

REPAIR, RESTORATION AND STRENGTHENING OF BUILDINGS

9.1 INTRODUCTION

The need to improve the ability of an existing building to withstand seismic forces arises usually from the evidence of damage and poor behaviour during a recent earthquake. It can arise also from calculations or by comparisons with similar buildings that have been damaged in other places. While in the first case the owner can be rather easily convinced to take measures to improve the strength of his building, in the second case dwellers that have much more stringent day-to-day needs are usually reluctant to invest money in the improvement of seismic safety. The problems of repairs, restoration and seismic strengthening of buildings are briefly stated below:

- (i) Before the occurrence of the probable earthquake, the required strengthening of seismically weak buildings is to be determined by a survey and analysis of the structures.
- (ii) Just after a damaging earthquake, temporary supports and emergency

repairs are to be carried so that precariously standing buildings may not collapse during aftershocks and the less damaged ones could be quickly brought back into use.

- (iii) The real repair and strengthening problems are faced at the stage after the earthquake when things start settling down. At this stage distinction has to be made in the type of action required, that is, repairs, restoration and strengthening, since the cost, time and skill required in the three may be quite different.

The decision as to whether a given building needs to be strengthened and to what degree, must be based on calculations that show if the levels of safety demanded by present codes and recommendations are met. Difficulties in establishing actual strength arise from the considerable uncertainties related with material properties and with the amount of strength deterioration due to age or to damage suffered from previous earthquakes. Thus, decisions are fre-

quently based on gross conservative assumptions about actual strength.

The method of repair and strengthening would naturally depend very largely on the structural scheme and materials used for the construction of the building in the first instance, the technology that is feasible to adopt quickly and on the amount of funds that can be assigned to the task, usually very limited. Some methods like “splints and bandages”, “wire mesh with gunitite”, “epoxy injection,” etc., have already been tried and applied in a few countries for repairing as well as strengthening earthquake damaged buildings. These as well as other possible methods will be discussed in this chapter.

9.2 REPAIR, RESTORATION AND STRENGTHENING CONCEPTS

The underlying concepts in the three operations are stated below:

9.2.1 Repairs

The main purpose of repairs is to bring back the architectural shape of the building so that all services start working and the functioning of building is resumed quickly. Repair does not pretend to improve the structural strength of the building and can be very deceptive for meeting the strength requirements of the next earthquake. The actions will include the following:

- (i) Patching up of defects such as cracks and fall of plaster.
- (ii) Repairing doors, windows, replacement of glass panes.
- (iii) Checking and repairing electric wiring.

(iv) Checking and repairing gas pipes, water pipes and plumbing services.

(v) Re-building non-structural walls, smoke chimneys, boundary walls, etc.

(vi) Re-plastering of walls as required.

(vii) Rearranging disturbed roofing tiles.

(viii) Relaying cracked flooring at ground level.

(ix) Redecoration — whitewashing, painting, etc.

The architectural repairs as stated above do not restore the original structural strength of cracked walls or columns and may sometimes be very illusive, since the redecorates building will hide all the weaknesses and the building will suffer even more severe damage if shaken again by an equal shock since the original energy absorbing capacity will not be available.

9.2.2 Restoration

It is the restitution of the strength the building had before the damage occurred. This type of action must be undertaken when there is evidence that the structural damage can be attributed to exceptional phenomena that are not likely to happen again and that the original strength provides an adequate level of safety.

The main purpose of restoration is to carry out structural repairs to load bearing elements. It may involve cutting portions of the elements and rebuilding them or simply adding more structural material so that the original strength is more or less restored. The process may involve inserting temporary supports, underpinning, etc. Some of the approaches are stated below:

- (i) Removal of portions of cracked masonry walls and piers and rebuilding them in richer mortar. Use of non-shrinking mortar will be preferable.
- (ii) 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. Several alternatives have been used.
- (iii) Injecting epoxy like material, which is strong in tension, into the cracks in walls, columns, beams, etc.

Where structural repairs are considered necessary, these should be carried out prior to or simultaneously with the architectural repairs so that total planning of work could be done in a coordinated manner and wastage is avoided.

9.2.3 Strengthening of existing buildings

The seismic behaviour of old existing buildings is affected by their original structural inadequacies, material degradation due to time, and alterations carried out during use over the years such as making new openings, addition of new parts inducing dissymmetry in plan and elevation, etc.

The possibility of substituting them with new earthquake resistant buildings is generally neglected due to historical, artistic, social and economical reasons. The complete replacement of the buildings in a given area will also lead to destroying a number of social and human links. Therefore seismic strengthening of existing damaged or undamaged buildings can be a definite requirement in same areas.

Strengthening is an improvement over the original strength when the evaluation

of the building indicates that the strength available before the damage was insufficient and restoration alone will not be adequate in future quakes.

The extent of the modifications must be determined by the general principles and design methods stated in earlier chapters, and should not be limited to increasing the strength of members that have been damaged, but should consider the overall behaviour of the structure. Commonly, strengthening procedures should aim at one or more of the following objectives:

- (i) Increasing the lateral strength in one or both directions, by reinforcement or by increasing wall areas or the number of walls and columns.
- (ii) 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.
- (iii) Eliminating features that are sources of weakness or that produce concentrations 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, large openings in walls without a proper peripheral reinforcement are examples of defect of this kind.
- (iv) Avoiding the possibility of brittle modes of failure by proper reinforce-

ment and connection of resisting members. Since its cost may go to as high as 50 to 60% of the cost of rebuilding, the justification of such strengthening must be fully considered.

The extent of modification must be found using the principles of strengthening discussed in Chapters 2, 3 and 4 and in accordance with the local factors applicable to each building.

9.3 REPAIR MATERIALS

The most common materials for damage repair works of various types are cement and steel. In many situations non-shrinking cement or an admixture like aluminium powder in the ordinary portland cement will be admissible. Steel may be required in many forms, like bolts, rods, angles, 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. They are described below:

9.3.1. Shotcrete

Shotcrete is a method of applying a combination of sand and portland cement which mixed pneumatically and conveyed in dry state to the nozzle of a pressure gun, where water is mixed and hydration takes place just prior to expulsion. The material bonds perfectly to properly prepared surface of masonry and steel. In versatility of appli-

cation to curved or irregular surfaces, its high strength after application and good physical characteristics, make for an ideal means to achieve added structural capability in walls and other elements. There are some minor restrictions of clearance, thickness, direction of application, etc.

9.3.2 Epoxy resins

Epoxy resins are excellent binding agents with high tensile strength. There are chemical preparations the compositions of which can be changed as per requirements. The epoxy components are mixed just prior to application. The product is of low viscosity and can be injected in small cracks too.

The higher viscosity epoxy resin can be used for surface coating or filling larger cracks or holes. The epoxy mixture strength is dependent upon the temperature of curing (lower strength for higher temperature) and method of application.

9.3.3 Epoxy mortar

For larger void spaces, it is possible to combine 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 Portland cement concrete. Thus the mortar is not a stiff material for replacing reinforced concrete. It is also reported that epoxy is a combustible material. Therefore it is not used alone. The sand aggregate mixed to form the epoxy mortar provides a heat sink for heat generated and it provides increased modulus of elasticity too.

9.3.4 Gypsum cement mortar

It has got rather limited use for structural application. It has lowest strength at failure among these three materials.

9.3.5 Quick-setting cement mortar

This material is patented and was originally developed for the use as a repair material for reinforced concrete floors adjacent to steel blast furnaces. It is a non-hydrous magnesium phosphate cement with two components, a liquid and a dry, which can be mixed in a manner similar to portland cement concrete.

9.3.6 Mechanical anchors

Mechanical type 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 polymer adhesives can be used.

9.4 TECHNIQUES TO RESTORE ORIGINAL STRENGTH

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

9.4.1 Small cracks

If the cracks are reasonably small (opening width = 0.075 cm), the technique to restore the original tensile strength of the cracked element is by pressure injection of epoxy. The procedure is as follows, *Fig 9.1 (a) and (b)*.

The external surfaces are cleaned of non-structural materials and plastic injection ports are placed along the surface of the cracks on both sides of the member and are secured in place with an epoxy sealant. The centre to centre spacing of these ports may be approximately equal to the thickness of the element. After the sealant has cured, a low viscosity epoxy resin is injected into one port at a time, beginning at the lowest part of the crack in case it is vertical or at one end of the crack in case it is horizontal.

The resin is injected till it is seen flowing from the opposite sides of the member at the corresponding port or from the next higher port on the same side of member. The injection port should be closed at this stage and injection equipment moved to the next port and so on.

The smaller the crack, higher is the pressure or more closely spaced should be the ports so as to obtain complete penetration of the epoxy material throughout the depth and width of 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. Two items should however be taken care of in such type of repair:

(i) In the case of loss of bond between reinforcing bar and concrete, if the concrete adjacent to the bar has been pulverised to a very fine powder, this powder will dam the epoxy from

saturation of the region. So it should be cleaned properly by air or water pressure prior to injection of epoxy.

(ii) It has been stated that cracks smaller than about 0.75 mm may be difficult

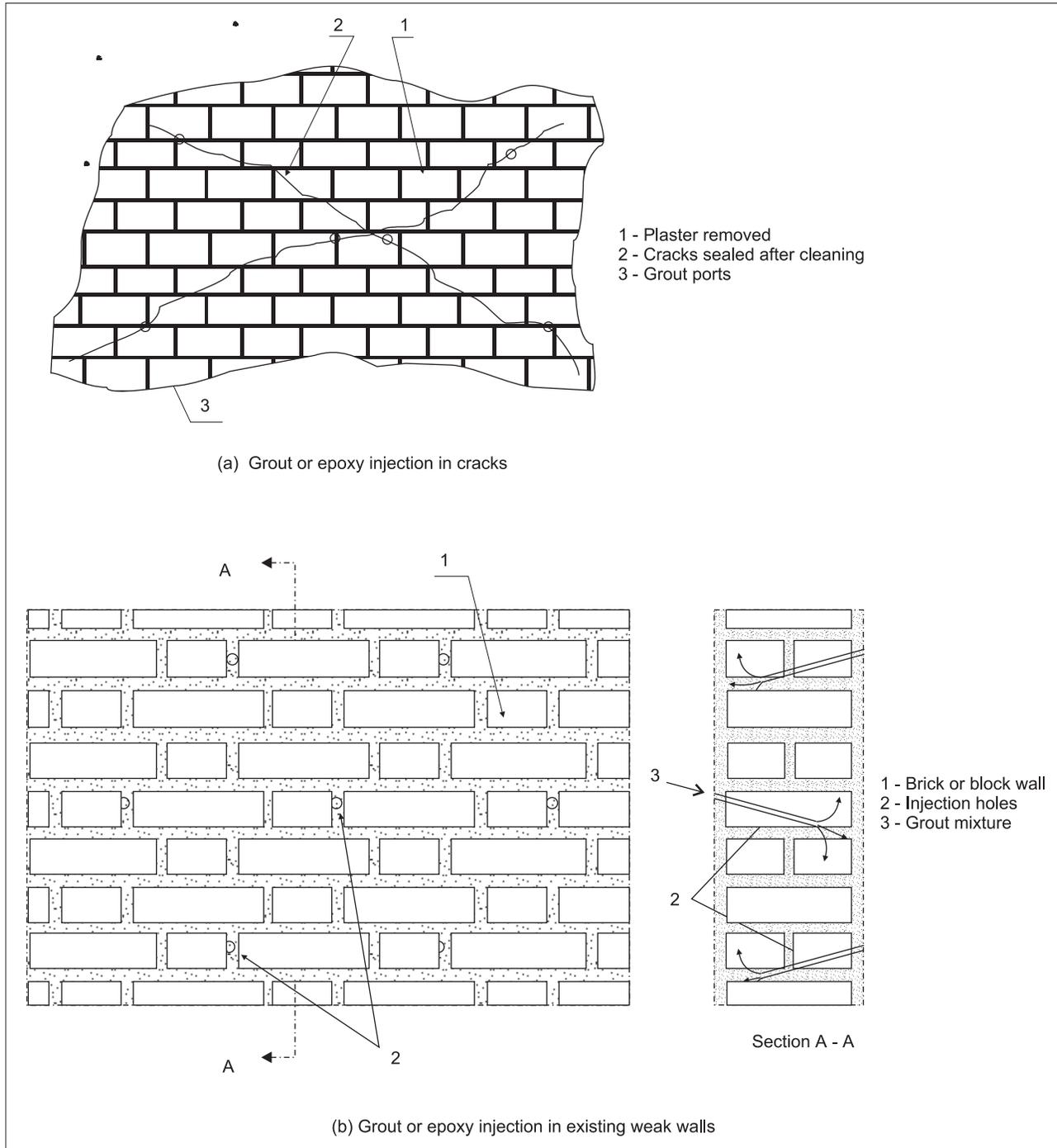


Fig 9.1 Strengthening of existing masonry

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to pressure inject. So cracks smaller than this should not be repaired by this method.

tion is indicated. The following procedure may be adopted.

9.4.2 Large cracks and crushed concrete

For cracks wider than about 6 mm or for regions in which the concrete or masonry has crushed, a treatment other than injection is indicated.

- (i) The loose material is removed and replaced with any of the materials mentioned earlier, *i.e.*, expansive cement mortar, quick setting cement or gypsum cement mortar, Fig 9.1 (c).

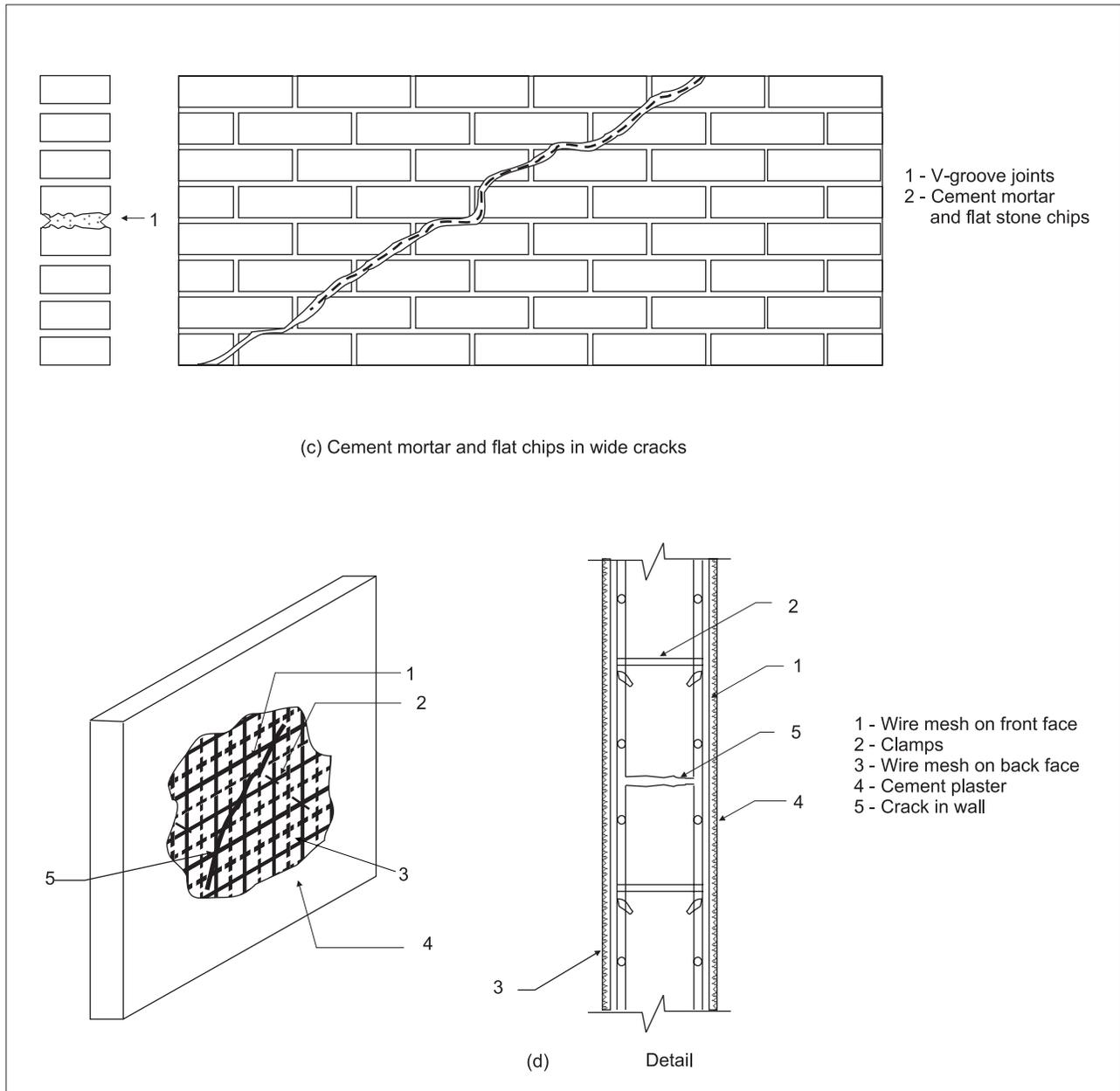


Fig 9.1 Strengthening of existing masonry

(ii) Where found necessary, additional shear or flexural reinforcement is provided in the region of repairs. This reinforcement could be covered by mortar to give further strength as well as protection to the reinforcement, Fig 9.1 (d).

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

(iv) In the case of damage to walls and floor diaphragms, steel mesh could be provided on the outside of the surface and nailed or bolted to the wall. Then it may be covered with plaster or micro-concrete, Fig 9.1 (d).

9.4.3 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.

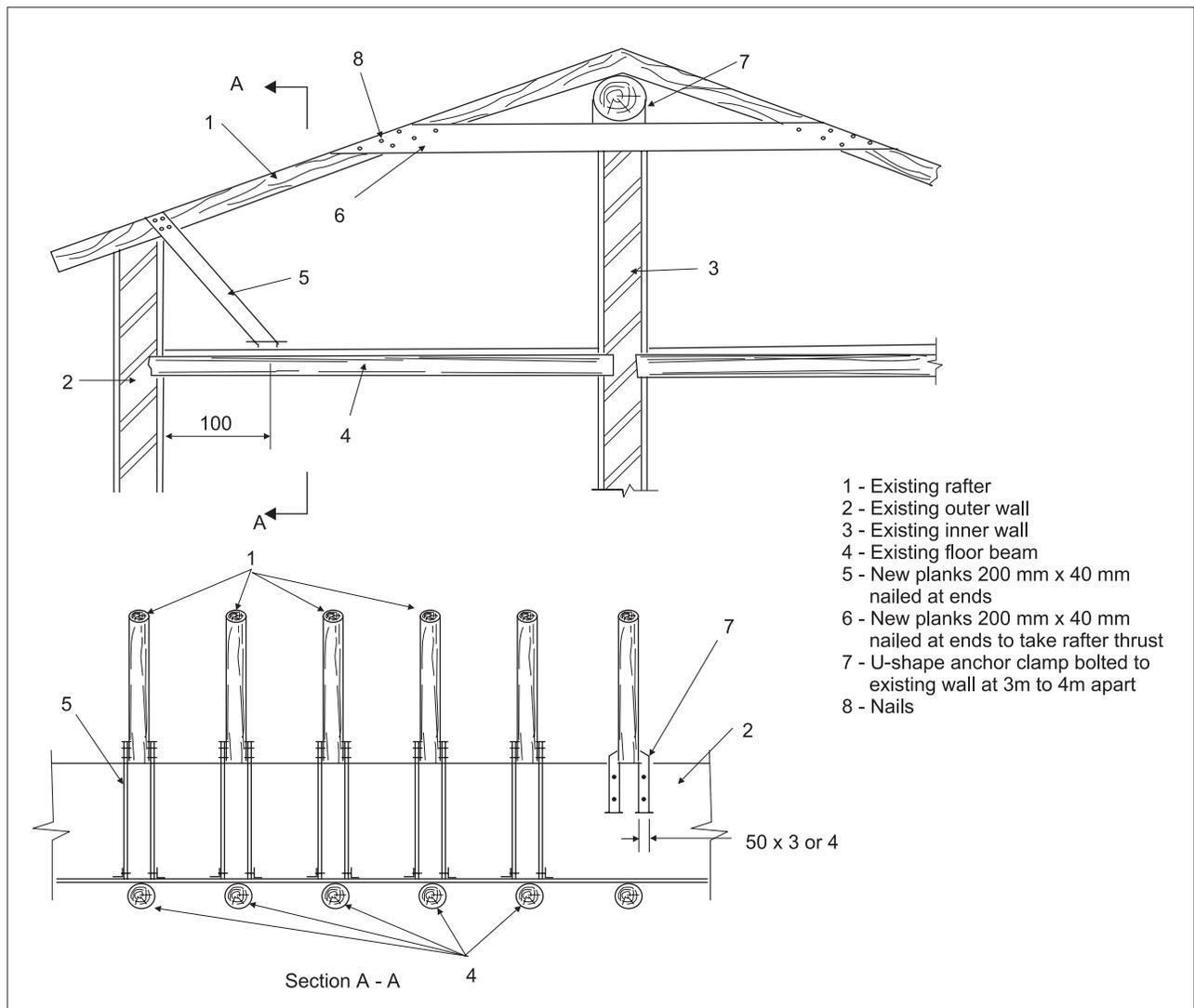


Fig 9.2 Roof modification to reduce thrust of walls

gated 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:

A hole larger than the bar is drilled. The hole is filled with epoxy, expanding cement, or other high strength grouting material.

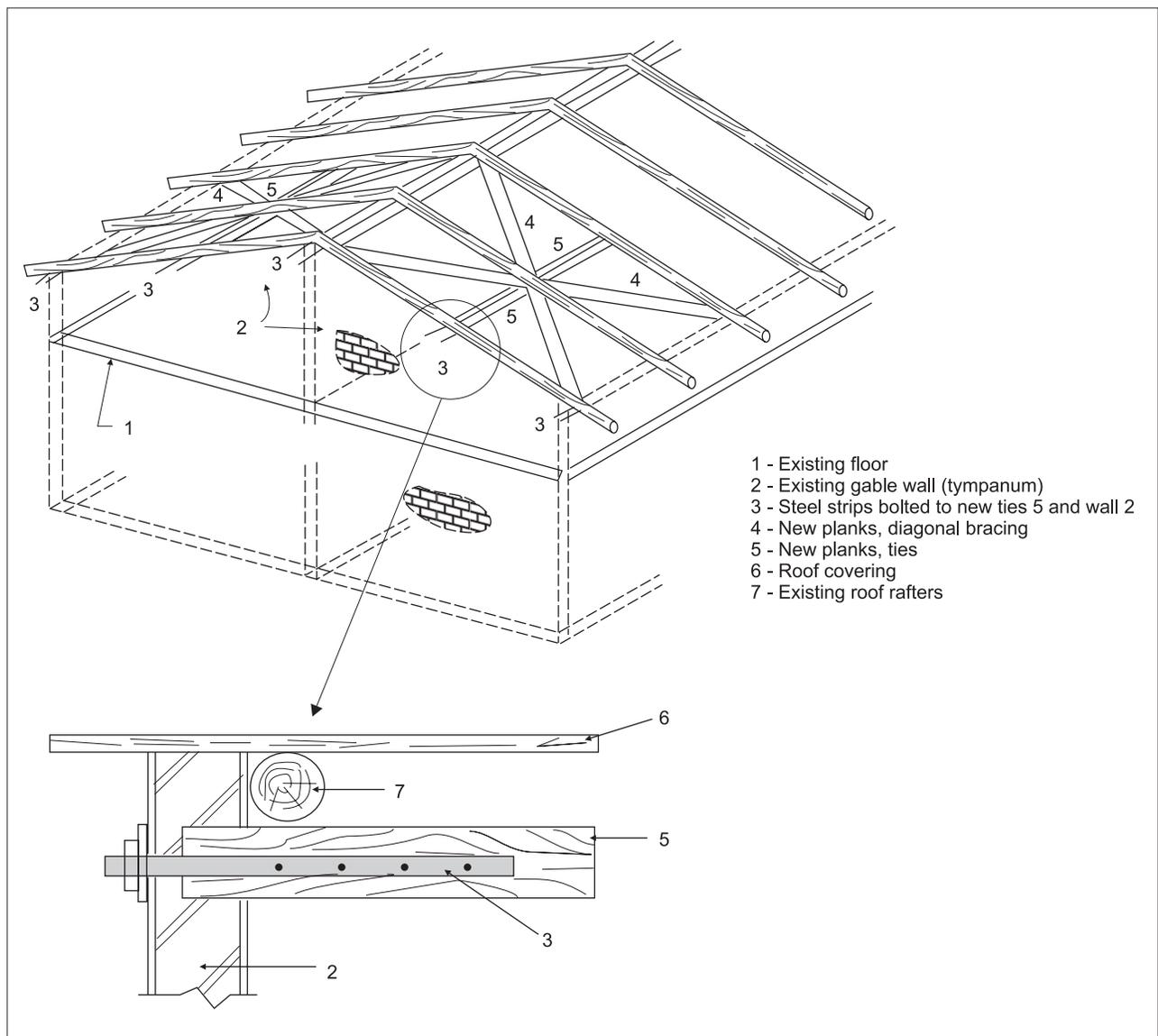


Fig 9.3 Details of new roof bracing

The bar is pushed into place and held there until the grout has set.

9.4.4 Fractured wooden members and joints

Since wood is an easily workable material, it will be easy to restore the strength of wooden members, beams, columns, struts and ties by splicing additional material. The weathered or rotten wood should first be removed. Nails, wood screws or

steelbolts will be most convenient as connectors. It will be advisable to use steel straps to cover all such splices and joints so as to keep them tight and stiff.

9.5 MODIFICATION OF ROOFS

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

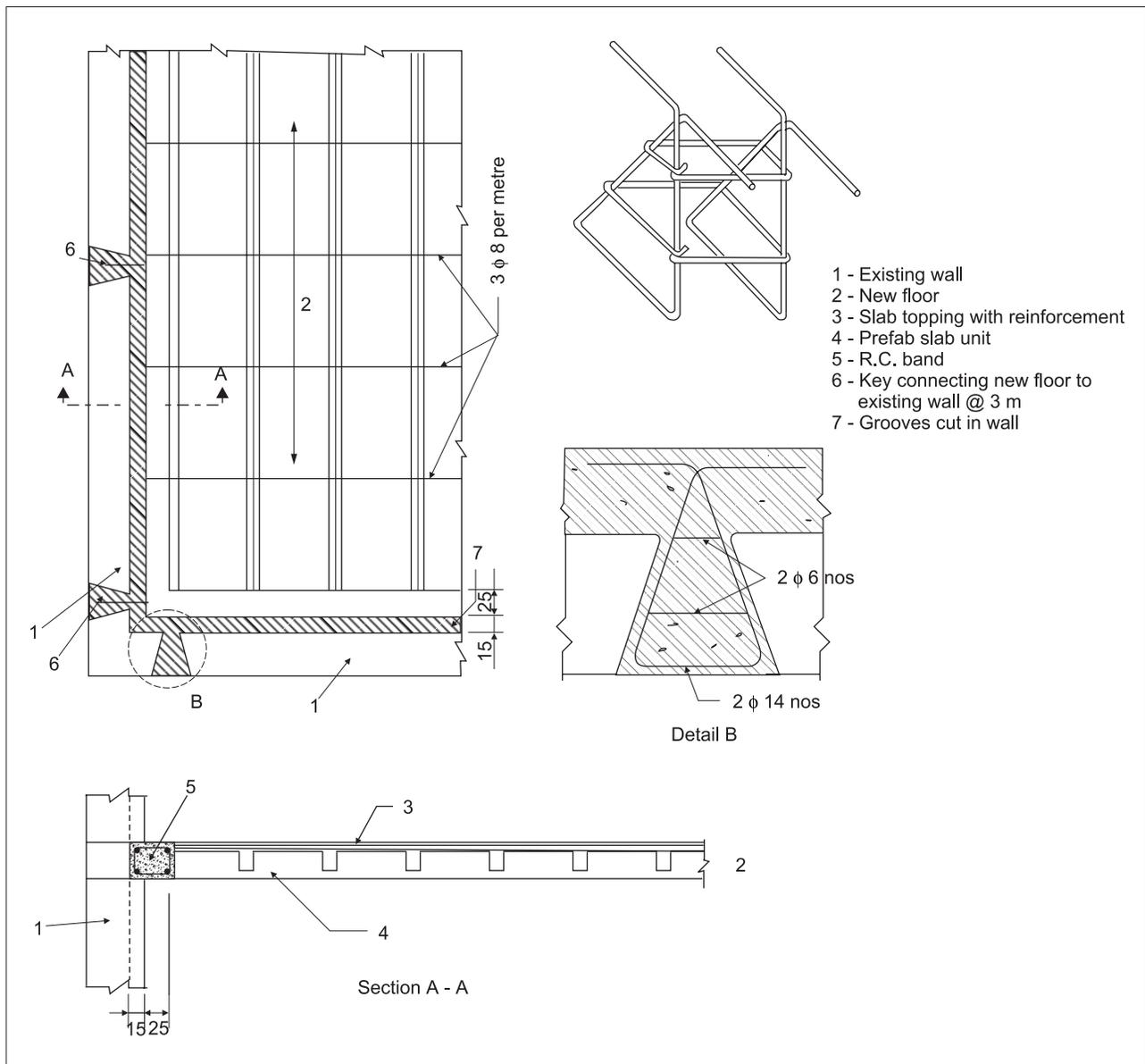


Fig 9.4 Integration and stiffening of an existing floor

lar, 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. RC elements may either have 40 mm cast-in-situ-concrete topping with 6 mm ϕ bars 150 mm c/c both ways or a horizontal cast-in-situ RC ring beam all round into which the ends of RC elements are embedded. Fig 9.4 shows one such detail.

- (vi) Roofs or floors consisting of steel joists and 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.

9.6 SUBSTITUTION OR STRENGTHENING OF SLABS

(a) Insertion of a new slab

A rigid slab inserted into existing walls plays an important role in the resisting mechanism of the building keeping the walls together and distributing seismic forces among the walls.

The slab has to be properly connected to the walls through appropriate keys. Fig 9.4 shows typical arrangement to be adopted while in Fig 9.5 some details are shown.

(b) Existing wooden slabs

In the case in which the existing slab is not removed the following actions have to be undertaken:

Stiffening of the slab

This can be achieved either by planks nailed perpendicularly to the existing ones, Fig 9.6 or by placing a RC thin slab over the old one, Fig 9.7.

In this case a steel network is nailed to the wooden slab and connected to the walls by a number of distributed steel anchors. These can be hammered into the interstices of the wall and a local hand cement grouting has to be applied for seating.

Connection of the slab to the walls

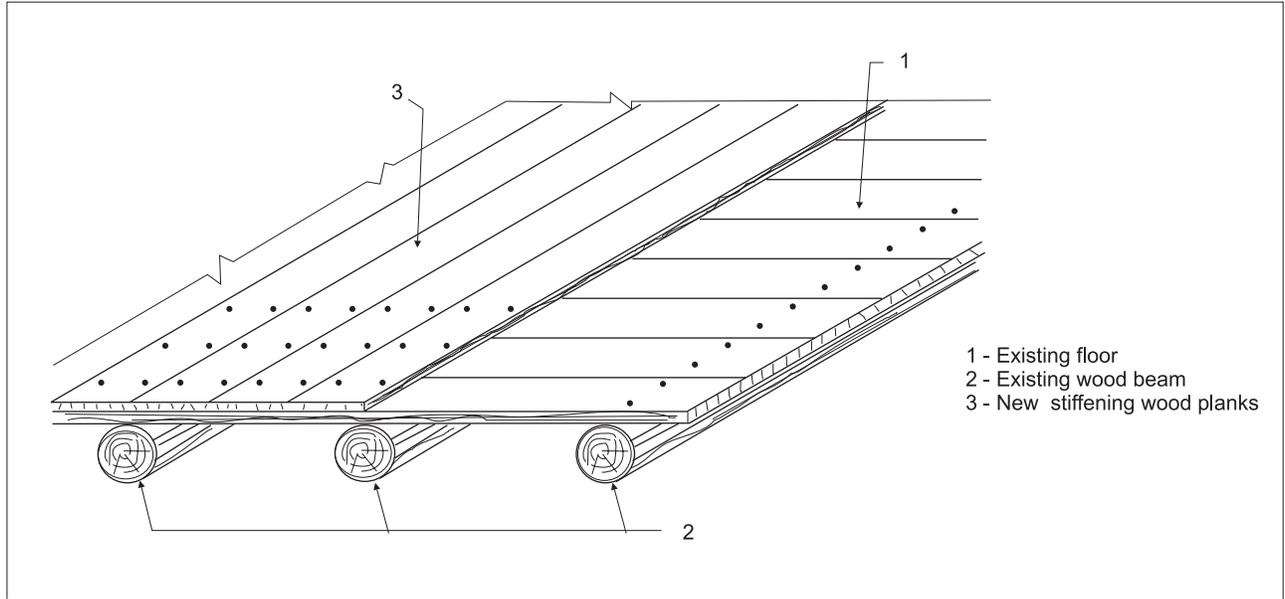
A proper link can be obtained by means of the devices shown in Figs 9.8. and 9.9.

They consist of flat steel bars nailed to the wooden supporting beams and to the wooden slab. Holes drilled in the walls to anchor them have to be infilled with cement. If a steel mesh has been used, the connection can be made as shown in Fig 9.5, i.e., inserting a small RC band into the existing walls, the band has to be keyed at least each 3 m.

9.7 PLANNAR MODIFICATIONS AND STRENGTHENING OF WALLS

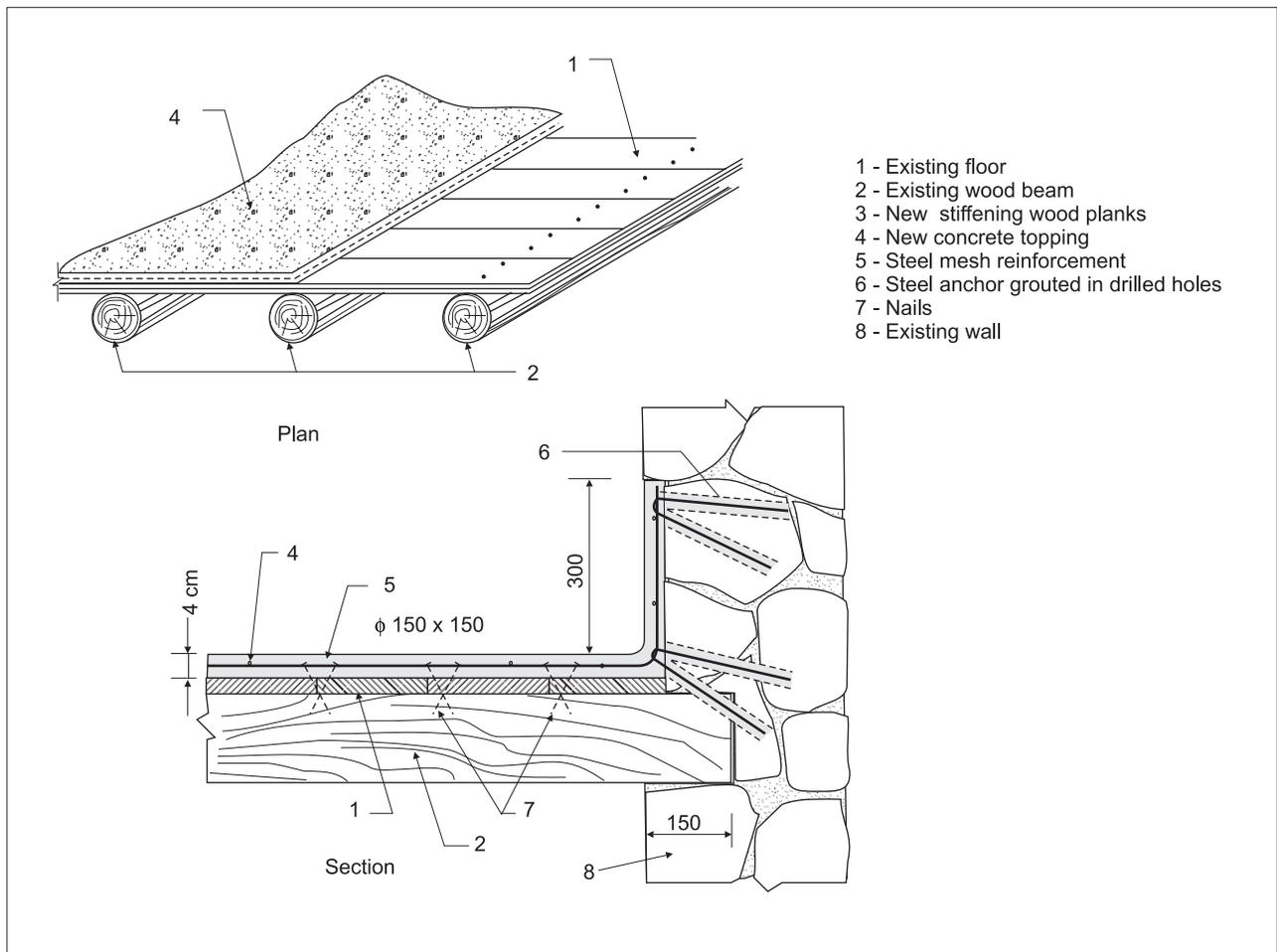
9.7.1 Inserting new walls

In the case the existing buildings show dissymetries which may produce dangerous torsional effects during earthquakes, the center of masses can be made coincident with the center of stiffness 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,



- 1 - Existing floor
- 2 - Existing wood beam
- 3 - New stiffening wood planks

Fig 9.6 Stiffening of wooden floor by wooden planks



- 1 - Existing floor
- 2 - Existing wood beam
- 3 - New stiffening wood planks
- 4 - New concrete topping
- 5 - Steel mesh reinforcement
- 6 - Steel anchor grouted in drilled holes
- 7 - Nails
- 8 - Existing wall

Fig 9.7 Stiffening wooden floor by reinforced concrete slab and connection to wall

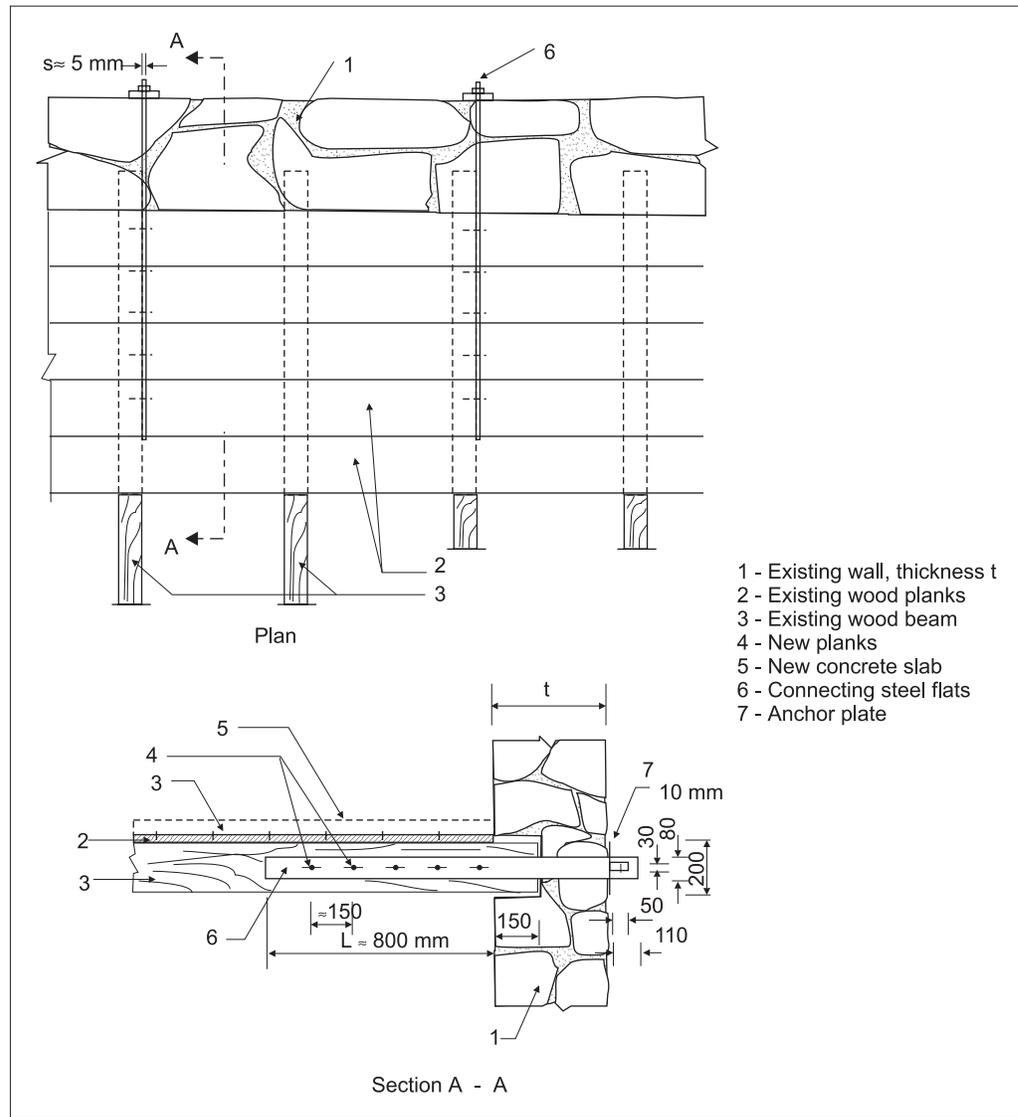


Fig 9.8 Connection of floor to wall

will be necessary for providing transverse supports to longitudinal walls of long bar-rack type buildings used for various purposes such as schools and dormitories.

The main problem in such modifications is the connection of new walls with old walls. *Figs 9.10.* and *9.11.* show two examples of connection of new walls to existing ones. The first case refers to a T-junction, the second figure to a corner junction. In both 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 cement infilling is made. In the second case however connection can be achieved by a number of steel bars inserted in small length drilled holes which substitute keys.

9.7.2 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 (c) by pre-stressing walls.

(a) Grouting

A number of holes are drilled in the wall, Fig 9.1. (2 to 4 m²). First water is injected in order to wash the wall inside and to im-

prove the cohesion between the grouted 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 cannot be relied on as far as the improving or con-

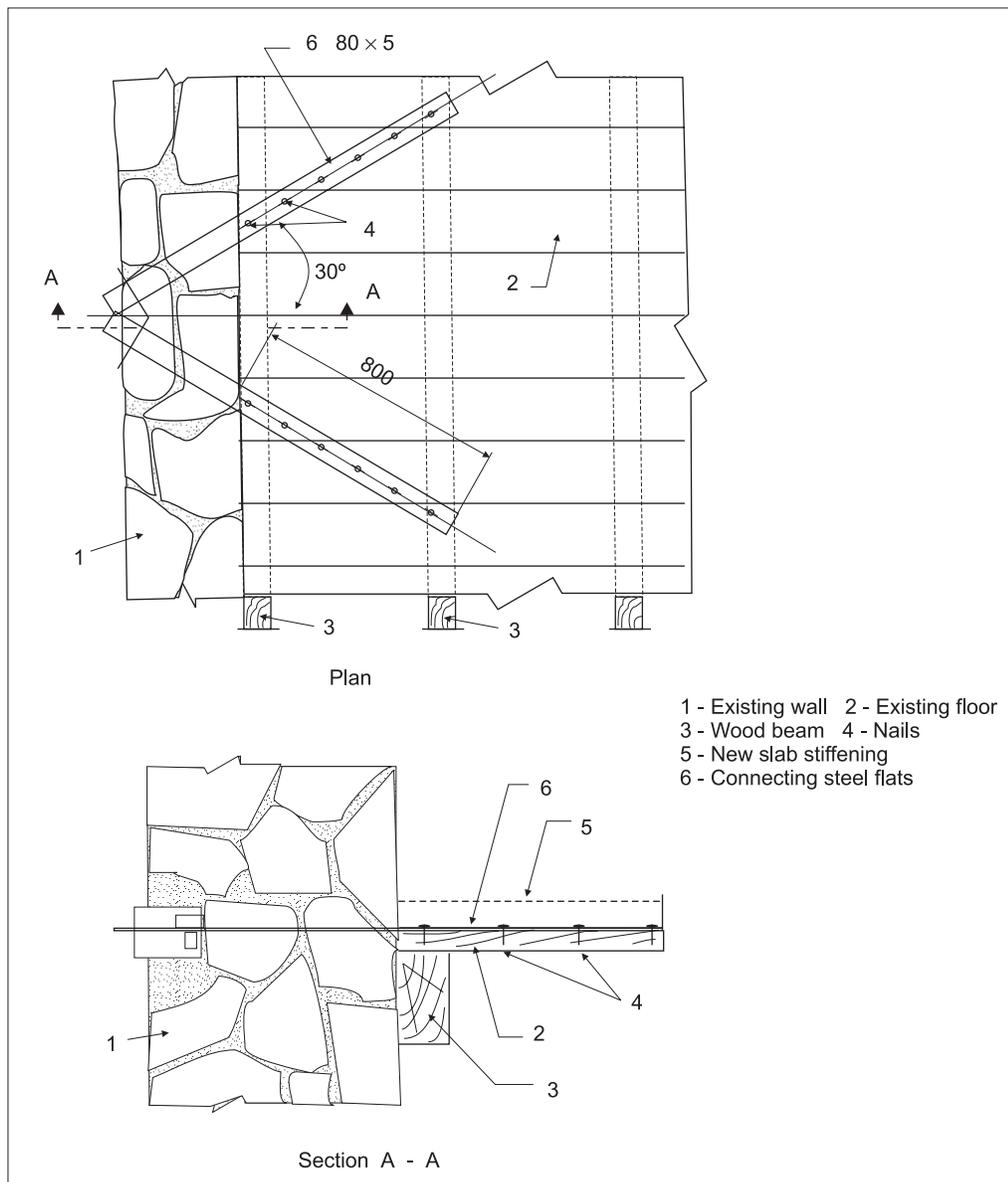


Fig 9.9 Connection of floor with wall

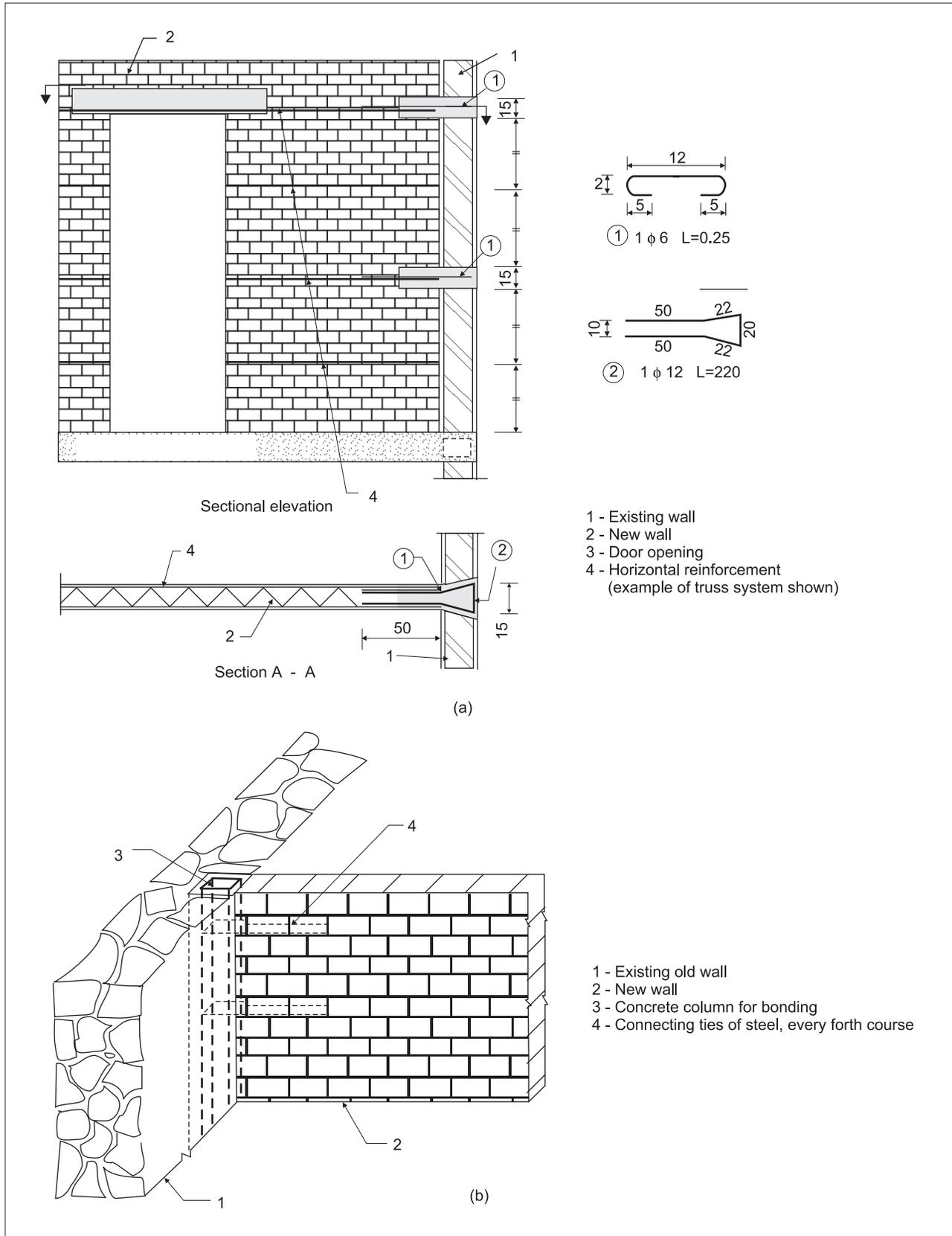


Fig 9.10 (a) Connection of new and old brick walls (T-junction) (b) Connection of new brick wall with existing stone wall

nection between orthogonal walls is concerned. Note that pressure needed for grouting can be obtained by gravity flow from super-elevated tanks.

(b) Strengthening with wire mesh

Two steel meshes (welded wire fabric with an elementary mesh of approximately 50×50 mm) are placed on the two sides of

the wall, they are connected by passing steel each 500 to 750 mm apart, Fig 9.12. A 20 to 40 mm thick cement mortar or micro-concrete layer is then applied on the two networks thus giving rise to two interconnected vertical plates. This system can also be used to improve connection of orthogonal walls.

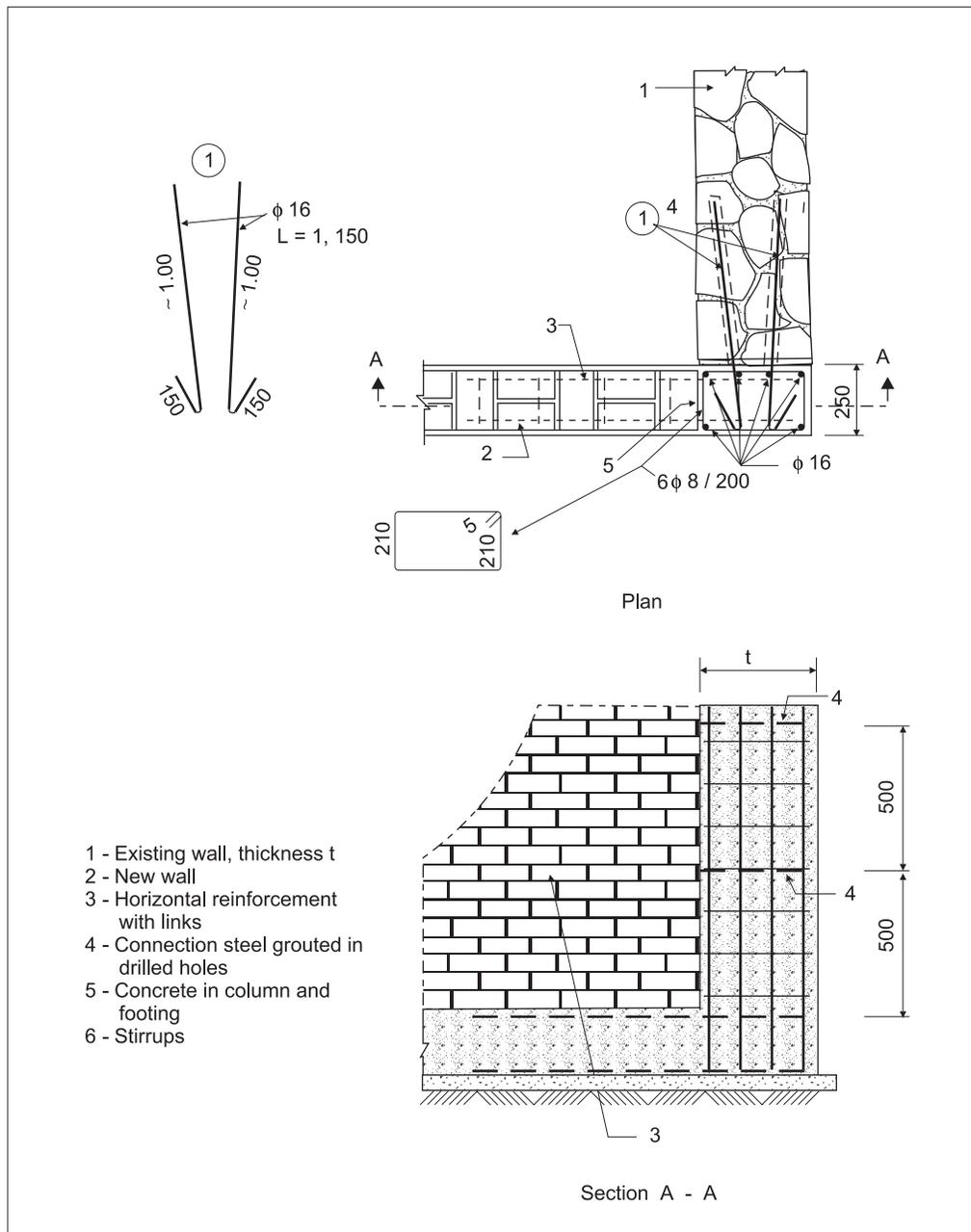


Fig 9.11 Connection of new and old walls (corner junction)

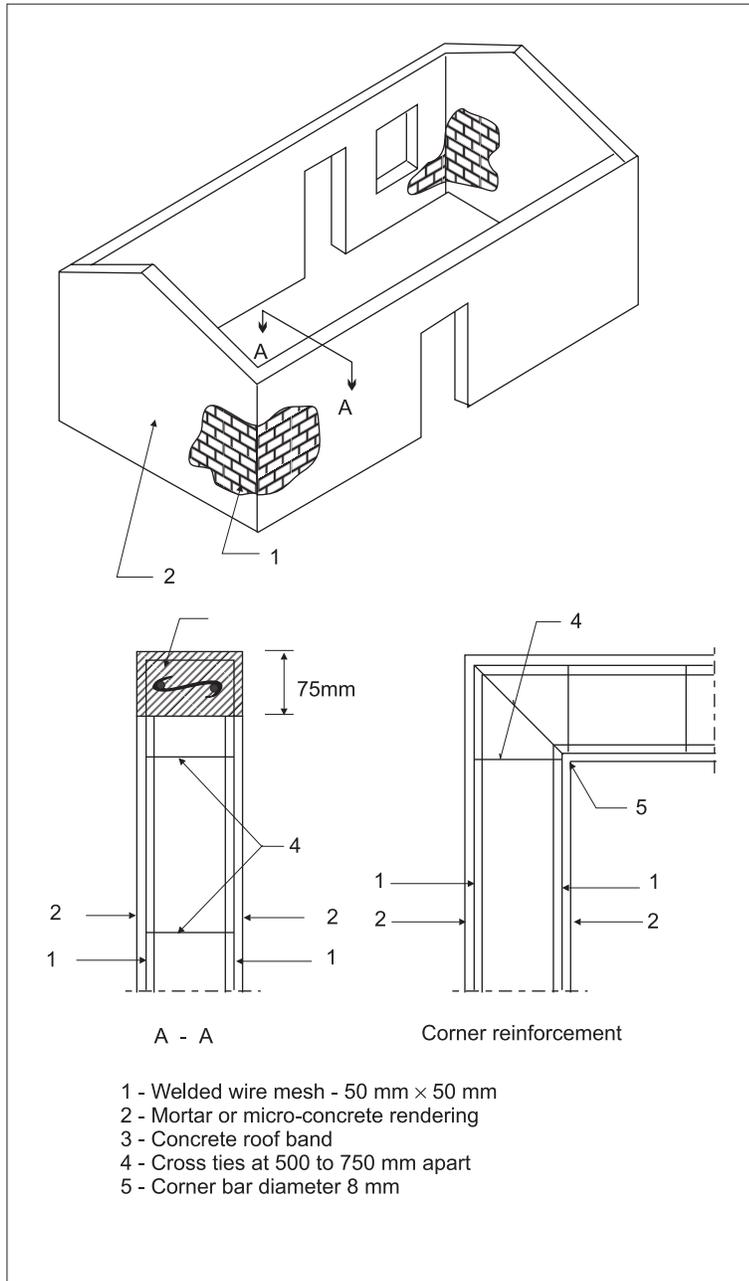


Fig 9.12 Strengthening with wire mesh and mortar

(c) 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 can be done by drilling inclined holes through them, inserting steel rods and injecting cement grout, Fig 9.13.

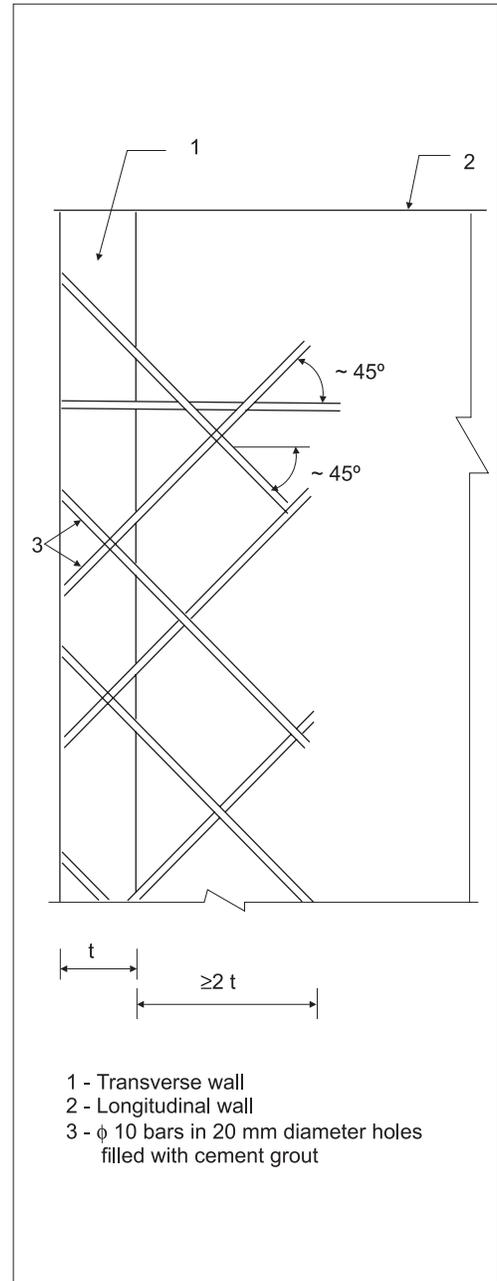


Fig 9.13 Sewing transverse walls with inclined bars

(d) Prestressing

A Horizontal compression state induced by horizontal tendons can be used to increase the shear strength of walls. Moreover this will also improve considerably the connections of orthogonal walls, Fig 9.14. The easiest way of affecting the precompression is to place two steel rods on the two sides of

the wall and strengthening them by turnbuckles. Note that good effects can be obtained by slight horizontal prestressing (about 0.1 MPa) on the vertical section of the wall. Prestressing is also useful to strengthen spandrel beam between two rows of openings in the case no rigid stab exists.

9.7.3 External binding

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

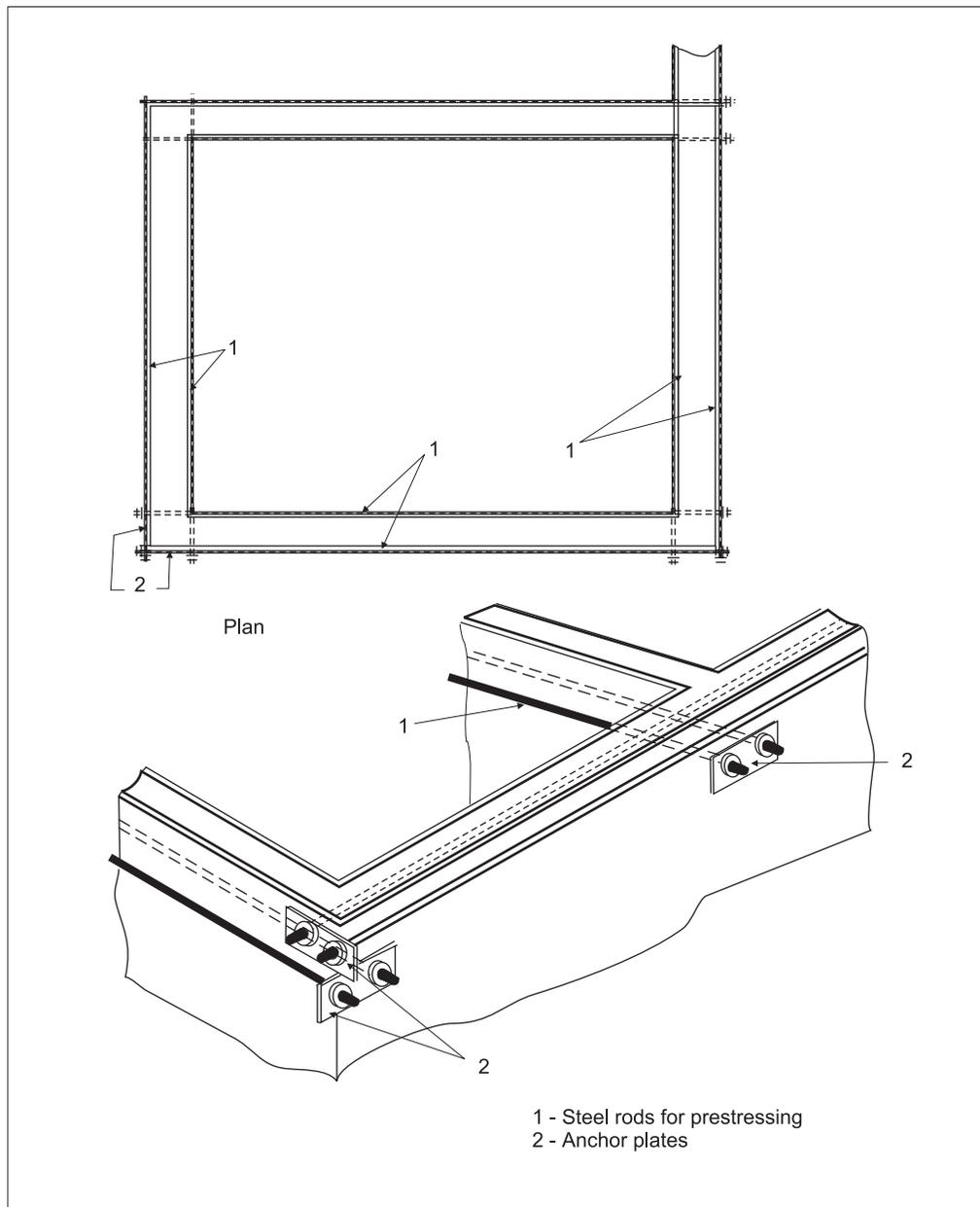


Fig 9.14 Strengthening of walls by prestressing

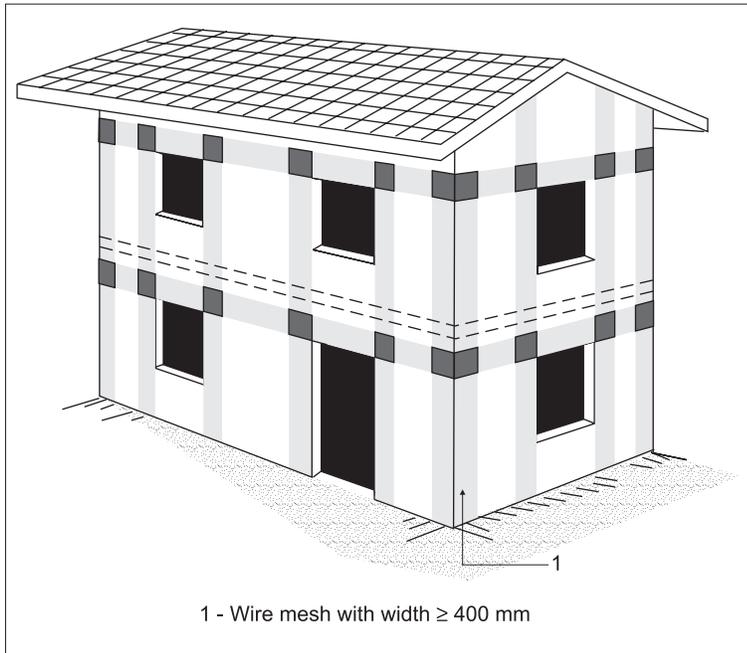


Fig 9.15 Splint and bandage strengthening technique

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 between openings and horizontal bandages over spandrel walls at suitable number of points only, Fig 9.15.

9.7.4 Other points

(i) Masonry arches If the walls have large arched openings in them, 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, Fig 9.16 (a). Alternatively, a lin-

hold the walls together and improve the integral box like action of the walls.

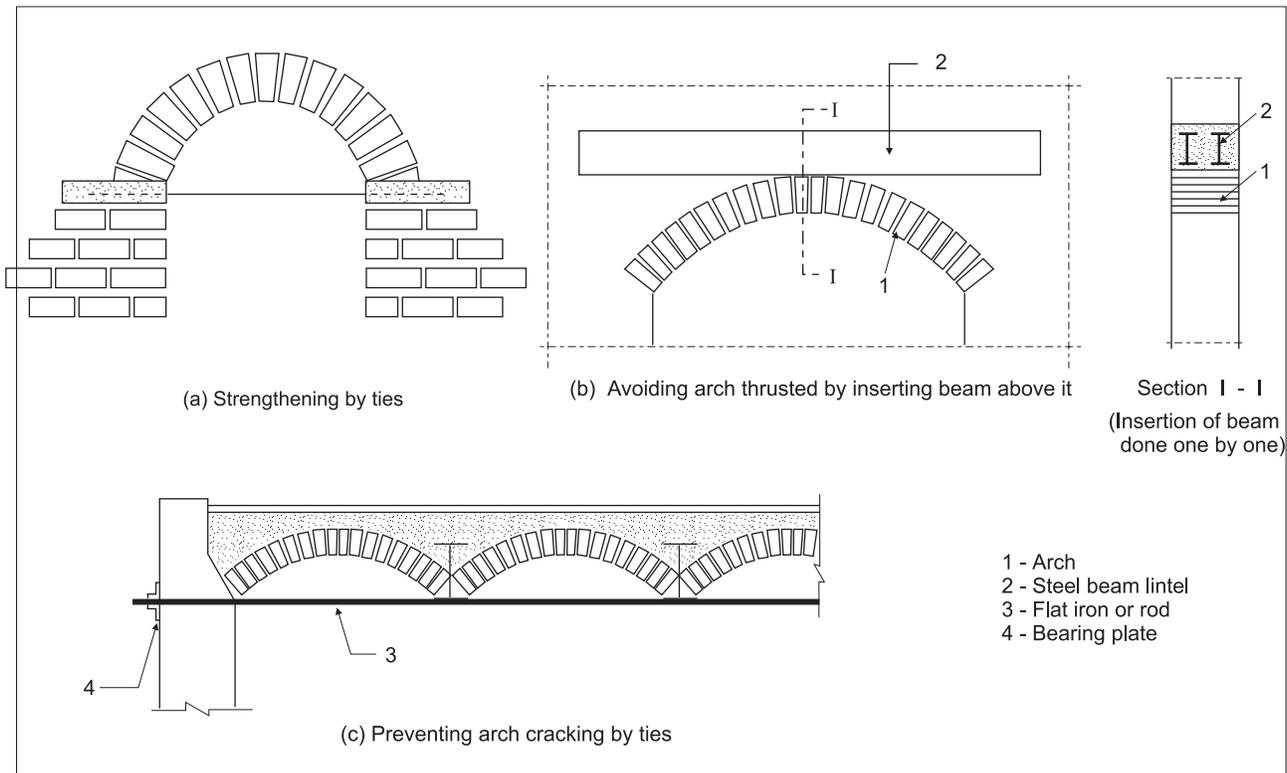


Fig 9.16 Strengthening an arched opening in masonry wall

tel 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 9.16 (b). In jack-arch roofs, flat iron bars or rods may be provided to connect the bot-

tom flanges of I-beams, connected by bolting or welding.

(ii) Random rubble masonry walls are most vulnerable to complete collapse and must be strengthened by inter-

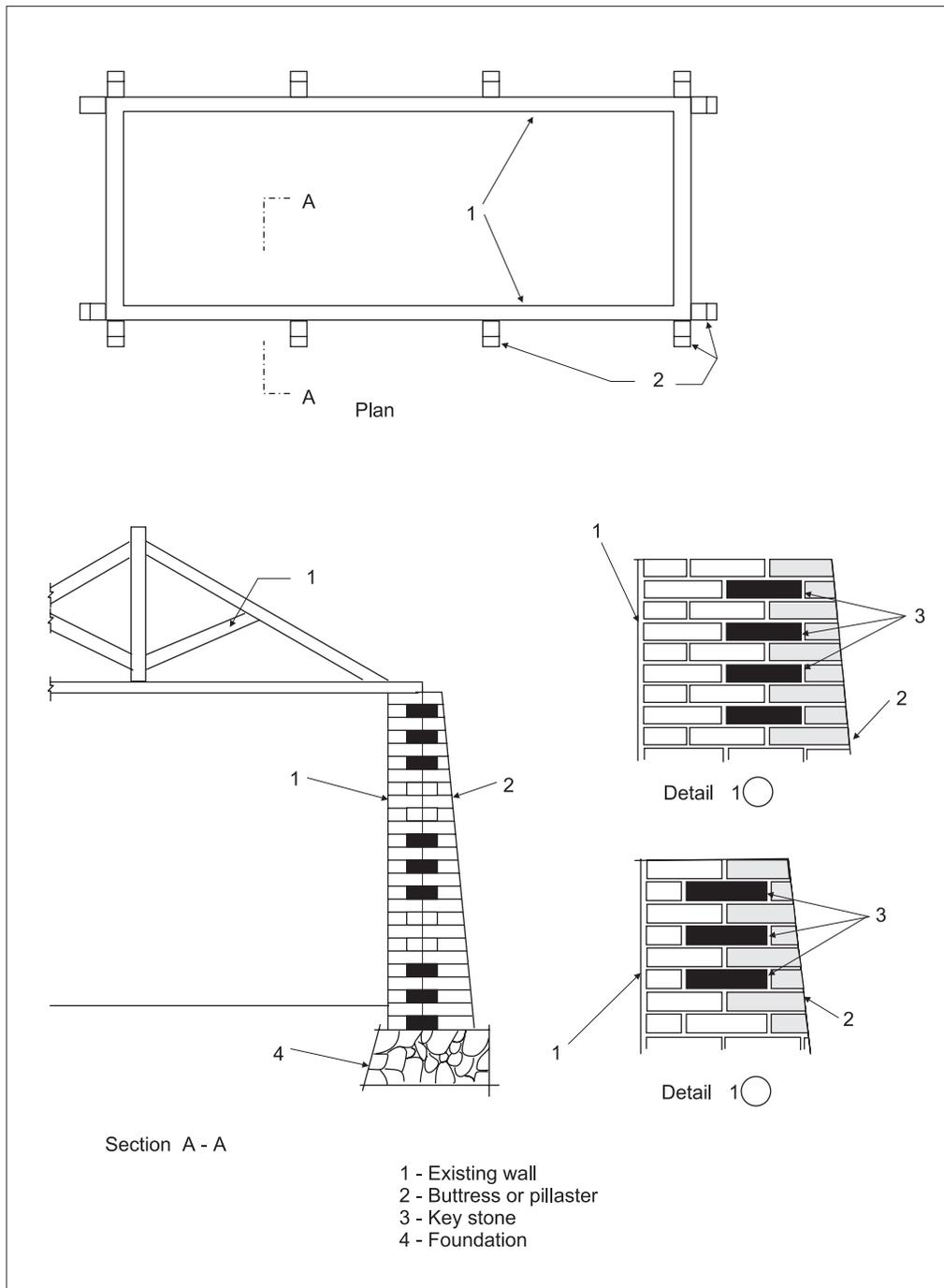


Fig 9.17 Strengthening of long walls by buttresses

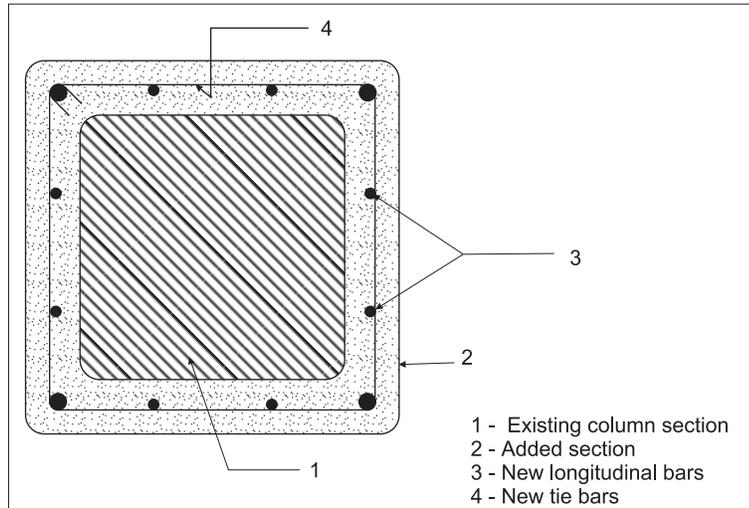


Fig 9.18 Jacketing a concrete column

nal impregnation by rich cement mortar grout in the ratio of 1:1 as explained in 9.7.2 (a) or better still covered with steel mesh and mortar as in 9.7.2 (b). Damaged portions of the wall, if any, should be reconstructed using richer mortar.

(iii) For bracing the longitudinal walls of long barrack type buildings, a portal type framework can be inserted

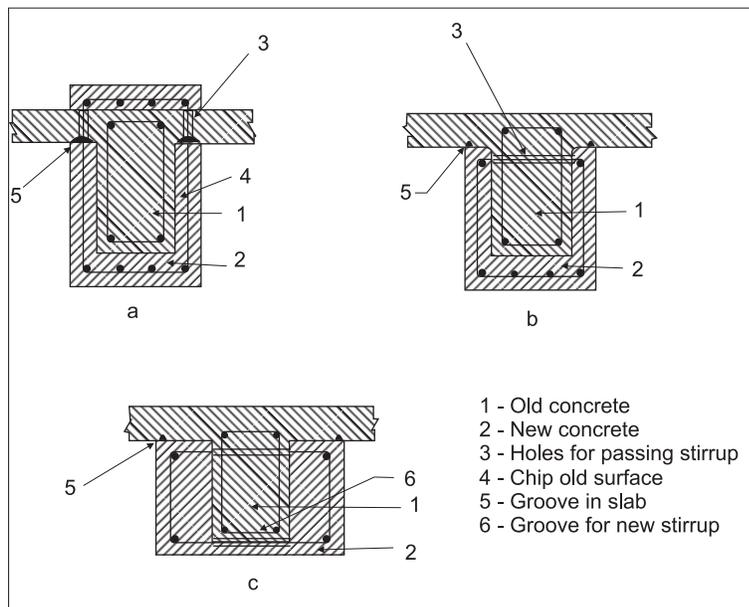


Fig 9.19 Increasing the section and reinforcement of existing beams

transverse to the walls and connected to them. Alternatively, masonry buttresses or, pillasters may be added externally as shown in Fig 9.17.

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

9.8 STRENGTHENING RC MEMBERS

The strengthening of reinforced concrete members is a task that should be carried out by a structural engineer according to calculations. Here only a few suggestions are included to illustrate the ways in which the strengthening could be done.

(i) RC columns can best be strengthened by jacketing, and by providing additional cage of longitudinal and lateral tie reinforcement around the columns and casting a concrete ring, Fig 9.18, the desired strength and ductility can thus be built-up.

(ii) Jacketing a reinforced concrete beam can also be done in the above manner. For holding the stirrup in this case, holes will have to be drilled through the slab, Fig 9.19.

(iii) Similar technique could be used for strengthening RC shear walls.

(iv) Inadequate sections of RC column and beams can also be strengthened by removing the cover to old steel, welding new steel to old steel and replacing the cover.

In all cases of adding new concrete to old concrete, the original surface should be roughened, groves made

in the appropriate direction for providing shear transfer. The ends of the additional steel are to be anchored in the adjacent beams or columns as the case may be.

- (v) RC beams can also be strengthened by applying prestress to it so that opposite moments are caused to those applied. The wires will run on both sides of the web outside and anchored against the end of the beam through a steel plate.

9.9 STRENGTHENING OF FOUNDATIONS

Seismic 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.

- (i) Introducing new load bearing members including foundations to relieve the already loaded members. Jacking operations may be needed in this process.
- (ii) 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.
- (iii) Providing apron around the building to prevent soaking of foundation directly and draining off the water.
- (iv) 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, Fig 9.20. To avoid digging the floor

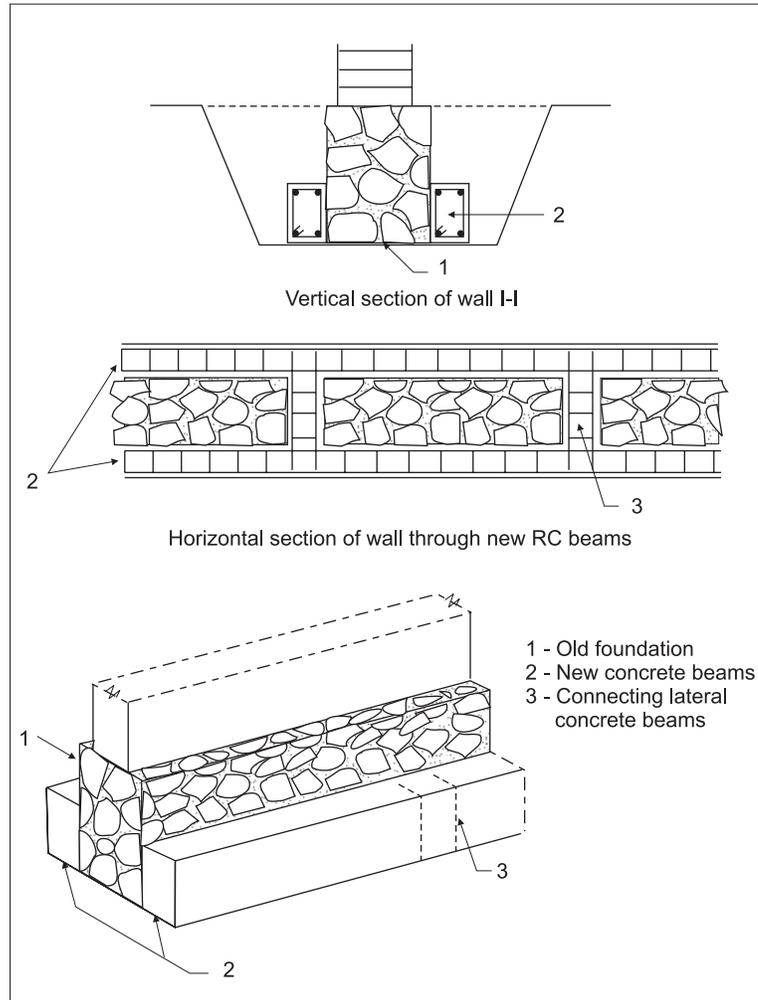


Fig 9.20 Improving a foundation by inserting lateral concrete beams

inside the building, the extra width could be provided only on the outside of external walls. The extra width may be provided above the existing footing or at the level of the existing footing. In any case the reinforced concrete strips and the walls have to be linked by a number of keys, inserted into the existing footing.

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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