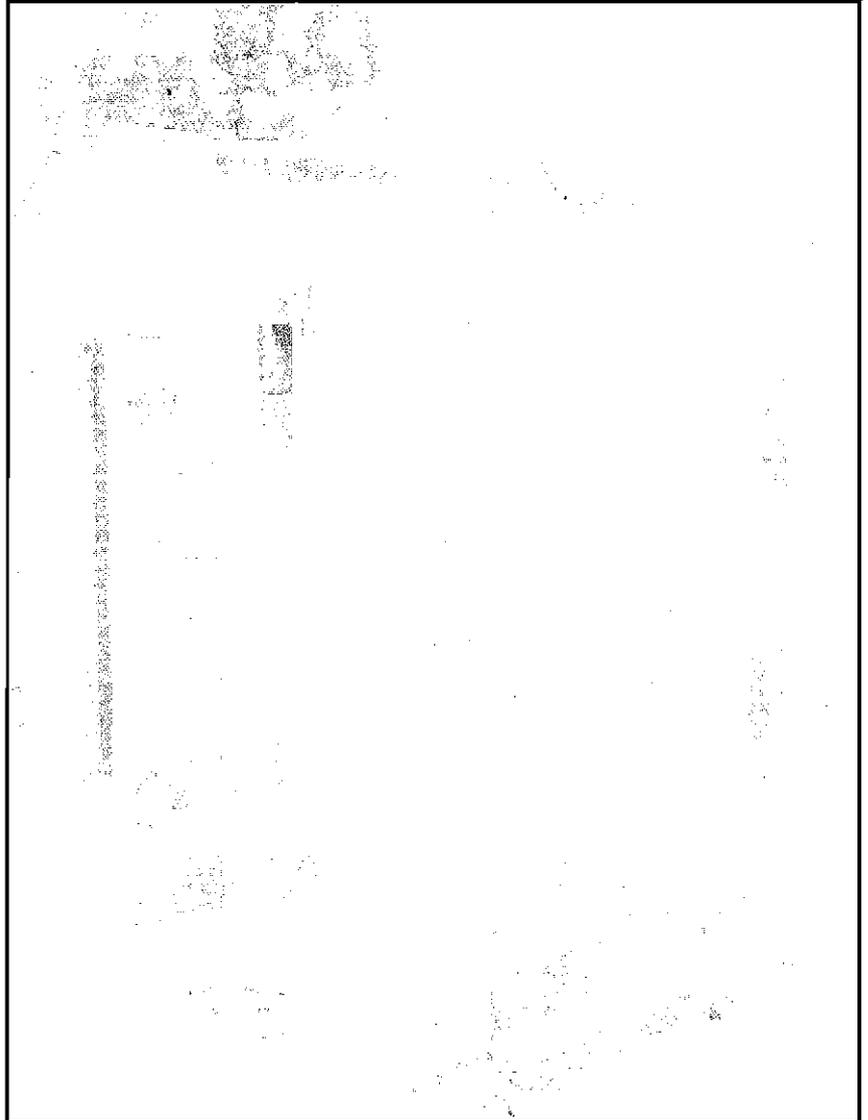
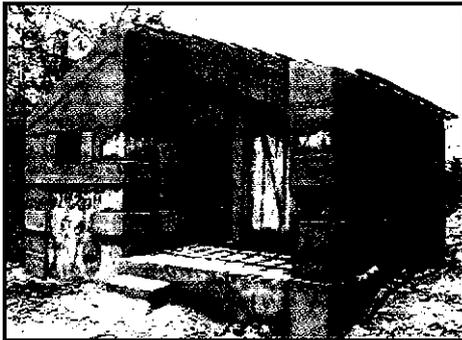




GOVERNMENT
OF
TAMILNADU

GUIDELINES FOR RETROFITTING OF BUILDINGS



RETROFIT FOR SAFETY...





R. SANTHANAM, I.A.S.,
STATE RELIEF COMMISSIONER



Chennai - 600 005.

FOREWORD

The Government of Tamil Nadu initiated a number of steps in consultation with experts, research institutions, technical universities and civil society organizations for formulating comprehensive guidelines for the reconstruction programme of houses damaged by the tsunami of 2004. More than 35,000 houses are being constructed in the first phase by various organizations including Tamil Nadu Slum Clearance Board for providing disaster resistant house to the tsunami affected families. Government also announced a comprehensive housing reconstruction policy to provide safe buildings resistant to different disasters like floods, cyclones, earthquake, tsunami, etc. in areas which are vulnerable to such disasters.

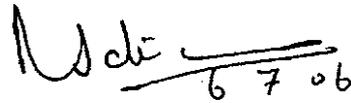
A number of training programmes were organized for the Engineers and Building Supervisors of various Non Governmental Organizations to sensitize them to follow good construction practices while building the structures. As a follow up on the supervision of the quality of such structures, the UNDP and NCRC came forward to undertake a study through a Non Governmental Organization Hunnarshaala. The findings of this study were also discussed with the District Collectors concerned in the month of April 2006. One of the major findings of this study was the need for comprehensive guidelines for retrofitting of non-engineered and traditional structures. The Orissa Development Technocrat Forum with the guidance of Prof A.R. Santhakumar has prepared the guidelines based on various practice and codes. The guidelines were circulated to the following team of experts for suggestions and modifications :-

p.t.o.

1. Dr. N. Lakshmanan, Director, Structural Engineering Research Centre.
2. Thiru K.R. Thiagarajan, Chief Engineer, Tamil Nadu Slum Clearance Board.
3. Dr. R. Senthil, Assistant Professor, Structural Engineering Division, Anna University.
4. Thiru S. Nagarajan, Deputy Chief Engineer (Buildings), Public Works Department.
5. Thiru M. Syed Mohamed Buthalib, Executive Engineer (Tsunami), O/c. SC & CRA.

These guidelines will not only be of use to the tsunami reconstruction programme but also in the retrofitting of non-engineered structures throughout the various districts of Tamil Nadu. I am sure that this measure would help in reducing the loss of precious lives in future disasters.

I compliment the team of experts co-ordinated by Thiru C.V. Sankar, I.A.S., Officer on Special Duty (Relief & Rehabilitation) who have brought out these guidelines for dissemination to all the stakeholders. I thank UNDP particularly Prof. A.R. Santhakumar and Er Alok Patnaik for taking the responsibility of bringing out this document at an appropriate time. All the organizations concerned including UNDP are requested to organize IEC campaigns as well as training programmes for communicating these guidelines to the widest audience possible.



R. SANTHANAM, I.A.S.,
Special Commissioner &
Commissioner of Revenue Administration.

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RETROFITTING OF NON-ENGINEERED BUILDINGS

1. INTRODUCTION

Many buildings are informally constructed in a traditional manner without formal design by qualified Engineers or Architects. Such buildings involve stone, brick, concrete blocks, rammed earth, wood posts and thatch roof or combination of some or all the above materials. They are built with mud, lime or cement mortar. Some times combination of mortars having a mix is also used. The safety of these non-engineered buildings against earthquakes is of great concern especially because most losses of lives during past-earthquake have occurred in such buildings. The term non-engineered building is defined rather vaguely to include those which are not specifically designed against seismic forces. In fact such buildings are built mostly with load bearing masonry wall, stud wall and wooden and other construction using combination of load bearing walls, piers in masonry, and columns in RC, steel or wood.

As per the 1991 Census of India, the country has preponderance of non-engineered housing stock in all seismic zones. Out of a total 195.0 million dwelling units, the various wall types used are given in Table 1.

Table 1: Various Wall Types used in India

Wall Type	Total Numbers	Percentage of Total
Earthen walls (mud, unburnt brick/block)	74.7 million	38.3%
Stones walls	21.7 million	11.1%
Burnt Brick walls	68.9 million	35.3%
Concrete walls	3.96 million	2.0%
Wood walls	3.12 million	1.6 %
GI and other metal sheets	1.02 million	0.5%
Bamboo thatch, leaves etc.	21.6 million	11.0%

The earthen and stone which account for 49.4% and burnt brick 35.3% : that is a total of 84.7% are vulnerable, if shaken by an earthquake of moderate to severe intensity. The collapse of masonry and Adobe dwellings gets occurs initiated in earthquakes of intensity V and large scale destruction take place when earthquakes of intensity VII. This was seen in Uttarkashi Earthquake in 1991, Killari earthquake of 1993 and Jabalpur earthquake of 1997, resulting in a large loss of lives. For safety of human lives and property, it is therefore essential that all new buildings are built with earthquake resisting features and existing vulnerable buildings in Zones V, IV and III without such features should be retrofitted in order to achieve at least the minimum life safety in future events.

This document describes guidelines and retrofit schemes for non-engineered traditional buildings with a view to ensure prevention of collapse of such buildings due to future possible earthquakes.

2. REPAIR, RESTORATION AND STRENGTHENING CONCEPTS

Buildings decay due to weather, load effects and foundation settlement etc. The building, if it has to resist an earthquake shock it should be safe under normal load and resist the lateral load without collapse. The types of intervention necessary to enhance the performance of the building can be broadly grouped under the following three categories - Repair, Restoration and Strengthening.

2.1 Repairs

The purpose of repairs is to rectify the observed defects and bring the building to reasonable architectural shape so that all services start functioning. This enables the use of building for its intended purpose. Repairs do not improve structural strength or stability. In fact a repaired building may be deceptive. It may hide the structural defects. Outwardly it may appear good. It may suffer from structural weakness. Such weakness may cause collapse during future earthquakes.

Repairs include following interventions

- i) Patching cracks and plastering.
- ii) Fixing doors, windows, broken glass panes.
- iii) Setting right electrical installation, wiring etc.
- iv) Fixing services such as gas lime, plumbing services including water pipes, sewerage line etc.
- v) Rebuilding non-structural walls, partition walls, plastering etc.
- vi) Re-fixing roof tiles
- vii) Repair to flooring and correcting slope for drainage etc
- viii) Providing decorative finishes, white washing.
- ix) Painting wood work.
- x) Attending to root leakage during rain etc.

In fact, repairs will hide the existing structural defects and hence donot guarantee for good performance when the structure is shaken by an earthquake.

2.2 Restoration

The main purpose is to structurally treat the building with an aim to restore its original strength. This intervention is undertaken for a damaged building if one is sure that the original strength provides an adequate level of safety for future earthquake disasters.

The action will involve cutting portions of wall and rebuilding them, inserting support, underpinning foundation, strengthening a weak component etc.

Some of the common restoration techniques are:

- i) Removal of a partition or defective wall and rebuilding it with richer mortar
- ii) Crack sealing using epoxy to regain the strength of a structural component.
- iii). Adding wire mesh on either side of a cracked component, crack stitching etc. with a view to strengthen it.

2.3 Strengthening of buildings against earthquake loads

Seismic forces are the most serious dynamic forces. Although various approaches to make the building safe by minimizing natural period, increasing damping etc, are practiced most common intervention for non-engineered building is strengthening it by various measures.

The seismic resistance of old existing non-engineered buildings is lowered with passage of time due to material property degradation and structural strength loss. This deterioration may occur due to climatic, biological or chemical causes. Strengthening is undertaken to enhance the original strength to the current requirement so that the desired protection of lives can be guaranteed as per the current codes of practice against possible future earthquakes. The level of strengthening should also consider the remaining life of the structure being strengthened.

Strengthening of a building will involve either component strength enhancement or structural system modification or both. It is expected to improve the overall strength in the following ways:

- i) Increasing the lateral load resistance by reinforcing or by introducing new walls and columns.
- ii) Introducing the continuity between the components of the structure to achieve ductile performance. This will include connection of wall with roof, including bands and ties between walls and introducing connections between roof and walls and wall to wall.
- iii) Eliminating existing weakness in an existing building by introducing symmetry in plan, changing location of mass, reducing large openings etc.
- iv) Avoiding brittle modes of failure. This will include improving anchorage and providing bracings in walls.

The extent of modification has to be determined based on the principle of introducing sufficient anchorage of all elements, providing bracing to vertical load carrying members in order to avoid premature mode of failure and to ensure continuity of all structural components in a building.

3. REPAIR MATERIALS

Cement and steel are common materials that are used for repair work. Various types of cement with properties such as shrinkage compensating, low heat and sulphate resistance are preferred for specific repair applications. Steel in the form of bolts, threaded rods, angles, channels and high strength pre-stressed steel can also be used. Wood, bamboo, casuarinas are often used for temporary supports, A brief summary of a few materials generally used in repair of non- engineered structures are given below:

3.1 Shotcrete

Shotcrete is a process in which compressed air forces mortar through a nozzle to be sprayed on a surface of a building at a high velocity. The materials used in shotcrete are generally same as those used for conventional mortar. The reinforcement provided is generally welded wire fabric and deformed bars tacked onto the surface.

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

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

Generally Shotcrete gun nozzle is held at 0.6 to 1.8 meter from the surface. In most cases Shotcrete can be applied in a single application for the required thickness. It is versatile as it can also be applied on curved or irregular surface. Its strength after application and its good physical characteristics make it ideal for strengthening weak members

3.2 Epoxy resins

These are used for the following:

1. to bond plastic concrete to hardened concrete
2. to bond rigid materials to one another
3. for patch work
4. for painting over concrete to give colour, resistance to chemicals, water and to give abrasion resistance.

They are excellent binding agents. The low viscosity resins can be injected into small cracks. The higher viscosity material is used as binding agent and for filling larger holes and cracks.

3.3 Epoxy mortar

The Epoxy mortar is made using epoxy resins and suitable sized aggregate (sand). They have high compressive strength, high tensile strength and low modulus of elasticity. In cement mortar or concrete,

the inclusion of epoxy can be considered as an incorporation of a second binder into the mix. The polymer mortars are two phase systems which forms co-matrix with cement. In cementations water phase, fine polymer particles of size 0.1 to 0.2 microns are dispersed. In cement polymer system, the polymer particles join and chain link reinforcing and there by increasing tensile and flexural strength. They achieve greater plasticity and tend to reduce the shrinkage stress. Hence they vastly improve the property of plain cement mortar.

3.4 Gypsum cement mortar

Based on hydraulic binder these readymade formulations are tailor made to give repair mortar material which is flowable and shrinkage free. Hence they can be applied in complicated locations and only addition of water is required at site. Cementitious mortars such as gypsum cement mortar have limited use for structural applications and are intended for hand/trowel applications.

3.5 Quick-setting cement mortar

These are patented mortars generally having two components. They come in pre-packed condition. They can be classified as

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

Various surface treatments used are shown in Table-2 indicating their properties and the defects they are intended to treat.

Table 2 : Different types of hand applied mortars

Sl. No.	Defect	Repair mortar type	Properties
1	Minor surface defect	A two pack polymers modified cementitious screed.	Gives a fair face finish. Good water proffing properties. Resist acids and gases.
2.	Surface cavities and honeycombed concrete	Highly adhesive, thixo-tropic mortar	Water proof and anti-carbonation finish. Good resistance to pollution.
3.	Powdery surfaces	A two components surface stabilizer	Binds powdery surfaces and evens out absorption characteristic.
4.	Surface protection	Resin rich water based elastic co-polymer	Highly resistant to CO ₂ diffusion and self cleaning.
5.	Surface barrier	A water based co-polymer	Resistant to fungal attack.
6.	Non-structural cracks	Non shrinking polyol filler	Easily applied elastic compound and cures at low temperature
7.	Minor voids of approximate size 50 x 50 x 50 mm	Rapid curing polymer modified cementitious co-polymer	High Strength when compacted in layers

8.	Major voids approximate size 100x100x100mm	Heavy duty thixotropic fiber reinforced polymer modified cementitious mortar.	Can be applied up to 100mm thick. Easy to mould.
9.	Bonding agent	Polymer modified cementitious surface impregnant.	High penetration into porous concrete creating enhanced adhesion
10.	Protection of steel reinforcement	A highly alkaline two component system of cementitious powder and polymer dispersion which react chemically to passivate steel	High penetration and enhanced adhesion to protect steel.

3.6 Micro-concrete

Based on hydraulic binders these readymade formulations are tailor made to give concrete which is flow able and free of shrinkage. They are applied in complicated location and in thin sections such as those met with in jacketing Table-3 gives important properties of the micro-concrete. They can be made either as type A (normal strength) or type B (high strength) depending on requirement.

Table 3 : Properties of micro concrete

Sl. No.	Properties	Type A	Type B
1	Comprehensive strength N/mm ²		
	24 hours	20	10
	3 days	30	15
	7 days	40	30
	28 days	50	40
2	Flexural strength N/mm ²		
	28days	5	3.5
3	Tensile strength N/mm ²		
	28 days	2	1.5
4	Young's modulus kN/mm ²	25	25
5	Un restrained expansion in %	1 to 4	1 to 4
6	Fresh concrete density kN/m ³	21-22	21-22

3.7 Fiber-reinforced concrete

Fiber reinforced concrete has better tensile strength and toughness compared to conventional concrete. They have also improved energy absorption capacity. These compositions offer high tensile strength, durability, ductility and enhanced energy absorption capacity. They are being increasingly used for structural strengthening.

3.8 Mechanical anchors

Mechanical type of anchors employs wedging action to provide anchorage. These can provide resistance against shear and tension. Some of these anchorages are specialized patented products which can be designed for a required tension or shear force.

3.9 Fiber or reinforced polymer (FRP and CFRP materials)

Carbon fiber reinforced plastic (CFRP) material consists of strong and stiff carbon fibers (approx. 7 micrometer diameter) embedded in an epoxy resin matrix. It has high strength to weight ratios and corrosion resistance thus helps reduce maintenance cost. They are manufactured in long lengths by pultrusion process, with unidirectional fibers ranging from 50-150mm wide and 1.2-1.4 mm thick having fiber volume content greater than 65%. They are black in color and are about 10 times as strong as mild steel but one fifth of its weight.

They have low density, high fatigue strength, and high wear resistance, vibration absorption and dimensional stability, high thermal and chemical stability. They are suitable to be used as a protective and strengthening "jacket". CFRP wraps can be used to strengthen masonry piers and walls especially for seismic loading.

3.10 Metal plates, steel and aluminum etc.

Application of bonded steel plate can increase the flexural and load carrying capacity, improve stiffness—thus reducing deflection and cracking and enhance shear capacity. The process of strengthening is usually bonding additional reinforcement to the external faces of the structure. The steel plate is attached to the structure either by anchor bolt or by chemical or epoxy bonding. Bolts are often used in conjunction with adhesive to provide mechanical anchor for the plate at the ends to prevent premature de-bonding due to peeling. The bolting also helps support the plates whilst the adhesive cures. Sometimes instead of steel plates for strengthening brickwork aluminum plates have also been used.

3.11 Ferro cement

Ferro cement is a type of reinforced cement mortar commonly made of hydraulic cement mortar reinforced with closely spaced layers of small diameter wire mesh". The mesh may be made of metallic or other suitable materials. Fineness of mortar matrix and its composition should be compatible with opening and tightness of the reinforcing system, it is meant to encapsulate. The matrix may contain discontinuous fibers.

Well designed Ferro cement wraps can be an economical alternative to CFRP wraps especially for non-engineered construction.

4. TECHNIQUES FOR STRENGTHENING

The term strengthening means the structural enhancement of existing weak members in such a way as to restore or increase their ultimate strength in bending, shear or direct tension and compression. Strengthening options may vary for specific case, depending on the problems to be addressed, and individual attention is needed to assess the suitability of the proposed intervention.

Some of the common forms of repair and strengthening techniques are described below:

4.1. Small cracks

Even fine cracks in load bearing members, which are un-reinforced, like masonry or plain concrete, will reduce their resistance against loads. Hence they should be marked carefully and critical ones repaired.

Cracks in width smaller than 0.75mm can be effectively repaired by pressure injection of epoxy.

The surfaces are thoroughly cleaned of loose materials and plastic injection ports are placed along the length of the cracks on both sides and secured in place with epoxy seal (Fig-1a). The ports can be installed at intervals approximately equal to thickness of the element being repaired.

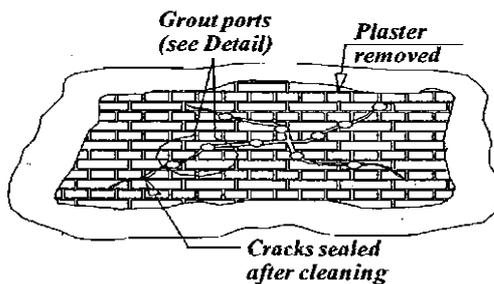


Fig-1.a1 Grout of Epoxy injection

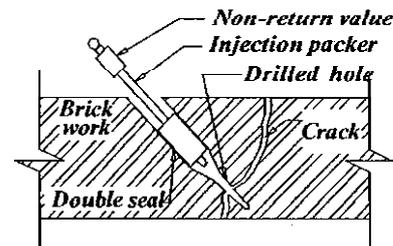


Fig-1.a2 Crack injection system

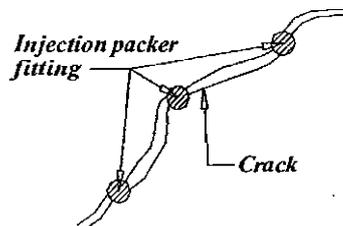


Fig-1a3 Grout Ports Details

After hardening of the seal low viscosity epoxy resin is injected into one port at a time sequentially beginning at the port of the lowest level and moving upwards.

The resin is pushed through the packer till it is seen flowing from the other end or a port at a level higher than where it is injected (Fig-1b). The injection port is closed at this juncture and the packer is moved to the next higher port.

This operation is repeated sequentially until we reach the top most part and the whole crack is filled with grout.

Longer cracks will permit longer packer spacing depending on thickness of the member. This technique can be used for all types member (beams, columns, walls or slabs). They can be utilized to repair small cracks in individual masonry blocks or fill large continuous cracks. Vacuum injection has a typical fill level of 95% and can fill fine cracks even as small as 0.025mm.

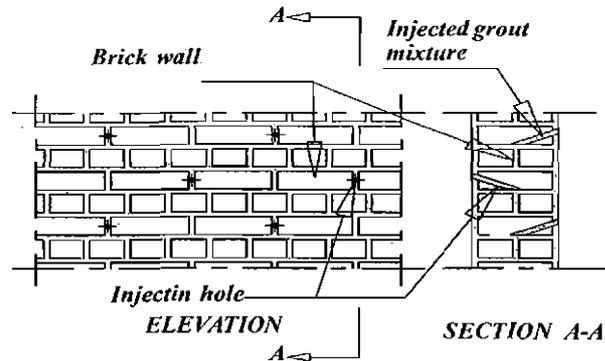


Fig-1b Grout or Epoxy injection in an existing weak wall

4.2 Large cracks and crushed material

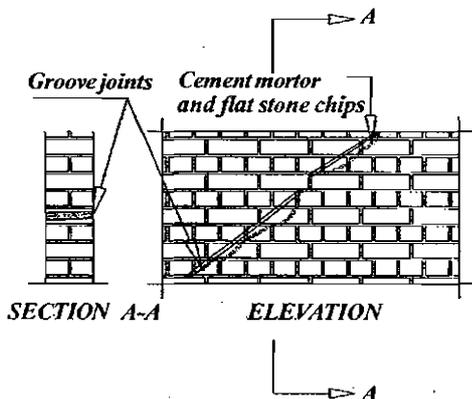


Fig-1c Cement mortar and flat-stone chips placed as filler in wide cracks

For cracks wider than 6mm and where brickwork or concrete is crushed, the following procedure is suitable:

- Loose material in the crack is removed and any of the repair mortar mentioned in Table 2 is filled.
- If necessary the crack is dressed to have a "V-groove" at both faces.
- At places where cracks are wide fillers like flat stone chips can be used (Fig-1c).
- Additional shear and/or flexural reinforcement are provided in the location of the repairs based on structural necessity.

- The added steel has to be protected properly by sufficient polymer mortar to prevent it from corrosion (Fig-1d).
- In case of walls or roof slabs additional mesh reinforcement is included either on one or both sides. This mesh reinforcement is generally nailed, tacked and tied by binding wire (Fig-1d).
- To prevent widening of the cracks they can be stitched (Fig-1e).

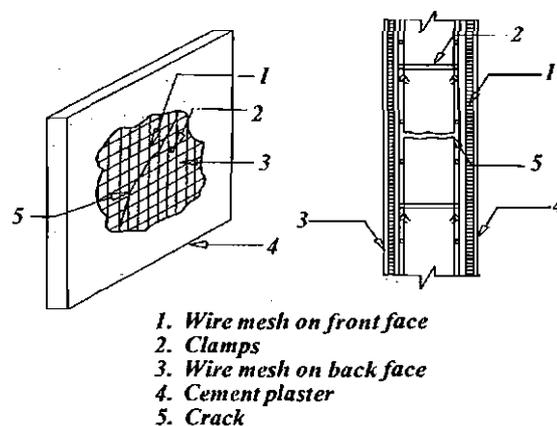


Fig-1d Mesh reinforcement repair for walls / roof slab

The stitching consists of drilling small holes of size 6 to 10mm on both side of the crack, cleaning the holes and anchoring legs of stitching dogs with short legs.

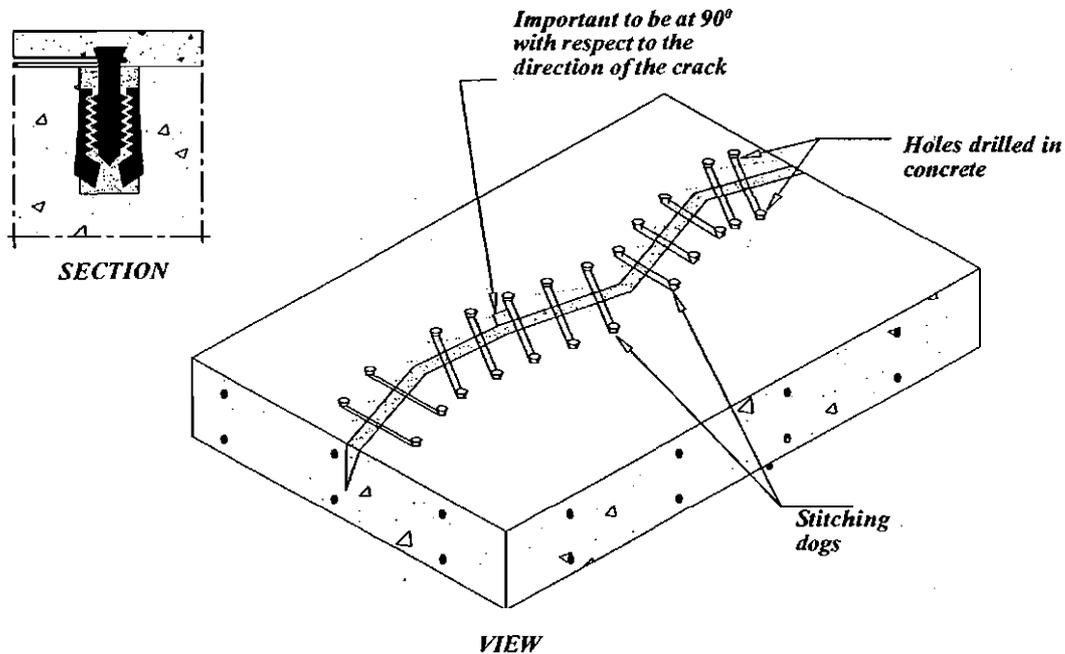


Fig-1.e Repair by stitching the cracks

The stitching dogs are variable length and orientation as shown. The spacing of reinforcement should be reduced at the ends of the crack. Stitching will not close the crack but prevent further propagation and widening.

4.3 Damaged reinforcement

In several instances the reinforcement is severely damaged showing signs of either buckling or elongation due to yielding. The element can be repaired by adding additional steel with old steel by lap welding.

Additional stirrup ties are added in the locations of damages and then jacket concrete to provide required confinement of concrete in the repaired zone.

Additional reinforcement will sometimes have to be pinned into either masonry or concrete. In such cases, a hole larger than the bar diameter is drilled. The hole is filled with grouting material. The reinforcement is then pushed into place and held till the grout hardens (Fig-2).

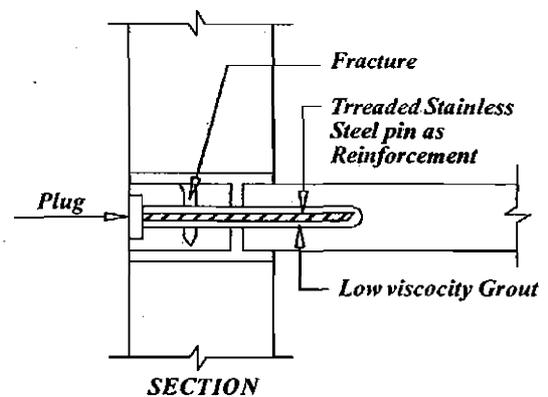


Fig-2 Pinning technique

4.4 Fractured wooden members

Decayed areas of timber usually occur in the bottom chord members of trusses because they are subjected to tensile forces which tend to pull the joint apart. Surgery is performed on decayed areas by shaving and gouging out decayed material. Reinforcement in the form of steel bars, carbon fibre, or glass fiber is inserted into predrilled holes filled with resin grout. The area is then shrouded and filled with resin and allowed to cure (Fig-3).

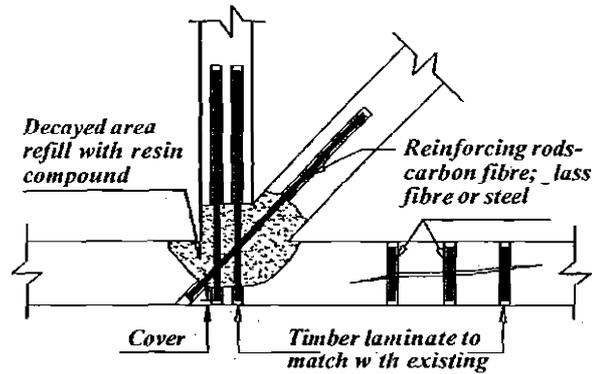


Fig-3 Repair of defective timber joint

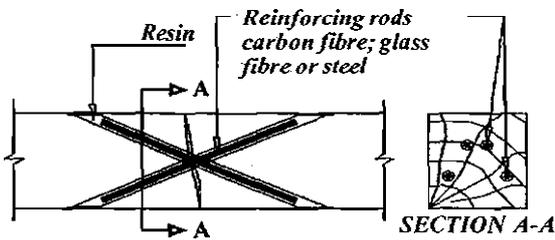


Fig-4 Repair of a completely fractured member

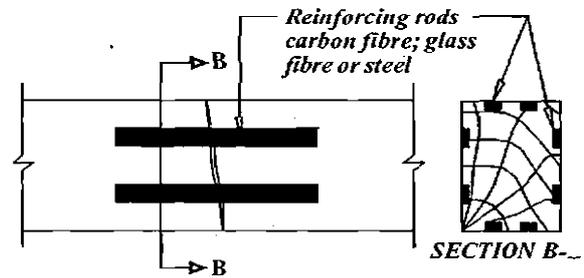


Fig-5 CFRP strips used in the repair of a timber member

If a member is cracked, split or rotted right through, a repair can be effected filling the void with resin and then reinforcing with rods and resin in two planes from opposite surfaces as shown in (Fig-4). Alternatively, CFRP strips can be bonded on the surface as shown with a timber laminate rendering the repair work invisible (Fig-5).

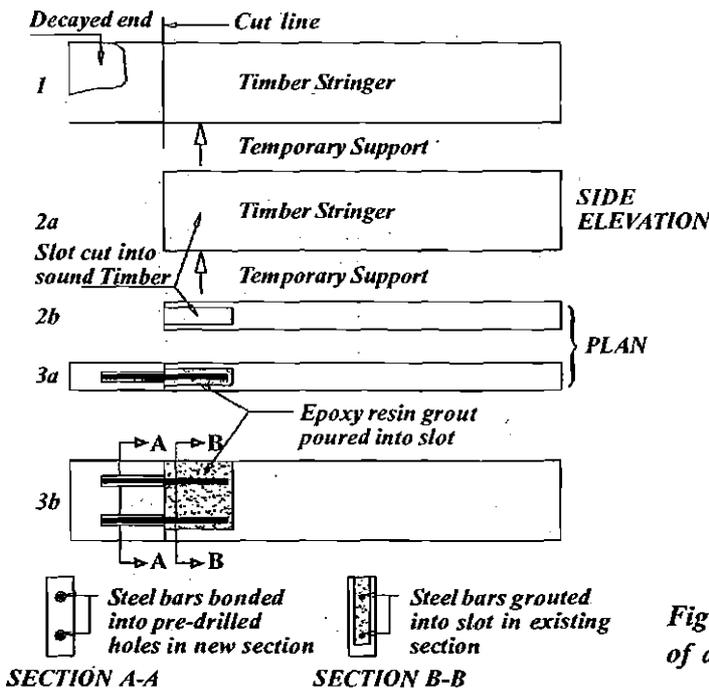


Fig-6 Repair of an end decay of a timber member

The particular problem of decaying ends of timber member such as in stringers and joists can be addressed by using steel bars in conjunction with epoxy resin. The decayed section is cut off and replaced with a new preformed section with protruding epoxy bonded reinforcement bars which are placed in slots cut in the good timber adjacent to the cut end. Epoxy mortar is then poured into the slot to bond the bars of the timber (Fig-6).

4.5 Defective timber joints

The failure of the joints connecting columns and girders frequently occur during lateral loading. The restoring forces at the joints are immobilized due to structural deterioration and roof weight. This leads to sliding after joint fracture (Fig-7a). Even buildings with horizontal bracings don't survive (Fig-7b and 7c).

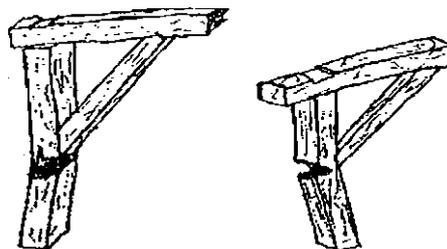


Fig-7a Joint fracture due to sliding

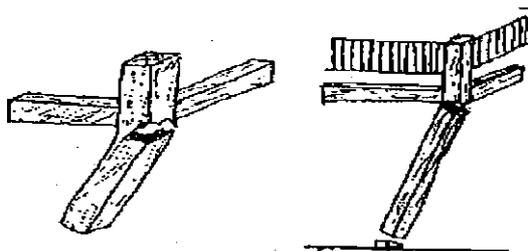


Fig-7b Joint fracture of corner column junction

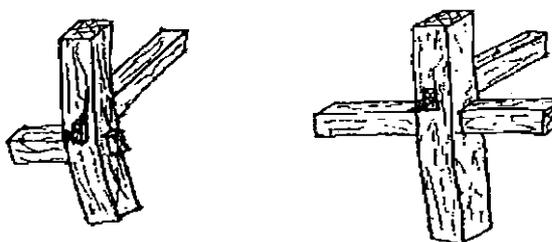
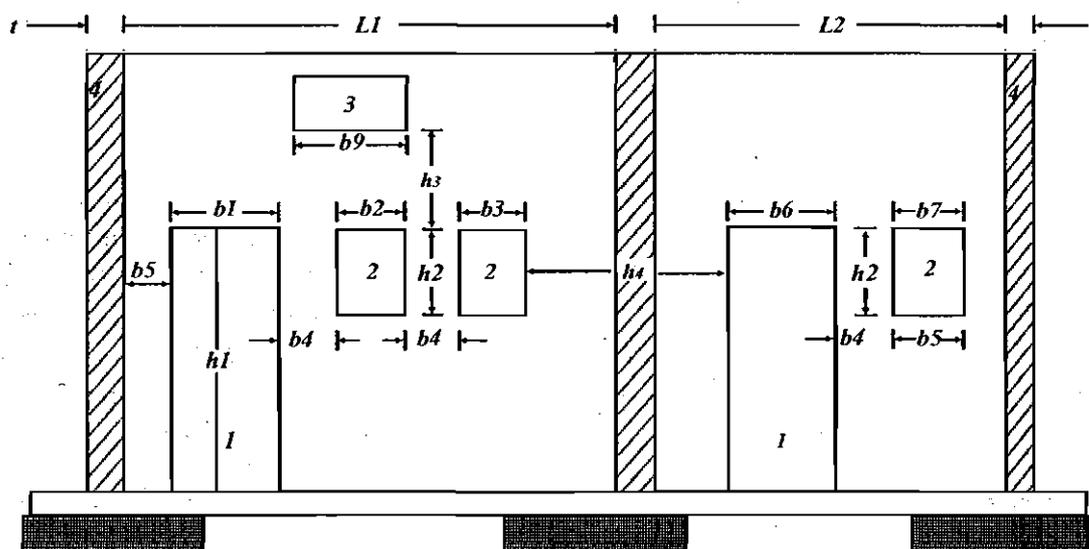


Fig-7c Horizontal bracing ineffective

4.6 Local modifications

Local modifications refer to strengthening of structural components such as walls locally. This can be achieved by local modification such as either closing the opening or providing reinforcement around it.



Note: 1. Door $b_1 + b_2 + b_3 \leq 0.5L_1$ for one storey $b_6 + b_7 \leq 0.5L_2$ for one storey $b_4 \leq 0.5L_2$ but not less than 600mm
 2. Window $0.40L_1$ for two storey $0.40L_2$ for two storey $b_5 \leq 0.25L_1$ but not less than 600mm
 3. Ventilator $0.33L_1$ for three storey $0.33L_2$ for three storey $b_3 \geq 600\text{mm}$ $0.5 \times (b_2 \text{ or } b_2)$ Whichever is more
 4. Cross wall

Fig-8 Requirements of openings

Opening should be located away from inside corner by a clear distance equal to $\frac{1}{4}$ of the height of the opening but not less than 60 cm. The horizontal pier width between two openings should be not less than $\frac{1}{2}$ of height of the shorter opening but not less than 60 cm. The total length should not exceed 50% of the length of the wall between consecutive cross walls in single storey construction, 40% in two storey construction and 33% in 3 storey construction. The requirements of opening with respect to good seismic performance are shown in Fig-8.

When the openings don't comply with the above requirements, they are reinforced or boxed in reinforced concrete all-round or reinforcement bars provided in jambs through the masonry (Fig-9).

Local modification includes supplementing the lintel bands and plinth bands and vertical ties having horizontal steel dowel bars as shown in Fig-9. This dowel bars are used at corners and T-junction to integrate the box action of walls. Dowels can be inserted at regular intervals of 50 cm and taken into the walls to sufficient length (Fig-10) so as to provide the full bond strength. Wooden dowels have also been successfully used instead of steel dowel.

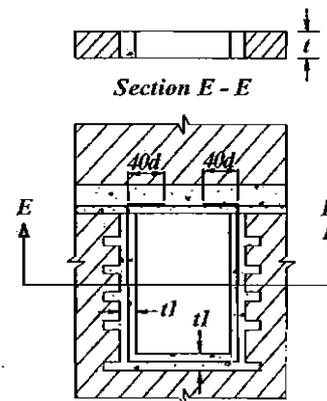


Fig-9 Strengthening masonry around an opening (window)

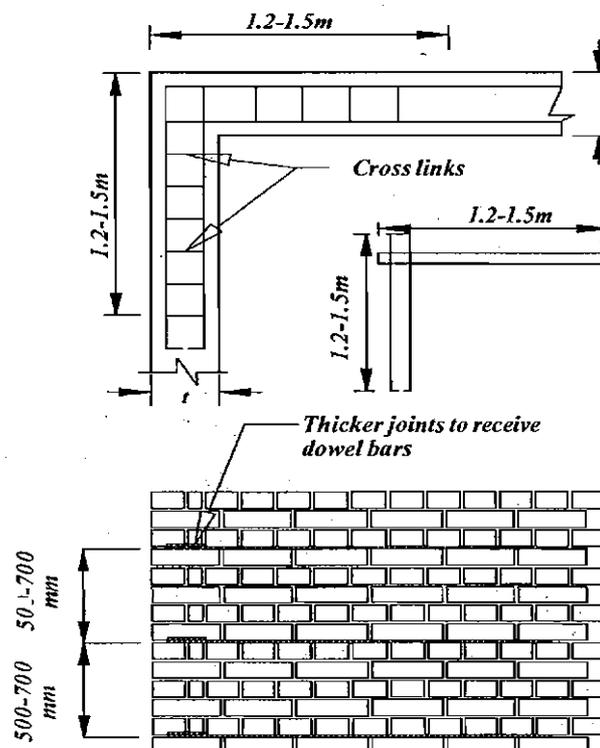


Fig-10 Insertion of steel down bars in corners and T-joints

4.7 Global modification

Global modification includes insertion of walls with the intension changing the lateral load performance of the building. This will relive overloaded members and ensure better seismic behavior. This is also undertaken to change the center of mass or center of stiffness of the building so that torsion due to unsymmetry is avoided.

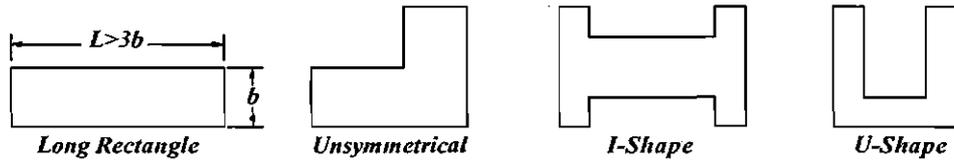
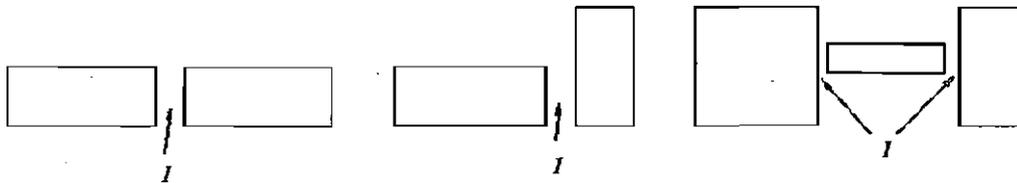


Fig-11a Building plans having many projections



Note : I-Separations (Separation should be 1 cm per story height with a minimum of 3cm)

Fig-11b Separation for improving behaviour of building

The building plans having large projection (Fig-11a) behave badly during earthquakes. Such buildings are retrofitted by making it as two separate blocks with sufficient separation in between them (Fig-11b).

A small building enclosure with properly interconnected walls acts like a rigid block. The long walls (Fig-12a) are vulnerable for out of plane collapse. For unframed walls of thickness “t” and wall spacing “a”, the wall spacing ratio a/t should not exceed 40. To ensure this cross walls are added as indicated in Fig-12b.

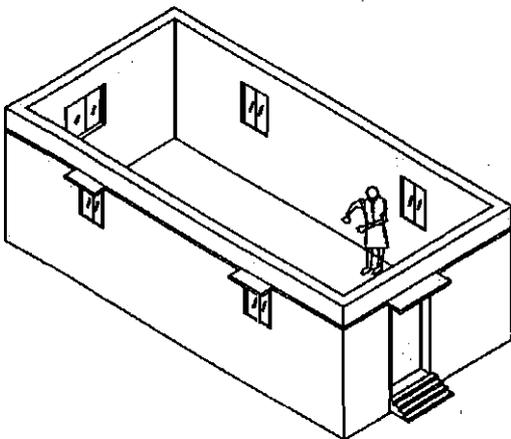


Fig-12a No cross walls - weak long walls in large boxes

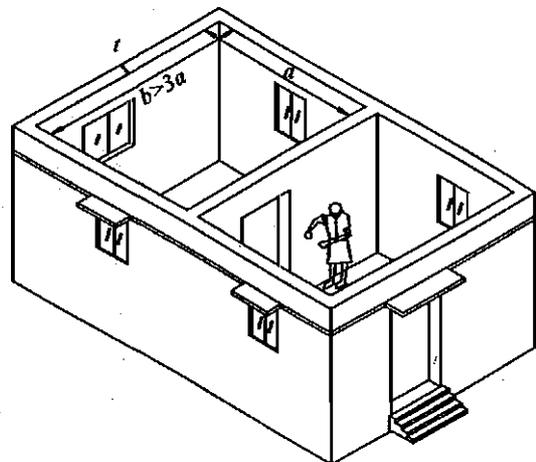


Fig-12b Insertion of cross walls to improve stability of long walls

4.8 FRP retrofit

FRP composites are tailor-able, flexible and are easy to apply. Hence they can be used in retrofit operation. They have thin profile and hence they can be made architecturally pleasing. They don't reduce the usable floor space. They can be used for masonry strength enhancement in the following ways :

1. near surface mounted using FRP rods,
2. surface mounted using FRP strips and
3. overlay using FRP wraps

1. Near surface mounted technique:

In this technique grooves are cut horizontally through mortar bed joints and vertically if needed. The depth of cut is about 25mm. The grooves are half filled with epoxy adhesive. Small diameter (6mm) FRP rods are inserted and pressed with another layer of adhesive (Fig-13).

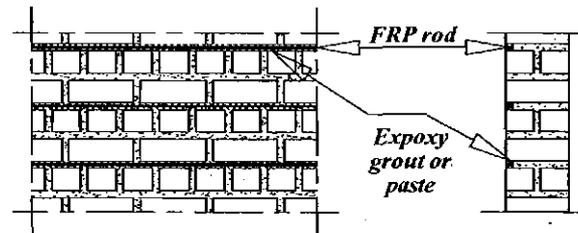


Fig-13 Application of near surface mounting technique for strengthening a masonry wall

2. Surface mounted techniques:

FRP strips are applied to masonry walls vertically and or diagonally to improve their out of plane capacity in both way bending. The diagonal strip application enhances the in-plane shear capacity by acting as tension chord of the diagonal brace.

3. Overlay technique:

The use of overlays to strengthen masonry walls is a well proven technique. This technique involve applying a layer of epoxy sealant to the surface of a masonry wall, impregnating the FRP wraps with epoxy 'saturant', placing 'the overlay on 'the wal' surface, and finally finishing with a layer of epoxy saturant.

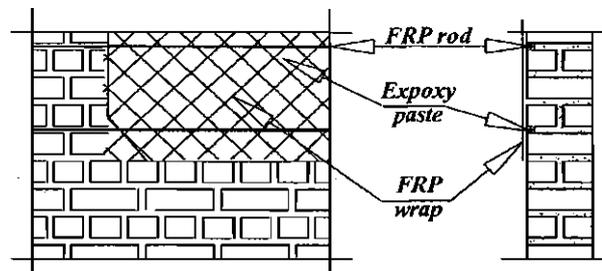


Fig-14 Anchoring system for FRP wraps using FRP rod

Bond is the key factor that determine the success of FRP retrofit system. An undesirable mode of failure is the peeling off of FRP layer due to insufficient bond length. Fig-14 shows a typical anchorage solution of an FRP wraps by an embedded FRP rod.

4.9 Strengthening by pre-stress

Over loaded or damaged beams can be effectively strengthened by externally placed tendons. Tendons can be anchored to the sides near the

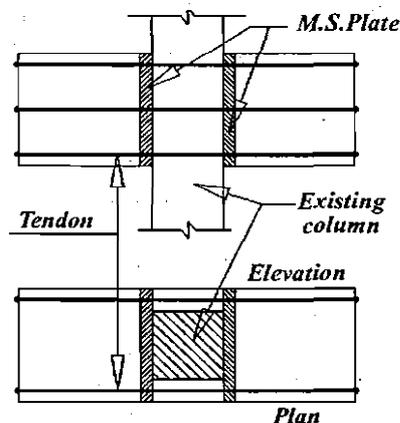


Fig-15 Transvers pre-stressing of bracket

ends or behind the diaphragm. Even timber trusses can be selectively pre stressed i.e. either individual member pre-stressing or structural truss system pre-stressing. Indeed even a bracket failure can be corrected by transverse pre-stressing (Fig-15). This case was practically applied to an industrial building for suppressing brittle shear failure mode of a corbel.

4.10 Stress reliving techniques.

This technique involves insertion of new structural member in order to relieve a overloaded or damaged component.

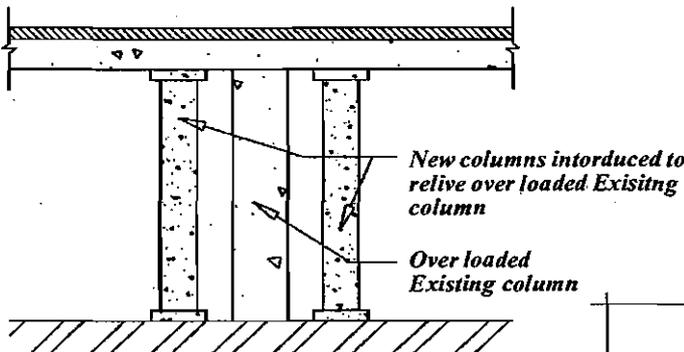


Fig-16a Insertion of new columns to relieve over loaded damaged column

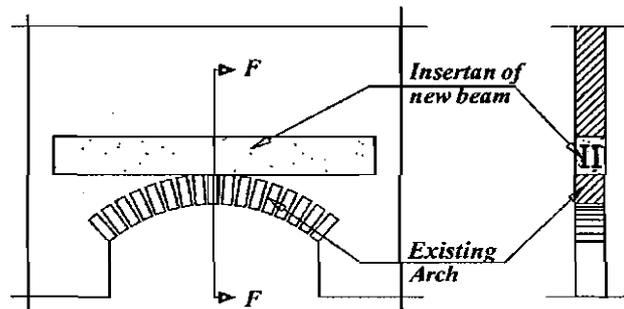
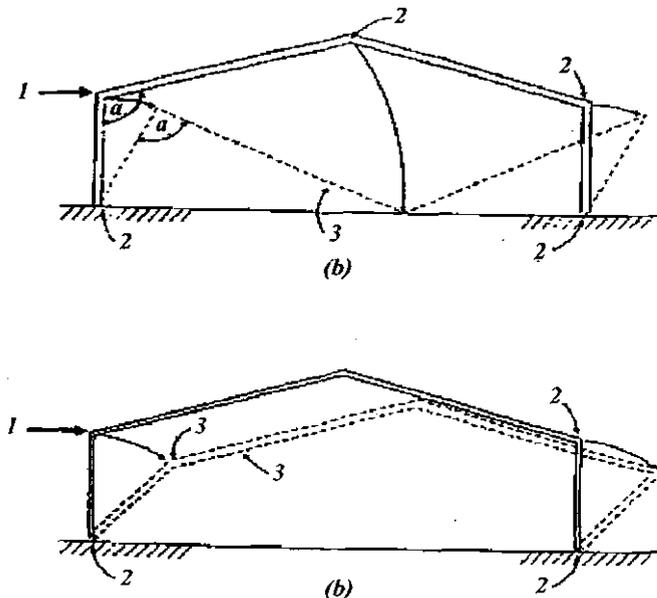


Fig-16b Avoiding arch thrust by inserting beam above it

A brick pillar or pier which is over loaded or damaged can be relieved by constructing pillar on either side of damaged pier as shown in Fig-16a. A weak brick arch can be repaired by lintels consisting of steel beams inserted above the arch to take load and relieve the arch (Fig-16b). In this case the pier below the arch is relieved of the lateral thrust due to the arch.

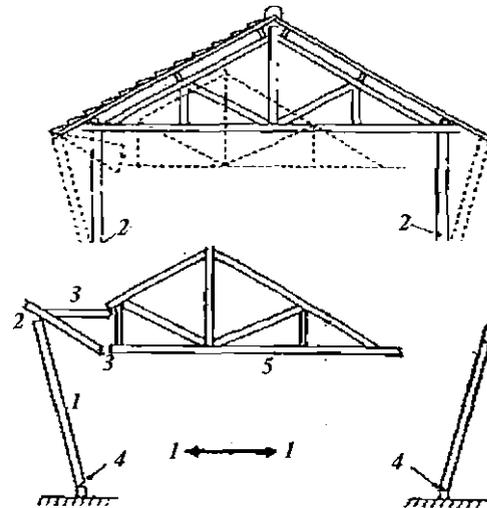
4.11 Bracing

Most of the non-engineering constructions do not have lateral load resistance. The rural hut made with casurina post is a typical example. The mode of a failure or collapse is shown in Fig-17a. Such failure is also common during earthquake in roof trusses supporting columns (Fig-17b). The Fig-17c shows how fixing bracing in rural hut stabilizes the structural system. Provision of opening for doors can be accommodated by providing bracing on either side of the door way as shown in Fig-17d. In case of earthen construction it is necessary to achieve seismic resistance by introducing diagonal members (bracing) in the planes of the walls as well as in the corners at top and/or lintel levels of the walls (Fig-17e). This is achieved by nailing or tying bamboo or casurina to vertical and horizontal framing members as shown in Fig-17f.



1. Earthquake force
2. Failure of joints
3. Collapsed frame

Fig-17a A collapse modes of a typical hut



1. Wall or column
2. Rupture of tie and rafter
3. Fracture
4. Collapse of truss

Fig-17b Failure mechanism of a truss system

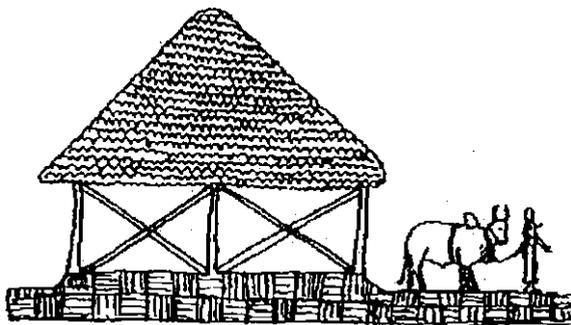


Fig-17c Fixing bracing to a rural hut

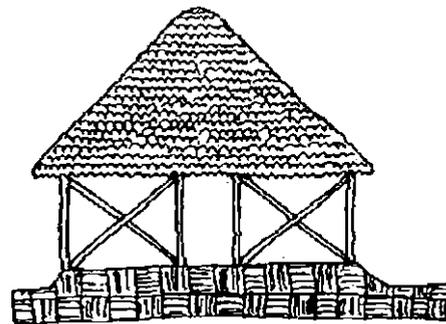


Fig-17d Provision for door opening by bracing on either side

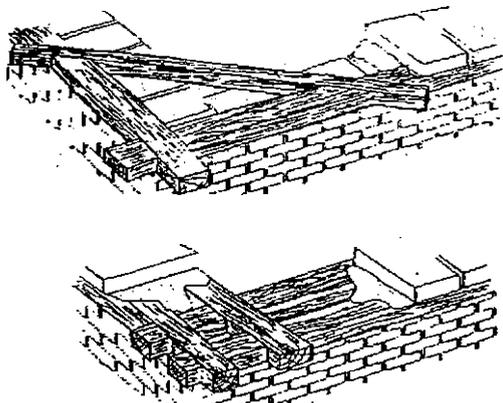


Fig-17e Collar band in the wall at lintel level.

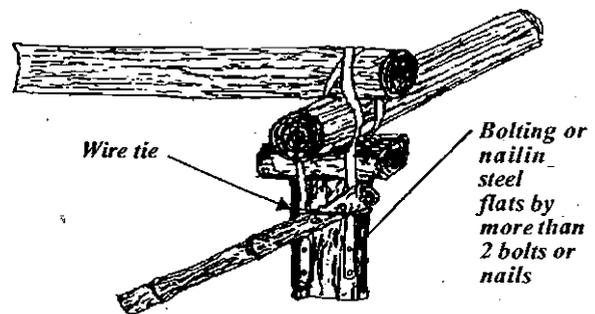


Fig-17f Joining vertical, horizontal and cross bracing members by steel flats and ties

4.12 Infilling

Weak R.C. frames can be stabilized by providing brick infilling at chosen location. Brick infilling will increase the later load capacity. The infilling will also affect the centre of stiffness of a building. Hence careful choice of infilling should be made so that increase in stiffness and strength of the frame in filled does not make other frames or members vulnerable.

4.13 Overall strengthening measures

The various types of non-engineered building can be classified as follows :

1. Earthen building
2. Barrack type wood frame building
3. Traditional single storey flat roof masonry building

Using the various technique discussed above the over all seismic resistance features that can be incorporated in these buildings are shown in Fig-19a, 19b and 19c.

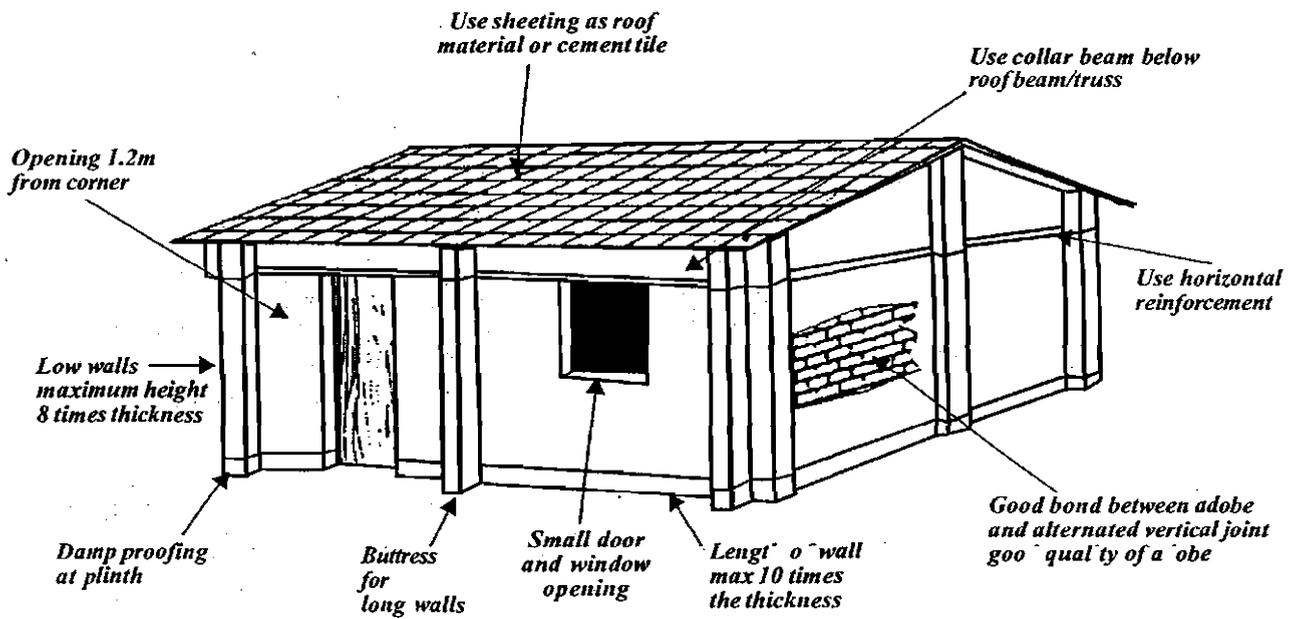
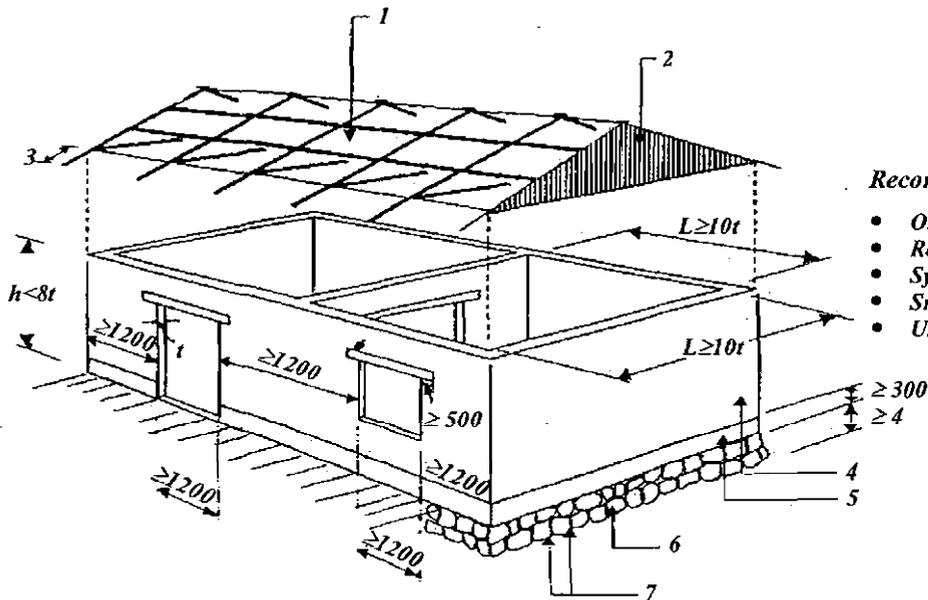
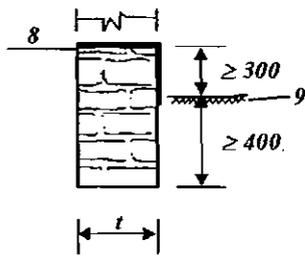


Fig-19a Features to introduced in a non-engineered earthen building

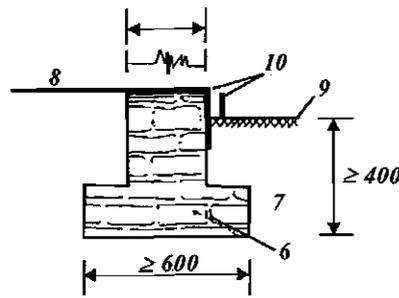


Recommended :

- One floor constructions
- Roughly squared rooms
- Symmetric distribution of walls
- Small openings
- Use of pillasters



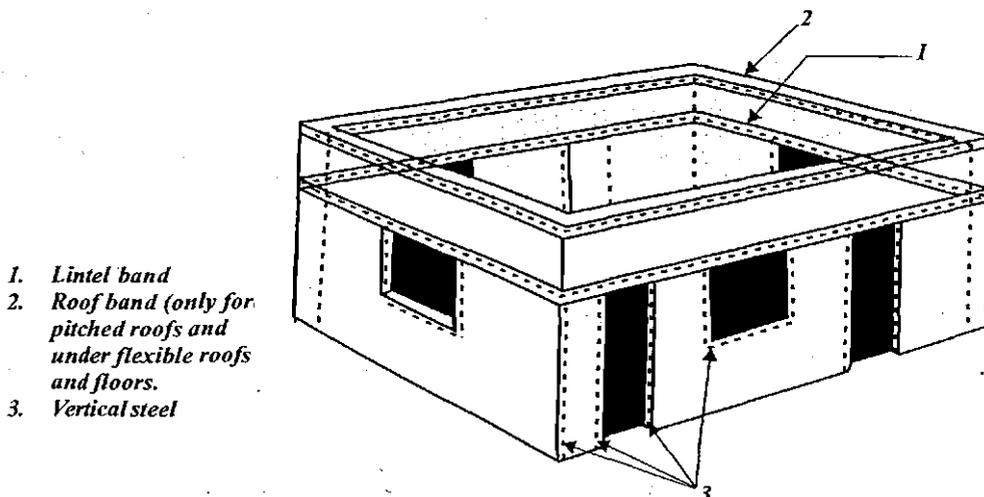
a) Firm Soil



b) Soft Soil

1. Lintel band
2. Light gable wall (matting or boarding)
3. Rain protection overhang about 500 mm
4. Stable plaster
5. Plinth height for flood protection
6. Stable foundation
7. Good mortar preferable non-clay. $t = \text{wall thickness. } t > h/8. t > L/10$
8. Floor level
9. Ground level
10. Waterproof layer

Fig-19b Features to be introduced in a non-engineered barrack type building



1. Lintel band
2. Roof band (only for pitched roofs and under flexible roofs and floors.
3. Vertical steel

Fig-19c Features to be introduced in a flat roof brick building

5. STRENGTHENING ROOF

The roof has to be water proof. It should distribute the lateral load to the walls. Hence it should act as a horizontal diaphragm. There are innumerable varieties of non engineered roofs. The most common types encountered in various parts of Tamil Nadu are considered here.

5.1. Timber roof truss

The timber roof trusses usually support tiles which are brittle and get easily dislodged. These should be replaced with iron corrugated sheets. False ceiling of brittle materials are dangerous. Ductile materials like bamboo mating or light foam substances can be used to replace brittle false ceiling. Anchors of roof trusses to supporting walls should be improved and the roof truss thrust on walls should be minimized or eliminated. This can be achieved by providing new bracing as shown in Fig-20.

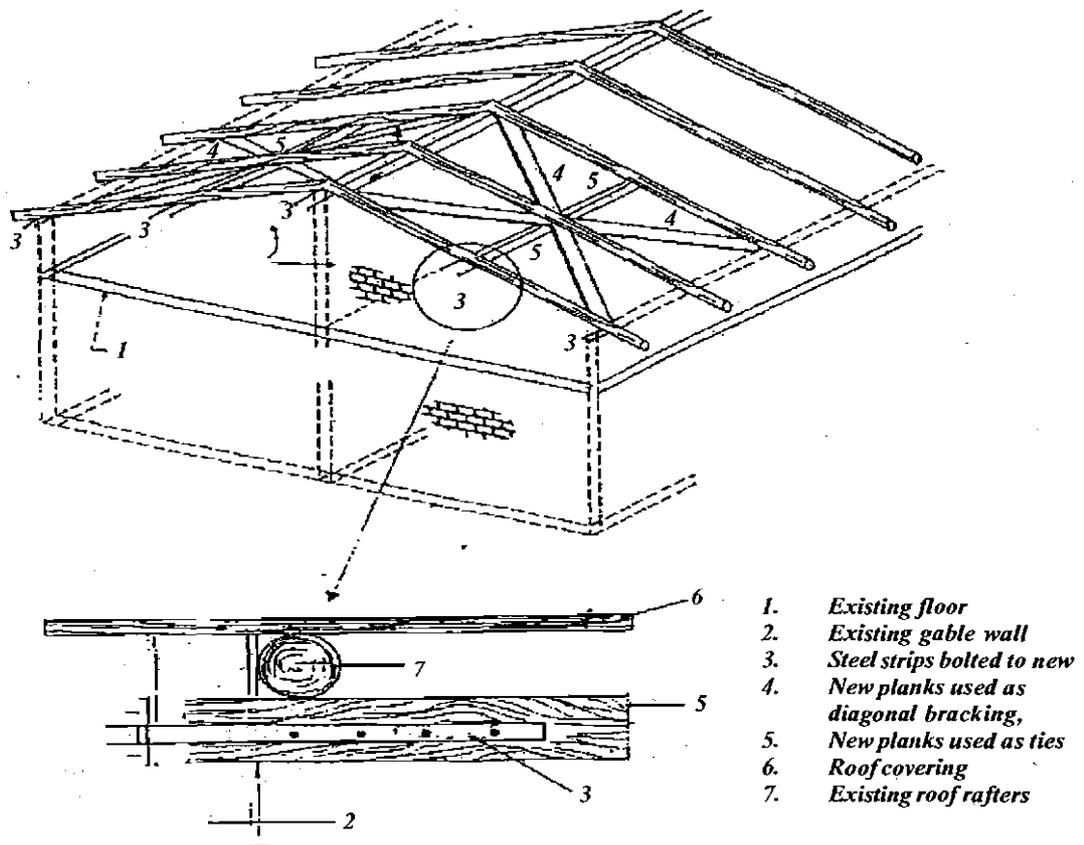


Fig-20 New bracing for a weak roof

5.2 Terrace roof

Where the roof consists of prefabricated unit like channel units or joists carrying brick tiles, integration of individual unit is a must. The prefabricated units can be integrated by cast in situ reinforced topping and an in situ R.C. ring beam as shown in Fig-21. These details can be very effectively adopted for Madras Terrace Roofing or pre cast channel unit roofing.

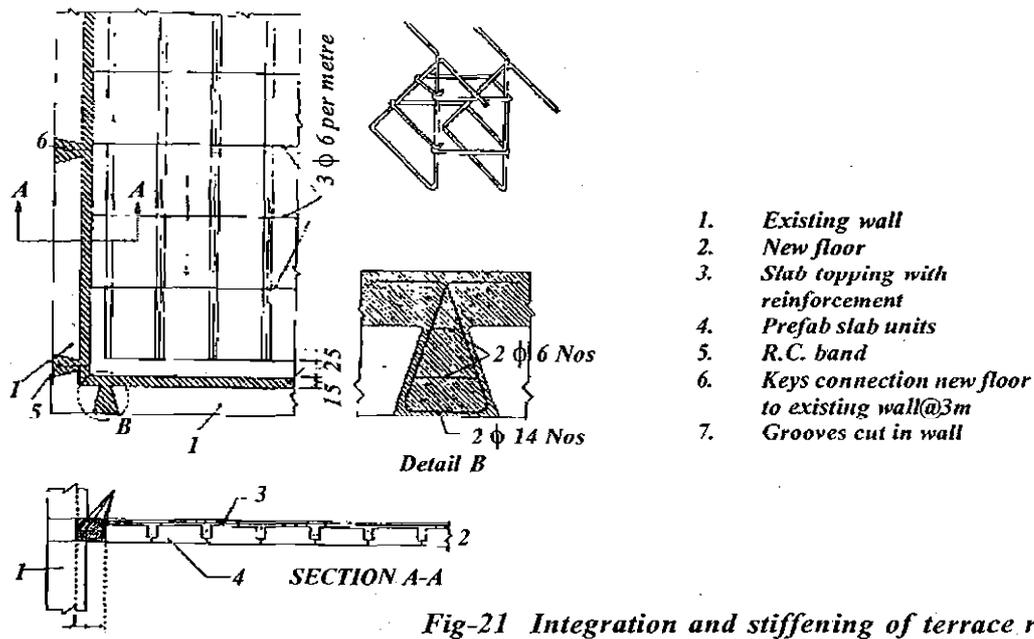


Fig-21 Integration and stiffening of terrace roofing

5.3 Light roofing sheets

The following damages are reported to light roofing sheets during cyclones. These include AC sheets, CGI sheets etc.

- a) Damages to the sheets with gabled roofs covered with light sheets such as AC sheet, GI sheets or tiles.
- b) "J" bolts fail due to lack of bearing area and hence they open out.

To avoid such failure galvanized U hook bolts at close spacing as shown in Fig- 22 should be used.

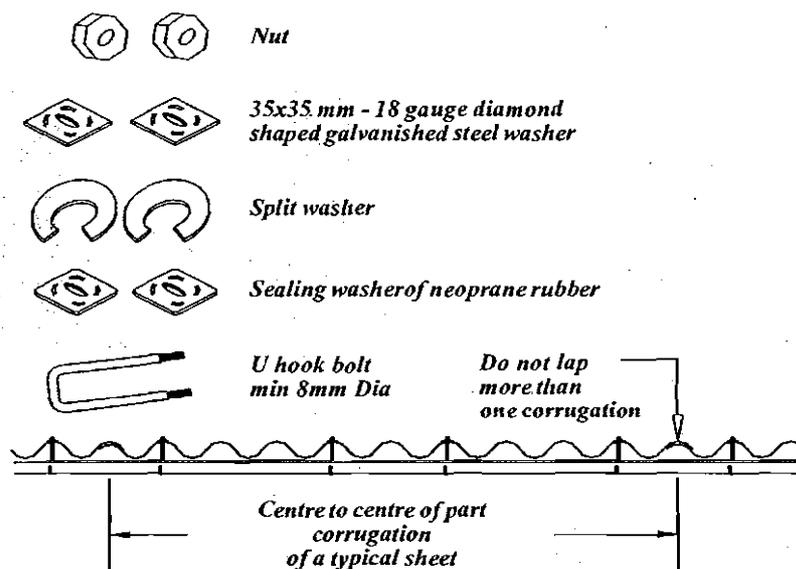


Fig-22 Corrugated sheet fixing

5.4 Thatch roof

Thatch roofs are widely used as roofing material in rural areas. Thatch roofs are blown due to wind, and get damaged during earthquakes in addition to being vulnerable for fire. The performance of the thatch roof can be significantly improved by adopting a few simple safeguards. These are discussed below:-

The performance of thatched roof can be improved by holding down the roof using ropes in a diagonal fashion. Instead of ropes for tying rafter and braces, metal straps and mild steel wires of suitable gauge will make the system behave in a ductile manner. The connection details are shown in Fig-23a. The vertical post should be properly anchored. Cross wooden pieces tied firmly below ground as shown in Fig-23b, provide good anchorage for the post.

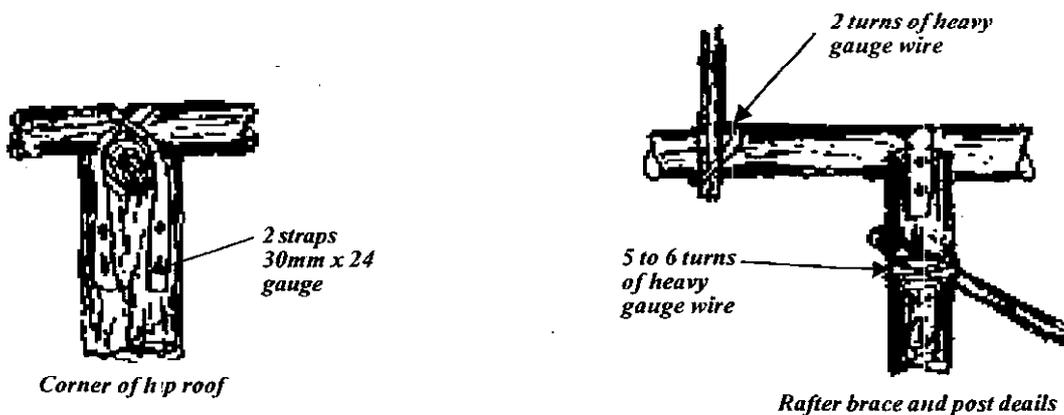
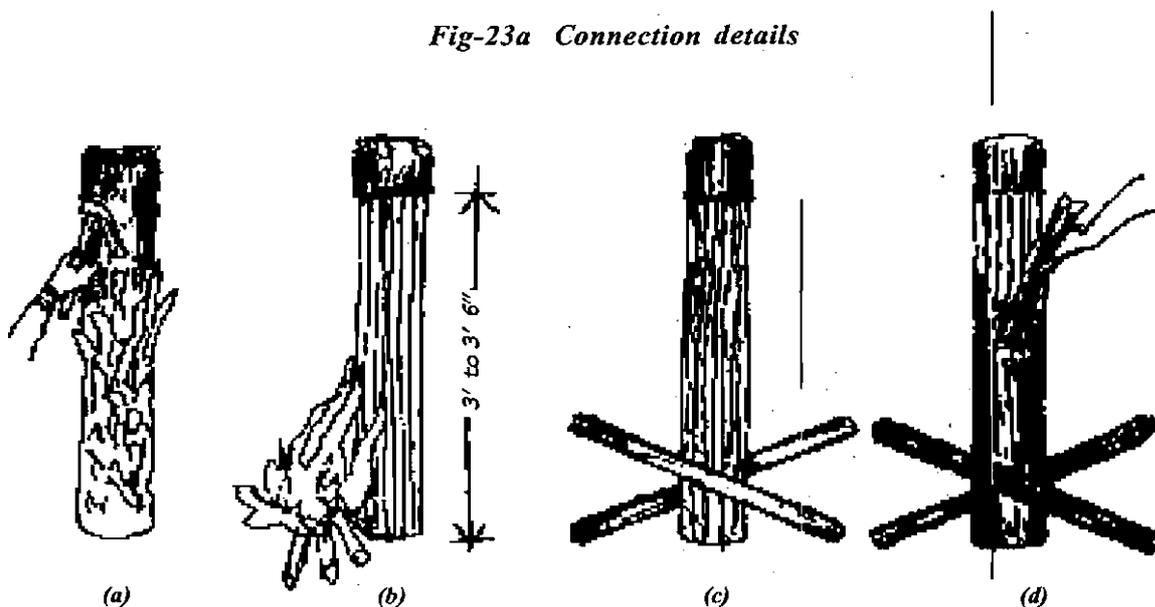


Fig-23a Connection details



- (a) Remove bark completely
- (b) Apply heat at the bottom so that there is a layer of carbon
- (c) Tie two sticks on either side of trunk,
- (d) Apply tar for portions being embedded in soil including cross sticks

Fig-23b Anchorage for posts

The portion of timber post below ground level should be protected by tar coat. Cross bracing on end panel, knee bracing and bracing in plan can improve the stability considerably (Fig-23c). In addition, one of the serious problems in thatch is inflammability during accident / earthquake because of electrical short circuit. Periodical fire retardant spray will ensure fire safety.

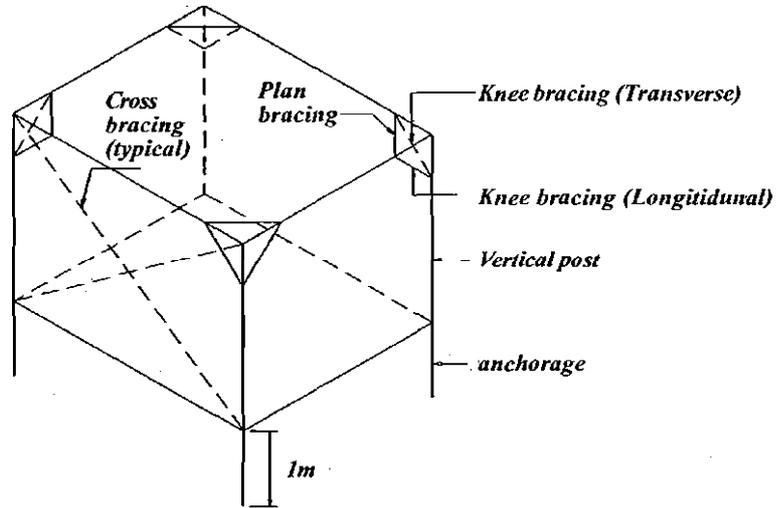
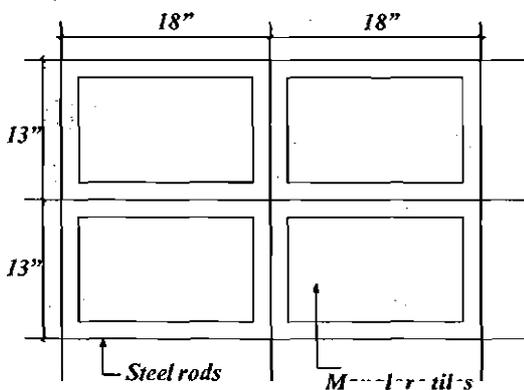


Fig-23c Improvements to structural scheme

5.5 Cost effective Roof-Filler slab

In cost effective filler slab, due to diaphragm action of the roof, there is a distinct danger of the filler tile getting dislodged and falling. In order to avoid such failures the filler roof should be provided with bearing support as indicated (Fig-24). It is essential to provide connection of roof with the walls through appropriate keys and collector elements. This figure shows typical arrangement to be adopted for ensuring good diaphragm action.



(a) The and reinforcement



(b) Bearing detail for tile

Fig-24 Filler slab roof details

6. REPAIRS TO FLOORS

Strengthening of the floors involve two issue from behavior point of view. Firstly the lateral load will generate in plane forces which should be resisted by the floor. For this the integrity of the floor will have to be improved by the provision of bracing and collector elements as well as tying the entire floor as an integral unit. Secondly the connection between the wall and floor will have to be improved so that seismic forces can be transferred from the floor to the walls. The following cases of floors, use a few of the typical details which can be adopted for seismic strengthening in such non-engineered construction.

6.1 Madras terrace roof

Madras terrace roofs are generally constructed on wooden rafter at a spacing of 0.45 meter spanning the walls. Small size bricks are laid across the wooden rafter in a brick-on-edge fashion diagonally and is ultimately topped with a layer of lime or cement mortar. For the roof this type of terrace is provided with brick jelly concrete and one or two courses of flat tiles. Such roof performs poorly during earthquake. In order to make them perform well, diaphragm action should be improved. This can be achieved by pinning and stitching the walls with the rafters at all edges. Generally it is preferable to use stainless steel pinning technique as shown in Fig-25a and Fig-25b. The pins ensure integration of the walls with the roof and provide for required collector elements for the diaphragm action.

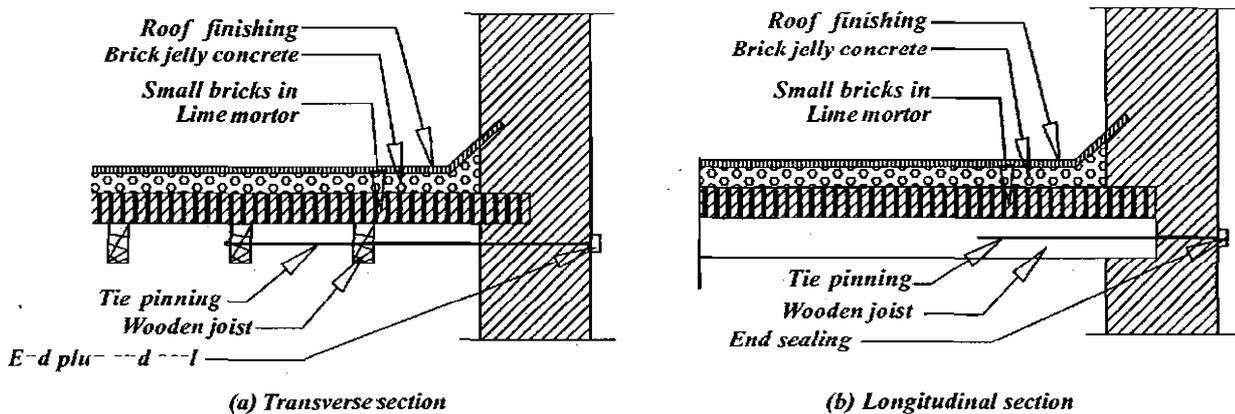


Fig-25 Steel pinning technique for madras terrace roof

6.2 Wooden floors

Stiffening of the existing wooden floor slab can be achieved by planks nailed perpendicular to the existing planks (Fig-26a) or by providing a thin R.C. slab over the old slab (Fig-26b). For the connection with the wall, a network of reinforcement is nailed to the planks and inserted into the wall at number of locations and grouted for sealing as shown in Fig-26b.

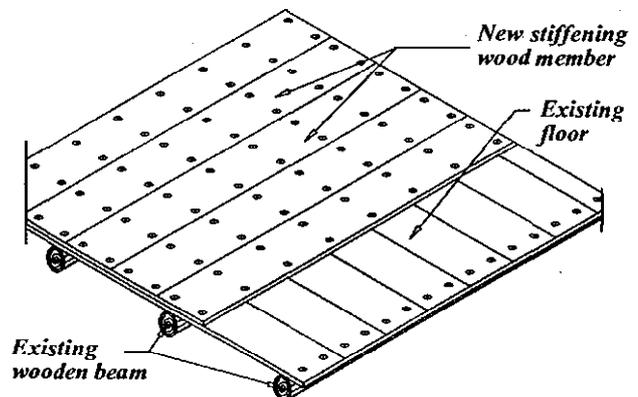


Fig-26a Stiffening of wooden floor by wooden planks

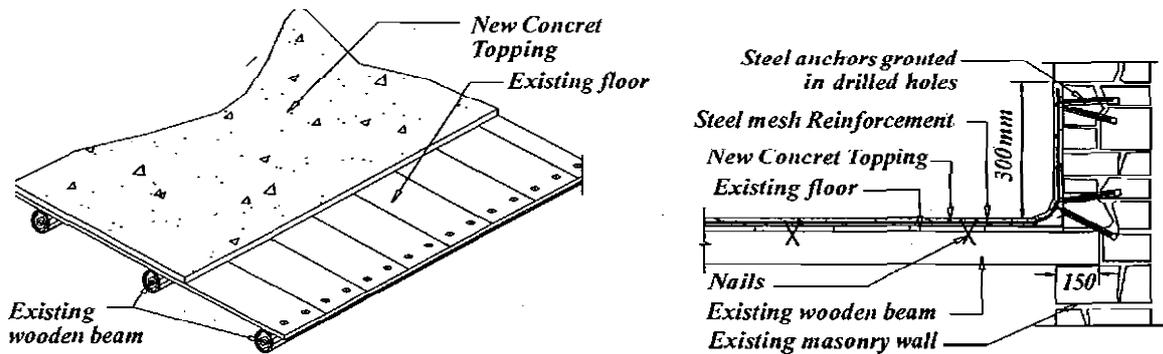


Fig-26b Stiffening wooden floor by reinforced concrete slab and connection to wall

6.3 Ja-k Arch Floor

Tie rods provided at the springing of arches will enable relieve the arch thrust on the wall (Fig-27). Alternatively the load on arch can be relieved by inserting the steel beam above the arch (Fig-16b). In either of these cases the transfer of load to the walls will be vertical and lateral thrust can be avoided.

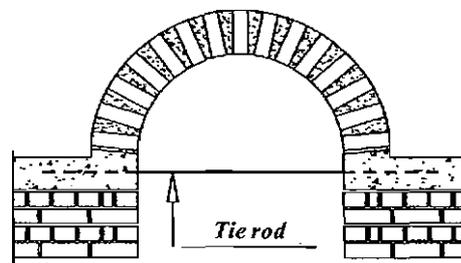


Fig-27 Strengthening by tiles

6.4 Connec.i.n o. floor to he wall

It is essential to have a proper connection between the floor and the wall. The device that can be used to ensure this is shown in Fig-28a and Fig-28b. The connection consists of flat steel nailed or bolted to the floor. Holes drilled in the walls to anchor them should be in-filled with grout. This technique can be adopted for wooden floor as well as R.C.C floors. In case of R.C.C floors, the flats will have to be connected to the floor by anchor bolting which expands and holds against the sides when tightened.

1. Existing wall
2. Existing floor
3. Wood beam
4. Nails
5. New slab stiffening
6. Connecting steel flats

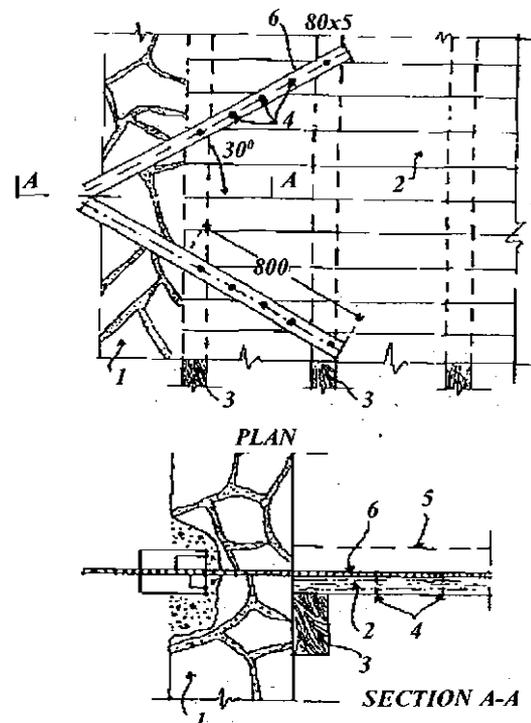
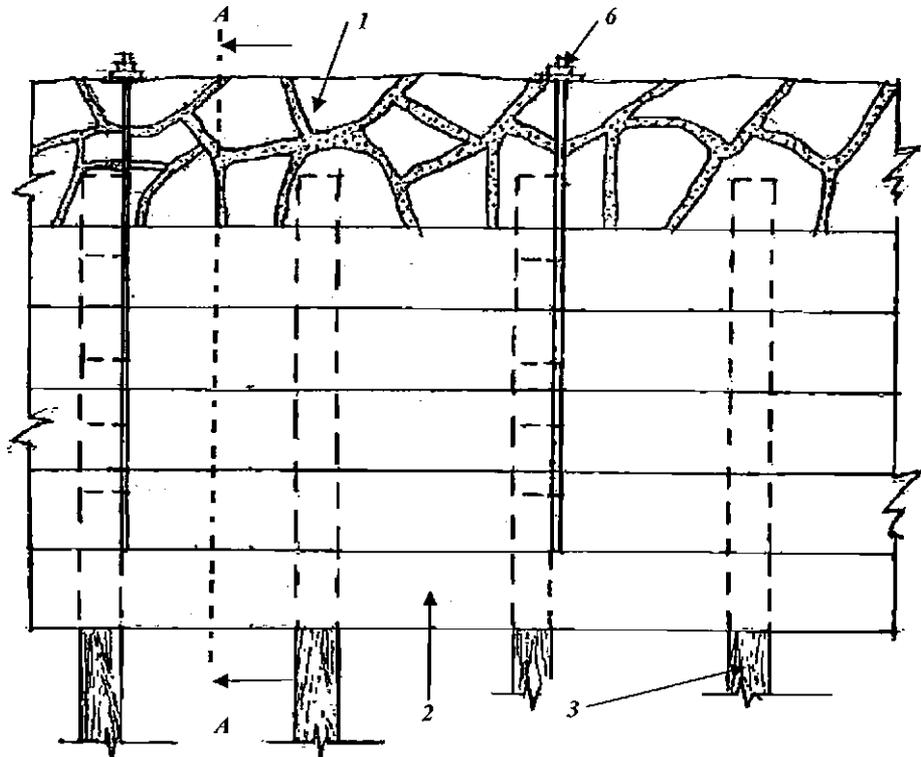
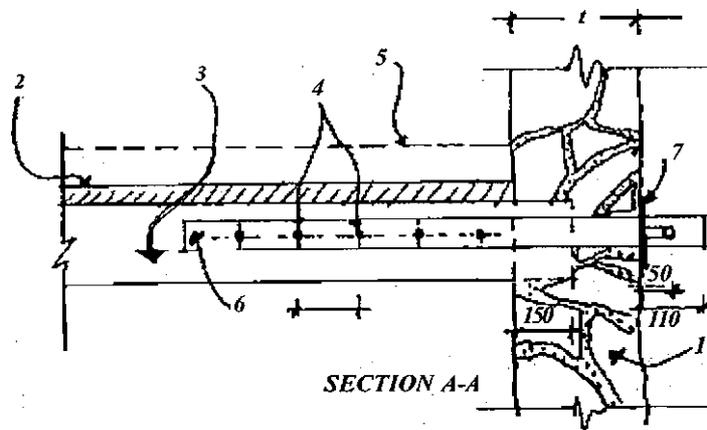


Fig-28a Connection of floor with wall



PLAN



SECTION A-A

1. Existing wall thickness t
2. Existing wood planks
3. Existing wood beam
4. New stiffening planks
5. New concrete slab
6. Connecting steel joists
7. Anchor plate

Fig-28b Connection of floor to wall

6.5 Replacement of floor

A rigid floor slab inserted into existing walls ties the walls and distributes the loads evenly. It enhances the seismic performance. Fig 29 shows the necessary details for the keying in the new floor with the walls. This technique can be adopted for cutting and removing the old floor and then inserting a new floor diaphragm.

7. MODIFICATION/STRENGTHENING OF THE WALL

In most traditional buildings masonry walls are used to support the roof. They also provide lateral load resistance. If they are not integrated with the structure, they are bound to fail in a brittle manner. The various methods of retrofitting the walls by strengthening and integrating with the rest of the structure is discussed below.

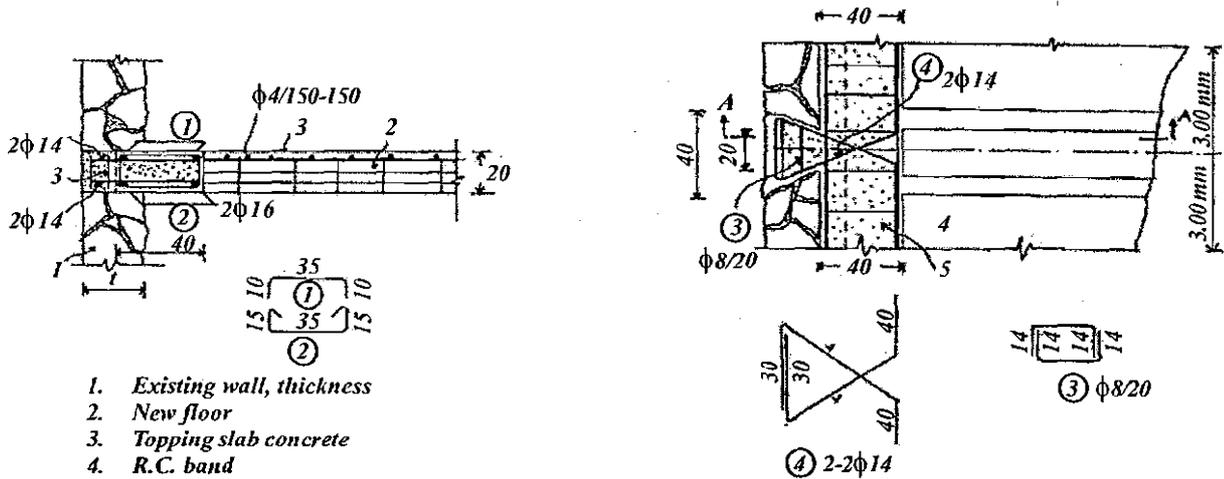


Fig-29 Details of inserted slab

7.1 Inserting new walls

In case, an existing building shows asymmetry which produce torsion during earthquakes, the centre of mass may be made to coincide with centre of stiffness by inserting new walls either internally (shear walls) or externally (buttresses). This type of intervention is common in long barrack type buildings used for schools or for other public utility. In such cases junction between new wall and old wall should be adequately connected. Such cases occur as either a "T" or "L" junction. Fig-30a and Fig-30b show the typical details of new and old walls.

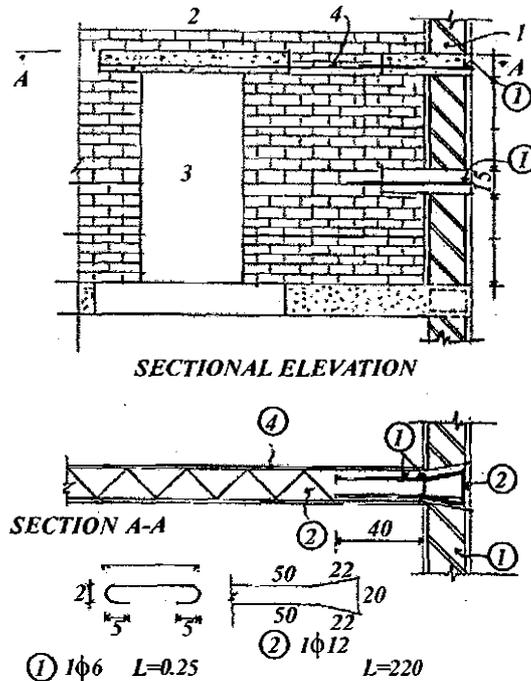


Fig-30a Connection of new and old brick wall (T junction)

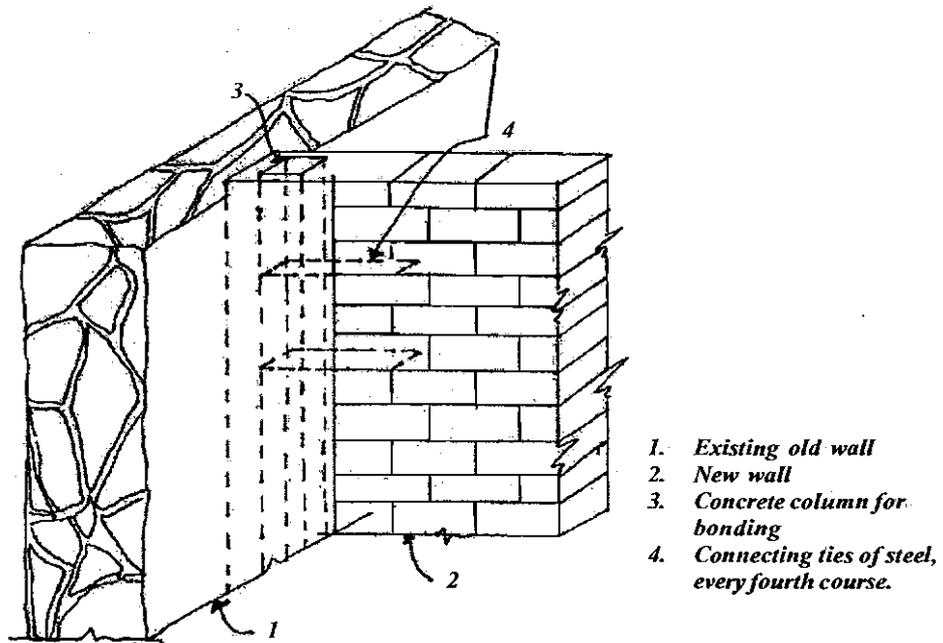


Fig-30b Connection of new brick wall with existing stone wall

7.2 Strengthening of existing wall

The walls can be strengthened by (a) grouting (b) confining by more ductile R.C, Ferro-cement or FRP lining and (c) by transverse pre-stressing. The method of strengthening using (a) grouting or (c) pre-stressing is discussed elsewhere. The method of confining by more ductile material i.e. wire mesh is discussed below:

Two steel meshes (welded wire fabric with the mesh size of (50mmX 50mm) is attached on both sides of the wall and connected by steel at 500 -700 mm interval Fig-31. A 25-40 mm thick micro concrete layer is applied on both sides and the connecting links are grouted. The sandwiched brickwork between the Ferro cement linings will behave well, when subjected to lateral load during earthquake.

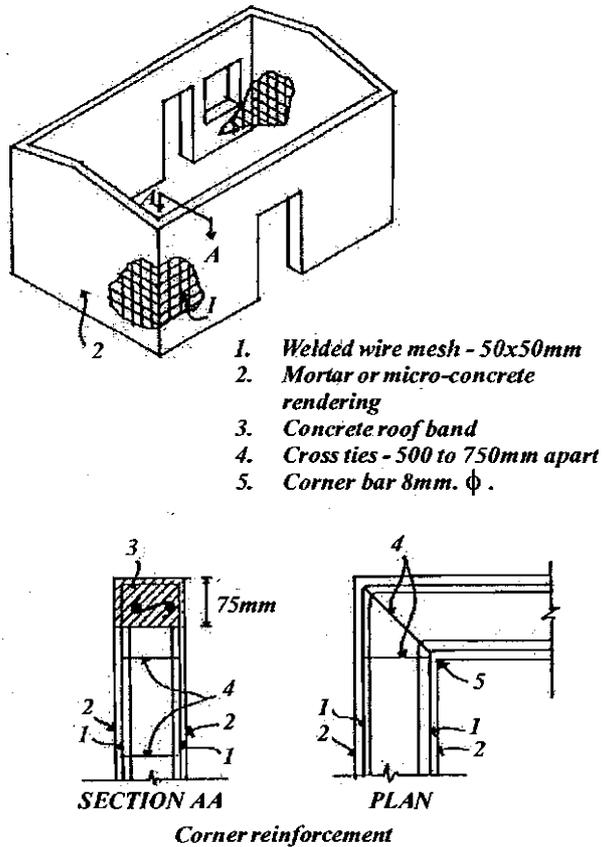


Fig-31 Strengthening with wire mesh and mortar

7.3 Strengthening wall to wall connection

T” and “L” junctions in masonry building can be integrated and anchored by effective sewing of perpendicular walls. For this holes are drilled in an inclined fashion and injected with polymer grout after inserting required steel reinforcement as shown in Fig-32.

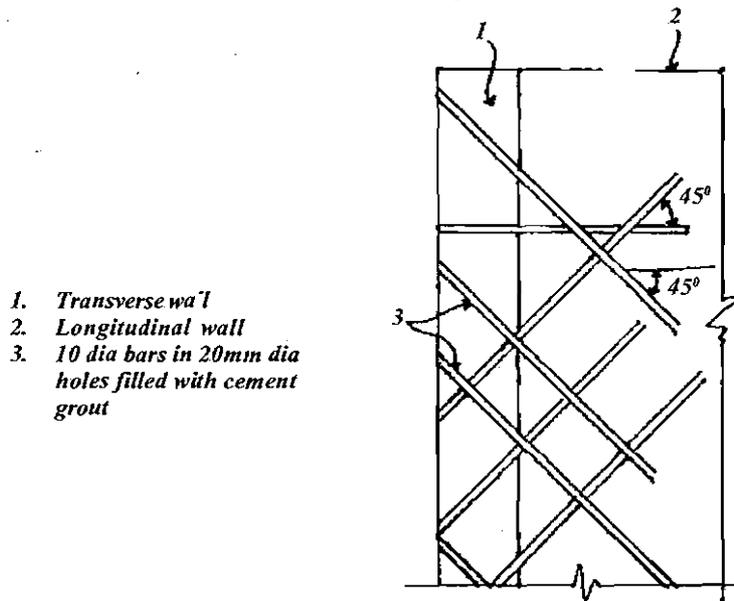


Fig-32 Sewing transverse walls with inclined reinforcements

7.4 Connections in stone walls

Connection of stone walls is invariably done using stitching technique. Stitching is always connected with grout injection to form the bond between steel and masonry as well as to provide corrosion protection.

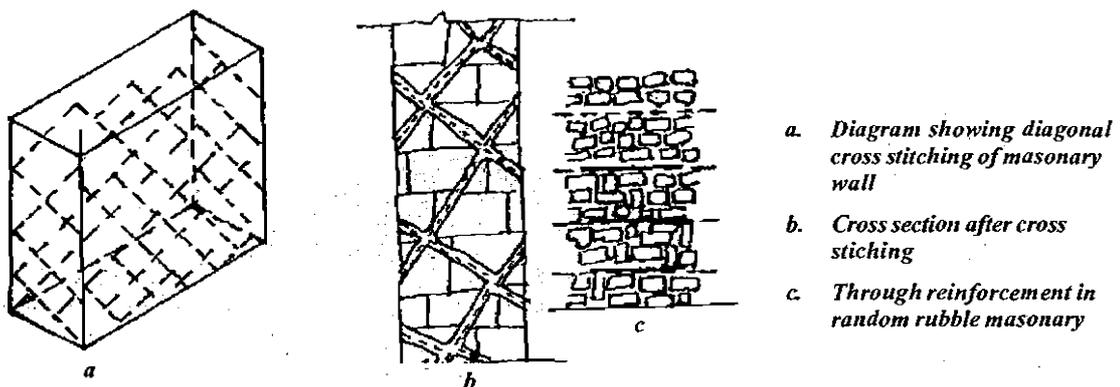


Fig-33 Concept of diagonal stitching

Fig-33 shows the concept of diagonal stitching of the wall. First the wall is grouted. Then drilling is done. In the preformed drill holes reinforcements are inserted and again grouted. In walls having leaves special attention is paid anchor the bars well. Generally 8-10 mm dia bars of HYSD Fe-415 are used for stitching. To ensure corrosion protection a minimum 20mm cover is essential. Proper spacers (cover blocks) must be attached to ensure 20 to 30 mm cover along the bars and at end anchorages.

7.5 Pre-stressing for wall strengthening

Un-reinforced masonry develops tension due to either in-plane or out-of-plane bending. Pre-stressing creates axial compression in the wall which suppresses the tension due to above causes. Internal pre-stressing has been used successfully to increase the strength and ductility of existing un-reinforced masonry. In situations where internal pre-stressing, is not feasible, post-tensioning of externally placed pre-stressing steel is often a viable option. The pre-stressing bars can be inserted in pairs on opposite sides of a wall so that out of plane bending is not introduced (Fig-34a). In single storey building, vertical steel can be anchor in the foundation. In multistory buildings, holes must be drilled through the floor and roof system. Fig 34a illustrates an example of the use of external horizontal post-tensioning to improve the structural integrity of a masonry wall.

7.6 External binding and keying (spilt and bandage strengthening technique)

Opposite walls can be held against internal cross walls by pre-stressing bars as explained in the previous section. Instead of anchoring it on steel plates it can be anchored on continuous steel channels running from cross wall to cross wall which will hold the structure together.

The technique of covering the wall with Ferro-cement may be used outside maintaining continuity at the joint. This is intended to strengthen the wall as well as bind them together. The covering may be in the form of vertical splints between opening and horizontal bandages over spandrel wall as shown in Fig-34b.

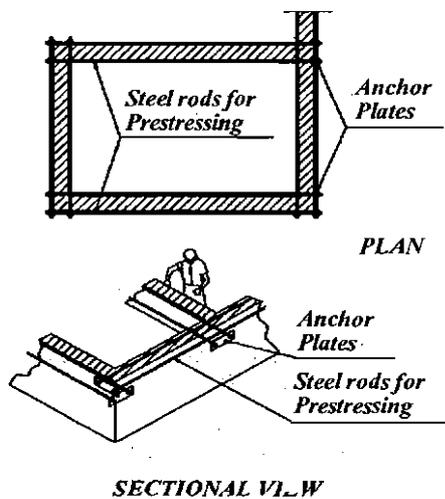


Fig-34a Strengthening of walls by pre-stressing

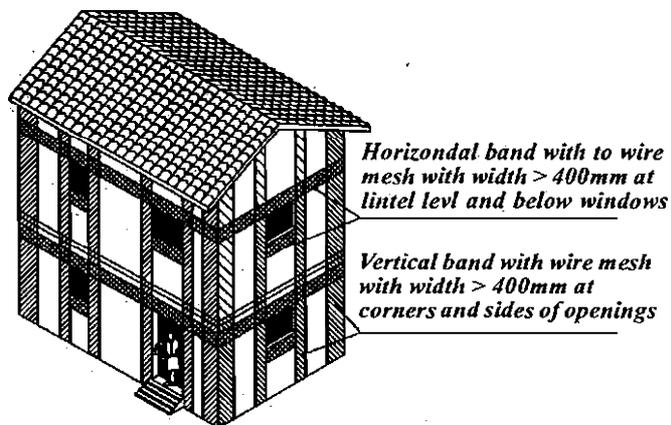


Fig-34b Splint and bandage strengthening technique

7.7 Strengthening the corners

If the stone wall built in mud mortar does not have enough through stones at the corners, provide a horizontal band at each outside corner as follows.

- (1) Remove plaster if any for a height of 400 mm at 80 mm above plinth level over a length of 300 mm more than the cross wall thickness at the corner. (Fig-35a).

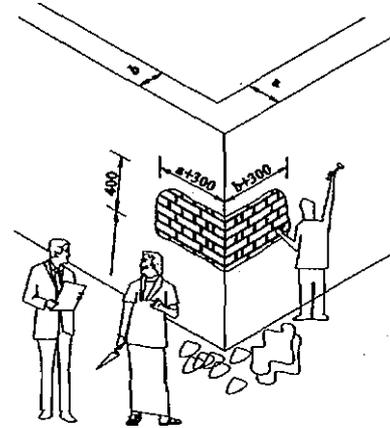


Fig-35a

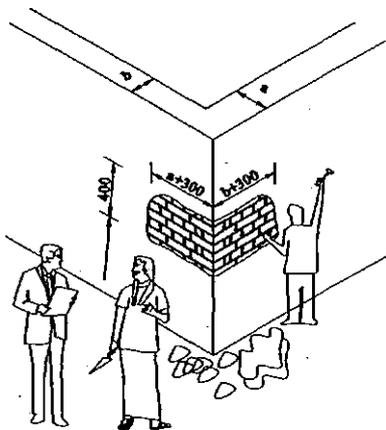


Fig-35b

- (2) Rake the exposed joints to a depth of 20mm. Clean the joints with a wire brush and remove dust (Fig-35b).

- 3) Take welded wire mesh of the 25 x 50mm (1"x2") size with 8 gauge wire (Fig. 35c)

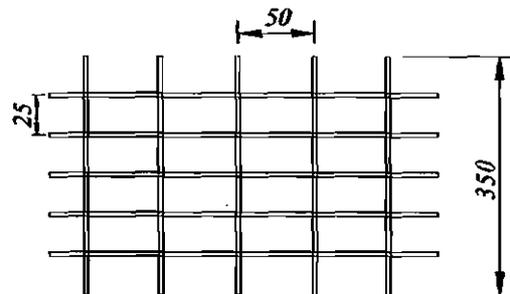


Fig-35c

- (4) The width of mesh should be 350mm. The length should be 60 mm (2'0") more than twice the thickness of the walls. Place the mesh on the wall but 15mm (5/8") away from the wall with the help of long nails with flat heads (Fig-35d).

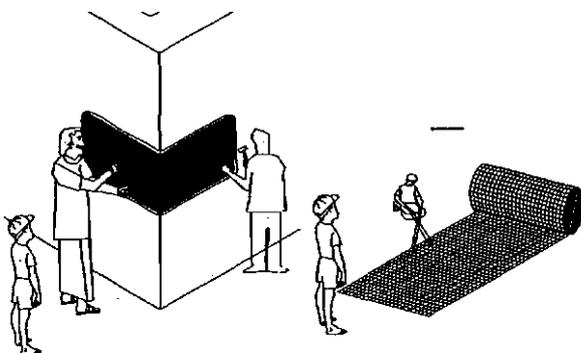


Fig-35d

- (5) Plaster with a cement sand plaster 1:4 (Fig 35e).
- (6) The plaster should be 35-38 mm (1¼" 1½") thick so that the mesh is covered by a 1 (½") thick cover.
- (7) Cure for at least 14 days.

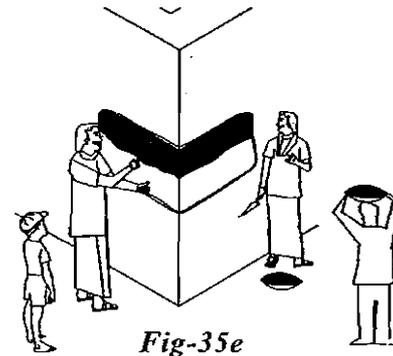


Fig-35e

7.8. Providing through stones

If the walls do not have through stones (headers), you will have to insert new through stones to prevent splitting of the walls during earthquakes.

- (1) Make through holes in your wall by removing single stones from the wall as shown (Fig-36a). There should be one hole per square meter. Removal of stone should be done gently so that surrounding stones are not disturbed (Fig- 36a).

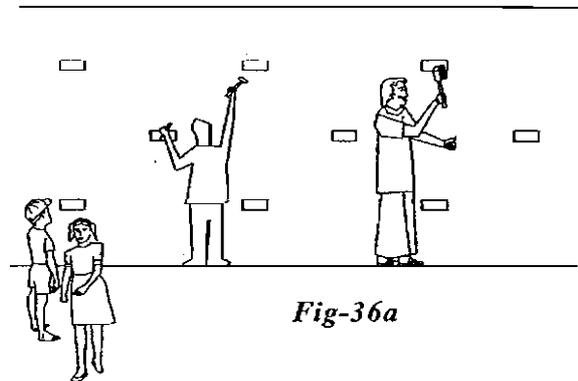


Fig-36a

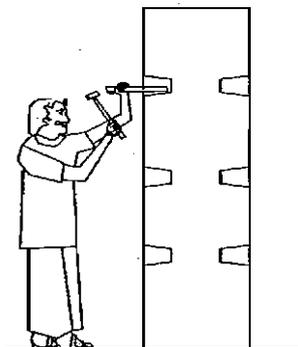


Fig-36b

- (2) Remove the infill material between the two removed stones like a small tunnel (Fig-36b).

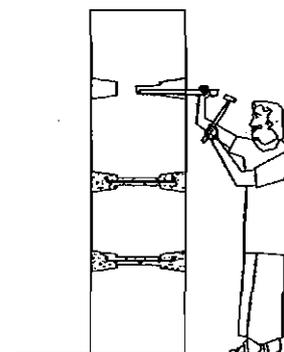


Fig-36c

- (3) Insert a hooked piece of steel from both sides and fill holes with concrete. Both ends of the steel rod should get embedded in the concrete (Fig-36c).

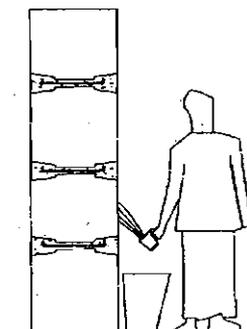


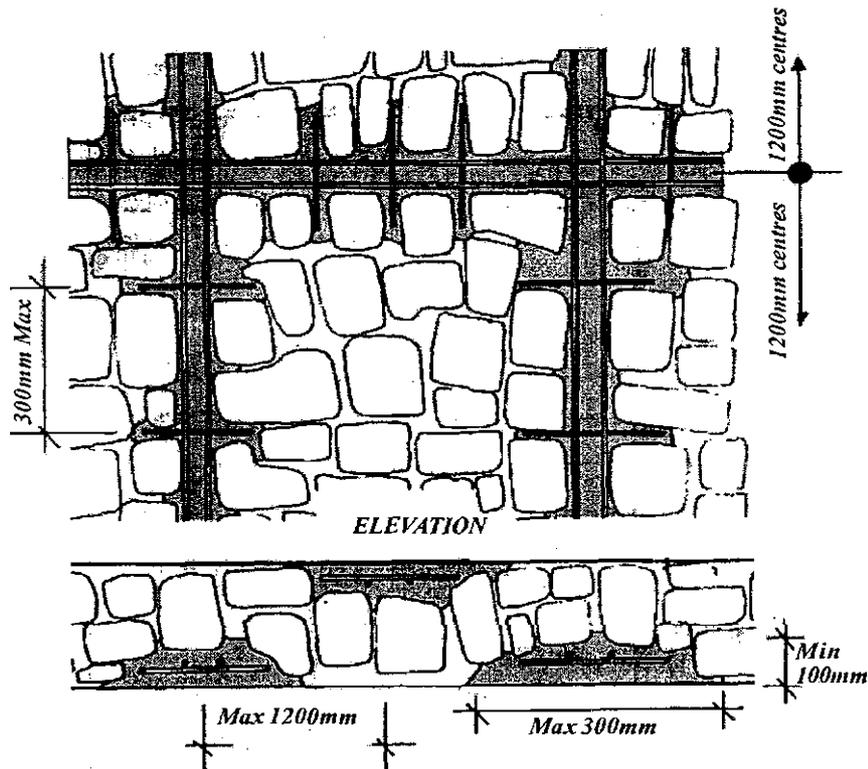
Fig-36d

- (4) Cure the ends regularly for at least for 7 days (Fig. 36d).

7.9 Reinforced concrete stitching belts on wall

Steps:

- Remove the plaster and small rubble from the face of the wall up to a minimum depth of 100mm.
- Clean the surface.
- Bind the rod as shown in (Fig-37). Concrete the bands from both sides.



Caution

- Note to be used in weakly bonded walls
- Suitable for walls, where sand / cement mortar bedding has been used.
- This method may not be applicable for all types of rubble wall construction

Fig-37 Provision of reinforced concrete stitching belts

Reasons for use and comments:

- It is used for wall thickness greater than 450mm.
- Use single bars and avoid lapping bar in the vertical column bands.
- Improve sheer resistance by binding and hooking.
- For walls less than 450mm thick, it will advisable to work at one face at one time rather than working on two faces simultaneously. Finally the bands in both faces can be integrated with through keys.
- This not suitable for weak walls.
- It is suitable for walls, where sand/cement mortar bed joints have been used.

8. OTHER MEMBERS

There are various other components in a building that need seismic strengthening. A few of the important components and the strengthening technique for these are summarized below.

8.1 Masonry Arches

Walls in historical building have large arched openings. The horizontal thrust of the arch will damage the supporting piers. In such cases it is necessary to install tie rod across the springing by drilling holes on both sides and grouting the steel rod. (Fig-38) Instead of steel rod, the tensile strength can also be imparted by embedding timber scantling.

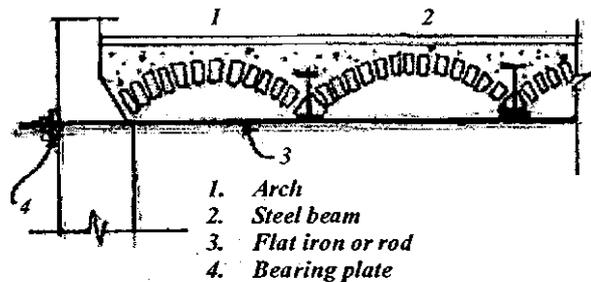
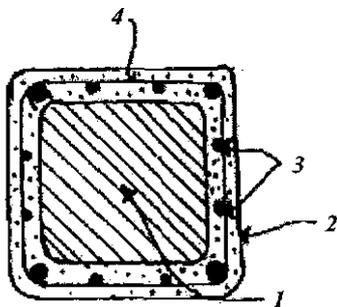


Fig-38 Strengthening jack arch floor roof

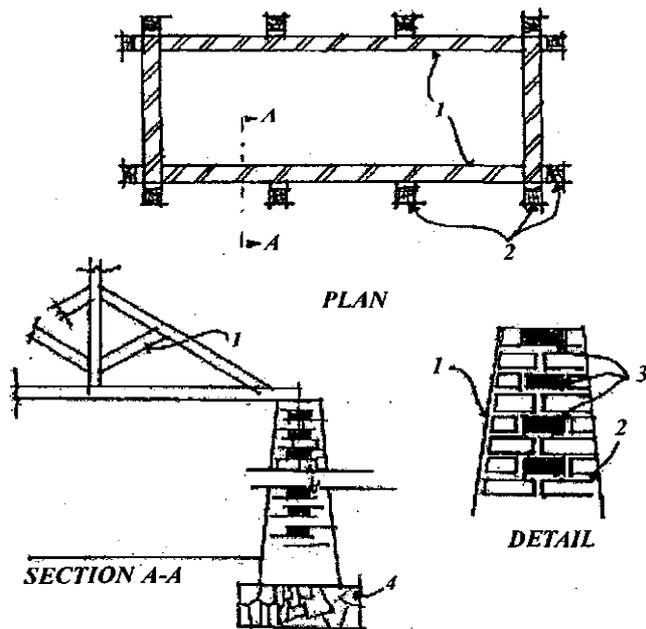
8.2 Pillar and pilasters

Weak pillars can be strengthened by jacketing technique shown in Fig-39a. For the longitudinal walls of the barrack type buildings, provision of pilasters on the outside, added externally as shown in Fig-39b will enhance lateral load resistance.



1. Existing column section
2. Jacketed section
3. New longitudinal bars
4. New tie bars

Fig-39a Jacketing a concrete column



1. Existing wall
2. Buttress or pilaster
3. Key stone
4. Foundation

Fig-39b Strengthening of long walls by buttresses

8.3 Partition wall

The partition walls in many structures are not designed and are the first ones to collapse during an earthquake. To avoid failure of the partition walls it should be integrated with the two transverse walls which the partition wall spans. Such tying of the partition wall will ensure significant reduction of non-structural damages during an earthquake.

8.4. Floor strengthening at ground level.

In long barrack type of building the ground beams in the longitudinal directions are weak and tend to buckle inwards. Hence they should brace at ground level if necessary by introducing stub columns as shown in Fig-40.

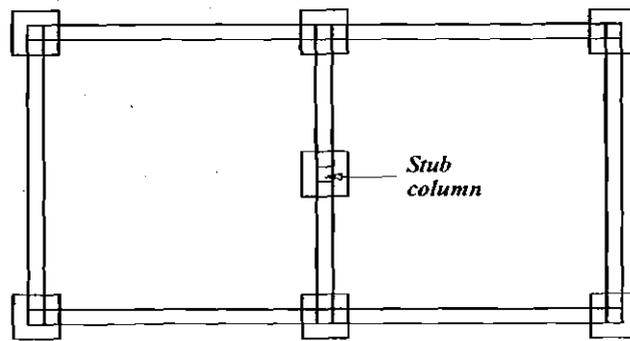


Fig-40 Introduction of stub column in long barrack type building

9. FOUNDATION

The entire lateral load should be ultimately transferred to the soil through the foundation. Strengthening foundation is an involved task and many times may require underpinning work. One common technique is to introduce a new load carrying member including foundation in order to relieve the existing overloaded foundation. Jacking operation may be needed for this. Another common technique is to improve the drainage around the foundation so that soil does not get saturated. This will avoid liquefaction of soil. In addition a good apron around the building will avoid soaking of foundation soil. Here a few typical foundation strengthening measures are summarized.

9.1. Spread Rubble Masonry wall Foundation

Adding strong strips made of R.C.C to the existing foundation as shown in Fig-41 will increase the bearing width. These strips will also bind the rubble masonry footing. To avoid digging the floor inside, the strip may also be added only on the outside eccentrically. In any case the strip has to be integrated with the original masonry footing by provision of number of keys at 1 to 1.5 m intervals as shown.

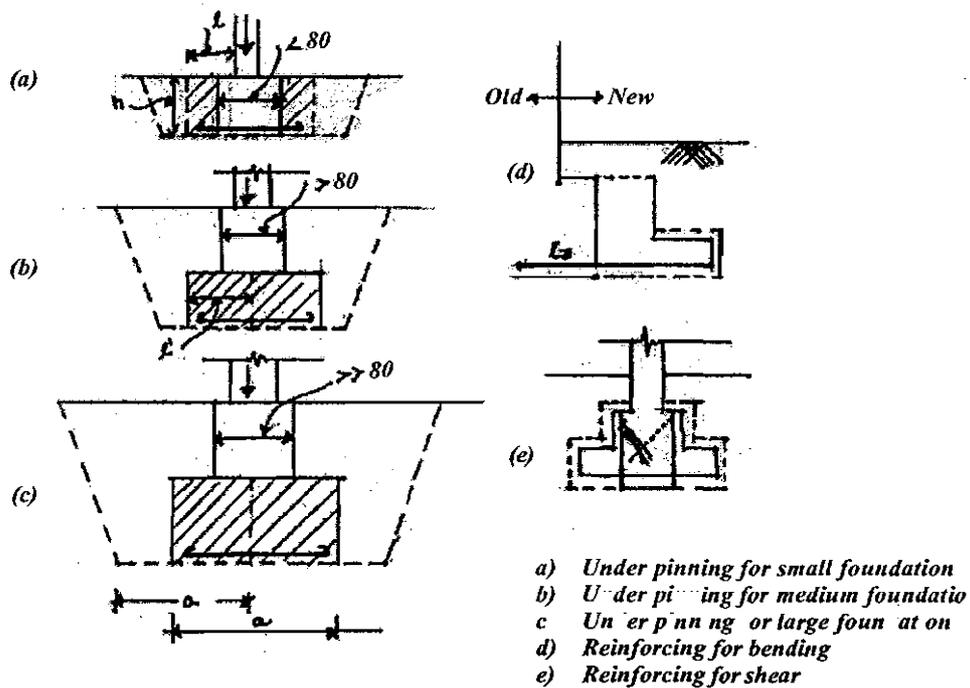


Fig-41 Increase in bearing width for foundation

9.2 Brick masonry wall foundation

The method suggested for random rubble masonry can also be used for brick masonry. In addition it may be necessary to give a mortar protection for brick masonry at least up to the plinth level.

9.3 Isolated brick masonry pillar foundation

A weak masonry isolated pillar may be underpinned by provision of underream piles as indicated in Fig-42. First two under ream pillars A and B are installed on either side of the pillar whose foundation requires under pinning. Next the reinforcement cage for needle beam is inserted just below ground beam and connected with the reinforcement in the pile. Finally the needle beam is concreted. The load from the pillar will be transferred to the two piles by the needle beam. Hence the weak foundation D will be completely relieved.

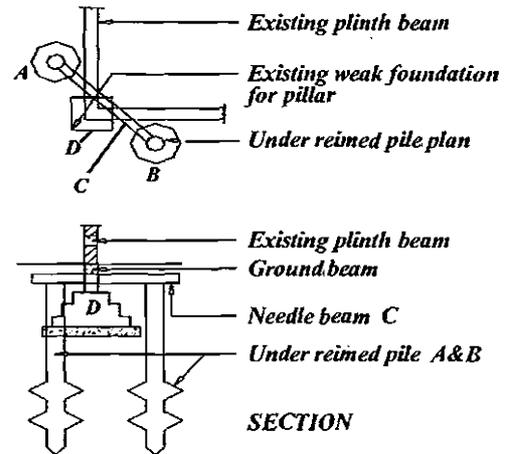


Fig-42 Under pinning for an individual pillar foundation

9.4 Walls without foundation

It may be required to provide a foundation for a wall which really is not having a good foundation. For instance wall XY does not have a foundation. First the under reamed piles A to H are installed as shown (Fig-43). Then needle beams 1 to 4 are inserted and then connected to pile at location A to H. It should be noted that piles E & C will be under tension under normal gravity load. However under seismic load compression and tension can reverse and hence the junctions A to H have to be detailed for withstanding reversed cyclic load (Fig-43).

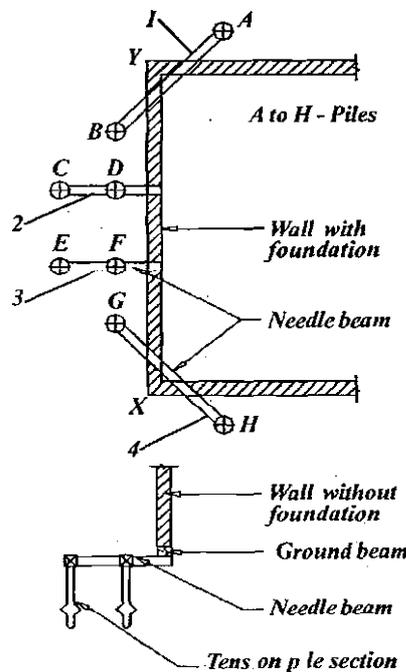


Fig-43 Under pinning foundation for a masonry wall

10. CASE STUDIES AND CODE COMPLIANCE

Application of repair technologies has been extensively used during repair and retrofitting of buildings damaged during Chamoli-Utharakashi earthquakes and during the recent Tsunami havoc on east coast of India. The damage has been classified as heavy damage (G3) and moderate damage (G2). Table-4 shows the technology option used and their demonstration in field. These have been adopted during the massive reconstruction programmes undertaken.

Table 4-Repair and Retrofitting items used at typical locations for rehabilitation of building damaged during Chamoli earthquake (1995)

No. of Houses			Crack repair	Cross wall stitching	Through element in stone masonry	Rebuilding part of wall	Reinforcing belts		Stiffness	
							Horizontal	Vertical	Floor	Roof
13,678 houses were collapsed	42,700 houses were subjected to heavy damage	69,353 houses were subjected to moderate damaged	Covered in section of this Guidelines							
			Sec. 4.1	Sec. 7.3	Sec. 7.8	Sec. 7.2	Sec. 7.7	Sec. 7.6	Sec. 6.2	Sec. 5.2

Note: 1- Section refers to items in this Guideline.

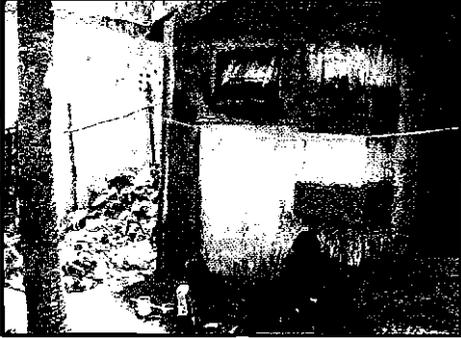
Time and again, during the survey of damage assessment, it was observed that the main reason for the damages to building and loss of life is due to collapse of buildings. Use of non-engineered construction method without adequate earthquake resistant feature have caused failures. Hence BIS have formulated special code of practice for earthquake safety of non-engineered building. It is essential that these code is followed in letter and spirit to ensure sustainable habitat development. These codes are included in the list of references given in section 12 of this guidelines.

11. SUMMARY

This guideline summarises methods of retrofitting of non engineered buildings. First the concept of repair, restoration and strengthening of building has been explained. A detail description of various materials generally used for repair is described. Next different strengthening methods used in seismic repair and retrofitting were elucidated. Subsequently strengthening methods of roofs, floors and foundation of different types of non-engineered structure have been described. The guidelines in intended to give the basis of repair and rehabilitation of non-engineered structures in order to make them perform efficiently without collapse during earthquakes. It is obvious that in working out details some differences can be observed as the availability of material and skill and economics will differ from place to place. Such variation in the building details should always be considered before arriving at the most appropriate rehabilitation procedure.

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(Houses retrofitted at Kovalam, Injambakkam
by *Initiatives in Habitat Development*)

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