GUIDELINES FOR

REPAIR, RESTORATION AND RETROFITTING OF MASONRY BUILDINGS IN KACHCHH EARTHQUAKE AFFECTED AREAS OF GUJARAT

GSDMA

GUJARAT STATE DISASTER MANAGEMENT AUTHORITY
GOVERNMENT OF GUJARAT

March - 2002

GUIDELINES FOR

REPAIR, RESTORATION AND RETROFITTING OF MASONRY BUILDINGS IN KACHCHH EARTHQUAKE AFFECTED AREAS OF GUJARAT

GSDMA

GUJARAT STATE DISASTER MANAGEMENT AUTHORITY
GOVERNMENT OF GUJARAT

March - 2002

FIRST PRINTING MARCH - 2002

Foreword

The earthquake on 26 January 2001 caused large-scale damage and destruction to residential buildings. In addition to the buildings that collapsed, over a million buildings were damaged; such buildings need minor and major repair. Needless to say that simple and superficial repair to buildings does not restore the lost strength; it only hides the cracks, leaving the building in a weakened state. Such buildings become vulnerable to the next earthquake, even with lesser magnitude. Consequently, it is necessary especially in the earthquake prone Kachchh district that people take appropriate actions in order to achieve not only the restoration of the lost structural strength to pre-disaster level, but also to upgrade the structure for earthquake resistance by retrofitting to the level envisaged by the Building Codes.

The present Guidelines on ***Repair, Restoration and Retrofitting of Masonry Buildings in Kachchh Earthquake Affected Areas of Gujarat*** will provide the much needed information to Engineers, NGOs and house owners so as to enable them to ensure long-time safety of rehabilitated houses and community buildings.

P.K. Mishra
Chief Executive Officer
Gujarat State Disaster Management Authority

Gandhinagar
February 2002

To The Reader

In earthquake engineering terminology, Repair, Restoration and Retrofitting have required the following meanings:

Repair : Actions taken for patching up of superficial defects and doing the finishes.

Restoration : Action taken for restoring the lost strength of Structural elements.

Retrofitting : Actions for upgrading the seismic restoring of an existing building. So that if becomes safer under the recurrence of likely future earthquakes.

Repair and restoration are applicable to damaged buildings, Only 'repair' will leave the building permanently weak. Restoration and repair will bring the strength of the building to pre-earthquake level.

Retrofitting is relevant to 'restored' as well as existing undamaged buildings which are otherwise weak against earthquake forces likely to occur in future according to Indian Standard Building Codes.

These Guidelines cover all three aspects as applicable to all types of masonry buildings whether used for housing or community activities. It is suggested that the three types of action are taken in the following order:

First, restore the building

Next, retrofit the building

Last, repair the building.

February 21, 2002
Gandhinagar

Dr. A.S. Arya
Seismic Advisor, GSDMA

REPAIR, RESTORATION AND RETROFITTING OF MASONRY BILDINGS IN KACHCHH EARTHQUAKE AFFECTED AREAS OF GUJARAT

CONTENTS

REPAIR, RESTORATION AND RETROFITTING OF MASONARY BUILDINGS KACHCHH EARETHQUAKE AFFECTED AREAS OF GUJARAT.

1. INTRODUCTION

The Kachchh earthquake in Gujarat occurred on the 26th January, 2001 and caused massive destruction to property and loss of life in the towns of Bhachau, Anjar, Rapar, Bhuj and Gandhidham as well as thousands of villages. This earthquake had a Richter Magnitude of 6.9 and surface magnitude Ms = 7.7 (USGS) and struck the region at 8.46 am local time, with the shaking lasting for a few minutes. Other major cities in Gujarat e.g., Ahmedabad and Jamnagar, which are hundreds of kilometres away, were also affected by the earthquake.

Thousands of people were killed or badly injured in stone masonry buildings in villages as well as in towns because of :

a) poorly constructed buildings, collapsing either totally or partially;

b) walls collapsing within narrow streets, burying people escaping into them;

c) untied roofs and cantilevers falling onto people;

d) free standing high boundary walls, parapets and balconies falling due to the sever shaking; and

e) gable walls falling over after cracking under lateral thrust of the roof.

Surprisingly, reinforced concrete frame buildings of very recent construction in cities like Bhuj, Gandhidham and Ahmedabad also behaved badly, many of them collapsing totally killing the inmates in hundreds. This happened because of

a) large open spaces at ground to first floor level, in buildings on stilt for parking or shops (soft storey collapses)

b) foundations restings on soft soils, absence of interconnecting plinth level beams; and

c) bad quality of design as well as construction.

Those buildings which were partly or totally destroyed have naturally to be rebuilt, and for safety in future, must be constructed using adequate earthquake resisting measures according to the various Indian standards and appropriate guidelines (see list of References.)

There are, however, many times more buildings which are standing in damaged condition with cracks of minor to major width and extent. They need restoration of lost strength as well as cosmetic repairs. Even when this is done, these buildings will remain vulnerable in future earthquakes.

The purpose of these guidelines is to address the issues of repair, restoration and seismic retrofitting of various types of *masonry buildings*. R C buildings will be covered in a separate guideline.

2. OBJECT AND SCOPE

These guidelines have the following objectives;

(i) To indicate appropriate methods of repair and restoration taking into account the building type and the type of damage.

(ii) To recommend methods of seismic strengthening to upgrade the strength of the building in line with the requirements of the seismic-zoning map of India (See IS : 1893-1984) and Earthquake Resistance Codes (IS : 4326-1993) and (IS:13828-1993).

The entire district Kachchh is placed in zone V with anticipated maximum seismic intensity of IX on MSK Intensity Scale. The Districts of Banaskantha, Patan, Surendranagar, Rajkot and Jamnagar have large parts in Zone IV with probable maximum Intensity VIII, and remaining parts of the State lie in Zone III with maximum probable Intensity VII. (See Seismic Map of Gujarat and Zonewise list of Talukas in GSDMA Guidelines, Ref.9.)

The retrofitting measures are worked out here for safety of existing damaged or undamaged buildings in future MSK Intensity occurrences in the area although in 26th January 2001 Kachchh earthquake the maximum MSK Intensity at any place may have been less than the maximum probable value as per the seismic zoning map.

The masonry buildings will include : Walls of brickwork, random rubble stone masonry and cut stone masonry whether used for housing or community buildings like Aanganwadis, Primary Health Centres, Schools or Panchaytghars; and Roofs with Mangalore Pattern (Morbi) tiles on wooden structures, CGI or AC sheet roofs on steel under-structure, or RC slabs.

3. CATEGORISATION OF DAMAGE

As specified usually in the MSK Intensity scale, five categories of damage are recognized and named as G1 to G5; G1 referring to very slight damage without loss of structural strength and G5 referring to complete collapse of the building. Description of these categories of damage as applicable to masonry buildings is presented in Table 1. So far as repair, restoration of structural strength and seismic strengthening to meet the codal requirements are concerned, Categories G1 to G3 are most relevant, since buildings or parts thereof subjected to category G4 in most cases have to be demolished and rebuilt.

4. CONCEPTS OF REPAIR, RESTORATION AND RETROFITTING

There is a need to distinguish between the terms repair, restoration and strengthening as described below:

Table 1. Damage Categories*

	Category	Walls *	Roof / Floors
0	No Damage	No Damage	No Damage
G 1	Slight Non-Structural Damage	Thin cracks in plaster, falling of plaster bits in limited parts.	Thin cracks in small areas, tiles only slightly disturbed
G2	Slight Structural Damage	Small cracks in walls, falling of plaster in large areas : damage to non-structural parts like *chhajjas,* parapets.	Small cracks in slabs/ A.C. sheets; tiles disturbed in about 10% area; minor damage in under-structure of sloping roof.
G3	Moderate Structural Damage	Large and deep cracks in walls; widespread cracking of walls, columns and piers; or collaps of one wall. The load carrying capacity of structure is partially reduced.	Large cracks inslabs; some AC sheets, broken; upto 25% tiles disturbed/fallen moderate damage to understructure of sloping roofs.
G4	Severe Structural Damage	Gaps occur in walls; two or more inner or outer walls collapse; Approximately fifty percent of the main structural elements fail. The building takes a dangerous state.	Floors badly cracked, part may fall; under- structure of sloping roof heavily damaged, part may fall; tiles badly affected & fallen.
G5	Collapse	A large part or whole of the building collapses.	A large part or whole floor and roof collapse or hang precariously.

* Based on I.A.E.E. Guidelines, further developed through observations in earthquakes in India, by Dr. A.S. Arya, Seismic Advisor, G S D M A.

4.1) Repair

It consists of *actions taken for patching up superficial defects*, re-plastering walls, repairing doors and windows and services such as the following :

i) Patching up of defects as cracks and fall of plaster and re-plastering if needed.

ii) Repairing doors, windows and replacement of glass panes.

iii) Checking and repairing electrical connections, gas connections, plumbing, heating, ventilation

iv) Rebuilding non-structural walls, chimneys, boundary walls.

v) Relaying cracked flooring at ground level and roofing sheets or tiles.

vi) Redecoration work (White or colour washing etc.)

It would be seen that *the repairing work carried out as above does not add any strength to the structure.*

4.2) Restoration

This includes *actions taken for restoring the lost strength of structural elements of the building.* This is done by making the columns, piers, beams and walls at least as strong as originally provided as follows:

i) Removal of portions of cracked masonry walls and piers, and rebuilding them in richer mortar. Usee 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 with micro-concrete or 1:3 cement -coarse sand plaster.

iii) Injecting neat cement slurry or epoxy like material, which is strong in tension, into the cracks in walls, columns, beams etc.

If the structural restoration is properly executed, the structure will be as strong as before the earthquake. It is also possible to strengthen a structure to take increased vertical loading, if required.

4.3) Seismic Strengthening (Retrofitting) :

It will involve *actions for upgrading the seismic resistance of an existing building so that it becomes safer under the occurrence of probable future earthquakes.*

The seismic behaviour of existing buildings is affected by their original structural inadequacies, material degradation due to aging and alterations carried out during use over time. The complete replacement of such buildings in a given area is just not possible due to a number of social, cultural and financial problems. Therefore, seismic strengthening of existing undamaged or damaged buildings is a definite requirement. Seismic strengthening *including* structural restoration and cosmetic repairs may some times cost upto 25 to 30 per cent of the cost of rebuilding although usually it may not exceed 12 to 15 per cent. Hence justification of strengthening work must be fully considered from cost point of view. The main items of seismic strengthening could be some or all of the following actions:

i) Modification of roofs,

ii) Substitution or strengthening of floors,

iii) Modification in the building plan,

iv) Strengthening of walls including provision of horizontal and vertical bands or belts, introduction of 'through' or header stones in thick stone walls, and injection grouting etc.,

v) Adding to the sections of beams and columns by casing or jacketing etc.,

vi) Adding shear walls or diagonal bracings,

vii) Strengthening of foundations if found necessary (but very difficult and expensive).

5. ASSESSMENT OF DAMAGE

The buildings to the restored and repaired should be thoroughly surveyed and various damages should be recorded on scaled drawings. The width and engths of each damage needs to the record to as to estimate the required materials and labour for restoration and repair properly.

It should also be assessed if during the process of restoration, some of the service lines will need to be disturbed, and their temporary bypassing may be needed. The expences should be included in the estimates.

6. USUAL DAMAGE TYPES IN MASONRY BUILDINGS.

The types of damage generally observed in various masonry buildings during the earthquake are listed in Table 2. Alongside, the actions to be taken for restoration of the lost strength are also suggested. Details of each such action are described in the following paragraphs.

Table - 2: Types of Damage in Masonry Buildings

	Damage Observed	Action for Restoration
a)	Different types of cracks seen in masonry walls	a) i,ii. Cracks to be fully filled using appropriate grout or mortar.
i.	Vertical cracks	iii. Cracks at the corners or T-junctions to be
ii.	Inclined cracks	filled as above but before that the walls at right
iii.	Cracks at the corners or	angles to be connected using ferro-cement
	Tjunctions, and separation of the cross-walls	corner plates.
b)	At some places, occurrence of many cracks close together in the walls, OR tilting of some wall portions out of plumb after separation OR bulging of stone wall after delamination, OR falling of some wall portions.	b) This type of cracked, fallen, tilted or bulged wall portion to be reconstructed using 1:6 or richer cement mortar after partial demolition of wall as required.
c)	Shifting of roofing tiles or rafters OR falling down and being broken	c) The roofing tiles to be removed for further work and the rafters to be properly positioned. The opposite rafters to be tied together by horizontal braces;the purlins to be adjusted and the tiles to be placed back properly.
d)	Breaking of A C Sheets	d) Replacement of the sheets, increasing number of fastenings.

7. METHODOLOGY FOR GROUTING OF CRACKS

7.1 Minor and medium cracks (crack width 0.5 mm to 5.0 mm)

Material/equipment required

(i) Plastic / Aluminium nipples of 12 mm dia (30 to 40 mm long).

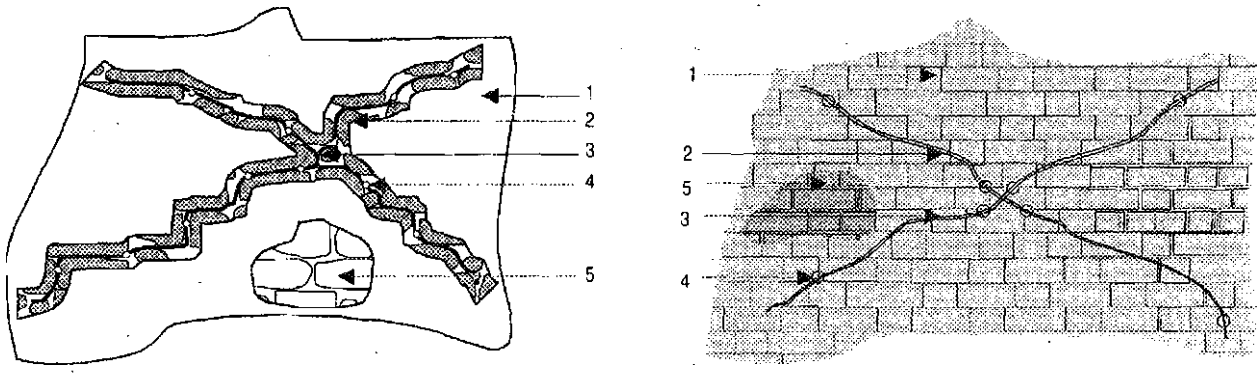
(ii) Non-shrink cement (shrinkomp of ACC or equivalent).

(iii) Polyster putty or 1:3 cement sand mortar for sealing of the cracks.

(iv) Compressor for injecting the slurry

Procedure:- See Fig.1

Step-1 Remove the plaster in the vicinity of crack exposing the cracked bare masonry.



ⓐ Stone wall ⓑ Brick wall

1- Plaster
2- Plaster removed and cracks cleaned
3- Cracks sealed with mortar or putty
4- Grout ports
5- Plaster fallen to be done again

Fig. 1 - Filling grout in cracks

Step-2 Make the shape of crack in the V-shape by chiselling out.

Step-3 Fix the grouting nipples in the V-groove on the faces of the wall at spacing of 150-200 mm c/c.

Step-4 Clean the crack with the Compressed air through nipples to ensure that the fine and loose material inside the cracked masonry has been removed.

Step-5 Seal the crack on both faces of the wall with polyster putty or cement mortar 1:3 (1-cement: 3-coarse sand) and allowed to gain strength.

Step-6 Inject water starting with nipple fixed at higher level and moving down so that the dust inside the cracks is washed off and masonry is saturated with water.

Step-7 Make cement slurry with 1 : 1 (1-non shrink cement: 1-water) and start injecting from lower most nipple till the cement slurry comes out from the next higher nipple and then move to next higher nipple.

Step-8 After injection grouting through all the nipples is complected, replaster the surface and finish the same.

7.2 Major crack (crack width more than 5.0 mm)

Material/equipment required

(i) Plastic/Aluminium nipples of 12 mm dia (30 to 40 mm long)

(ii) Polyester putty or 1:3 cement-sand mortar for sealing of cracks.

(iii) Non-shrink cement (shrinkomp of ACC or equivalent).

(iv) Compressor for injecting the slurry.

(v) Galvanised steel wire fabric (16 to 14 gauge i.e. 1.5 to 2.03mm dia wire) with 25 mm x 25 mm mesh size.

(vi) Galvanised steel clamping rod of 3.15 mm dia, or 5 mm dia 150 mm long wire nails.

Procedure:-

Step-1 Remove the plaster in the vicinity of crack exposing the cracked bare masonry.

Step-2 Make the shape of crack in the V-shape by chiseling out.

Step-3 Clean the crack with compressed air.

Step-4 Fix the grouting nipples in the V-groove in both faces of the wall at spacing of 150-200 mm c/c.

Step-5 Clean the crack with the compressed air through nipples to ensure that the fine and loose material inside the cracked masonry has been removed.

Step-6 Seal the crack on both the faces of the wall with polyester putty or cement mortar 1:3 (1-cement:3-coarse sand) and allowed to gain strength.

Sept-7 Inject water starting with nipples fixed at higher level and moving down so that the dust inside the crack is washed off and masonry is saturated with water.

Step-8 Make cement slurry with 1:2: W (1-non shrink cement : 2-fine sand : just enough water) and start injecting from lower most nipple till the slurry comes out from the next higher nipple and then move to next higher nipple.

Step-9 After injection grouting through all the nipples is completed, replaster the surface and finish the same.

Alternative Procedure:- See Fig.2

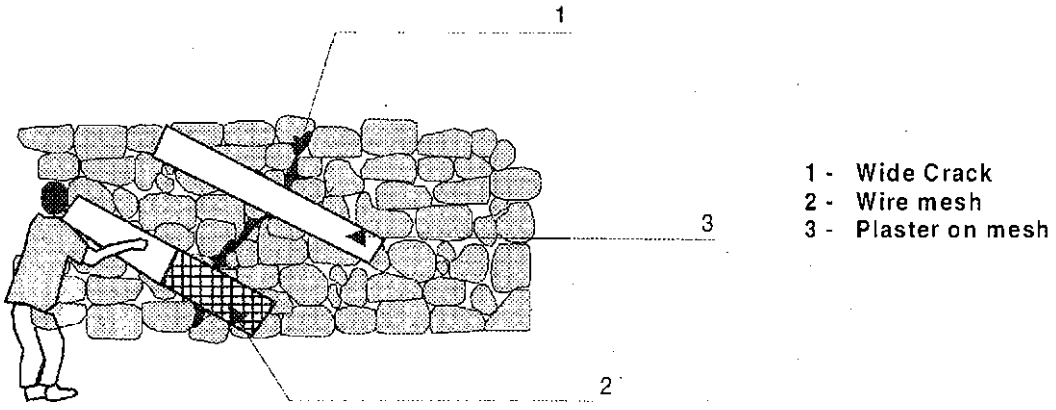


Fig. 2 - Fixing mesh across wide cracks

Step-1 Remove the plaster in the vicinity of crack exposing the cracked bare masonry.

Step-2 Make the shape of crack in the V-shape by chiseling out.

Step-3 Clean the crack with compressed air.

Step-4 Fill the crack with cement mortar 1:3:W (1-non shrink cement : 3-fine sand : necessary water) from both sides as deep as feasible.

Step-5 Provide wire mesh on both the faces of wall after removal of plaster in the region of repair to a width of 150 mm on each side of the crack.

Step-6 Clamp the mesh with the wall using clamps or wire nails at the spacing of 300 mm c/c.

Step-7 Plaster the meshed area with cement sand mortar of 1:3, covering the mesh by a minimum of 12 mm.

8. INSTALLING FERRO-CEMENT PLATES AT THE CORNERS

Before filling the cracks as in Para 7, use galvanized weld-mesh 'g14' (2.0mm wires @25x25mm mash) over a length of 500-600 mm on each side of the crack both inside and outside of the room in a depth of 300mm at windows sill on about 900 mm height above the floor (Fig.3) and another one at lintel level or about 2 m above the floor. But if horizontal seismic belt is to be provided at the lintel level, the second mesh is not required.

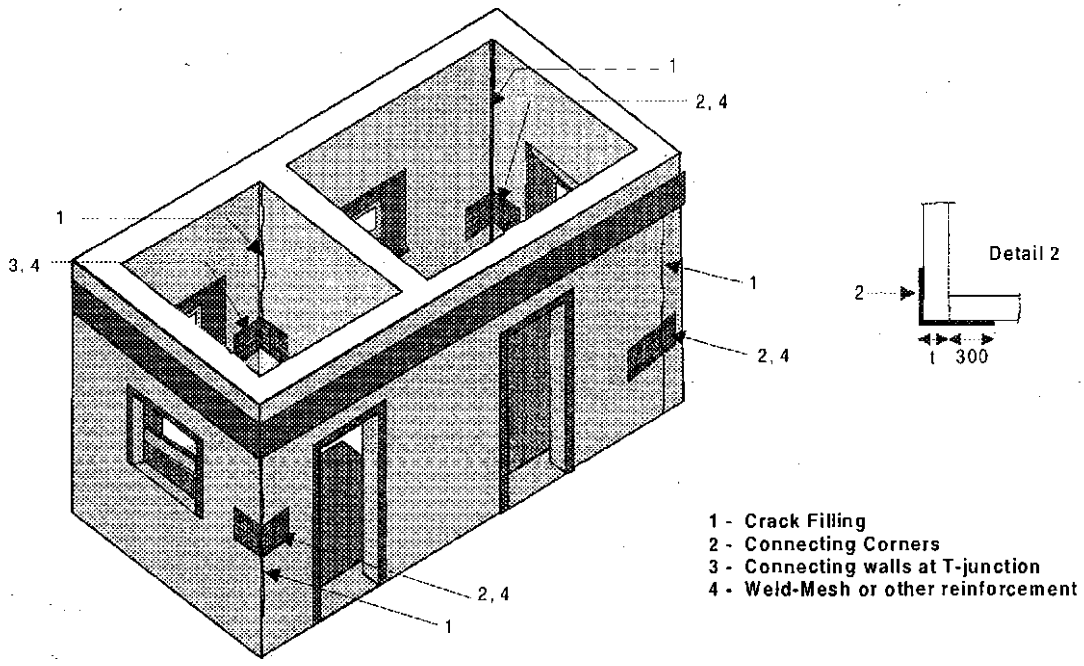
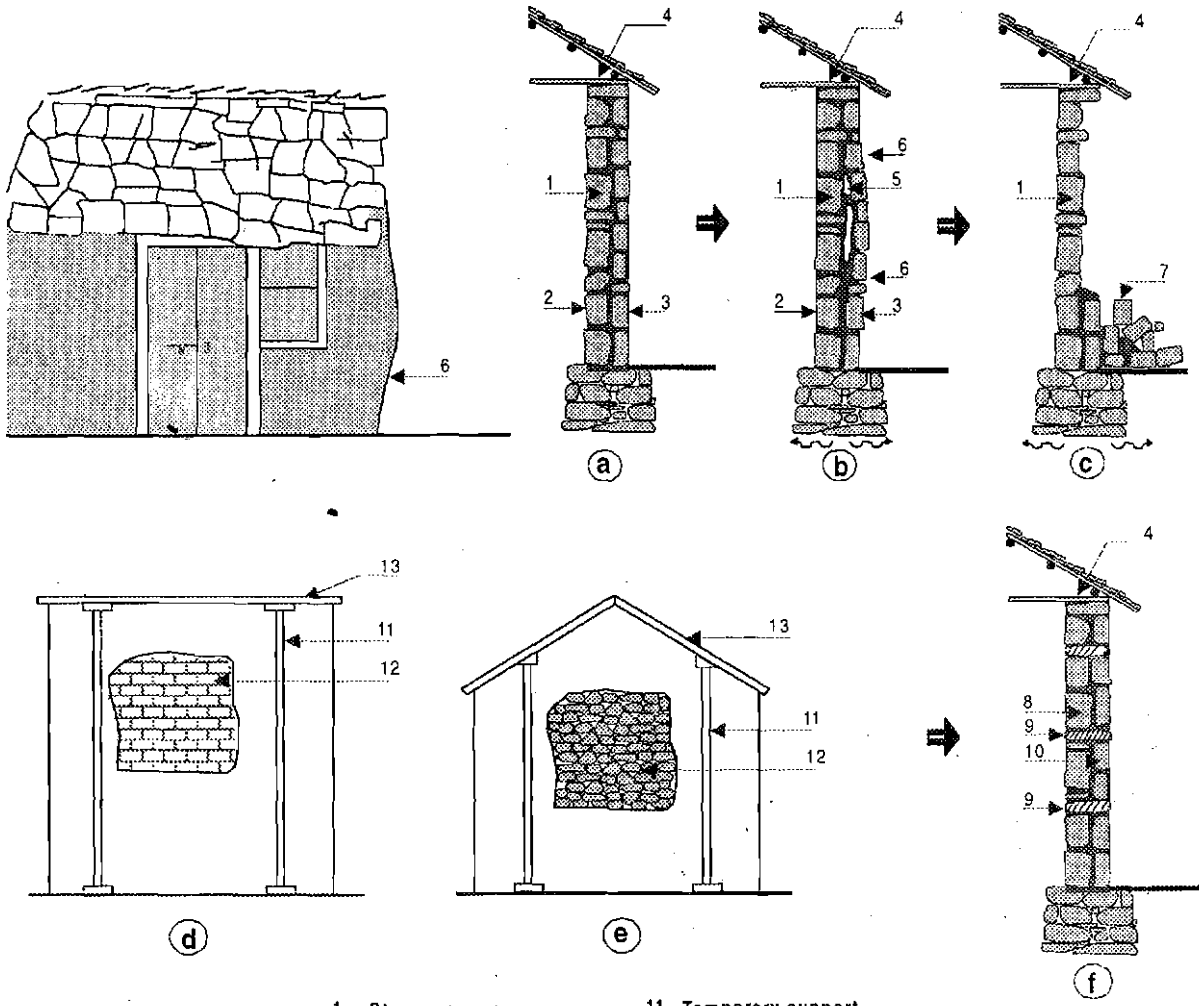


Fig.3 - Connection of cracked walls at corners and junctions

9. REBUILDING PORTIONS OF THE WALL

(i) Generally the random stone walls are seen to be 450-600 mm thick, built by two wythes vertically (Fig.4.1). During an earthquake, the wythes get separated and either one or both

get bulged (Fig.4.2) which even fall away under further vibrations (Fig.4.3). For preventing such delamination, it is necessary to use 'through' stones or RCC elements. These should be installed while rebuilding the wall (Fig.4.4).



1 - Stone masonry
2 - Inner wythe
3 - Outer wythe
4 - Roof joist
5 - Delamination of wythe
6 - Bulging in earthquake
7 - Outer wythe fallen
8 - Old masonry
9 - Bond stone
10- New masonry
11 - Temporary support
12 - Cracked wall portion
13 - Roof

Fig.4 - Rebuilding part of wall

(ii) Where portions of wall require rebuilding, the roof resting on the wall should first be supported by wooden struts, (Fig-4a,b). Then the damaged portion of the wall should be dismantled. The new portion of the wall should be constructed using cement-sand mortar of 1:6 cement-sand mortar in walls built originally in weak mortar, but using 1:4 mix for walls originally built in cement mortar.

10. EARTHQUAKE RESISTANT RETROFITTING OF BUILDINGS

For achieving safety of buildings against collapse in a future severe earthquake, the following retrofitting actions are recommanded. The amount and placing of the retrofitting element depends upon the seismic zone, the importance of the building and the stiffness of the base soil. The Categorisation of Buildings is given in Table 3.

Table 3- Simplified Building Categories in the Seismic

Seismic Zone	Ordinary Buildings	Important Buildings
V	**D**	**E**
IV	**C**	**D**
III	**B**	**C**

1. This Categorisation is in line with IS : 1893 - 2001 where the maximum respons in short period range is taken as uniform for all soils.
2. Housing falls under Ordinary buildings. The community building may be considered under Important buildings.

i) Check length, height and thickness of walls and modify to conform to the Code: IS:4326 and IS:13828-1993 (see Table 3).

ii) Check the positions and sizes of openings in walls and modify as required, or provide reinforcement.

iii) If there are no 'through' stones in thick stone walls, then provide RC headers by making 'through' hole by removing the stones in opposite wythes, inserting an iron link and filling the hole with concrete.

iv) Provide seismic belt below roof and above door/window lintel level. For this use weld mesh reinforcement.

v) Provide vertical reinforcement at the corners and T-junction of walls, either using bars or ferro-cement with weld-mesh reinforcement.

vi Modify the roof structure by providing additional bracing elements and fix it to the seismic band/belt.

11. CONTROL ON LENGTH, HEIGHT, THICKNESS OF WALLS

a) R.R Stone Masonary.

The wall length should not exceed 5m between cross walls in case of mud mortar and 6m in cement mortar case. If length exceeds these, provide internal wall at a spacing not farther than 4m (see Fig.5). The thickness of new wall should not exceed 400mm. The wall height should not exceed 2.7m in mud mortar and 2.9m in cement mortar (see Table 4).

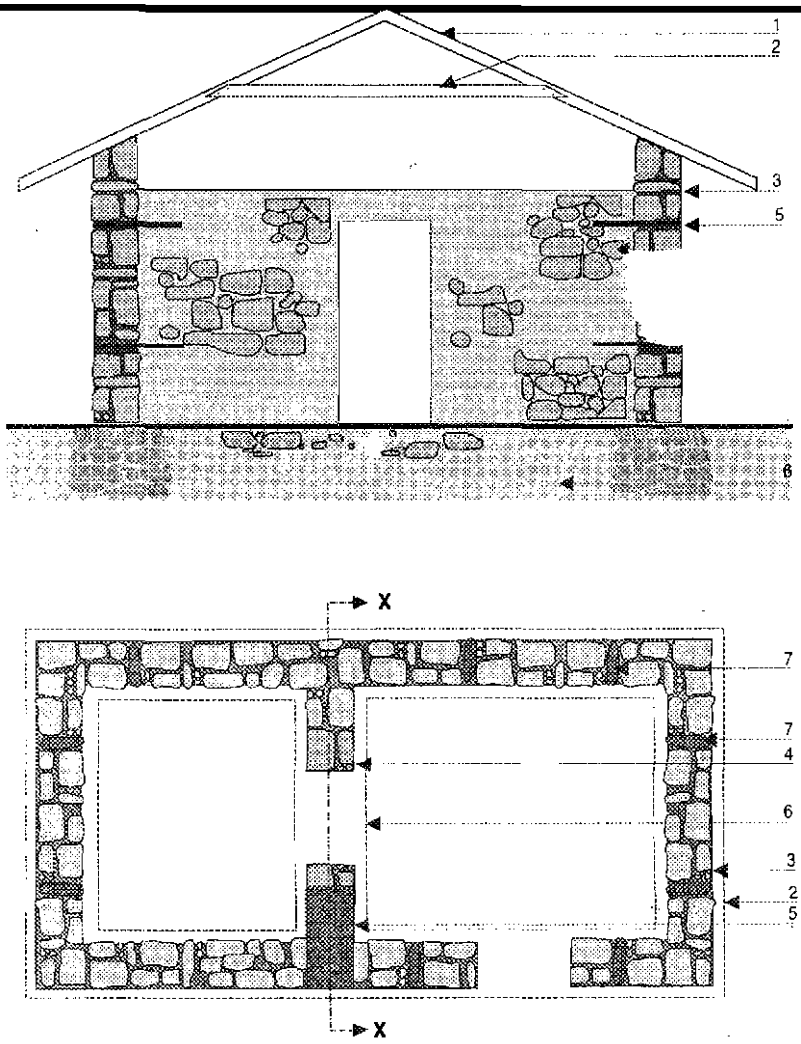


Fig. 5 - Strengthening of long walls by cross wall

Table 4- Control on Length, Height & Thickness of Walls

Type of Masonry	Maximum Length of Walls in Room	Maximum Height of Storey
(a) R R Stone Masonry		
- in Mud Mortar	5 m	2.7 m
- in Cement Mortar	6 m	2.9 m
(b) Rectangular Unit Walls - in Cement Mortar	35 t but $\leq$ 7.0 m	15 t but $\leq$ 3.5m
	t = thickness of wall	t = thickness of wall

b) Rectangular Unit Masonry in cement mortar.

The wall length should not exceed 35 t and the height should exceed 15 t where t = thickness of wall. See Table 4.

12. CONTROL ON DOOR AND WINDOW OPENINGS IN MASONRY

i) Door and window opening should satisfy the following :

Distance of jamb from internal corner not less than 450mm and distance between two consecutive openings should be 600mm or more in case of R R masonry and 560mm in rectangular unit masonry . In case of R R masonry in mud mortar, there should preferably be only one door or window in one wall not exceeding one-third of the wall lenght in the room. The combined length of openings in a wall of rectangular unit masonry building in cement mortar to be restricted to 0.5 L in one storey, 0.42 L in two storey and 0.33 L in three storey building where L is the length of the wall.

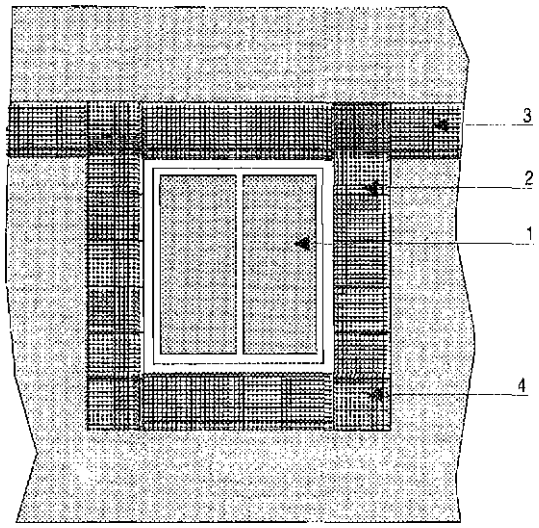


Fig. 6 - Reinforcing around opening

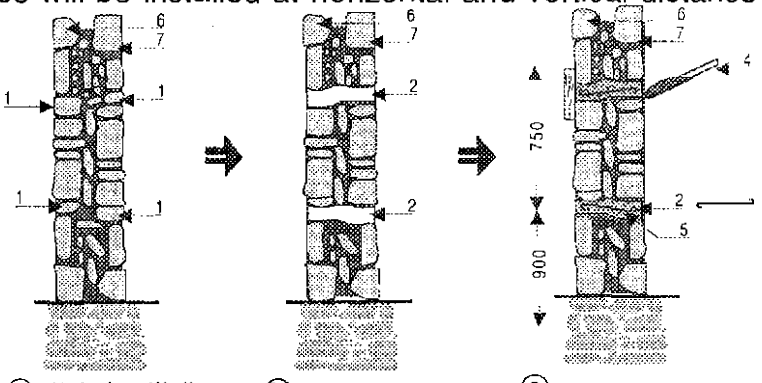
ii) If the above conditions are not satisfied, action be taken to close an opening or reduce its size. Otherwise, provide strengthening around the opening (Fig.6). For detail of reinforcement, see see Para 16.

13. MAKING 'THROUGH' BOND ELEMENTS IN R.R. STONE WALL (Fig.7)

a) Select points where 'through' stones will be installed at horizontal and vertical distance of about one meter apart, with 50cm horizontal stagger.

b) Remove the plaster from the surface exposing the stones. Remove the mortar around the u i i dept g ly, not violently, so as to expose the stone on all sides.

c) Loosen the stone by means of gentle pushes side ways and up and down by means of a small crowbar, so that the other stones of the walls are not disturbed. Pull out the stone slowly, holding it by both hands.



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

Fig. 7 - Providing R.C. 'through' elements for 'stitching' stone wythes

d) Remove inner material gradually so that a 75mm size hole can be made in the wal Bigger hole is not needed.

e) Locate position of the opposite stone on the other face of the wall by gentle tapping in the hole. Remove the identified stone slowly by same gentle process.

f) The hole so made through the wall may be bigger in size on both faces and narrower inside resembling a dumbbell shape. This is good. It does not matter if the hole is inclined instead of being horizontal.

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

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

14. PROVIDING HORIZONTAL SEISMIC BELTS

14.1 Seismic Belt Locations

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

Note : *On small wall lengths in a room (less than 5m) seismic band only on the outside face will suffice. In this case these should be connected by ties going across the rooms (see Fig.8).*

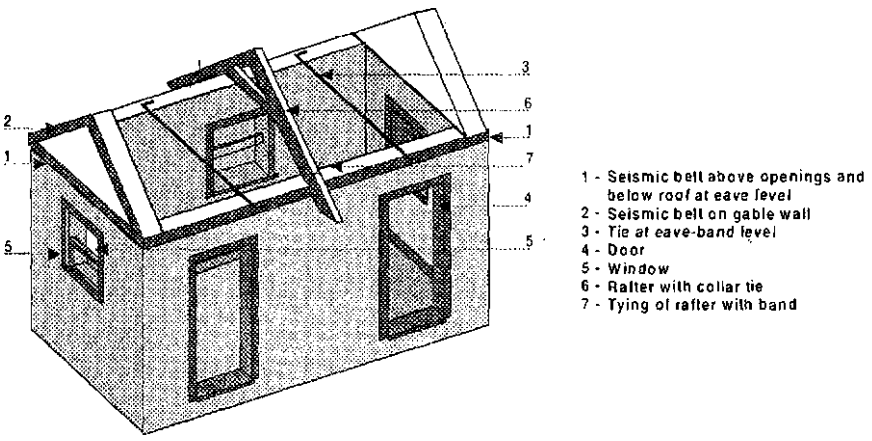


Fig. 8 - Overall arrangement of seismic belts (roofing removed)

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

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

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

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

14.2. Description of reinforcement in belt.

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

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

Table 5- Mesh Reinforcement in Seismic Belts in Various Building Categories.

Length of Wall	Cat. B			Cat. C			Cat. D			Cat. E		
m	Gauge	N	H	Gauge	N	H	Gauge	N	H	Gauge	N	H
≤ 5.0	g14	9	250	g13	9	250	g12	9	250	g10	10	280
6.0	g13	9	250	g12	9	250	g10	10	280	g10	14	380
7.0	g12	9	250	g10	10	280	g10	14	380	g10	18	460
8.0	g10	9	250	g10	14	380	g10	18	460	g10	23	580

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

15. VERTICAL SEISMIC BELT AT CORNERS

Vertical reinforcing is required at the corners of rooms and junctions of walls as per Table 6. Alternatively MW 21 weld mesh of equivalent longitudinal area could also be used. The width of this belt on each side of the corner has to be kept 25mm extra to the width of the mesh.

This reinforcement should be started 300mm below the plinth level and continued into the .../e..e .e.. ...iz..... ..... (_ee Fig._).

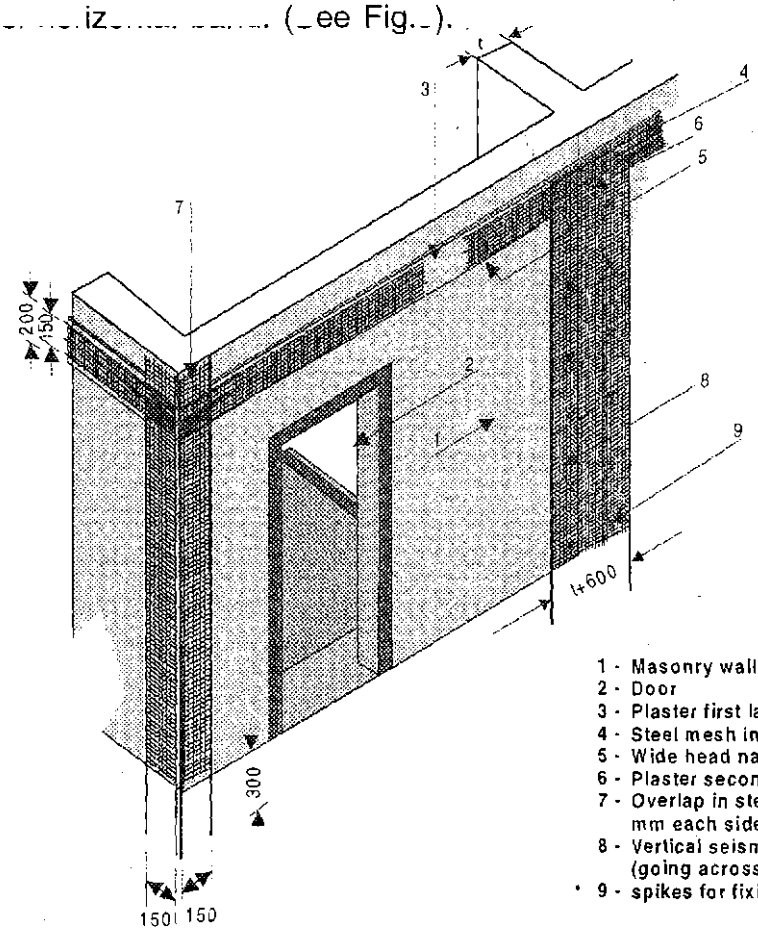


Fig. 9 - Vertical seismic belts at corner and junction

Table 6-Vertical Bar or Mesh Reinforcement in Vertical Belt at Corners of Rooms

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

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

16. SEISMIC BELTS AROUND DOOR/WINDOW OPENINGS

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

i) In category **D** and **E** buildings for resistance against earthquake forces.

ii) For restoring the strength of the piers in any building category when badly damaged in an earthquake.

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

*i) In Cat.**D** & **E** buildings*

Mesh of gauge 10 with 10 wires in vertical direction spaced at 25 mm in a belt width of 280 mm.

*ii) In Cat. **C** buildings*

Mesh of gauge 12 with 9 wires in vertical directon spaced at 25 mm in a belt width of 250 mm.

17. METHOD OF FIXING SEISMIC BELTS

The reinforcement specified in Paras 8, 14, 15 and 16 is to be finally attached to the stone wall by nails or connectors and cement mortar. For this purpose either 1:3 cement-coarse sand mortar or micro-concrete 1:1.5:3 is used. It is applied in two layers like plaster as described below.

Steps to construct the Belt

Step-1 Remove plaster in the height of the belt.

Step-2 Rake out mortar joints to 12-15 mm depth.

Step-3 Clean the surface and wet it with water.

Step-4 Apply neat cement slurry and apply first coat of 12 mm thickness. Roughen its surface after initial set.

Step-5 Fix the mesh with 150 mm long nails at about 300 mm apart while plaster is still green.

Step-6 Apply second coat of plaster of 16 mm thickness.

Note :

1. *The mesh should be continuous with 200mm overlap at the corner or elsehere.*
2. *Using galvanized binding wire, tie up the roof rafters with the nails of the eave level belt before applying the plaster over the mesh.*
3. *In brick and Bela stone walls, it will be easy to drill or chisel out holes of 75 mm dia. In that case, instead of the nails, use 3 mm galvanized mild steel wires through the holes to hold and clamp the longitudinal wires every 450 mm c/c.*

18. PROVIDING VERTICAL REINFORCEMENT AT CORNERS, JUNCTIONS OF WALLS.

The vertical reinforcement consisting of TOR bar as per Table 6 or equivlent shall be provided on the inside corner of room starting from 750 mm below the ground floor going upto the roof slab, passing through each middle floor through holes made in the slabs. (See Fig.10) The reinforcement will be connected to the walls by using L shape dowels of 8 mm TOR bar, the vertical leg of 400 mm length firmly tied to the vertical reinforcement bars and the horizontal leg of minimum 150 mm length embedded in the walls through 75 mm dia. holes drilled in the wall into which the 8 mm dia. leg of the dowel will be grouted using non- hrink cement cum polymer grout. Such dowels will be provided, first one just above plinth level and then at about every 1 m distance apart. The corner reinforcement will be covered with 1:3 cement mortar or 1:1 1/2 :3 micro concrete fully bonded ith the alls giving minimum cover of 15 mm on the bar.

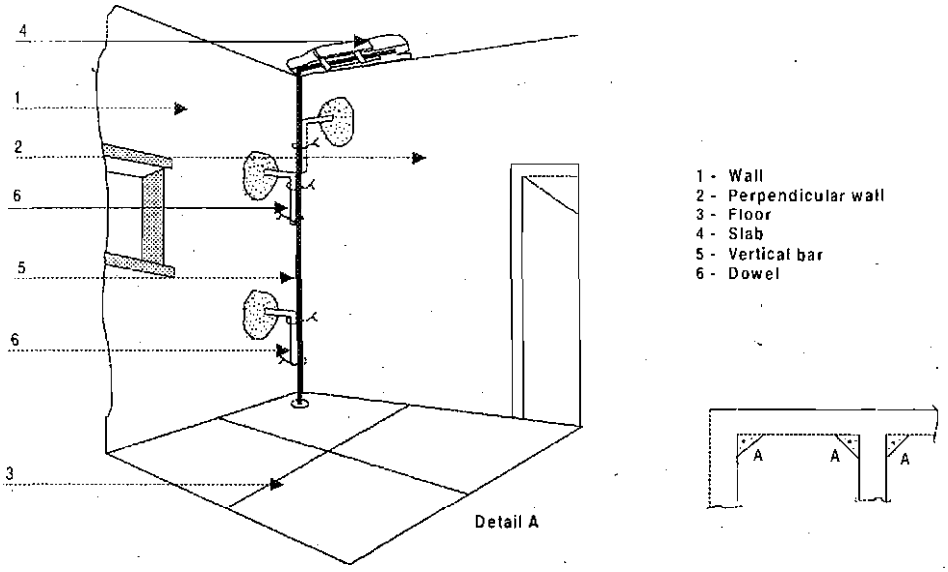
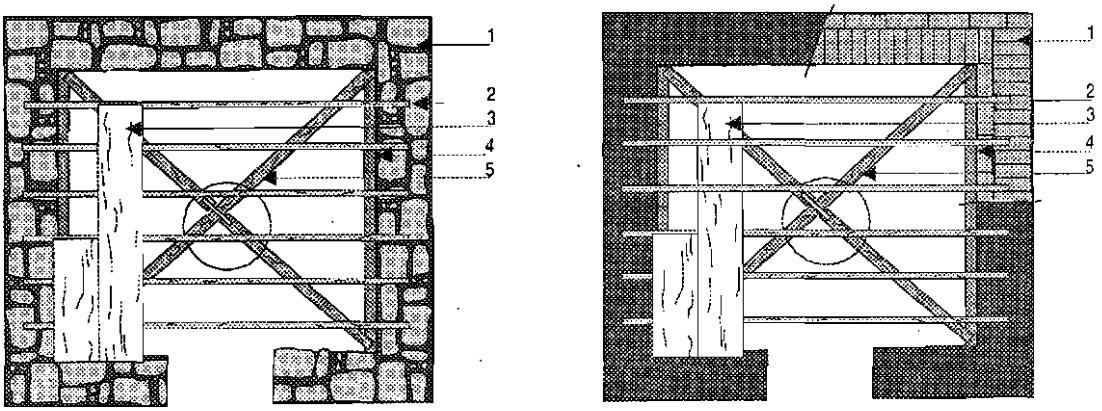


Fig. 10 - Vertical bar at inside corner

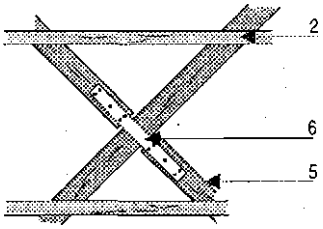
19. STIFFENING THE FLAT WOODEN FLOOR/ROOF

Many of the damaged houses have flat floor or roof made of wood joists covered with wooden planks and earth. For making such roof/floor rigid, long planks 100mm wide and 25 mm thick should be nailed at both ends of the joists from below. Additionally, similar planks or galvanized metal strips 1.5 mm thick 50 mm wide should be nailed diagonally also. See Fig.11.



ⓐ Stone building

ⓑ Brick building

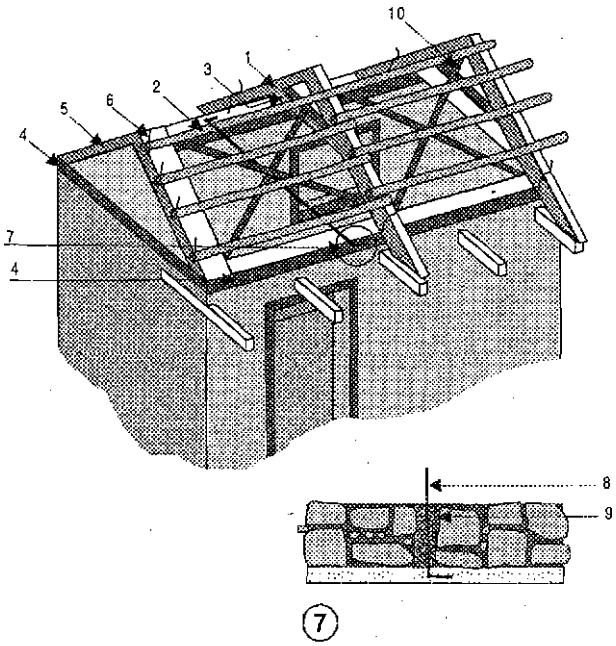


1 - Wall
2 - Wood joist
3 - Wood plank
4 - Tie plank under ends of joist
5 - Diagonal ties
6 - Joint by nailing through 3 mm flat iron

Fig. 11 - Stiffening flat wooden floor/roof

20. STIFFENING THE SLOPING ROOF STRUCTURE

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



⑦

1 - Principal rafter
2 - Purlin
3 - Horizontal tie
4 - Seismic belt below roof
5 - Seismic belt on gable
6 - Tying wire
7 - Detail of tie
8 - Tie rod
9 - Concrete filled in hole

Fig. 12 - Stiffening of sloping roof structure

earthquakes. For stiffening such roofs, the rafters should be tied with the seismic belt as in Note under para 17, and the opposite rafters, on both sides of the ridge need to be connected near about mid-height of the roof through cross ties nailed to the rafters (see Fig. 12).

21. ALTERNATIVE OF CHANGING THE ROOF

While repairing and retrofitting the house, if it is desired to replace the roof structure or tiles with AC or CGI roof, take the following steps:-

i) Complete the repair and retrofitting work of the first storey including provision of 'through' elements.

ii) Stiffen the first floor wooden deck.

iii) Complete the horizontal and vertical seismic belts in the first storey, keep the vertical mesh reinforcement extending beyond the first storey by 300mm and leave uncovered.

iv) Complete the repair and retrofitting of the second storey.

v) Now open the roof structure and remove gable portion upto eave level.

vi) It will be preferable to use seismic bands, instead of belts in this case. Therefore, construct the vertical seismic belts and the eave level and gable *bands* together,taking the vertical steel in the bands. Anchor steel wires in the bands and extend out for tying down the rafters and purlins.

vii) Now erect the rafters, tie them with bands and fix the tie to make A-frames.

viii) Instal diagonal bracing in the plane of the rafters.

ix) Erect the purlins over the rafters, tie them with rafters and gable bands. Bolt down the AC or CGI sheets to the purlins using J or U bolts with iron and bitumen washers.

EXAMPLE OF RETROFITTING A HOUSE AT KHARIROHAR, DIST. KACHCHH

The retrofitted house is shown in the photograph (Fig. 13).

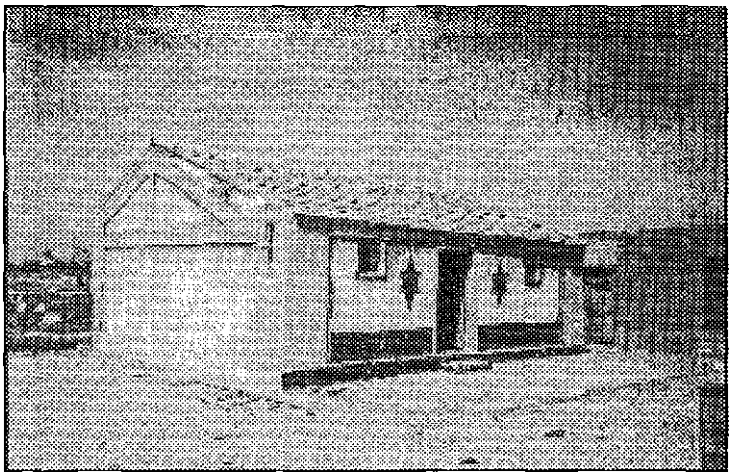


Fig-13 Retrofitted House

The house was built using random rubble stone masonry walls with the roof of Mangalore Pattern (Morbi) tiles resting on wooden under-structures. The following retrofitting elements were installed. The cost of the items in the whole house of 60 m^2 plinth area is also given:

	Retrofitting Element	Rupees	Rs/m^2
1.	Reinforced concrete bond elements (Headers), with 8 mm dia. TOR steel bar in M15 (1:2:4) C.C., 50 Nos @ 70/-	3500	41.70
2.	Corner Strengthening with 25mm x 25mm weld-mesh, anchor with 150 mm long Nails & Header, 32 mm thick plastering with (1:4) proportion (inside & outside), 52 m^2 @ 215.0	11180	186.30
3.	R.C.C. Band at Lintel Level with 25 mm x 25 mm weld-mesh, anchor at 1.2 m c/c & 150 mm Long Nails, plastering 32 mm thick (1:4) proportion, 12.2 m^2 @ 215.0	2623	43.70
4.	Diagonal Bracing for Gable wall, anchor with 4Nos. Header and 3 mm G.I. wire, 2Nos. @ 400.00	800	13.30
5.	Roof Bracing (wall plate), anchor with 75 x 25 mm size wooden Patti, 100 mm long Nails and 3 mm G.I. Wire, 85.4 m @ 16.40	1400	23.30
6.	Plastering (32 mm) thick, (1:4) proportion, with chicken mesh 6.52 m^2 @ 107.60	701	11.70
	Total	**20204**	**336.70**

Taking the cost of an earthquake resistant new similar house as Rs. 3000.00 per m^2, the retrofitting cost works out to 11.2% only. In other words against rebuilding cost of the house of Rs. 1.80 lacs, the retrofitting cost is about Rs. 20,000/- only.

* Source : Kutch Nav Nirman Abhiyan

REFERENCES

1. Arya, A.S. et. al. (1986), *Guidelines for Earthquake Resistant Non-Engineered Construction*, IAEE Committee, The International Association for Earthquake Engineering, Tokyo.
2. Arya, A.S. (1988), " Repair and Strengthening of Damaged Stone Houses after Dhamar Earthquake, North Yemen ", *IX World Conference on Earthquake Engineering,* Tokyo-Kyoto, Aug. 2-9, Vol. VIII, pp. 1141-1146.
3. Arya, A.S. (1994), *Retrofitting of Stone Houses in Marathwada Area of Maharashtra,* Building Materials and Technology Promotion Council (BMTPC), Ministry of Urban Development, Govt.of India.
4. Arya, A.S. (1996), "Seismic Retrofitting of Stone Houses in Marathwada Area, India", *Paper No. 2174, XI World Conference on Earthquake Engineering, Acupulco, Maxico.*
5. Arya A.S. (1997), *Guidelines for Damage Assessment and Post Earthquake Action, Part-2, Brick Houses with Clay Tile Roofing,* pub. Building Materials and Technology Promotion Council, Ministry of Urban Development, Govt.of India.
6. Arya A.S. (1999), *Repair and Retrofitting of Buildings in the Chamoli Rarthquake Affected Areas*, Building Materials and Technology Promotion Council, Ministry of Urban Development. Govt. of India.
7. I:S:4326-1993, *Earthquake Resistant Design and Construction of Buildings - Code of Practice*, Bureau of Indian Standards, New Delhi.
8. I:S:13935-1993, *Repair and Seismic Strengthening of Building - Guidelines*, Bureau of Indian Standards, New Delhi.
9. *Reconstruction and New Construction of Houses in Kachchh Earthquake Affected Area of Gujarat*, (II printing), (GSDMA) Gujarat State Disaster Management Authority, Govt. of Gujarat, January, 2002.