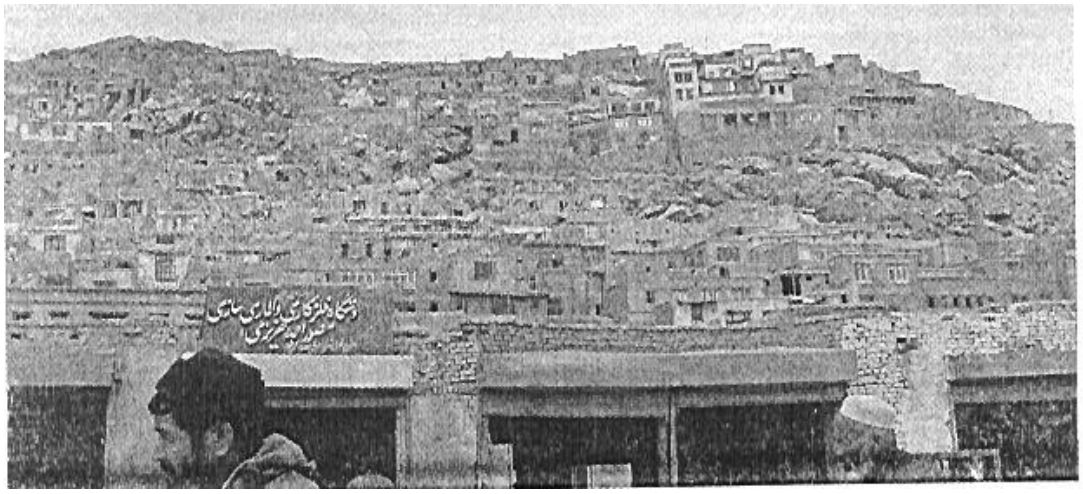
UN/DESA PROJECT INT/98/X70 (UNCRD)
Contract No. 8960

GUIDELINES FOR

REPAIR, RESTORATION AND SEISMIC RETROFITTING OF MASONRY BUILDINGS

Part-IV
Repair, Restoration and Seismic Retrofitting of Masonry Buildings



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PREFACE

United Nations DESA, in consultation with United Nation Centre for Regional Development, Disaster Management Office Kobe, offered a Consultant Contract to the author for performing the following specific services.

1. To develop a guideline for earthquake safe construction with mud (new construction) and stone houses (both new construction and retrofitting) to be used by masons and house owners.

2. To develop training materials for use of engineers in the design and construction of masonry buildings of all types and detailing of reinforced concrete buildings for achieving adequate performance during earthquakes;

3. To develop a model design of earthquake safe school and a community center, using appropriate locally available materials with elements for its earthquake protection;

4. To provide advisory services during the training of engineers in Kabul, Afghanistan, and;

5. To submit a report to UNDESA-UNCRD, including the guidelines, training materials and model design.

In order to fulfil the requirements of preparing the guidelines for earthquake safe construction including new constructions and retrofitting of masonary buildings as well as to develop training material for use of engineers in the design and construction of masonary buildings of all types and detailing of reinforced concrete buildings for achieving adequate performance during earthquakes, the Consultant has planned to prepared the guidelines in following five parts so that they could be conveniently used for various purposes of training and guidance.

Part I Earthquake Resistant Design of Buildings
Part II Earthquake Resistant Design and Construction of Rectangular Unit Masonry Buildings
Part III Earthquake Resistant Construction of Stone Buildings
Part IV Repair, Restoration and Seismic Retrofitting of Masonry Buildings
Part V Earthquake Resistant Construction of Earthen Houses

The present document is ***Part IV*-Repair, Restoration and Seismic Retrofitting of Masonry Buildings.** It covers the topic of restoration of lost strength of cracked masonry walls, cosmetic repair, as well as their seismic retrofitting. Methods of seismic retrofitting will equally apply to existing weak masonry buildings for upgrading their seismic safety in various seismic zones of Afghanistan. This part will be useful for providing training of the engineers as well as masons, and providing help in improving the safety of such building in future probable earthquakes.

March 2003

A.S. Arya
Consultant

CONTENTS

Part IV

REPAIR, RESTORATION AND SEISMIC RETROFITTING OF MASONARY BUILDINGS

1. INTRODUCTION

In the last twelve years, Afghanistan has suffered severe to moderate building damages from three earthquakes in 1991, 1998 and 2002 which killed in all, more than 10000 persons, in several villages. Besides, thousand of building have been damaged during two decades of civil strife in the country. Whereas there is need for reconstruction of collapsed or severely damaged buildings, repairing and retrofitting of moderately damaged buildings will be a time saving and economical option instead of their demolition and reconstruction.

People are killed or badly injured during strong ground shaking in stone masonry buildings in villages as well as in towns because of the following contributing factors:

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.

Many times, buildings which are standing in damaged condition with cracks of minor to major width and extent, are repaired superficially, that is, with cosmetic repairs. When this is done, these buildings will remain very vulnerable to severe damage in future earthquakes due to the hidden cracks in the walls.

The purpose of these guidelines is to address the issues of repair, restoration and seismic retrofitting of various types of *masonry buildings*.

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 buildings in line with the requirements of the seismic-zoning map of Afghanistan (See part I) and Earthquake Resistance Codes of India (IS : 4326-1993) and (IS:13828-1993).

The retrofitting measures are worked out here for safety of existing damaged or undamaged buildings in future MSK Intensity occurrences in the various seismic zones.

The masonry buildings will include : Walls of brickwork, random rubble stone masonry and cut stone masonry whether used for housing or community buildings.

3. CATEGORISATION OF DAMAGE

As specified usually in the MSK Intensity scale, five Grades 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 (See Table 4.1 in Part-I). Description of these Grades of damage as applicable to masonry buildings is presented in Table 1 for ready reference. So far as repair, restoration of structural strength and seismic strengthening to meet the codal requirements are concerned, Grades G1 to G3 are most relevant, since buildings or parts thereof subjected to Grades G4 and G5 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:

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.

Table 1. Damage Grades*

	Category	Walls *	Roof / Floors
0	No Damage	No Damage	No Damage
G1	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.

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

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.*

**Based on I.A.E.E. Guidelines, further developed through observations in earthquakes in India, by Dr. A.S. Arya, Professor Emeritus, Deptt. of Earthquake Engineering, Indian Institute of Technology, Roorkee, Roorkee.*

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. Use of non-shrinking mortar will be preferable.

ii) Addition of reinforcing mesh on both faces of the cracked wall, holding it to the wall through spikes or bolts and then covering it suitably 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 length 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.

7. METHODOLOGY FOR GROUTING OF CRACKS

For grouting of cracks in any masonry wall, the *grout* has to be chosen appropriately to suit the mortar used in the masonry.

For masonry done in cement-sand or lime mortars, the grout may consist of cement slurry made from *Non-shrink* cement and water in the ratio of 1:1 by volume.

Table - 2: Types of Damage in Masonry Buildings

	Damage Observed	Action for Restoration
a)	Different types of cracks seen in masonry walls	
	i. Vertical cracks	i,ii. Cracks to be fully filled using appropriate grout or mortar.
	ii. Inclined cracks	
	iii. Cracks at the corners or T-junctions, and separation of the cross-walls	iii. Cracks at the corners or T-junctions to be filled as above but before that the walls at right angles to be connected using ferro-cement 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 mortar, richer than originally used, after partial partial demolition of wall as required.
c)	Shifting of roofing joists or rafters OR falling down and being broken	c) The covering tiles to be removed for further work and the joints/logs/rafters to be properly positioned.

For masonry in mud mortar, the grout may be made using *non-shrink* cement + sandy soil + fine sand mix in the proportions in 1:1:3 with enough water to make it into slurry. The soil and sand will be sieved through 0.5 mm sieve.

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) Appropriate grout to be chosen.

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

(iv) Compressor for injecting the slurry or a container at a height of 1.2 to 1.5 m above the cracks with flexible hose pipe for flow of grout by gravity.

Procedure:- See Fig.1

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 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.

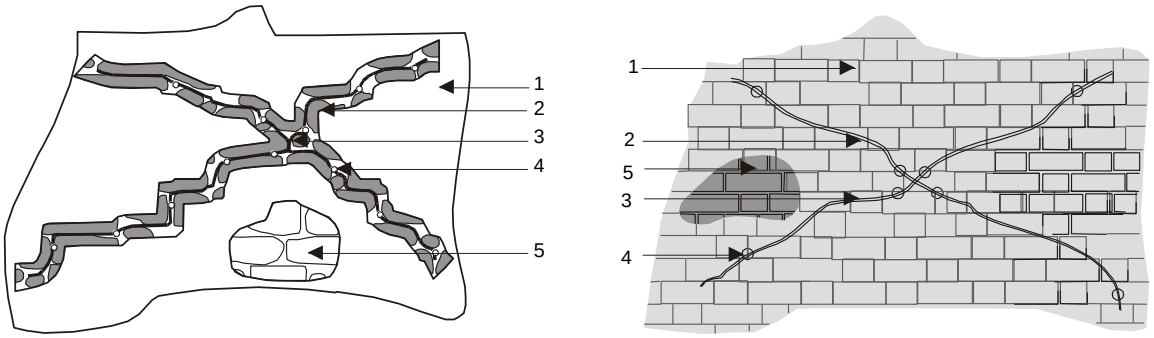
Step-4 Clean the crack with the Compressed air through nipples to ensure that the fine and loose material inside the cracked masonry has been removed.

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 allow 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. (Water injection should *not* be done in the case of mud mortar masonry).

Step-7 Start injecting the grout from lower most nipple till it 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.



ⓐ **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

7.2 Major crack (crack width more than 5.0 mm)

Grout for masonry in cement or lime mortar may consist of non-shrink cement + sand in 1:3 proportion

Grout for masonry in mud may be kept as non shrink cement + sandy soil + sand in 1:1:3 proportion (soil and sand will be sieved through 1 mm sieve)

Material/equipment required for grouting

(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) Appropriate Grout

(iv) Compressor for injecting the slurry.

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. (Water *not* to be injected in mud mortar masonry)

Step-8 Start injecting the grout 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

Material required for ferrocement plate covering

(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.

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

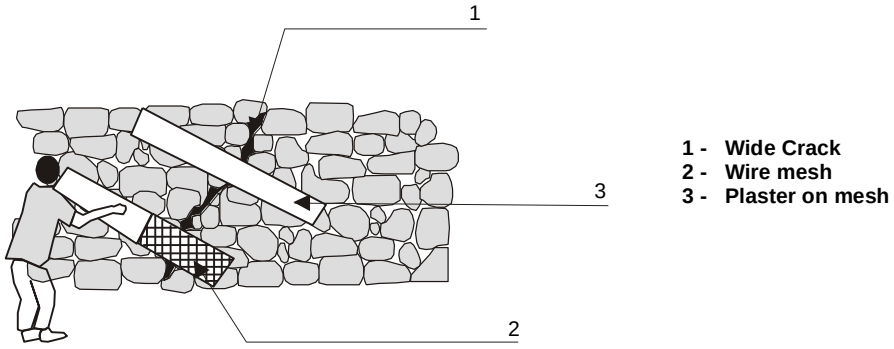


Fig. 2 - Fixing mesh across wide cracks

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+water (1-non shrink cement : 3 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**

After filling the cracks as in Para **7**, use galvanized weld-mesh ‘g14’ (2.0mm wires @25x25mm mesh) 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.

The steps to be taken for installing the meshes are given in Para 17.

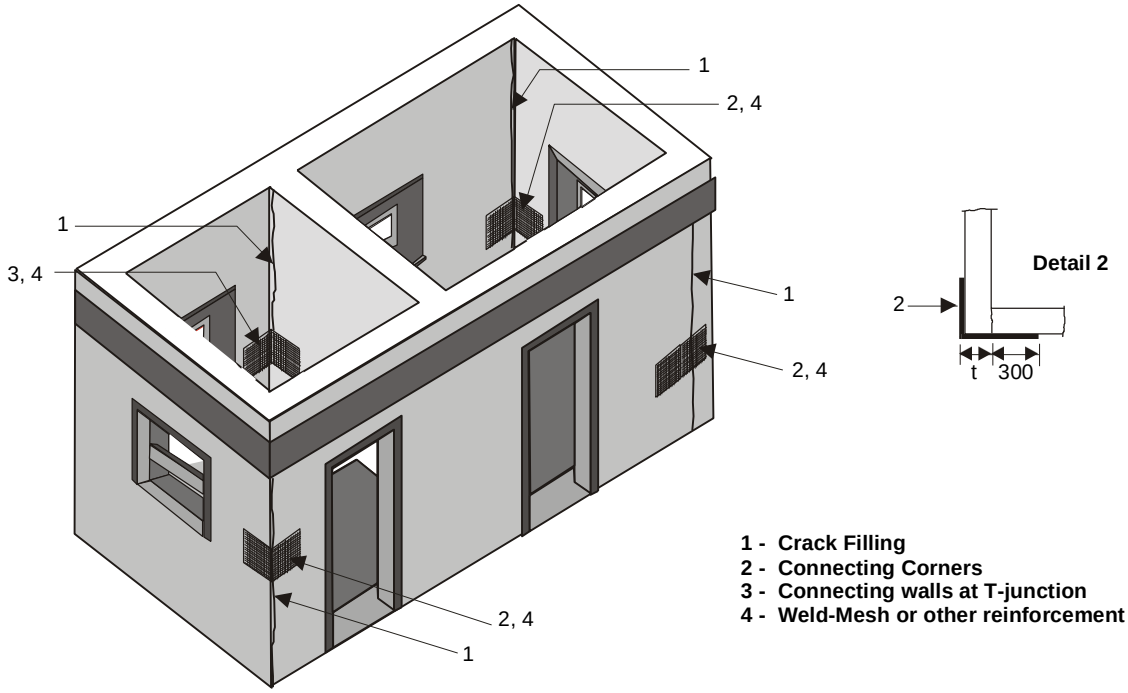
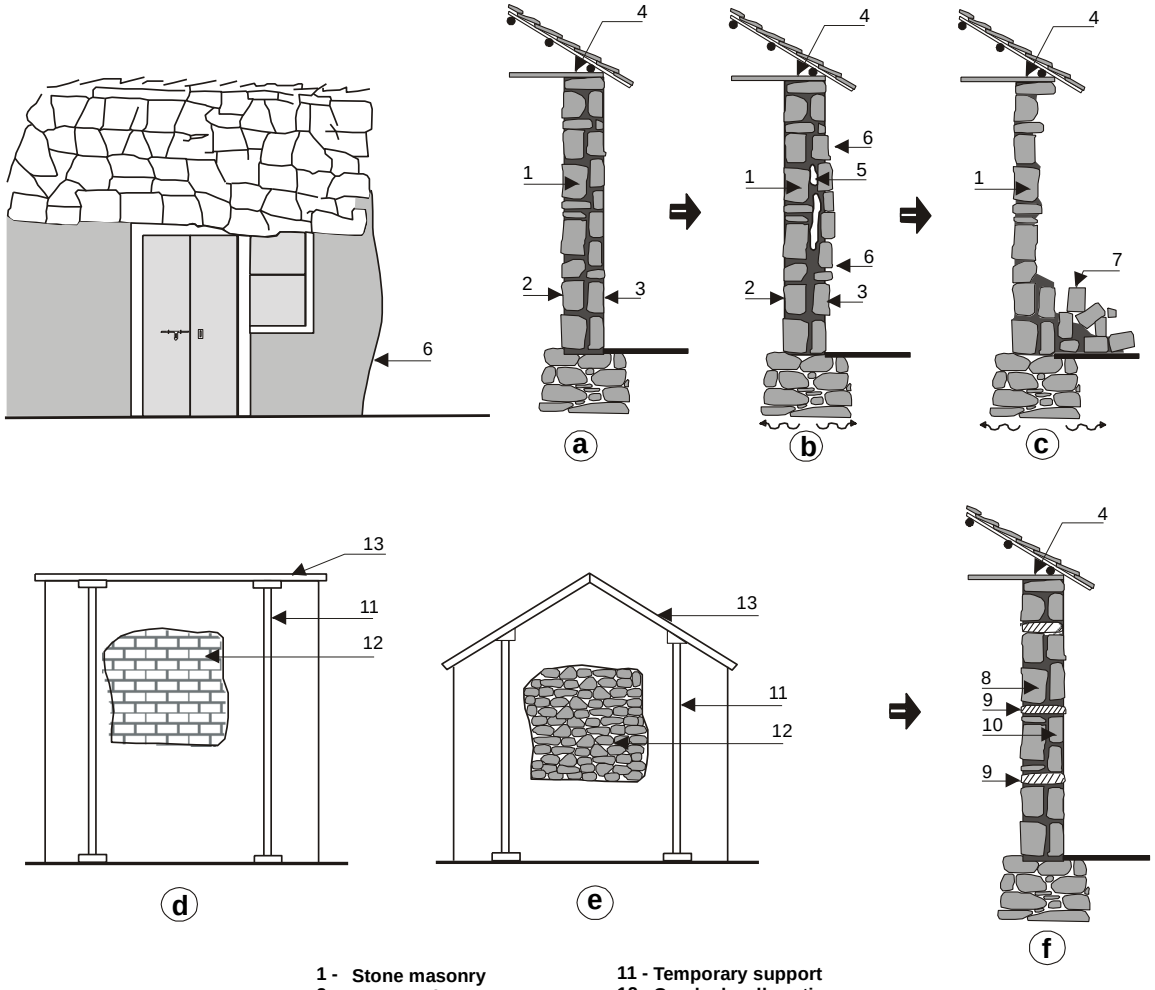


Fig.3 - Connection of cracked walls at corners and junctions

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.4a). During an earthquake, the wythes get separated and either one or both get bulged (Fig.4b) which even fall away under further vibrations (Fig.4c). For preventing such delamination, it is necessary to use 'through' stones or RCC elements. These should be installed while rebuilding the wall (Fig.4f).

(ii) Where portions of wall require rebuilding, the roof resting on the wall should first be supported by wooden struts, (Fig-4d,e). 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.



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

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 (See Parts II & III). This Categorisation is in line with IS : 1893 - 2002 where the maximum response in short period range is taken as uniform for all soils. Housing falls under Ordinary buildings. The community buildings are considered under Important buildings.

Table 3- Simplified Building Categories in the Seismic

	Zone D	Zone C	Zone AB
Housing	B	C	D
Community Buildings	C	D	E

i) Check length, height and thickness of walls and modify to conform to recommendation given in Part II for Rectangular Unit Masonry Buildings and Part III for Stone Masonry Buildings (See Para 11 for ready reference)

ii) Check the positions and sizes of openings in masonry walls and modify as required, or provide reinforcement (See Parts II & III) See Para 12 for ready reference).

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 7m in cement mortar case. If length exceeds these, provide internal wall at a spacing not farther than 4m in mud mortar and 5 m in cement mortar case (See Fig. 5). The thickness of new wall should not exceed 400mm. The wall height should not exceed 2.7m in mud mortar and 3.2m in cement mortar (see Table 4).

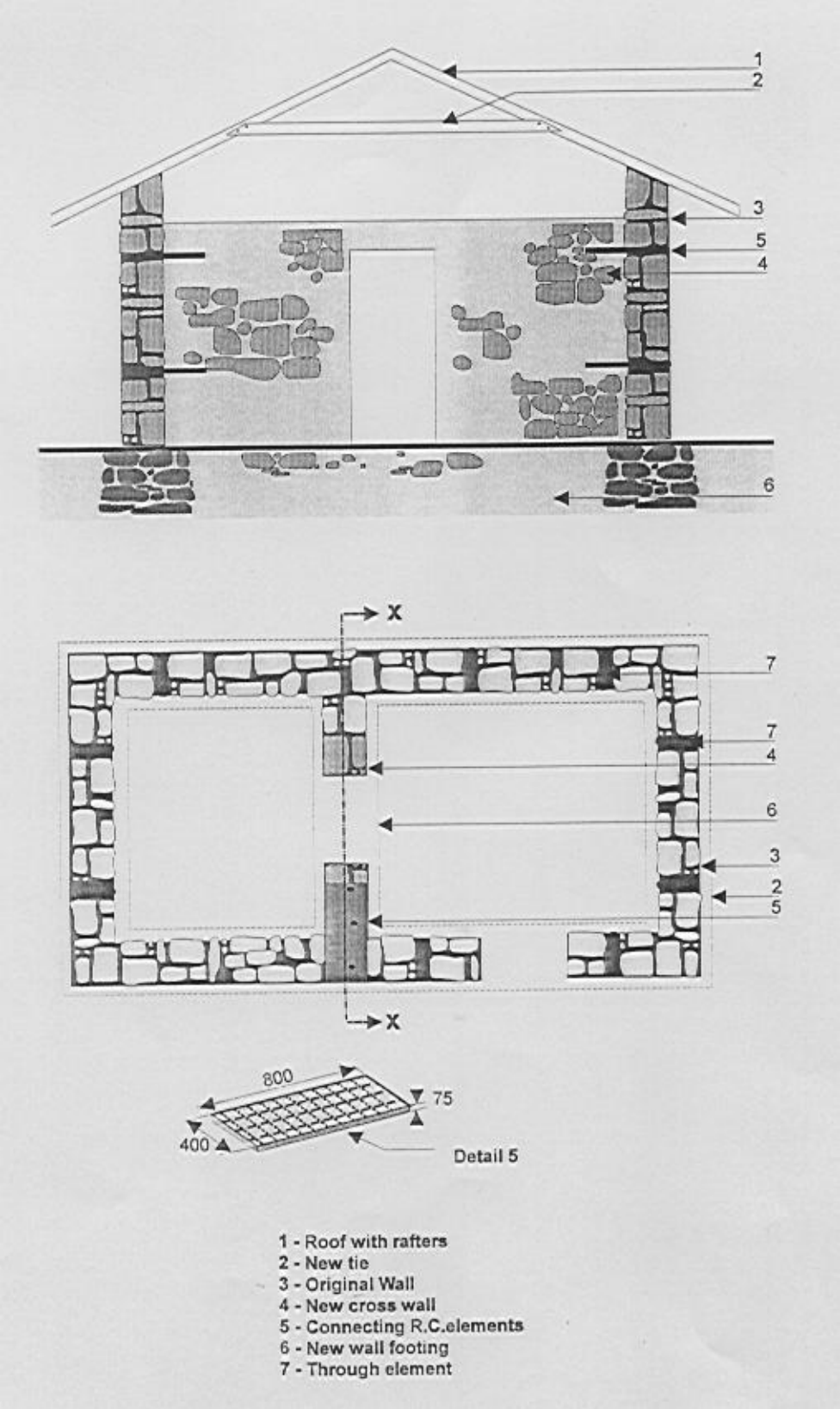


Fig. 5(a) Introducing New Internal Wall

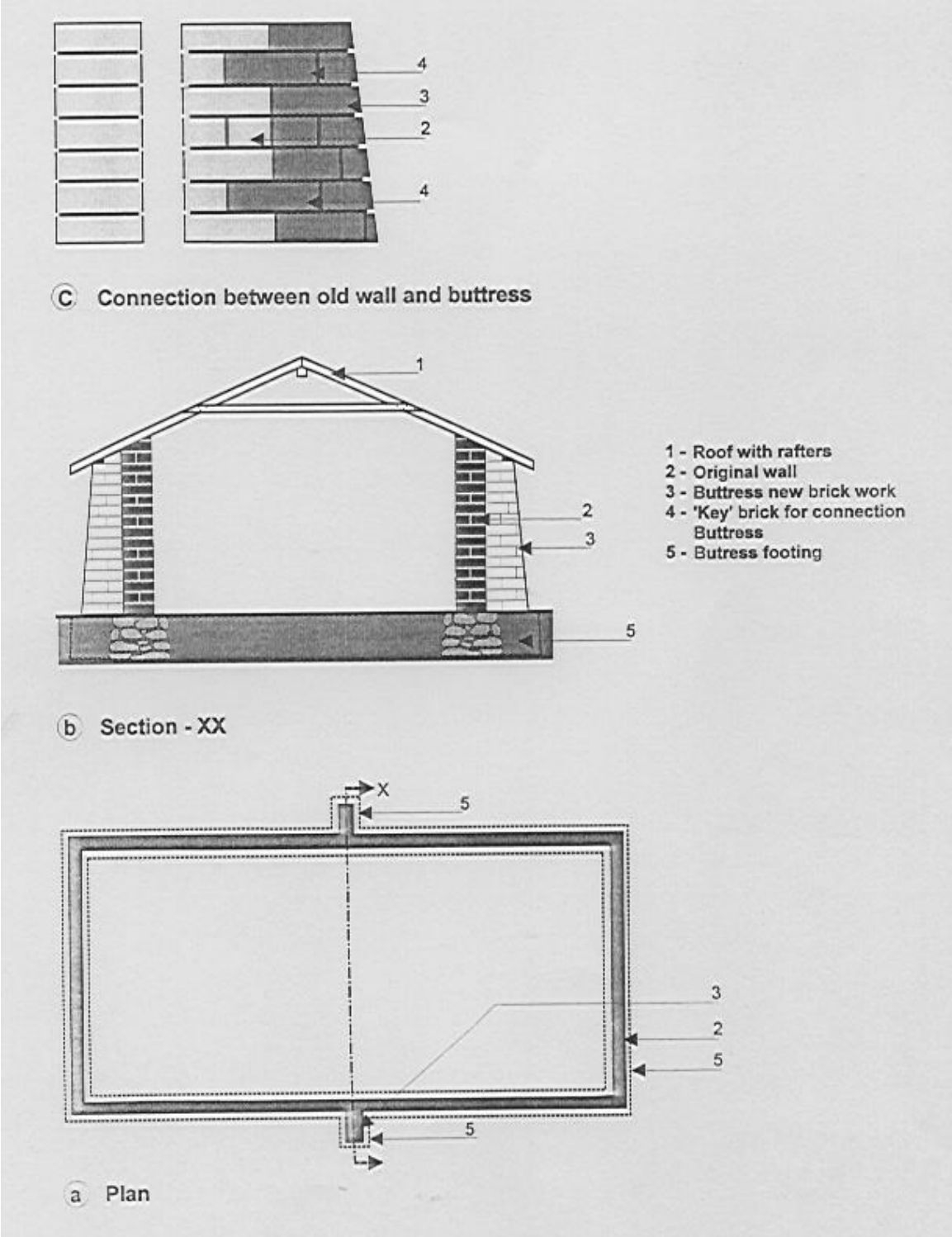


Fig. 5(b) Adding Pilasters/Buttresses to Long Walls

b) Rectangular Unit Masonry in cement mortar.

The wall length should not exceed 35 t and the height should not exceed 15 t where t = thickness of wall. See Table 4. In case of longer room, external pilasters/battresses may be added as shown in Fig. 5(b)

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	7 m	3.2 m
(b) Rectangular Unit Walls - in Cement Mortar	35 t but $\leq$ 7.0 m t = thickness of wall	15 t but $\leq$ 3.5m t = thickness of wall

12. CONTROL ON DOOR AND WINDOW OPENINGS IN MASONRY

i) Door and window openings 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 both in cement mortar. 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.

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**.

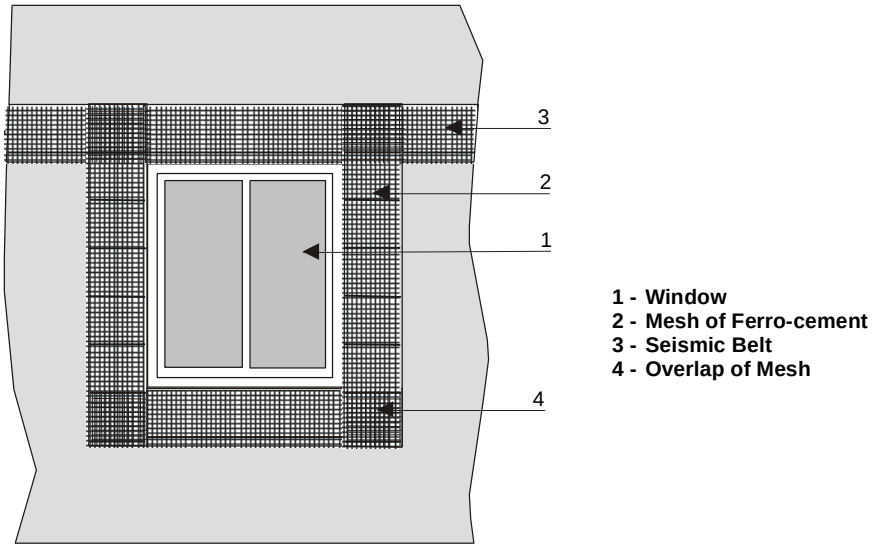


Fig. 6 - Reinforcing around opening

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 stone to sufficient depth gently, not violently, so as to expose the stone on all sides.

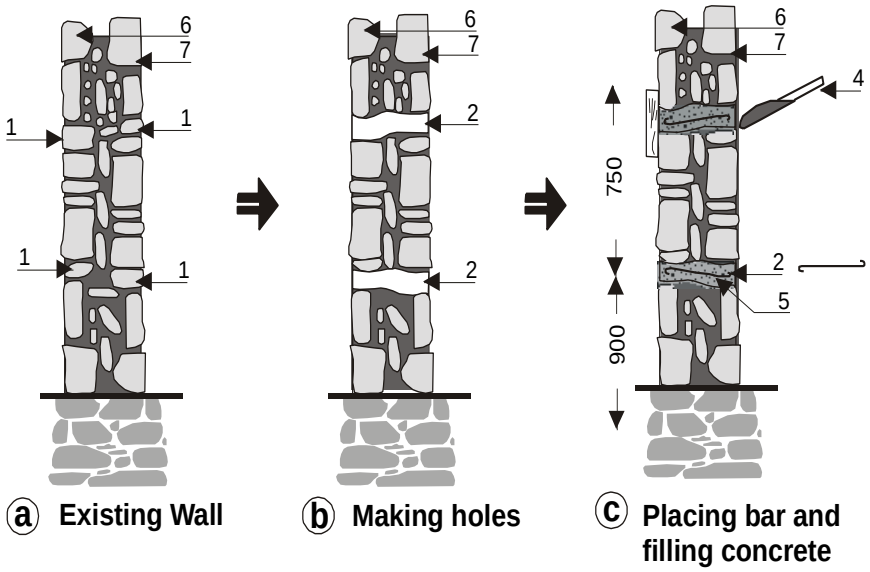
c) Loosen the stone by means of gentle pushes side ways and up and down by means of a small crowbar, so that the other stones of the walls are not disturbed. Pull out the stone slowly, holding it by both hands.

d) Remove inner material gradually so that a 75mm size hole can be made in the wall. 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.



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

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 (i) just above lintels of door and window openings and (ii) just 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).*

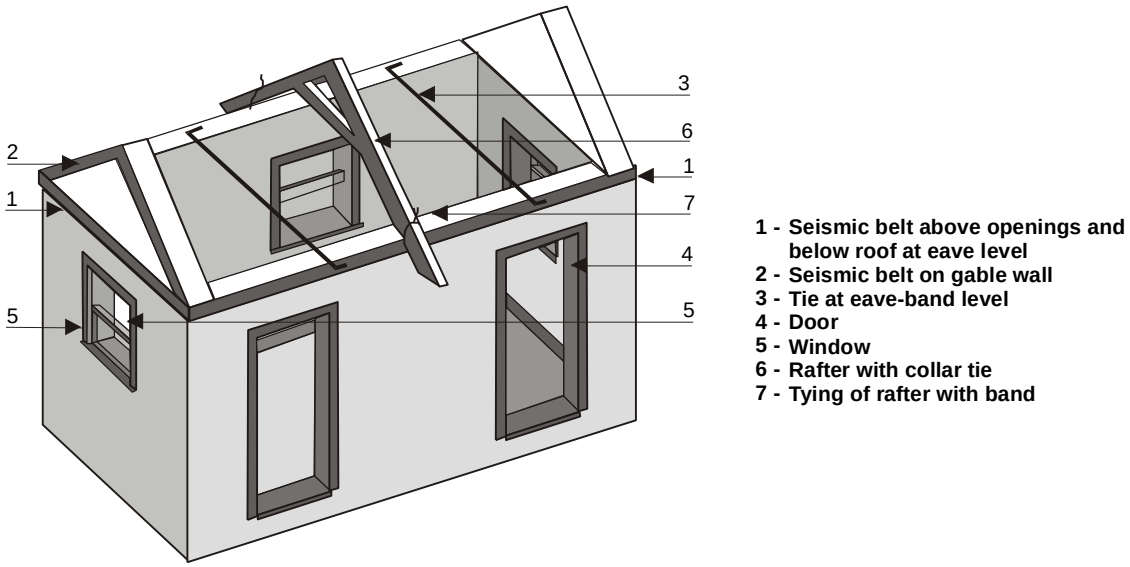


Fig. 8 - Overall arrangement of seismic belts (roofing removed)

ii) The belt just below roof or floor 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 ceiling/eave level above the top of door in less than 900 mm, only the ceiling/eave level belt may be provided and lintel level belt 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 M	Cat. B			Cat. C			Cat. D & E		
	Gauge	N	H	Gauge	N	H	Gauge	N	H
≤5.0	g13	8	225	g13	9	250	g13	10	275
6.0	g13	9	250	g13	10	275	g13 +2 bars of 6 ϕ	10	275
7.0	g13	10	275	g13 +2bars of 6 ϕ	10	275	g13 +3 bars of 6 ϕ	10	275
8.0	g13 +2 bars of 6 ϕ	10	275	g13 +3 bars of 6 ϕ	10	275	g13 +4 bars of 6 ϕ	10	275

1. Gauge: g13 = 2.34 mm dia of wire.
2. N = Number of main longitudinal wires in the belt at spacing of 25 mm. Additional longitudinal bars will be 6 mm dia mild steel tied to mesh at 150 mm c/c.
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 roof/eave level horizontal band. (See Fig.9).

Notes regarding Table 6

1. Gauge 13 (2.34 mm dia galvanized mesh with 20 mm spacing of wires) shall be used. Additional longitudinal bar will be one T8 mm dia HSD tied to mesh at 150 mm c/c
2. Single bar, if used, shall be HSD or TOR type, if two bars be used in a T-junction, the diameter can be as follws. For One of T10 or T12 take 2 of T8, and for One of T16 take 2 of T12
3. N = Number of longitudinal wires in the mesh, T' represents HSD or TOR.
4. B = Width of the micro concrete belt, 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.

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

No. of Storeys	Storeys	Cat. B			Cat. C			Cat. D & E		
		Single Bar.mm	Mesh		Single Bar. mm	Mesh		Single Bar. mm	Mesh	
			N	B		N	B		N	B
One	One	-	-	-	-	-	-	10	20	500
Two	Top	-	-	-	-	-	-	10	20	500
	Bottom	-	-	-	-	-	-	12	28	700
Three	Top	-	-	-	10	20	500	10	20	500
	Middle	-	-	-	10	20	500	12	28	700
	Bottom	-	-	-	12	28	700	12	28	700

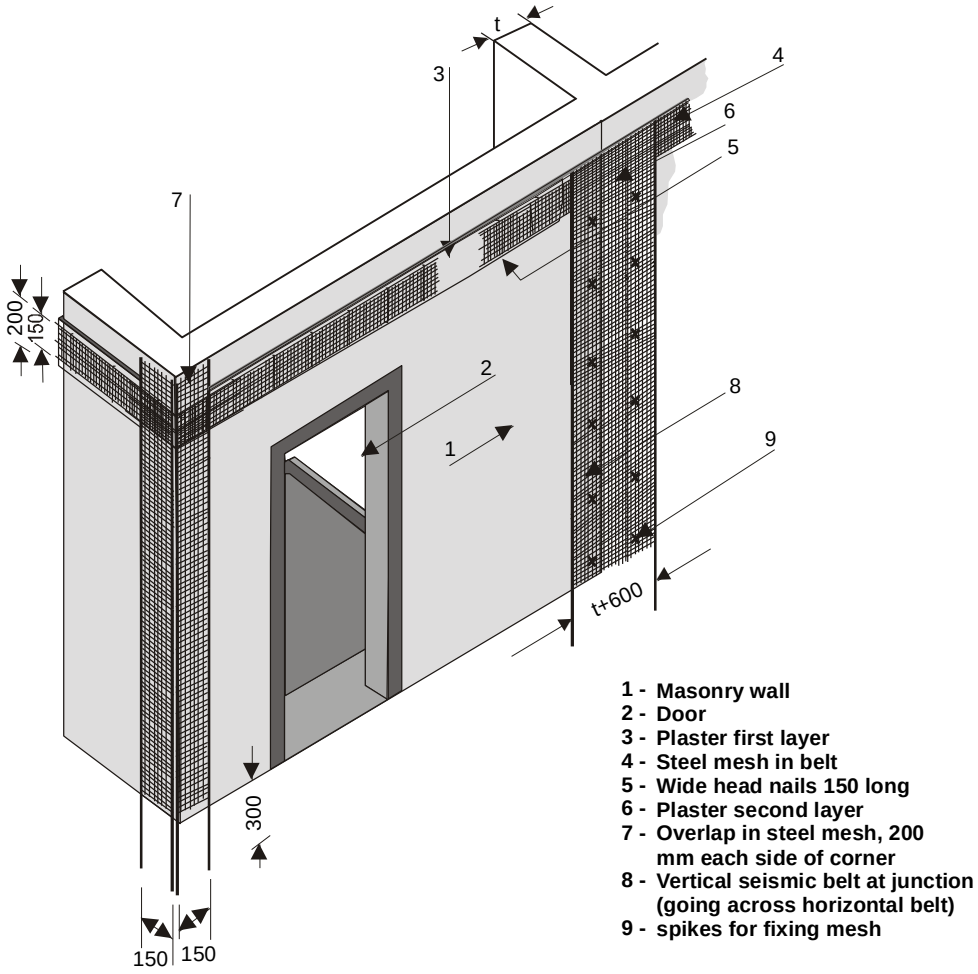


Fig. 9 - Vertical seismic belts at corner and junction

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

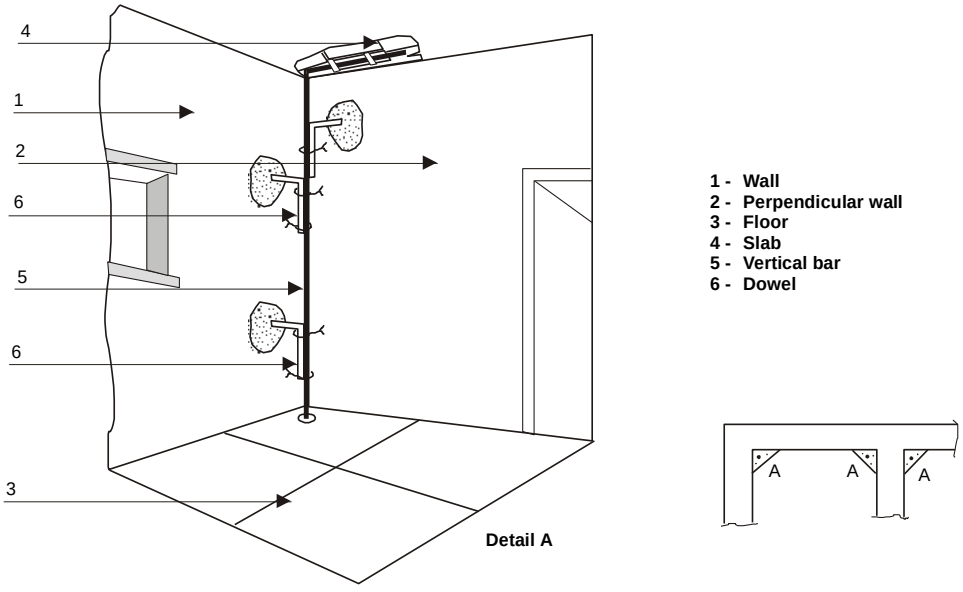
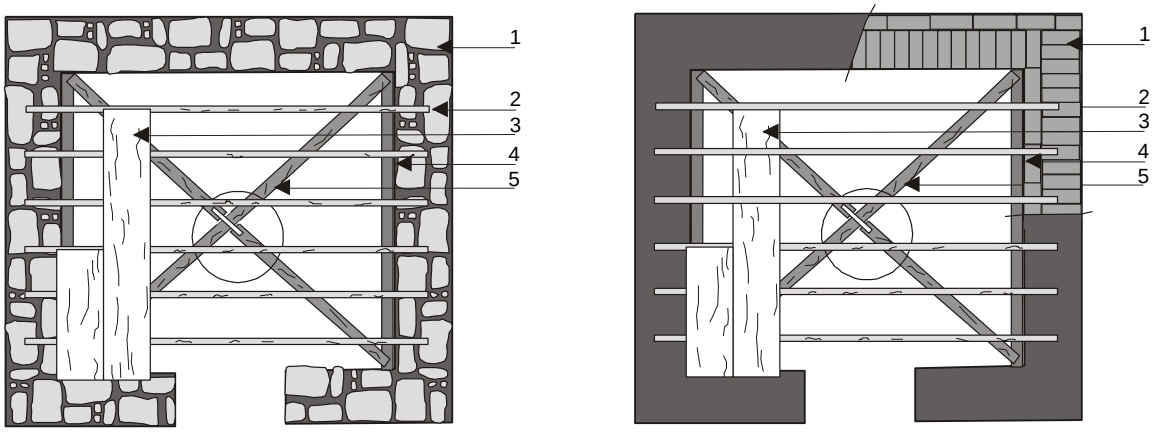


Fig. 10 - Vertical bar at inside corner

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 with the walls giving a minimum cover of 15 mm on the bar.

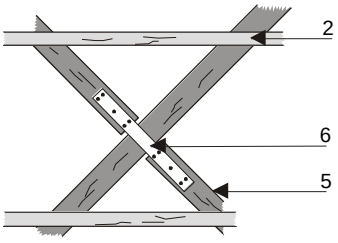
19. STIFFENING THE FLAT WOODEN FLOOR/ROOF

Many of the damaged houses have flat floor or roof made of wood logs or timber 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 logs/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. STIFFNING THE SLOPING ROOFS STRUCTURE.

Most of the sloping roof are usually made of rafters, purlins with covering of burnt clay tiles or corrugated galvanized iron (CGI) sheets or asbestos – cement (AC) sheets on top. In Afghanistan sloping roofs on reinforced concrete slabs are also some times used. Such roofs push the walls outward during 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). The important point in retrofitting is the provision of seismic belts just below eave level and the gable level.

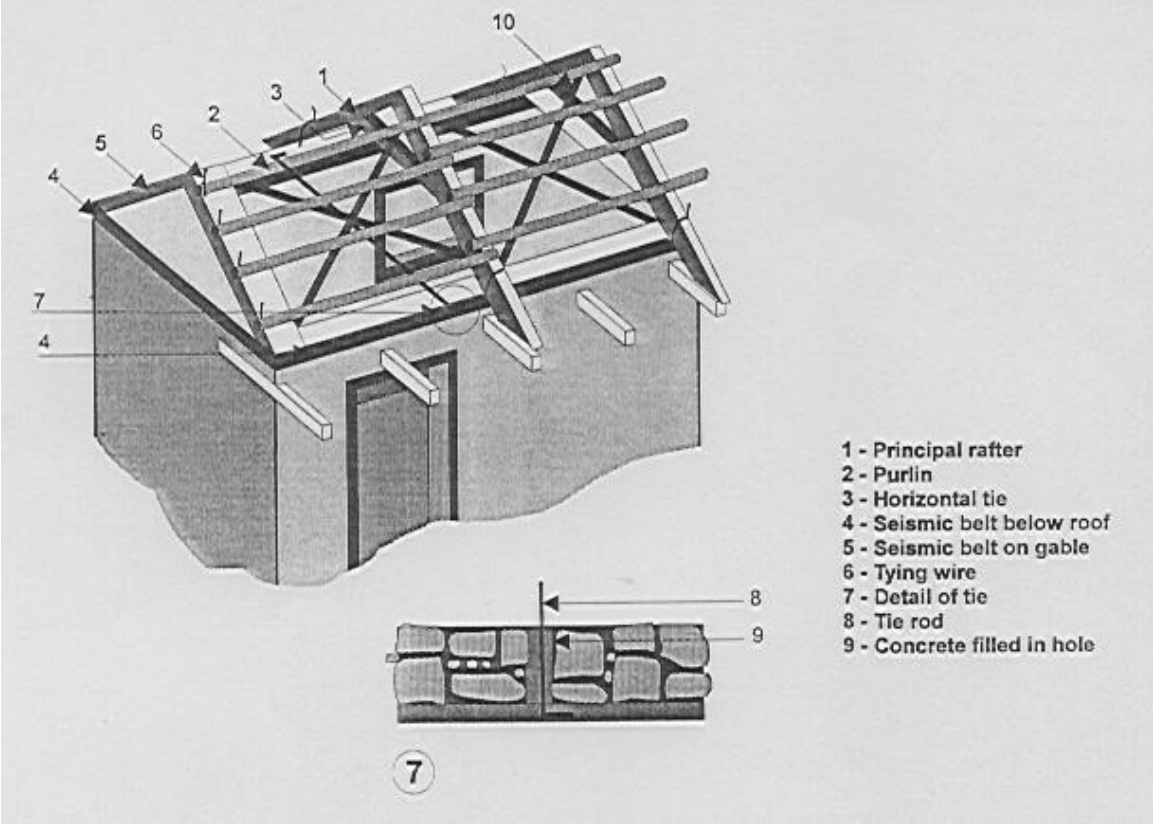


Fig. 12 – Stiffening of sloping roof structure

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. I:S:4326-1993, *Earthquake Resistant Design and Construction of Buildings - Code of Practice*, Bureau of Indian Standards, New Delhi.
6. I:S:13935-1993, *Repair and Seismic Strengthening of Building - Guidelines*, Bureau of Indian Standards, New Delhi.