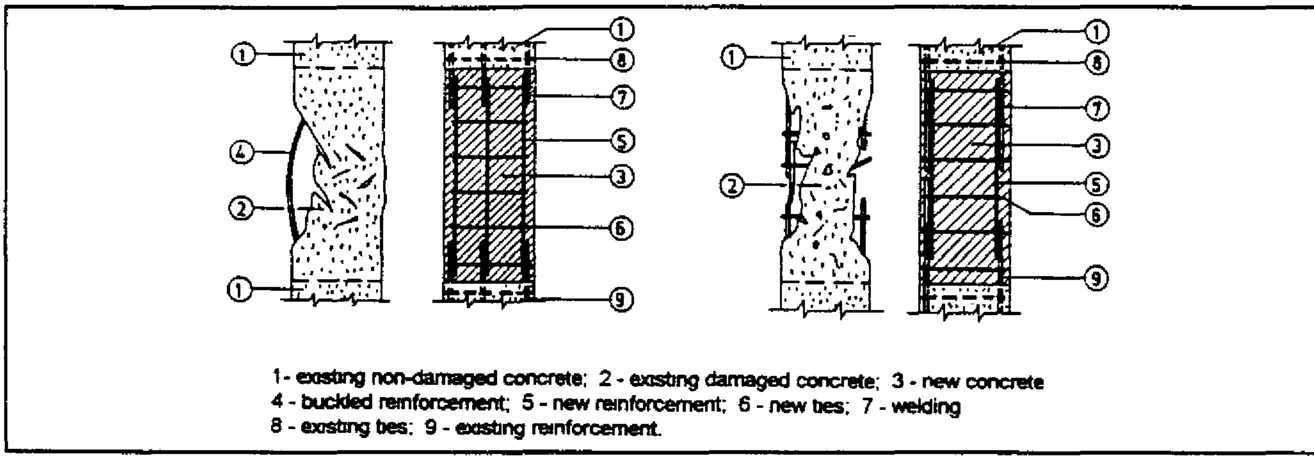


Figure 12.2-3 Removal and Placement of Damaged Parts [3]

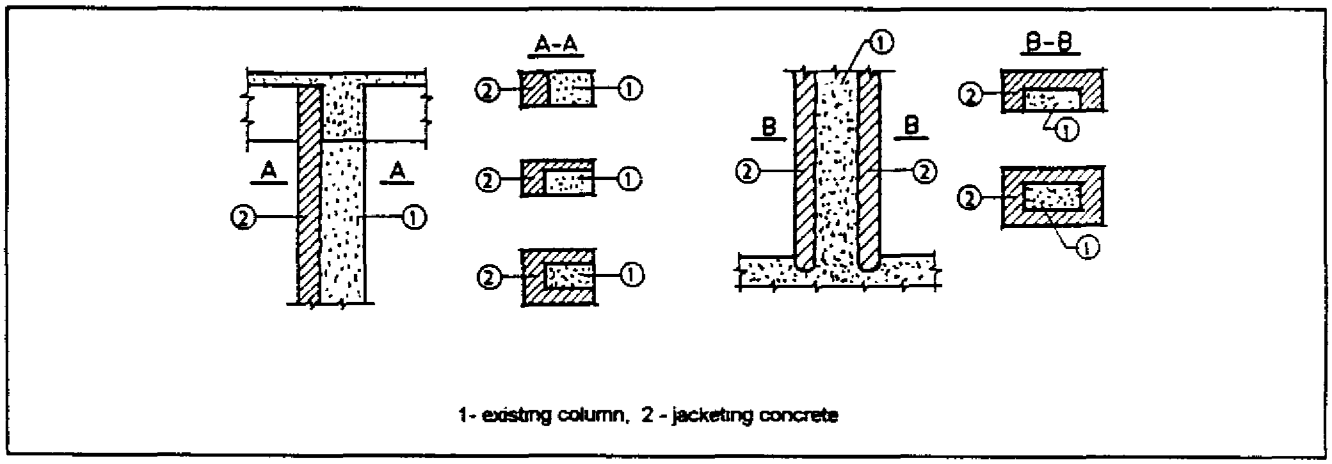
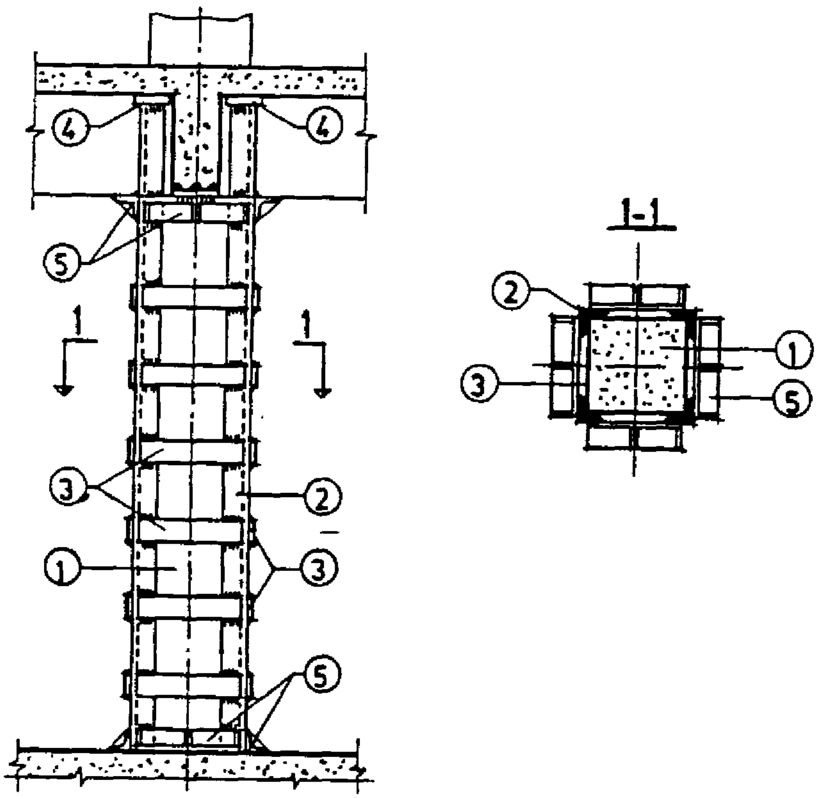


Figure 12.2-4 Reinforced Concrete Jacketing [3]



1 - existing column; 2 - steel angle profile; 3 - steel plate
4 - supporting plate, 5 - angle profile

Figure 12.2-6 Steel Profile Jacketing

Topic 12.3: Strengthening of Beams

The strengthening of beams is to provide strength and stiffness of beams to resist gravity and seismic loads. The chosen pro cedure must provide strength and stiffness to the beams in relation to the columns, so as to avoid creating structures of the 'strong-girder/weak-column' type, which tend to force seismic hinging and distress into the column.

Depending on the type of damage (cracking, crushing of concrete, rupture of reinforcement or ties), the techniques for repairing and strengthening beams are quite similar to those for columns.

Local Repairs

Injection is applied for repair of damaged beams with slight cracks only. Epoxy or cement grout injections are made.

Removal and replacement should be applied when heavy damage like crushing of concrete, deterioration of bond or rupture of reinforcement occurs. Before the removal of crushed concrete or rupture reinforcement, the damaged beam must be temporally supported. The replacement procedure for beams is similar to that of columns. More attention must be paid to compact the new concrete under existing beams or slabs, which is extremely difficult if placement access is not provided from the top surface of the beam.

Reinforced Concrete Jacketing

Reinforced concrete jacketing is done by adding concrete on one, three or four sides of a beam. To create bonds between old and new concrete and for welding of the added reinforcement to the existing, the concrete cover must be chipped away. An irregular shaped concrete surface, combined with anchoring welded stirrups, provide good shear and tensile connection of the jacket to the beam.

Reliable anchorage of vertical bars in joint areas by sufficient length or by welding to anchors, is of great importance. Shear and ductility improvement can be provided by stirrups on all sides of the beam. The legs of the stirrup should penetrate and be anchored into the slab at the top of the jacket.

One-sided jackets (Figure 12.3-1) adding strength only to the beam soffit, should be used only when it is necessary to increase the flexural strength of a beam. The connection between existing and new longitudinal reinforcement is achieved by welded connection bars (See Figure 12.3-1). The concrete cover should be chipped away up to the reinforcement and higher at existing stirrups. Additional stirrups welded to the exist ing ones provide the connection between the existing beam and the newly-added concrete. The longitudinal reinforcement bars should be anchored in the support region by welding the rein forcement to a collar of steel angle profile, at the top of the column.

Four-sided jacketing (Figure 12.3-2) or beam encasement adds flexural and shear strength because of the increase of rein forcement area and concrete cross section. The additional lo ngitudinal reinforcement should be connected with the existing reinforcement by diagonally welded bent bars or small steel plates. The stirrups pass through holes drilled in the slab and surround the whole beam. These holes can also be used to place the concrete in the part of the jacket beneath the slab. Addi tional reinforcement for negative bending moments must be added over the slab surface into the beam region and outside of the existing column. Special attention must be paid to the anchorage of the longitudinal bars in the joint region of the column jacket.

Jacketing three sides of the beam can also be installed beneath the soffit of the slab (Figure 12.3-3). Shotcrete is the most feasible method of installing this type of jacket. Its weakness is the anchorage of the new stirrups at the top of the jacket. This detail is inferior to that shown in Figure 12.3-2 as the effectiveness of the detail depends on the dynamic strength of the power driven nails and the stiffness of the strand to pro vide effective anchorage for the new

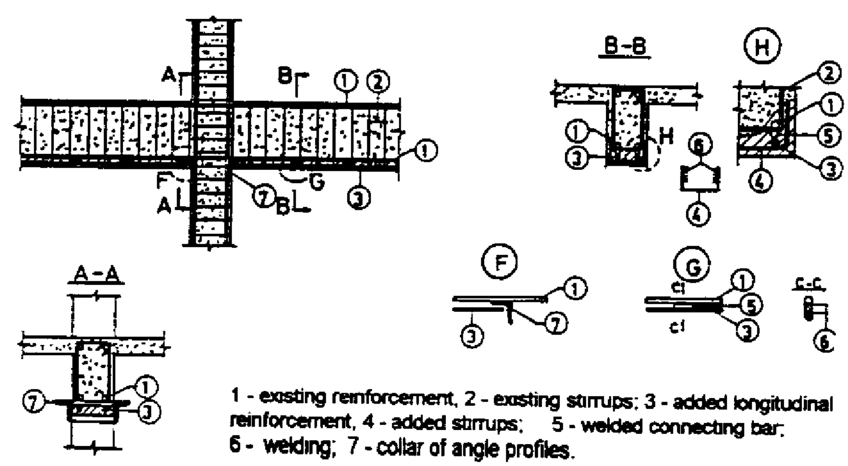


Figure 12.3-1 One-sided Jacket [3]

stirrups. Increased strength might be achieved by using a continuous steel plate with epoxy resin bolts installed in the concrete, with the new stirrups welded to or hooked around the steel plate.

Reinforced concrete jacketing of beams should conform to the following:

- The strength of the new materials should be greater than that of the existing beam.
- The thickness of the jacket should not be less than 4 cm for shotcrete application or 8 cm for cast-in-situ concrete.
- Top and bottom reinforcement should be anchored within column joint area with full development length, beginning from the face of the column, or continuous through the joint region.
- At support regions, the stirrup spacing must not be more than 1/4 of the beam height. Outside this region, the stirrup spacing can be doubled.
- The beams must not be made too stiff or strong with respect to the columns

Repairing Gravity Load Capacity of Beams

Steel rods can be used to improve the shear resistance of damaged or undamaged beams. It can be performed by vertical or diagonal external clamps (Figures 12.3-4 a/b). The clamps consist of round rods with threads at the end tightened with nuts Vertical clamps are fixed on angle profiles, but diagonal clamps are welded to longitudinal reinforcement to resist the longitudinal component of force. If load reversal is anticipated, four-sided jacketing is the preferred method for strengthening.

Steel plate reinforcement is a new technique which can be used for beams subject primarily to static loading to improve their shear strength or mid-span flexural strength. The steel plates are attached to concrete surfaces of the reinforced concrete members by gluing with epoxy resin. During the epoxy hardening, the steel plates must be clamped to the concrete member It is recommended that the steel plates also be anchored by either nails shot into the concrete or anchor bolts (wedged or epoxied) It is advisable for the beam to be smoothed with a thin layer of expansive cement mortar for plates with thickness more than 3 mm. In this case, wedge anchor bolts must be applied. Special attention must be paid to corrosion and fire protection, especially considering the total loss of epoxy resin strength at temperatures higher than 250°C This procedure is not recommended for beams subject to cyclic loading due to earthquake forces.

reinforced concrete, strengthening, local repair, jacketing, beam, beam shear.

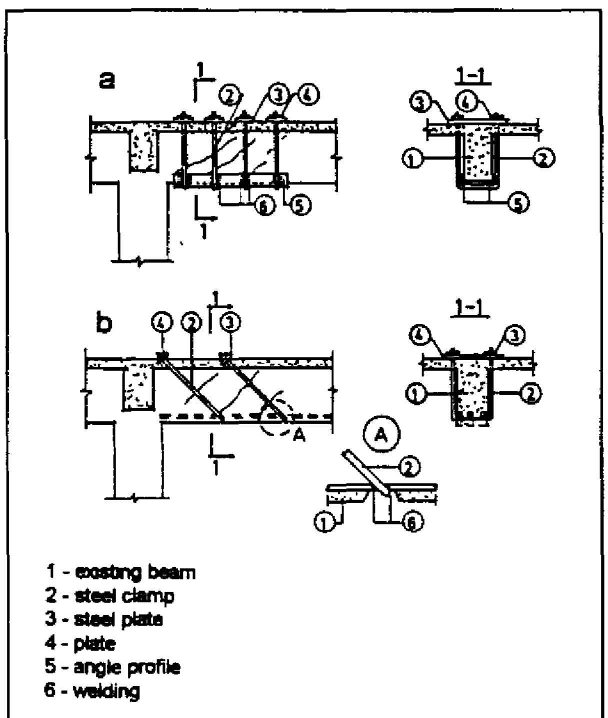


Figure 12.3-4 Improving Shear Resistance by External Clamps

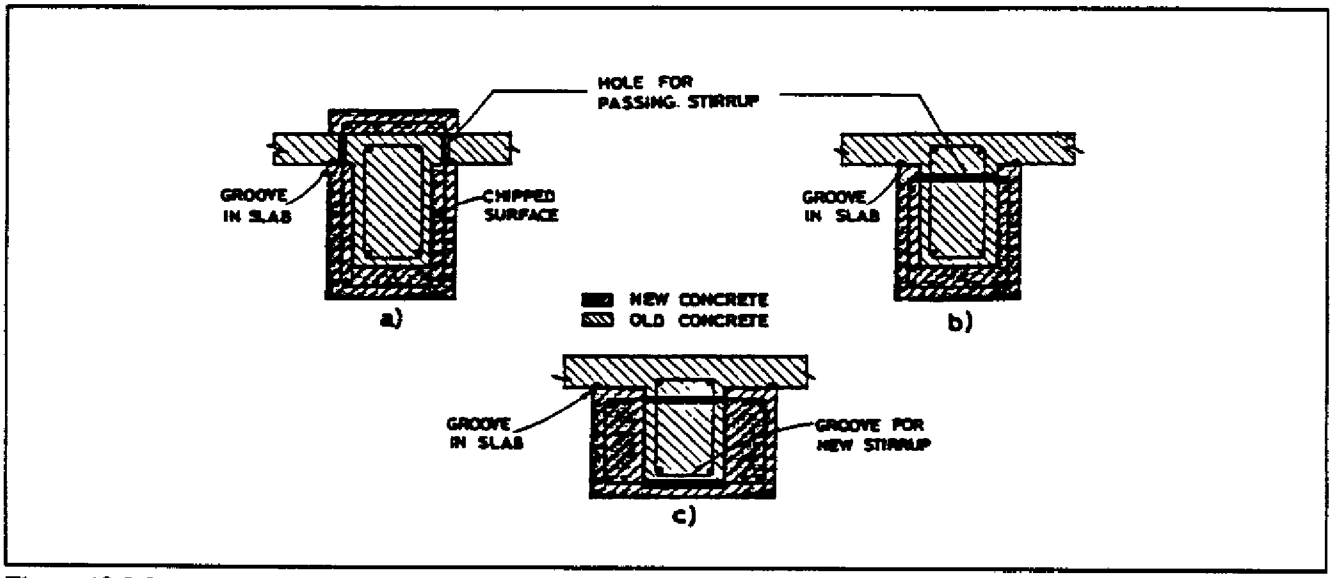


Figure 12.3-2 Three and Four-sided Jacketing [1]

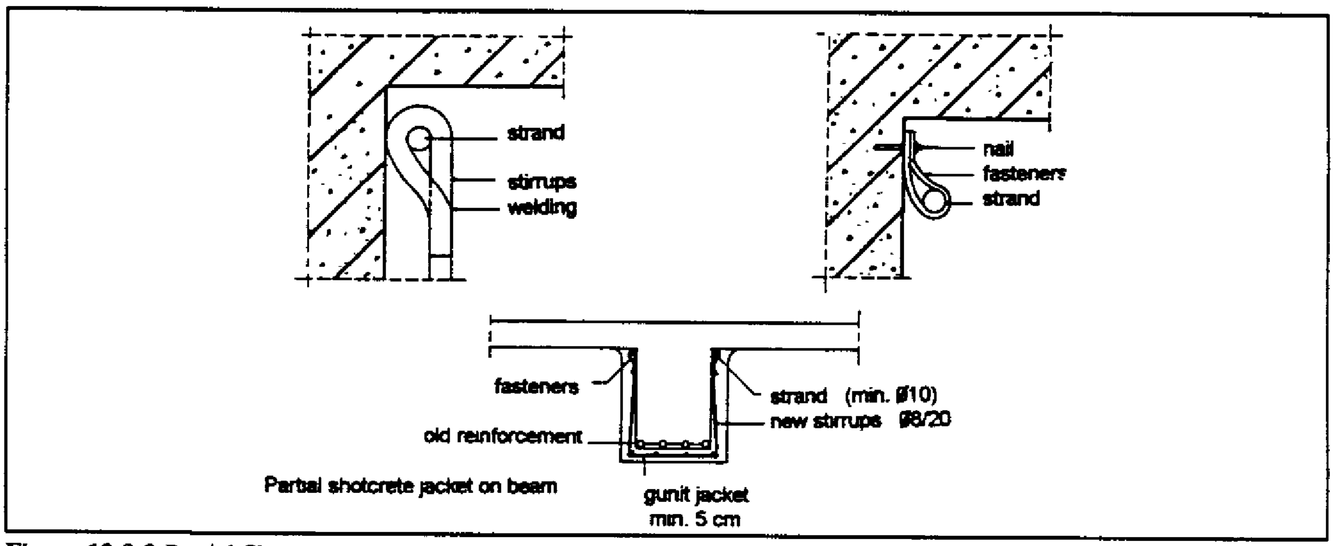


Figure 12.3-3 Partial Shotcrete on Beam [3]

Topic 12.4: Strengthening of Reinforced Concrete Walls

R.C walls, because of their great stiffness and lateral strength, provide the most earthquake resistance of the building. Therefore, a severely damaged or a poorly designed shear wall must be repaired or strengthened in order that the structure's strength for seismic force can be improved.

Local Repairs
Injection with epoxy resin for crack repairs in shear walls has become a standard practice over the last decade. If neither bond deterioration nor concrete crushing have occurred, epoxy injections are capable of restoring approximately the original wall strength. However, the repaired wall will never achieve the stiffness of the original wall. Not all of the small cracks can be epoxy injected. Another disadvantage is the rapid loss of strength of epoxy under fire. Epoxy repair of walls is simple, fast and economical, without changing the original wall size and without evacuation of the inhabitants. Higher strength in walls than the original strength cannot be attained by epoxy injections. Therefore, if additional strength is required, another technique must be used.

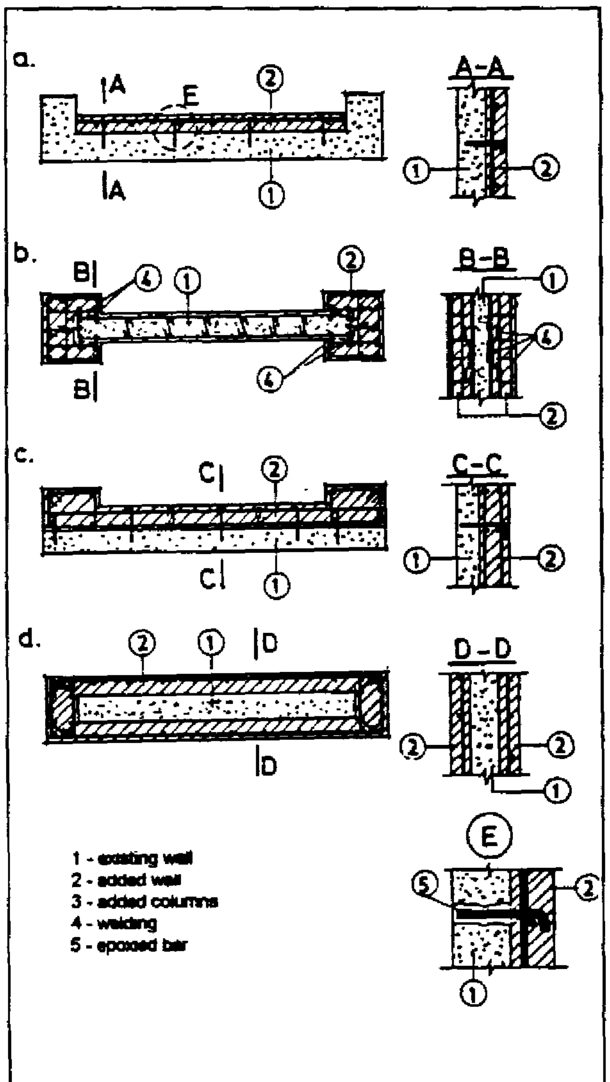


Figure 12.4-1 Adding Strenght to existing Concrete Shear Wall

Removal and replacement should be applied for large cracks, partially crushed concrete and buckled reinforcement. After removing the loose concrete and roughening and cleaning the remaining surface, additional reinforcement or welded wire fabric should be placed. The choice of repair material (polymer mortar, cement mortar, concrete or shotcrete) depends on the degree of damage, the desired repair characteristics and the site conditions. Non-shrinkage or expansive cement for mortar and concrete is often desirable. Special care must be paid to adequately compact the new concrete, especially at contact regions with the existing concrete.

Increase of Wall Size
Thickening the wall with reinforced concrete should be applied when the original strength of a damaged or undamaged wall is insufficient. There are different ways to add strength to an existing concrete shear wall (12.4-1). Shotcrete is a frequently used technique in strengthening concrete shear walls.
When shear strength is to be increased, thickening the web with additional reinforced concrete is necessary (Figure 12.4-1). For this web reinforcement (horizontal and vertical bars) is added. The reinforcement and the concrete must be anchored to the existing wall by roughening of the surface and by special anchor bolts.
An appropriate solution is the application of epoxied bars with 90° hooks. Anchorage of the added web reinforcement can also be achieved by epoxying dowels in holes drilled into the wall.
If an increase in flexural strength of a shear wall is required, reinforced flanges must be added to both ends of the wall (Figure 12.41). The new flange concrete must be confined by appropriately detailed, closely spaced hoops and cross ties. The anchorage of the flange concrete to the original wall is very important. It can be performed by welding of special bent bar connectors to the new and theold reinforcement or by epoxied anchor bars.
If both flexural and shear strength must be increased, reinforced concrete must be added to both parts - the web and the cross- sections ends. Solutions with one-sided (Figure 12.3-4) or two-sided (Figure 12.3-4) web thickening are possible. The two-sided solution gives better results but it is more expensive and requires access to both sides of the wall. Ties through holes, in the wall, and hooking around the reinforcement on each side provide a basketing effect, which adds strength to the wall. An example of a two-sided shear wall strengthening is given in Figure 12.4-2.

Shear forces between the shear wall and the floor slab must be transmitted. For this purpose, concrete dowel connections are made by opening holes through the slab. These holes also serve to concrete the new wall parts beneath the slab. Diagonal reinforcement bars, passing through the slab and anchored in the upper story and lower story walls, provide an additional connection for shear transfer.

To provide a bond between the old and the new concrete and for welding connection bars to the reinforcement, some concrete cover must be chipped away. The original wall surface should be roughened, any paint or plaster removed. Additional shear is transmitted from the existing to the new wall by epoxied dowels in the existing surface

Reinforced concrete thickening of shear walls should also conform to the following:

- The strength of the new materials should be greater than those of the existing walls.
- The web thickness of the new material should be at least 5 cm. The thickness of the new shear wall flanges should be at least 10 cm.
- Both the horizontal web reinforcement and the vertical web reinforcement must not be less than 0.0025 times the gross area of the wall thickening.
- The area of the vertical reinforcement concentrated at the wall ends must not be less than 0.0025 times the gross area of the newly added cross section.
- The end wall ties should not be less than 8 mm in diameter. The tie spacing should be no more than the thickness of the wall end thickening or maximum 15 cm.
- The new concrete should be anchored to the existing concrete with epoxied hooked dowels at a maximum of 60 cm in each direction and the existing wall surface should be thoroughly roughened.

reinforced concrete, strengthening, wall, local repair, shear wall.

1 - existing wall, 2 - existing slab, 3 - added longitudinal reinforcement; 4- added wire fabric; 5 - diagonal connecting bars; 6 - added ties

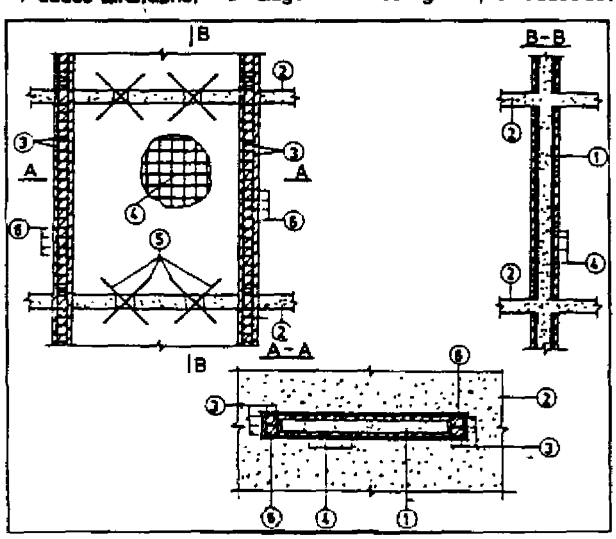


Figure 12.4-2 Two-sided Shear Wall Strenghtening

Topic 12.5: Strengthening of Slabs

Slabs have to carry vertical gravity loads. However, they must also provide diaphragm action and be compatible with all lateral resistant elements of the structure. Therefore, slabs must possess strength and stiffness. Damages in slabs generally occur in locations with irregularities such as near large openings, at concentration of forces close to widely spaced shear walls and at staircase landings Repair of slabs is necessary when damage occurs. Strengthening is applied when there is insufficient slab strength or for increased strength in the region of newly-introduced shear walls

Local Repairs

Injection should be applied for repair of cracks. Epoxy or cement grout can be used Restoration of the connection between the separated concrete parts can be achieved.

Removal and replacement procedures should be applied in cases of spalled concrete and broken or buckled reinforcement. Floor slabs or staircase slabs can be repaired in this manner (Figure 12.5-1). After the removal of the unsound materials, new reinforcement is incorporated and it is welded to the existing reinforcement. Concrete with better properties than the existing concrete should be used.

Increasing Slab Thickness

Strengthening by thickening of slabs should be applied in cases of insufficient strength or stiffness The thickening can be done above or under the existing slab In the first case (Figure 12.5-2(a)), the flexural strength is increased because of the increased effective depth and ability to add negative reinforcement as supports. In the second case (Figure 12.5-2(b)), the flexural strength increases because of the newly added tension reinforcement. In the case of 'a', normal concrete is used, in the case of 'b', the application of shotcrete is more suitable. The strengthening according to case 'a' provides greater floor slab stiffness for diaphragm action and is strongly recommended. In case 'b', the performance will be improved if the beams are also jacketed

For compatibility of the slab and the newly-added reinforced concrete, an excellent shear bond is of great importance. It can be achieved by the following:

- Reinforced concrete lugs (Figure 12 5-3(a)).
- Roughing the surface, realized by gluing of sand grains with epoxy resin (Figure 12 5-3(a)).

Epoxied steel dowel bars (Figure 12 5-3(b)). Additionally shaped concrete lugs in slab voids (Figure 12.5-3(c)). Steel dowels made either by steel angle, anchored by power concrete nails or by epoxied bolts or wedge anchor bolts (Figure 12 5-3(d))

Roughening of the surface improves the bond between original and new concrete It can also be performed by sandblasting or by chipping with special mechanical equipment

reinforced concrete, strengthening, slab, local repair

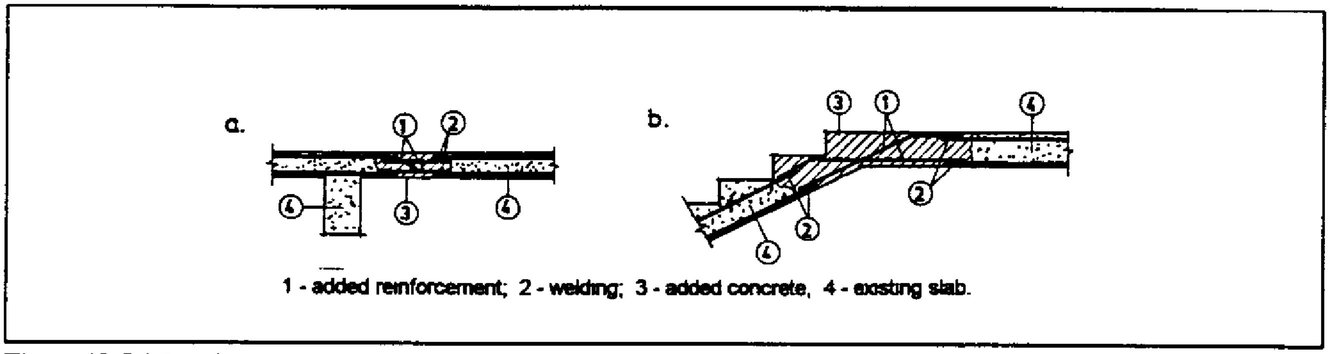


Figure 12.5-1 Reinforcement of Floor Slabs or Staircase Slabs

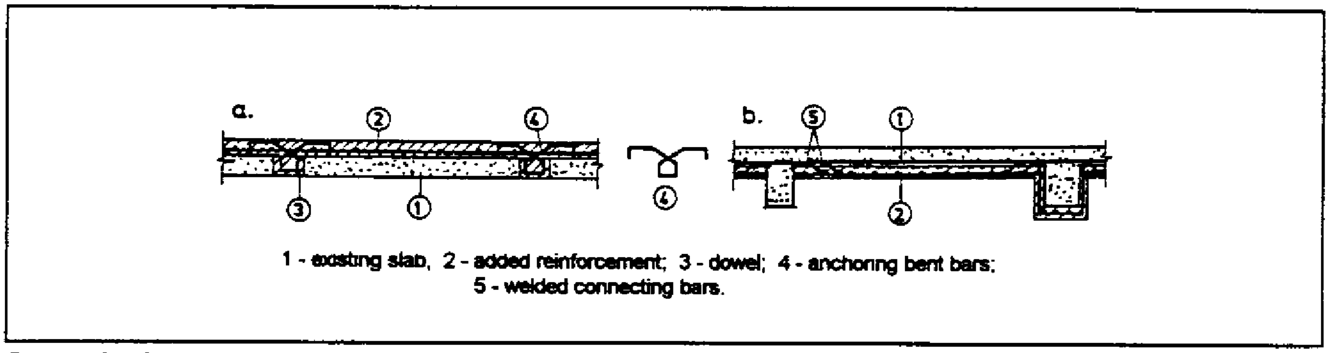


Figure 12.5-2 Strenghtening by Thickening of Slabs

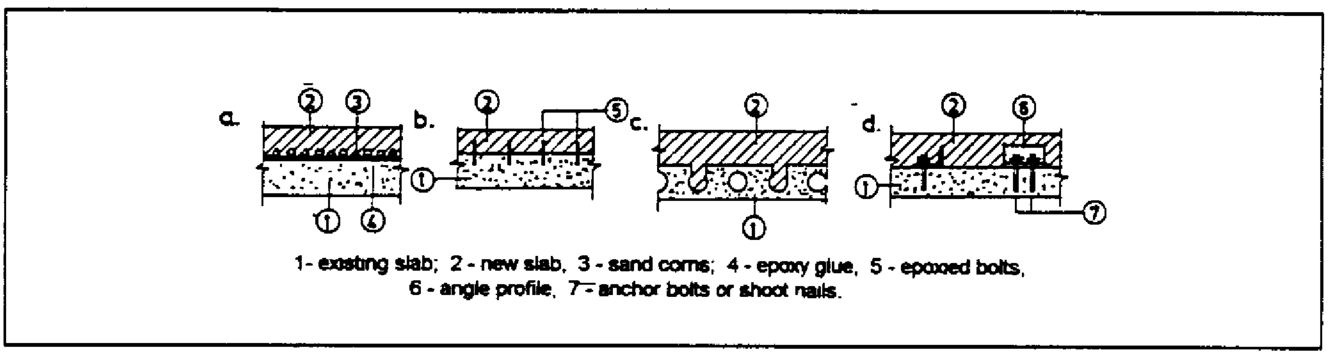


Figure 12.5-3 Achieving Excellent Shear Bond

SESSION 13: DESIGN, CONSTRUCTION AND STRENGTHENING OF MASONRY CONSTRUCTION

Topic 13.1: Design and Construction of Masonry Constructions

Since masonry failure is so common, some earthquake codes ban the use of unreinforced masonry in multi-storey buildings. Economic reasons lie behind the wide use for low-rise structural buildings and as infill to frame structures. Failures of both reinforced and unreinforced masonry (in plane and out of plane) are common. Cracks are often concentrated around openings and corners. Cracking frequently follows the mortar joints and has a diagonal form. Horizontal and vertical reinforcement in masonry walls tie the building together and make it act as one strong unit.

Mortar

Since tensile and shear strength are important for seismic resistance of masonry walls, the use of mud or very lean mortars is unsuitable. A mortar mix cement:sand equal to 1:6 by volume or equivalent in strength should be the minimum. Appropriate mixes for various categories of construction are recommended in Table 13.1-1. (The strength of the mortars decreasing from I to IV)

Category of construction	Proportion of Cement-Lime-Sand
I	Cement-sand 1 4 or Cement-lime-sand1 1 6 or richer
II	Cement-lime-sand 1 2.9 or richer
III	Cement-sand 1.6 or richer
IV	Cement-sand 1·6 or Lime-Cinder* or richer

*) see topic 3.2

Table 13.1-1 Recommended Mortar Mixes

Openings in Walls

Studies of the effect of openings on the strength of walls indicate that they should be small in size and centrally located. The following are some guidelines on the size and position of openings:

1. Openings to be located away from the corner by a clear distance equal to at least 1/4 of the height of openings.
2. The total length of openings not to exceed half the length of the wall between consecutive cross walls
3. The horizontal distance between two openings (pier width) to be not less than 1/2 of the height of the shorter opening (Figure 13 1-1)
4. The vertical distance from an opening to an opening directly above it not to be less than 60 cm nor less than 1/2 of the width of the bigger opening (Figure 13.1-1).
5. When the openings do not comply with requirements (1) to (4), they should either be boxed in reinforced concrete all around or reinforcing bars should be provided at the jambs through the masonry (Figure 13 1-2).

Horizontal Reinforcement in Walls

As stated earlier, horizontal reinforcing of walls is required for gaining horizontal bending strength against plate-action for out of plane inertia load and for tying the perpendicular walls together In the partition walls, horizontal reinforcement helps preventing shrinkage and temperature cracks The following reinforcing arrangements are necessary

Horizontal Band or Ring Beam:

The most important horizontal reinforcement is through reinforced concrete bands provided continuously through all (load bearing longitudinal and transverse) walls A band consists of two (or four) longitudinal steel bars with links or stirrups embedded in 7,5 cm (or 15 cm) thick concrete (Figure 13.1-3). The thickness of a band should be equal to a multiple of the masonry unit and its width should be equal to the thickness of the wall. The steel bars are located close to the wall faces and full continuity is provided at corners and junctions. The minimum size of band and amount of reinforcement will depend upon the unsupported length of wall between cross walls and the effective seismic coefficient, based on seismic zone, importance of buildings, type of soil and storey of the building.

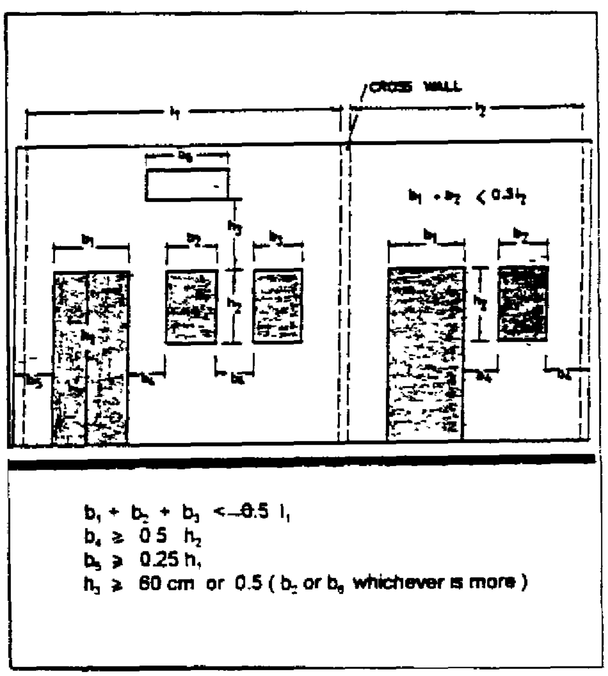


Figure 13.1-1 Recommendation Regarding Openings in Bearing Walls [1]

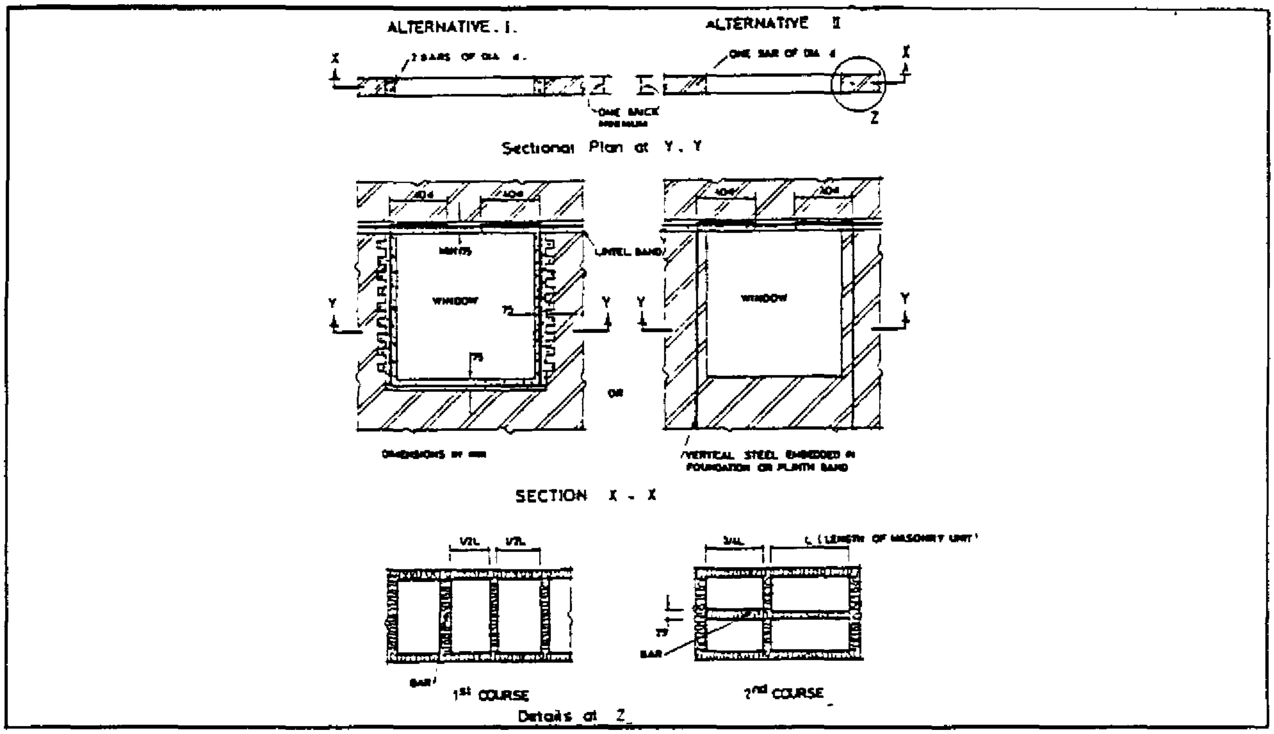


Figure 13.1-2 Reinforcement of Masonry around Openings [1]

Appropriate steel and concrete sizes are recommended for various buildings in Table 13.1-2. Such bands are to be located at critical levels of the building, namely plinth, lintel, roof and gables according to requirements.

Longitudinal Steel in R.C. Bands								
Span (m)	Category I		Category II		Category III		Category IV	
	No of Bars	Dia of Bars	No. of Bars	Dia of Bars	No. of Bars	Dia of Bars	No. of Bars	Dia of Bars
5	2	12	2	10	2	10	2	8
6	2	14	2	12	2	10	2	10
7	2	16	2	14	2	12	2	10

notes

1 Width of the RC band is to be the same as the tickness of wall. Wall tickness shall be 20 cm minimum.

2 The vertical tickness of RC band may be kept minimum 7,5 cm where two logitudinal bars are specified and 15 cm where four longitudinal bars specified.

3 Concrete mix to be 1:2:4 by volume or having 20 N/mm2cube crushing strenght at 28 days.

4 The longitudinal bars shall be held in position by steel links or stirrumps 6 mm dia. spaced at 15 cm apart (see figure 13 1-3)

Table 13.1-2 Recommendation for Steel in R.C. Band

1 Plinth Band: This should be provided in those cases where the soil is soft or uneven in its properties, as it usually happens on sloping sites It will also serve as damp course.

2. Lintel Band: This is the most important band to be incor porates in all door and window lintels. Its reinforcement should be extra to the lintel band steel and be provided in all storeys

3. Roof Band: This band is required at eave level of trussed roofs (Figure 13.1-5) and also below or on level with such floors which consist of joists and covering elements so as properly to integrate them at ends and fix into the walls

4. Gable Band: Masonry gable ends must have the triangular portion of masonry enclosed in a triangular band. Its horizontal part will be continuous with the eave level band on longitudinal walls (Figure 13.1-4).

In the case of adobe construction in zones B and C (but not to be allowed in A) timber runners may be used on both sides of the walls, interconnected at regular interval through cross pieces and made continuous at corners and T-junctions of walls

Dowels at Corners and Junctions

As an alternative to the band described in (A), steel dowel bars may be used at corners and T-junctions to integrate the box action of walls. Dowels (Figure 13.1-6) are placed in every fourth course or at about 50 cm intervals and taken into the walls to sufficient length so as to provide the full bond strength. Wooden dowels can also be used instead of steel. How ever, these dowels do not serve to reinforce the walls in horizontal bending except near the junctions

Reinforcement of Partitions and Infills

Partitions and infill panels are necessarily thin walls and need reinforcing for their out of plane stability. The easiest method will be to provide a thin steel mesh or welded wire fabric every fourth course or 30 cm height (Figure 13.1-7). This reinforcement must be dowelled into the bounding walls or columns at the ends or nailed to wooden columns in wood frame construction.

Vertical Reinforcement in Walls

The need for vertical reinforcement of shear walls at critical sections has been shown by the effect of past earthquakes. The critical sections are the jambs of openings and the corners of walls. The amount of vertical reinforcing steel will depend upon several factors such as the number of storeys, storey heights, the effective seismic coefficient based on seismic zone, importance of the building and soil foundation type. Values based on rough estimates for building are given in Table 13.1-3 for ready use. The steel bars are to be installed at critical sections, that is the corners of walls and jambs of doors right from the foundation concrete and covered with cement concrete in cavities, made around them during masonry construction. This concrete mix should be kept to 1:2:4 by volume or richer and made with small aggregates. Typical arrangements of placing the vertical steel in brick work are shown in Figure 13.1-8. The jamb steel is shown in Figure 13.1-2. The jamb steel of window openings will be easiest to be provided in box form around it. The vertical steel of opening may be stopped by embedding it into the lintel band but the vertical steel at corners and junctions of walls must be taken into the floor and roof slabs or roof band. All bars should be securely fixed at the bottom to the foundation.

One of the advantages of hollow blocks is that they can be easily reinforced: rods are set vertically in cavities which are then filled with concrete and compacted by ramming.

If normal aggregate is used there is the fear that some stones will jam between the rod and the block preventing the rest of the concrete from filling the whole of the cavity. This can be prevented by using concrete of high plasticity and with small aggregate (grout) and making the cavity large enough to permit the concrete to fall on all sides of the rod without jamming (Figure 13.1-9).

Where block walls are used the shortest dimension of a cavity should never be less than 50 mm. Where the shortest dimension is between 50 mm and 100 mm the concrete mix should be 1 part cement: 2 parts sand: aggregate of size between 12 and 5 mm. Where the shortest dimension of the cavity is more than 100 mm the size of the aggregate may be increased to 20 mm.

The pours of concrete should never be more than 1.2 m in height. There is a practical difficulty about fixing the bars at the bottom; if bars are cast into the foundation they will project the full height of the wall and it will not be easy to lift blocks over them. One way of overcoming this difficulty is to leave kicker bars projecting from the foundation for at least 1000 mm. Then, when the wall is halfway up, inserting bars from the top into the cavities and filling them with con crete; care should be taken when filling so that the upper bar is near the middle of the cavity and not pressed against one side.

	Diameter Steel bar in mm at each critical Section for Category*			
No. of Storeys	**Cat. I**	**Cat. II**	**Cat. III**	**Cat. IV**
One -	16	14	12	Nil
Two Top	16	14	12	Nil
Bottom	20	16	14	12
Three Top	16	14	12	Nil
Middle	20	16	14	12
Bottom	20	16	16	14

* Equivalent area of twisted grip bars or a number of mild steel bars could be used but the diameter should not be less than 12 mm.

Table 13.1-3 Recommendations For Vertical Steel At Critical Sections

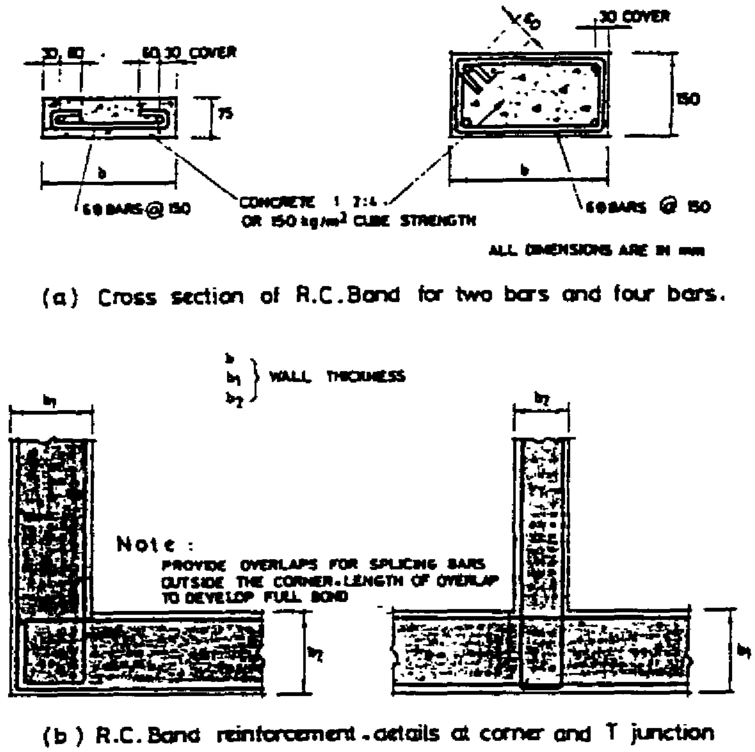
Framing of thin masonry wall

If load bearing walls are made thinner than 20 cm, excluding plastering on both sides, reinforced concrete framing columns and collar beams are necessary, as shown in Figure 3.1-2(c), which are constructed to have full bond with the walls. Columns are located at all corners and junctions of walls as well as on both sides of door openings. The collar beams are provided at bottom as well as at top of storeys. Typical reinforcing details are shown in Figure 13.1-10 (see Topic 13.2).

Note: To achieve good concrete bond with masonry, masonry should be raised first to a certain height and con crete poured against the masonry, the wooden form being used only on open sides of the column.

It is not suggested to use walls thinner than 20 cm due to the slenderness effect and the great amount of steel reinforcement required.

masonry design, mortar, wall, band, reinforcement, roof, grouting, framing.



In areas where timber for shuttering is expensive a simple method of making a ring beam is to precast U-shape concrete blocks: these are laid on top of the wall, reinforcement is laid in them and the U is filled with concrete.

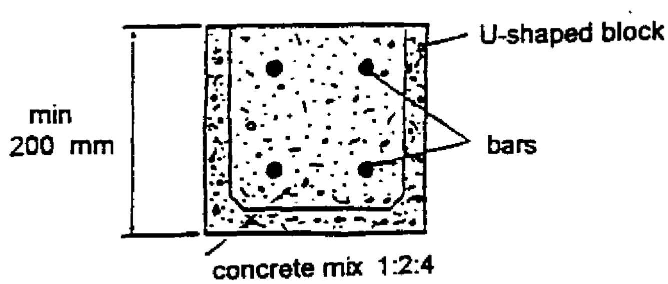


Figure 13.1-3 Reinforcement in R.C. Band [1,7]

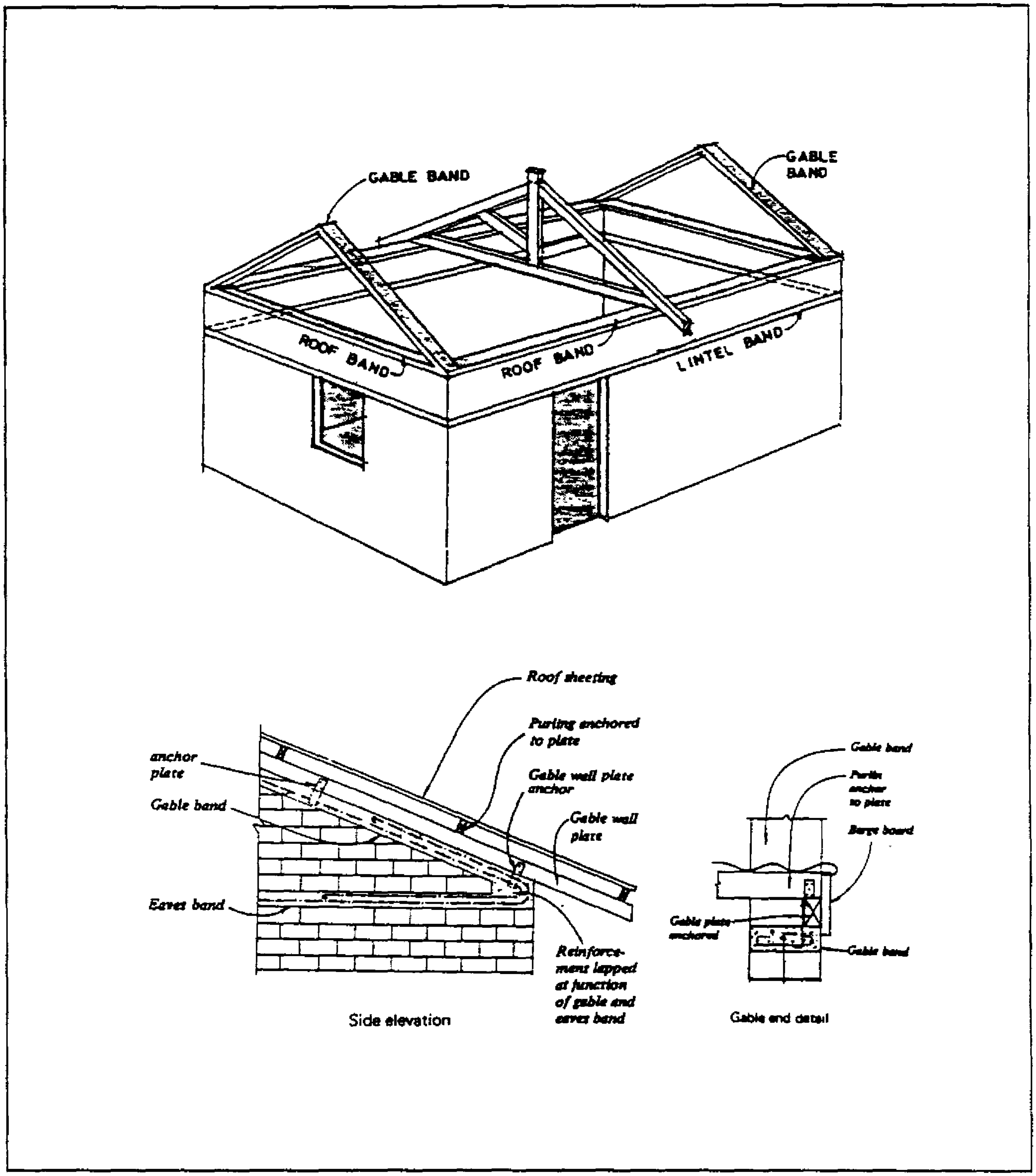


Figure 13.1-4 Gable Band Details [1.2]

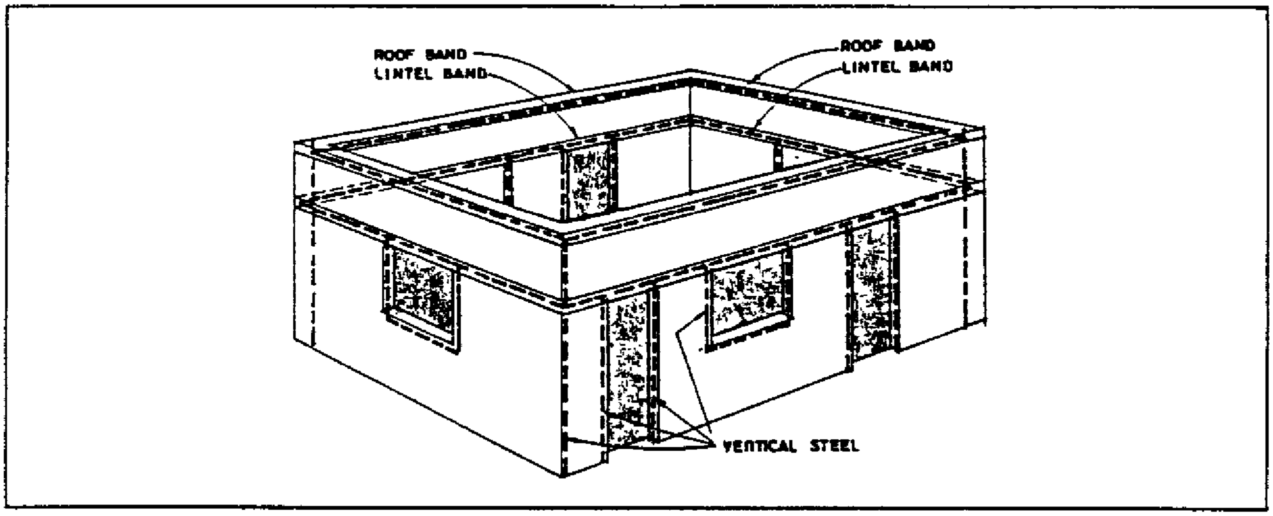


Figure 13.1-5 Gable Band and Roof Band in Barrack Type Buildings [1]

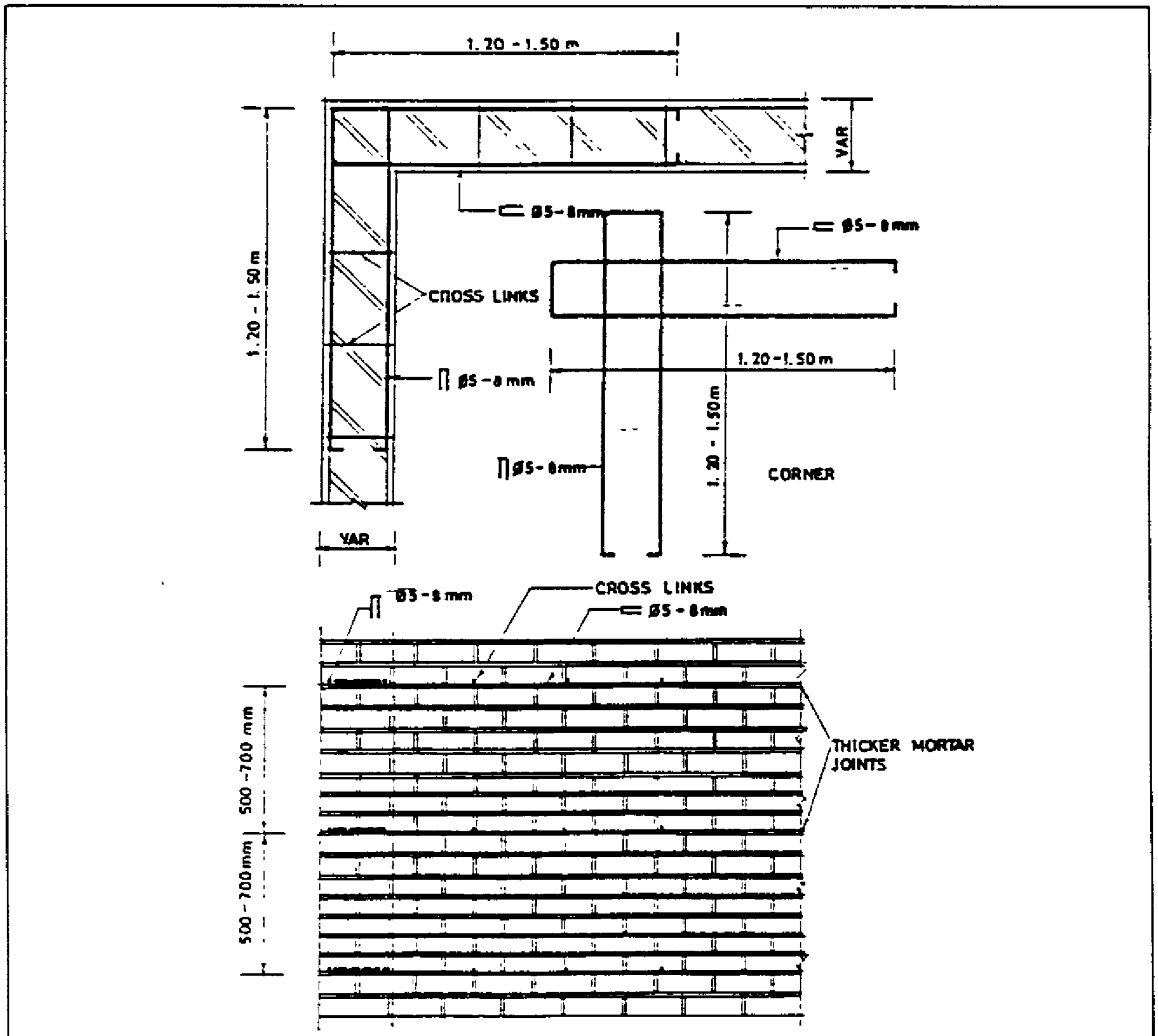


Figure 13.1-6a Horizontal Reinforcement Placed in Joint [1]

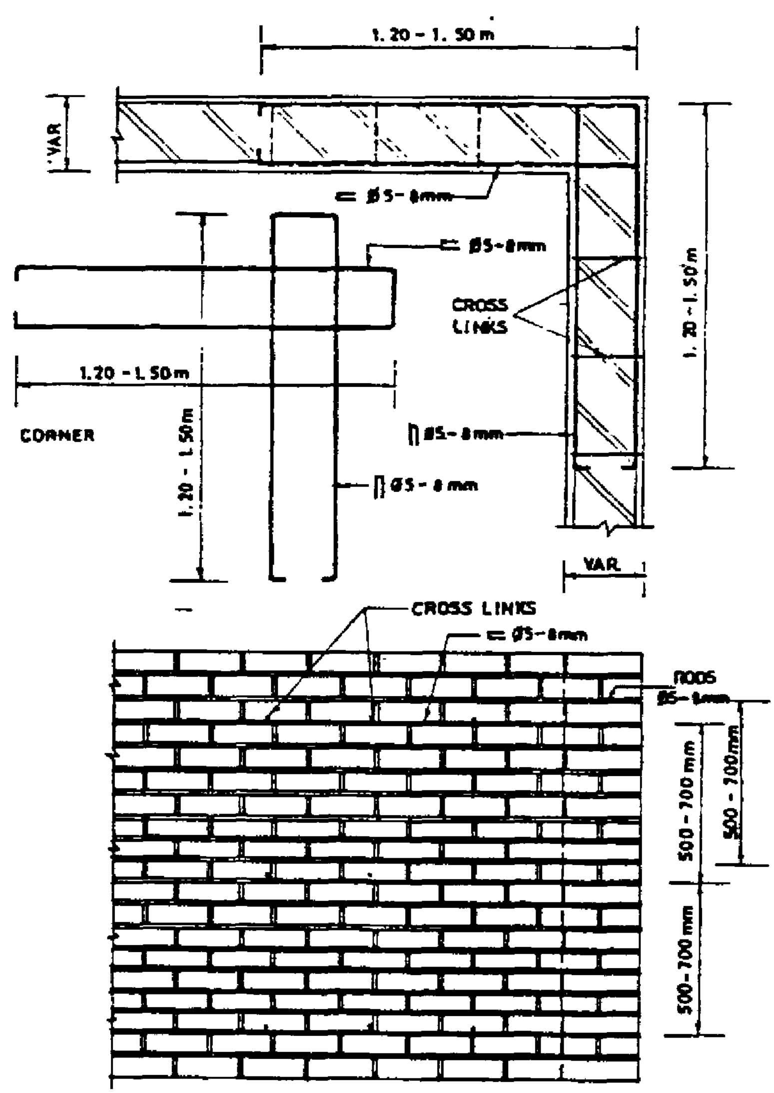


Figure 13.1-6b Horizontal Reinforcement in Adjacent Joint [1]

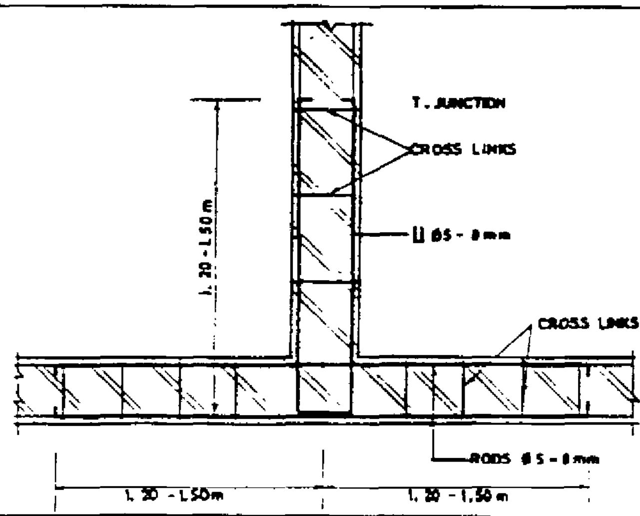


Figure 13.1-6c Horizontal Reinforcementat T- Junction [1]

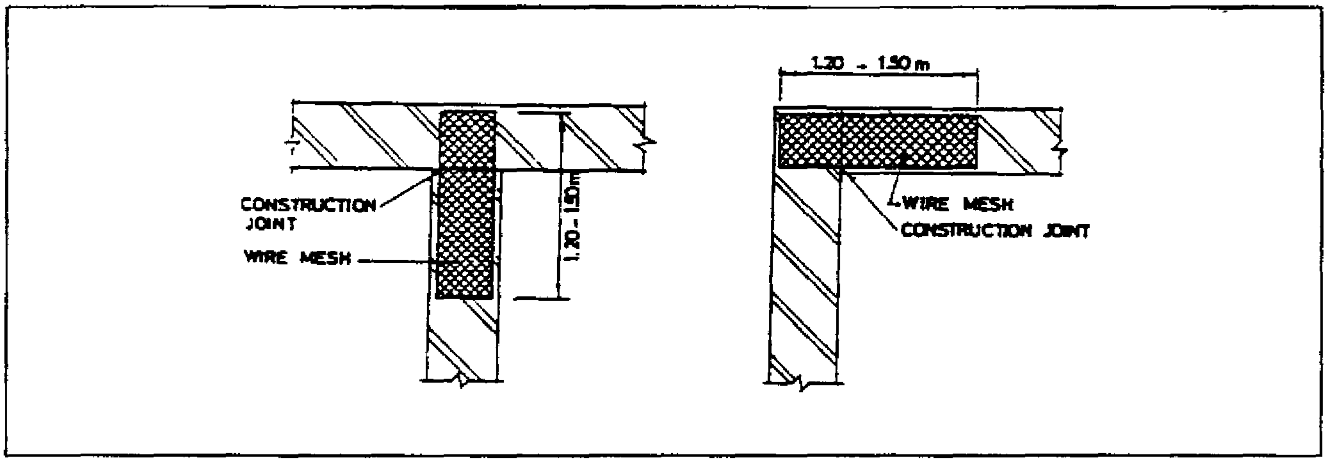


Figure 13.1-6d Horizontal Reinforcement by Wire Fabric at Junction and Corner [1]

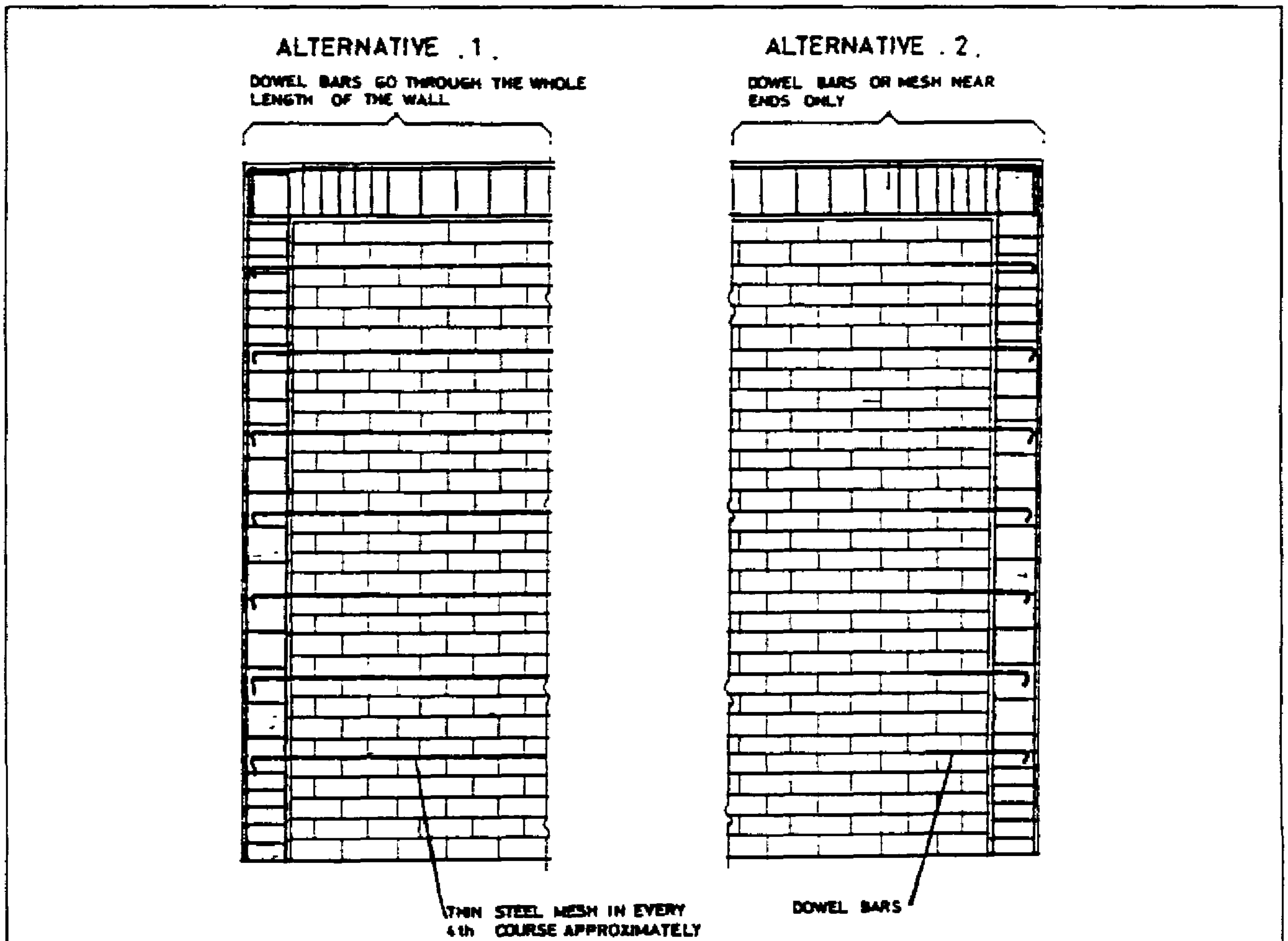


Figure 13.1-7 Brick Infill with RC Frame by Dowel Bars [1]

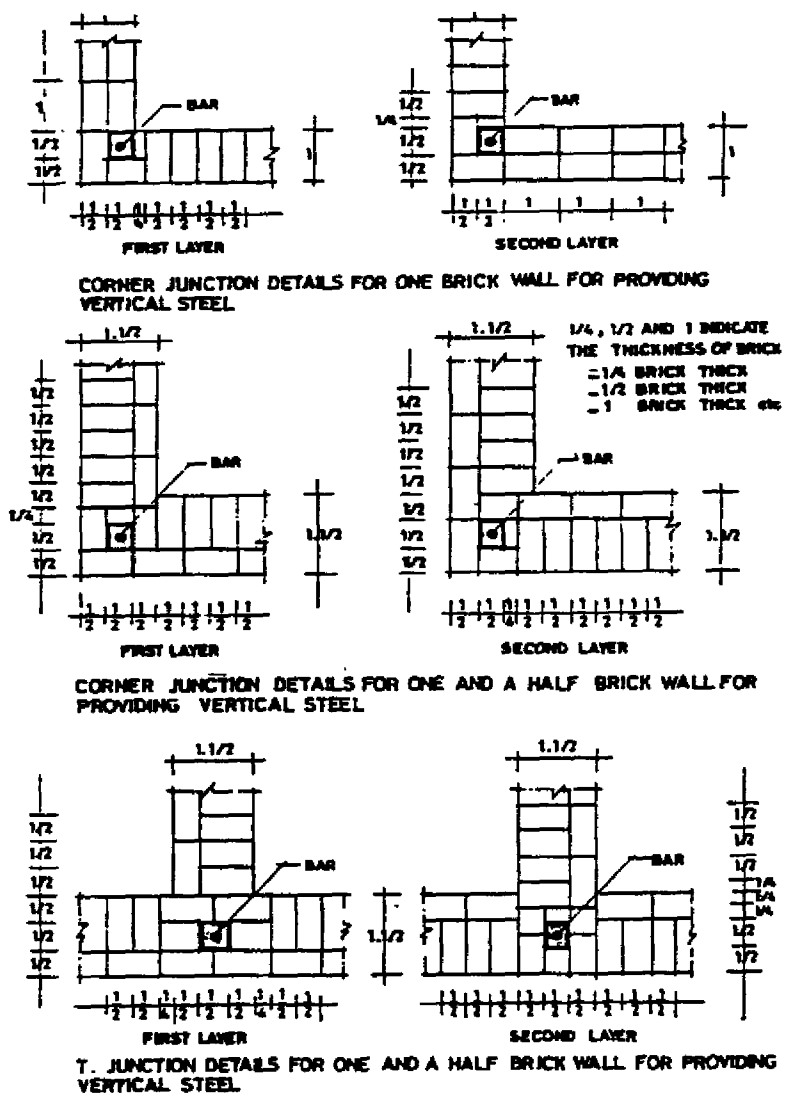


Figure 13.1-8 Vertical Reinforcement in Masonry Walls [1].

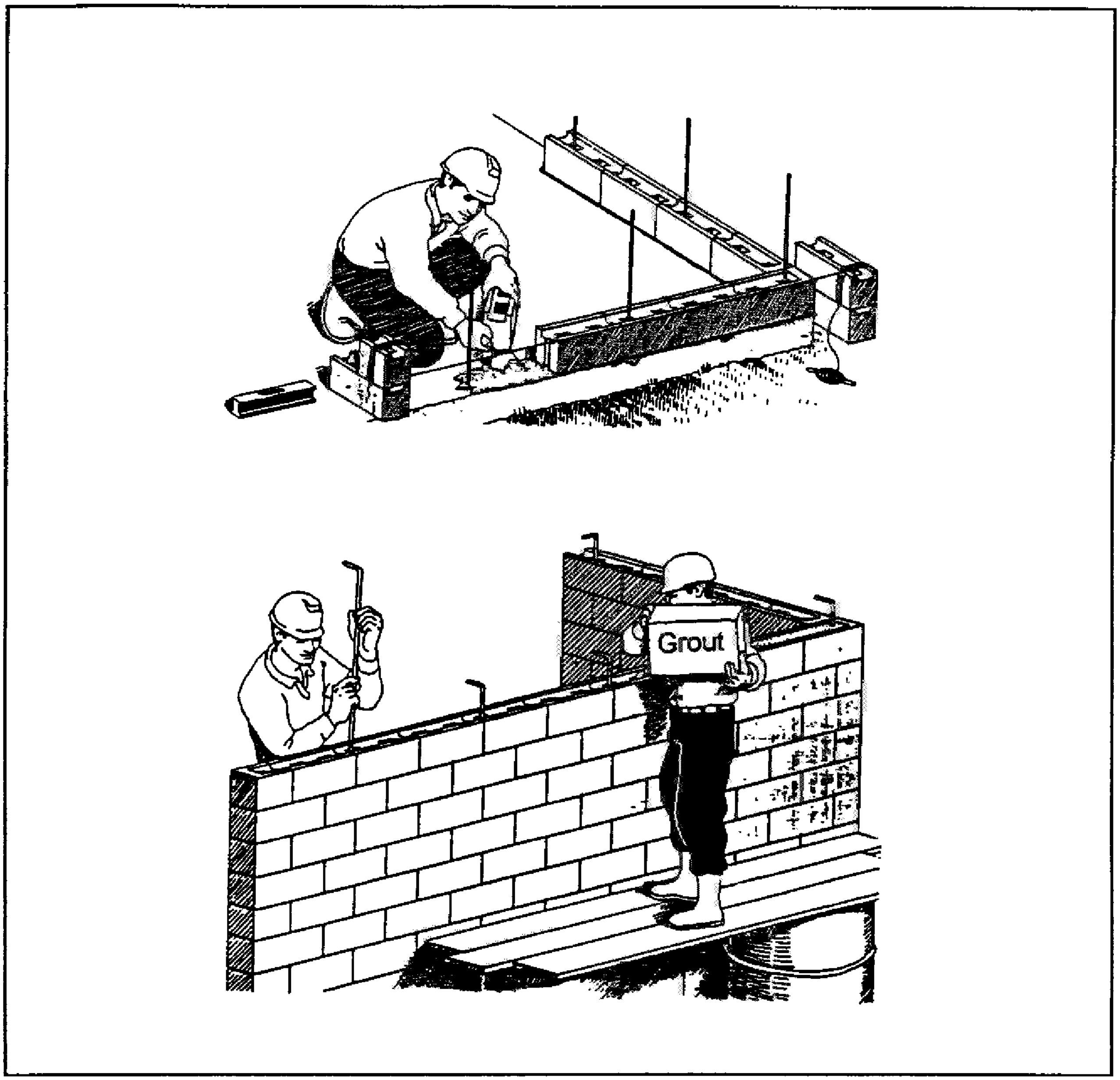


Figure 13.1-9 Vertical Reinforcement in Hollow Block Masonry using Grout [11].

Figure 13.1-9a Collapsed brick buildings at Osoppo, Friuli, Italy. This M 6.5 event caused very severe losses to brick buildings. An old lesson was repeated, viz. that brick is not suitable for structural elements in earthquake zones.

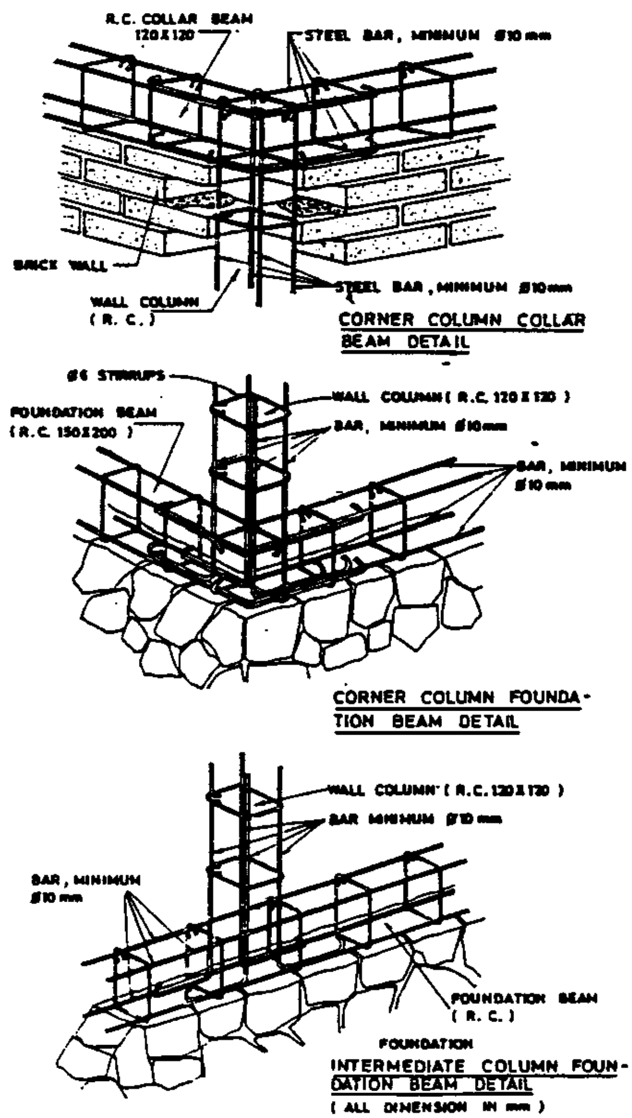


Figure 13.1-10 Typical Reinforcing Details of Thin Wall Masonry [1]