, it will be necessary to apply tie rods or tie beams at springing levels or above them (Figure 13.1-25).

2. Random rubble masonry walls easily collapse completely and must be strengthened by internal impregnation by rich cement mortar grout in the ratio of 1.1 or, better still, covered with steel mesh and mortar (see "strengthening existing walls"). Damaged portions of the wall should be reconstructed using richer mortar and bonding devices as shown in Figure 16.1-2.

3. For bracing longitudinal walls of long, barrack- type buildings, a portal type framework can be inserted transverse to the walls and connected to them. The framework may be of steel, timber or reinforced concrete. Alternatively, masonry buttresses may be added externally (Figure 13.1-26).

4. In framed buildings, the lateral resistance can be improved by inserting knee braces or full diagonal braces or inserting infill walls.

masonry, strengthening, wall, grouting, jacketing, arch, bandage, buttress, tie, stone masonry.

SESSION 14: TIMBER CONSTRUCTIONS

Topic 14.1: Timber Constructions

Timber has a high strength/weight ratio and is very suitable for earthquake resistant construction. Unlike steel, timber does not have the advantage of elastic behavior but it has a high damping value, which is favorable for earthquake resistant structures.

Therefore, timber is an excellent material for earthquake resistance. It is light, strong, easily braced and capable of absorbing energy. Its strengths or weaknesses lie in the connections. The presence of knots and of other defects make timber a non-homogeneous material and its quality has a considerable effect on its performance in earthquakes.

Timber must be preserved and protected from moisture to avoid deterioration of its strength through decay or other attack. Precautions must also be taken to minimize the danger of fire.

The joints in timber frame members should be made tight and strong and covered with steel straps or wires to maintain them in good condition. The superstructure is rigidly fixed into the plinth masonry or concrete foundation as shown in Figure 14.1-1.

Two types of construction are common in timber buildings.

- Stud-wall construction
- Brick-nogged timber frame construction.

Stud-Wall Construction

The stud-wall construction consists of timber studs and corner posts framed into sills, top plates and wall plates. Horizontal struts and diagonal braces are used to stiffen the frame against lateral loads.
The wall covering may consist of matting made from bamboo, vegetation, timber boarding or the like. Typical details of stud walls are shown in Figure 14.1-2.

Note: If the sheathing boards are properly nailed to the timber frame, the diagonal bracing may be reduced or even omitted.

The grouping of timber as well as typical permissible stress was given in Table 8.1-4. Based on these properties, Table 14.1-1 gives the spacing of timber studs which may be used in load bearing walls. Table 14.1-2 gives the finished size of diagonal brace for different zones in stud wall construction.

Group of Timber*	Single Storeyed or First Floor of the Double Storeyed Buildings		Ground Floor of Double Storeyed Buildings	
	Exterior Wall [cm]	Interior Wall [cm]	Exterior Wall [cm]	Interior Wall [cm]
A	100	100	50	50
A and C	100	80	50	40

Table 14.1-1 Maximum Spacing Of 40x90 Mm Finished Size Studs In Stud Wall Construction

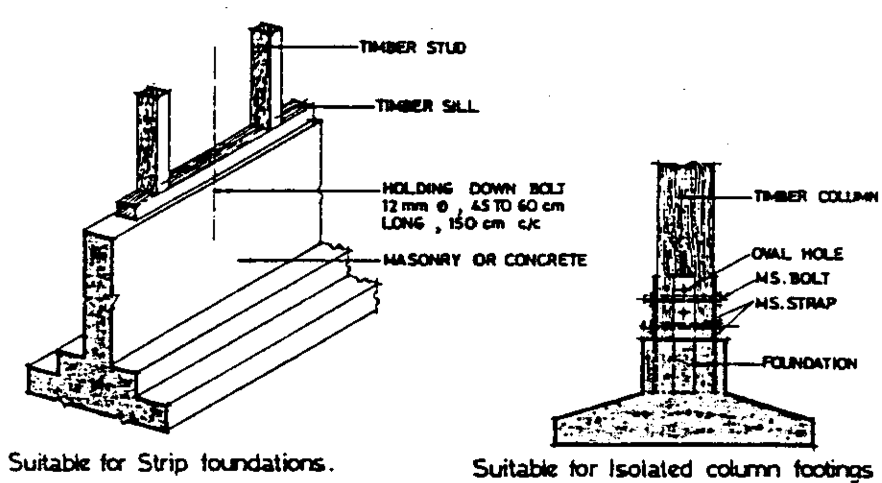

Figure 14.1-1 Details of Connection of Column with Foundation [1].

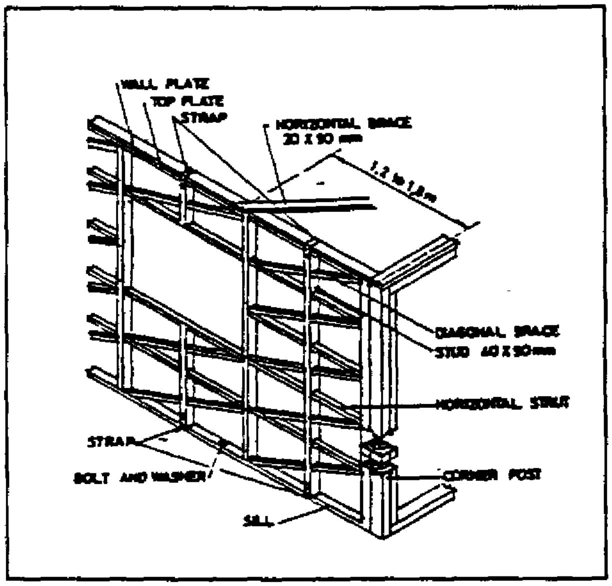

Figure 14.1-2 Timber Framing in Stud Wall Construction with Opening in Wall [1].

Brick Nogged Timber Frame Construction

The brick nogged timber frame consists of intermediate verticals, columns, sills, wall plates, horizontal nogging members and diagonal braces framed into each other. The space between framing members is filled with tight fitting brick masonry in stretcher bond. Typical details of brick nogged timber frame construction are shown in Figure 14.1-3

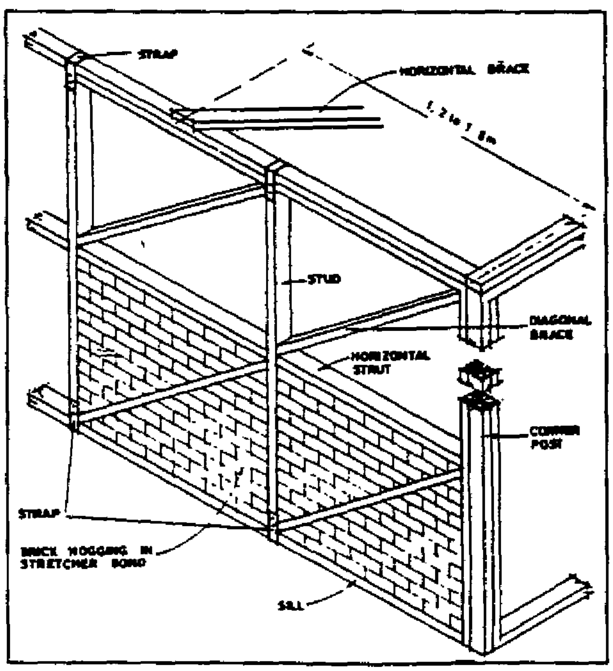

Figure 14.1-3 Brick Nogged Timber Frame [1]

Cate-gory	Group of Tim-ber*	Single Storeyed or First Floor of the Double Storeyed Buildings		Ground Floor of Double Storeyed Buildings	
		Ex-terior Wall [cm]	In-terior Wall [cm]	Ex-terior Wall [cm]	In-terior Wall [cm]
I, II	A, B, C	20x40 20x40	20x40 30x40	20x40 30x40	30x40 30x40
III, IV	A, B, C	20x40	20x40	20x40	20x40

* Group of timber defined in Table 8.1-4

Table 14.1-2 Minimum Finished Size Of Diagonal Braces

Spa-cing (m)	Group of Tim-ber*	Single Storeyed or First Floor of the Double Storeyed Buildings		Ground Floor of Double Storeyed Buildings	
		Ex-terior Wall [cm]	In-terior Wall [cm]	Ex-terior Wall [cm]	In-terior Wall [cm]
1.0	A	50x100	50x100	50x100	70x100
	B, C	50x100	50x100	70x100	90x100
	A	50x100	70x100	70x100	80x100
1.5	B, C	70x100	80x100	80x100	100x10 0

* Group of timber defined in Table 8.1-4

Table 14.1-3 Minimum Finished Sizes of Verticals in Brick Nogged Timber Frame Construction.

The vertical framing members in brick nogged load bearing walls should have minimum finished sizes as specified in Table 14.1-3. The sizes of diagonal bracing members should be the same as in Table 14 1-2 The horizontal framing members in brick construction should be spaced not more than one meter apart. The minimum finished sizes are recommended in Table 14.1-4.

Spacing of Verticals	Size (mm x mm)
1.5	70x100
1.0	50x100
0.5	25x100

Table 14.1-4 Minimum Finished Sizes of Horizontal Nogging Members Construction.

Roofs

In timber constructions, truss frames are often used for roofing. The stability of the roofs is essential under earthquake conditions Therefore the frames should be braced in the sloping plane and preferably in the horizontal plane as well (Figure 14.1-4).

timber construction, roof, wall, stud, frame.

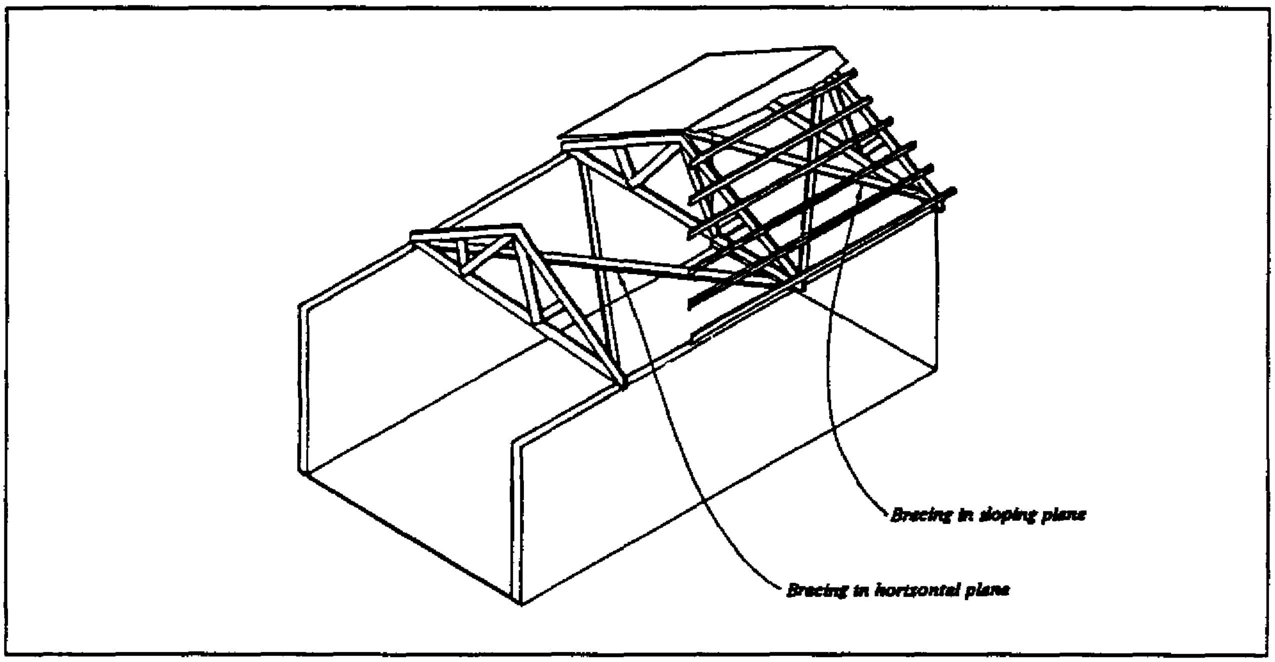

Figure 14.1-4 Bracing of Timber Roof [2].

SESSION 15: DESIGN OF CLAY, MUD AND ADOBE CONSTRUCTIONS

Topic 15.1: Clay, Mud and Adobe Constructions

There are many areas in the world where small buildings are constructed in clay, mud or unburnt sun-dried bricks laid in mud mortar This is called Adobe construction. Due to negligible tensile and shear strength of adobe and the heavy weight of such buildings, they are quite unsuitable in seismic zones A, B and C. However the economic condition of many people obliges them to continue to build their houses in this way. Therefore, although safety considerations in earthquake zones will demand banning of such constructions, practical necessity of providing at least a shelter to people will justify their continuation in the future With this view, suggestions are given here to incorporate some earthquake resistance into such buildings.

Recognizing that methods of forming, drying, stacking and transporting adobe are peculiar to local conditions, recommendations are made here only in those respects which will have general application.

The main causes of failure of adobe buildings in earthquakes are briefly illustrated in Figure 15.1-1.

Construction of Walls
The following principles of bonds in masonry should be adopted for construction of adobe walls

1. all courses should be laid level.
2. the vertical joints should be interrupted between two consecutive courses by overlap of adobes.
3. the clay mud should be the same as used in making the adobe.
4. the right angle joints between walls should be made such that the walls are properly joined together and a through vertical joint is avoided.
5. the walls should be covered with water repellent plaster on the outside by mixing bitumen cut-back in mud-mortar or by using lime mortars. Lime-pozzuolana mortars can also be used.

Dimensions of Walls

1. The length of a wall, between two consecutive walls at right angles to it, should not be greater than 10 times the wall thickness.
2. When a longer wall is required, the walls should be strengthened by intermediate vertical buttresses.
3. The height of the wall should not be greater than 7 times its thickness. Maximum wall height 3 0 m. Minimum wall thickness 40 cm.

The main causes of failure of adobe buildings in earthquake are briefly illustrated:

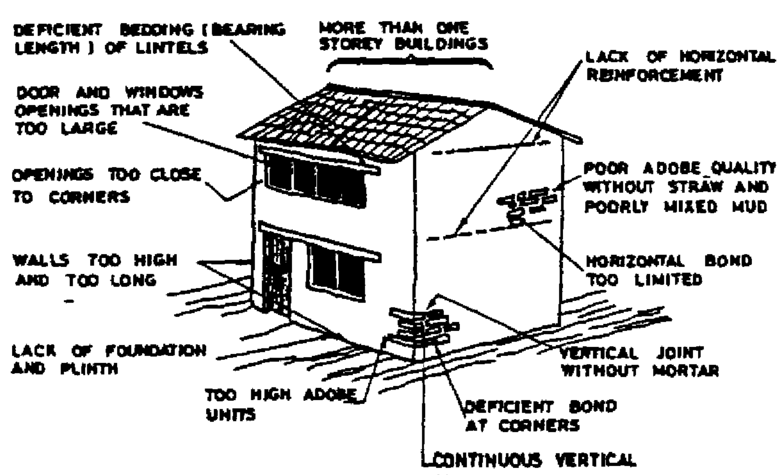

Figure 15.1-1 Graphic Summary of Causes of Failure

4. The height of the adobe building should be restricted to one storey plus attic only.

Openings in Walls

1 The width of an opening should not be greater than 1.0 m.

2. The distance between an outside corner and the opening should be not less than 1,2 m.

3 The sum of the widths of openings in a wall should not exceed one-third of the total wall length.

4. The bearing length (embedment) of lintels on each side of an opening should not be less than 50 cm.

Plinth Masonry

The wall above foundation up to plinth level should preferably be constructed from stone or burnt bricks laid in lime or cement mortar The height of plinth should be above the flood water line or a minimum of 30 cm above ground level. It will be preferable to use a waterproofing layer at the plinth level before starting the construction of the superstructure wall If adobe itself is used, the outside face of plinth should be protected against water damage by suitable facia or plaster. A water drain should be built slightly away from the wall to protect it from seepage.

Foundations

1. The strip foundation for the walls should have a width of at least 1 1/2 times the thickness of wall.

2. The foundation should preferably be made in cement concrete. Lime could be used in place of cement.

a. List five degrees of damage.
b. Which cases are beyond repair?
c. How can the decision of demolition be taken?

construction design, adobe masonry.

SESSION 16: REINFORCEMENT AND STRENGTHENING OF LOW COST CONSTRUCTIONS

Topic 16.1: Heavy wall constructions

Heavy wall constructions suffer much damage during earthquakes due to the great horizontal forces acting on them, the low quality of materials and construction, and the lack of horizontal and vertical bonding and reinforcing. Heavy walls are appropriate in hot-arid, tropical uplands and very cold climates because of their high thermal capacity. The main principles and methods for the seismic improvement of heavy walls is described here.

Heavy wall constructions can be made of:

- stone masonry
- adobe masonry
- rammed earth
- brick masonry

In general, the above constructions can be improved in 3 different ways:

1. by adding reinforcement, with materials with a high tensile strength, such as steel, wire mesh, wood, bamboo, and other vegetable materials. The reinforcement can be horizontal, vertical, and around openings,
2. by improving the quality of materials, such as stabilization of adobe or soil,
3. by improving construction quality, including connections

The Improvement of Stone Masonry

1 *Reinforcing*

Horizontal reinforcing is very useful. This could include the following systems:

- Wooden tie-beams, at several heights of the construction, preferably double, one at each side of the wall, with horizontal wooden connections at regular distances (Figure 16.1-1).
- Concrete beams instead of wood.
- Wood or steel at intersections and corners, and horizontally through the wall at several places.
- Wire mesh in horizontal joints at several levels.

Vertical reinforcement has proved very useful as well. This could take the form of:

- Concrete columns at corners and intersections.
- Vertical steel bars incorporated in the masonry at the same places (Figure 16 1-2).
- A wooden frame In case a wooden frame is used both vertically and horizontally to reinforce stone masonry, it is worthwhile to include diagonal bracing.

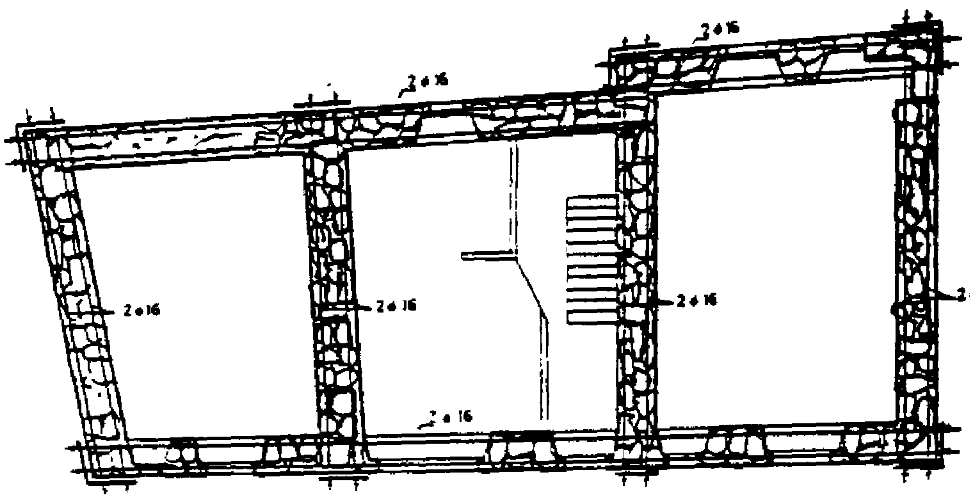

Figure 16.1-1 Horizontal Strengthening of Rubble Stone Masonry by Steel Ties [3]

Wire mesh in the plaster, on one or both sides of the wall, serves both as horizontal and vertical reinforcement.

2 *Quality of material*

- The use of angular, preferably dressed stones, increases the bond in the wall enormously.
- The use of slates - very flat natural stones - is also better than random rubble masonry.
- The improvement of mortar quality increases the bond in a wall as well. Therefore, wherever available and affordable, the use of cement, lime or gypsum mortar - in that order of preference - should be encouraged.

Quality of construction

- It is very important to achieve a good masonry bond. Stones should always be used as flat as possible, and dressed wherever needed to fit gaps, rather than using large quantities of mortar and small stones to fill up voids. Masonry walls should occasionally have stones that reach through the whole thickness of the wall ('through-stones'). Wooden and steel dowels help to create the same effect as the through-stones. (Figure 16.1-2)

- The roof and floors should be very well anchored to the walls. To spread the weight of a roof or floor equally over the wall, wall plates or tie-beams which are well anchored are effective.

The improvement of adobe masonry

1 *Reinforcing*

1.1 General aspects

A continuous horizontal reinforcement at roof level is very much desirable in order to tie the walls together, and to create a fixed base for the roof. This continuous reinforcing at lintel level is needed if openings are frequent. Proper connection of ties placed at right angles at the corners and junctions of walls should be ensured. These could be in the following forms:

1 Unfinished rough cut lumber, single pieces provided with diagonal members for bracing at corners (Figure 16.1-3(a))

2. Unfinished rough cut lumber, two pieces in parallel with halved joints at corners and junctions of walls (Figure 16 1-3(b)). The lumbers may be half round.

3. Sawn lumber 5 x 10 cm in section, placed in parallel as in (2) above (Figure 16.1-3(b)). The whole assembly is to be covered with clay mud and a minimum of two but maximum of four courses of adobe laid over it, before placing the roof

Construction of buttresses by projecting walls beyond the cor ner and T-junctions will help to retain the

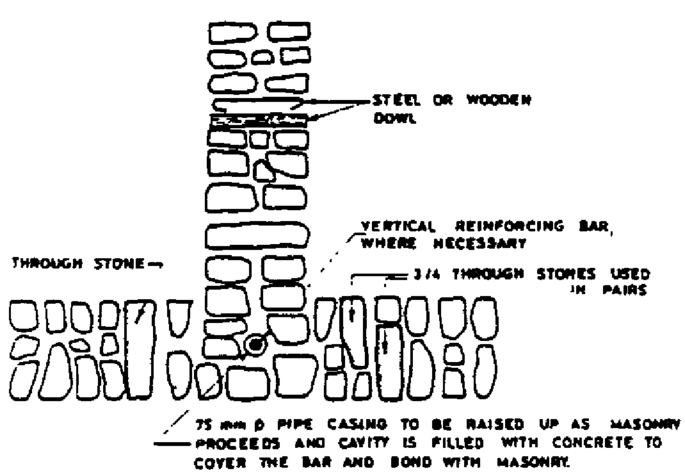

Figure 16.1-2 Reinforcement of Rubble Stone Masonry [1]