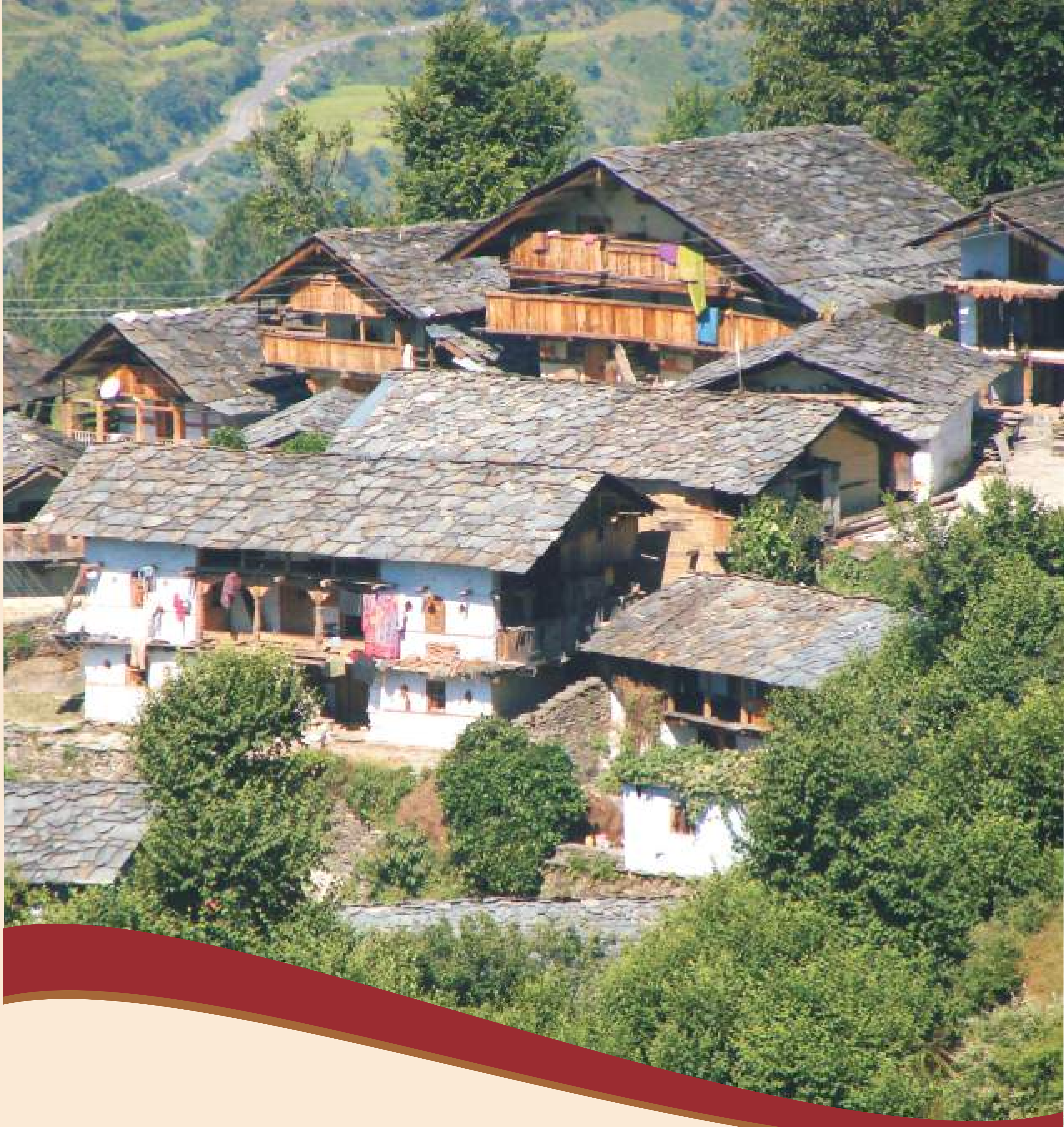

Manual for Restoration and Retrofitting of Buildings in Uttarakhand and Himachal Pradesh

bmtpc

For reducing vulnerability of existing buildings made with vernacular building technologies of masonry construction

Manual for Restoration and Retrofitting of Buildings in Uttarakhand and Himachal Pradesh

For reducing vulnerability of existing buildings made with vernacular building technologies of masonry construction in the States of Uttarakhand and Himachal Pradesh of India

A joint publication of

bmtpc

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Ministry of Housing and Urban Poverty Alleviation, Government of India
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NCPDP

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PREFACE

The Himalayan region has witnessed frequent earthquakes in the past. They have demonstrated that the majority of buildings in this region are vulnerable. In the aftermath of the recent earthquakes, three serious issues have surfaced concerning the vulnerability of the buildings in the face of potentially destructive natural phenomena and the safety of the occupants of these buildings.

First and foremost is the fact that the people have lost confidence in the local materials, namely stone for walling and slate for roofing, and also in the building techniques that they have been using. As a result, in case of the reconstruction of the damaged houses, and even in case of new construction, people have begun shifting to construction technologies that use much non-local materials, such as brick, cement and steel, without understanding the real causes of destruction, and the long-term consequences of the shift. Because of fear, some have even opted to dismantle the existing useable buildings, damaged or otherwise, and rebuild differently.

Secondly, the damaged houses have been repaired poorly without proper know-how and right materials. As a result these houses where people continue to live are now even more vulnerable than before with the occupants being completely unaware of it.

Lastly, in case of most of the undamaged buildings the people have continued living in them, once again completely ignorant of the danger. There is neither any awareness of the option of retrofitting, nor any expertise locally available for retrofitting.

This manual is prepared for the restoration and vulnerability reduction through retrofitting of the existing buildings in Uttarakhand and Himachal Pradesh situated in the Western Himalayan belt of India. It covers the most popular building systems other than the reinforced concrete frame, which the people are likely to continue using for decades to come. It includes the local natural hazards, primarily earthquake, along with cyclone and flood that could be withstood through retrofitting of the existing building.

The document is based on (a) Studies that were undertaken immediately after the earthquakes of 1991 and 1999 by a team of experts from TARU, New Delhi, commissioned by BMTPC; (b) The retrofitting work carried out by the NCPDP team in Uttarakhand at different periods in 1999, 2000, 2002, 2008 and, most recently, in 2009; (c) A three part series of guidelines brought out by BMTPC in the aftermath of Chamoli Earthquake of 1999; and finally (d) the relevant IS Codes for “Repair, Restoration and Retrofitting of Masonry Buildings”.

It would be appropriate to mention here that the practical experience of Shri Rajendra Desai and Ms. Rupal Desai and team over more than one and a half decades in retrofitting of several hundred vernacular structures in widely differing regions of the country including Latur in Maharashtra, Gujarat, Kashmir, and Uttarakhand has provided a sound footing in the preparation of this manual.

This guide will provide valuable information to those who want to repair their houses and to those who want to strengthen their existing buildings for ensuring their safety against future earthquakes. This will help them save their scarce resources. In addition, this will help those who, for mere want of safety, are ready to replace their comfortable traditionally built houses with not- so- comfortable houses built with modern technology.

Dr.Shailesh Kr.Agrawal
Executive Director
BMTPC

ACKNOWLEDGEMENT

First and foremost, we must acknowledge that it was Dr. Shailesh Kumar Agarwal, Executive Director or BMTPC who planted the seeds of the idea of making this manual. Without his initiative this would not have become a reality. With Uttarakhand and Himachal Pradesh being in the region of very high seismicity, and with a large number of existing buildings that are vulnerable, this is a need of the hour.

Just as the work was under way, a personal tragedy brought the work to a near standstill. In this situation it was only the patience and words of encouragement from Shri J.K.Prasad, Chief of Building Materials in BMTPC that helped us continue with the task and bring it to its meaningful conclusion. His feedback on the manual has played a vital role in the development of this manual.

While putting together our lessons of the restoration and retrofitting-related work in making this book, one person that comes to our mind is Dr. A.S.Arya, ex-professor, IIT-Roorkee, who has been a constant source of guidance as well as encouragement in our work on the existing buildings in different parts of the country.

We thank Shri Piyush Rautela of Disaster Management and Mitigation Centre of Dehradun, Uttarakhand for providing us an opportunity of retrofitting of an old brick masonry school building in the heart of Dehradun, and also his concurrence for including this building as a case study in this manual.

For all our work in Uttarakhand during the past decade, we are most thankful for the committed support and valuable input of Shri R.K.Mukerji and Shri Pawan Jain, both from Dehradun, without whose guidance, liaison and initiative, our work would have been far more difficult.

As in all our recent publications, the special input by Shri B.J.Karani, as a non-technical outsider, in the form of reviewing of all the written matter and ensuring a logical flow of information is most valuable, though not so visible.

Finally, we must acknowledge the support of Ms. Brinda Pancholi for some of the eye-catching illustrations that she made for the Manual, and zeal of NCPDP team, especially Harshad Talpada, our engineer, and Ajay Kankrecha, computer expert, without which putting together this whole book would have been much more difficult and time consuming.

Last, but not the least, we do acknowledge the role of local community members and enthusiastic building artisans without whose cooperation and support in their villages we could not have gained the firsthand knowledge on the vernacular construction as well as the retrofitting of local buildings.

Rupal Desai - Rajendra Desai

Ahmedabad, India.

TABLE OF CONTENTS

ABBREVIATIONS

WORDS	ABBREVIATIONS
AC	Asbestos cement
Approx.	Approximately
BB	Burnt brick
BBCM	Burnt brick in cement mortar
BBMM	Burnt brick in mud mortar
BIS	Bureau of Indian standards
Bldg.	Building
CB	Concrete Block
Cem.	Cement
CGI	Corrugated galvanized iron
CM	Cement mortar
cm.	Centimeter
cft.	Cubic foot
cum.	Cubic meter
CWM	Chicken wire mesh
dia.	Diameter
dist.	Distance
ea.	Each
eqk.	Earthquake
fdn.	Foundation
ft.	Foot, Feet
ga.	Gauge
GI	Galvanized iron
gr.	Ground
horz.	Horizontal
hr.	Hour
HSD	High Strength Deformed
ht.	Height
ltr.	Liter
in.	Inch
kg.	Kilogram
km.	Kilometer

WORDS	ABBREVIATIONS
liq.	Liquid
lvl.	Level
m.	Meter
max.	Maximum
min.	Minimum, Minute
mm.	Millimeter
MPT	Manglore Pattern tile
MS	Mild steel
No.,no.,nos.	Number, Numbers
OPC	Oridinary Portland cement
PC	Pre-cast concrete
PCRC	Pre-cast reinforced concrete
PPC	Pozzolonic portland cement
RB	Reinforced Brick
RC, RCC	Reinforced concrete
reinf.	Reinforcement
rmt.	Running meter
RR	Random rubble
sec.	Second
sft.	Square foot
ssm.	Seismic
smt.	Square meter
sq.	Square
st.	Storey
thk.	Thickness
UCRC	Un-coursed rubble masonry in cement mortar
UCRM	Un-coursed rubble masonry in mud mortar
vert.	Vertical
wt.	Weight
WWM	Welded wire mesh
yds.	Yards

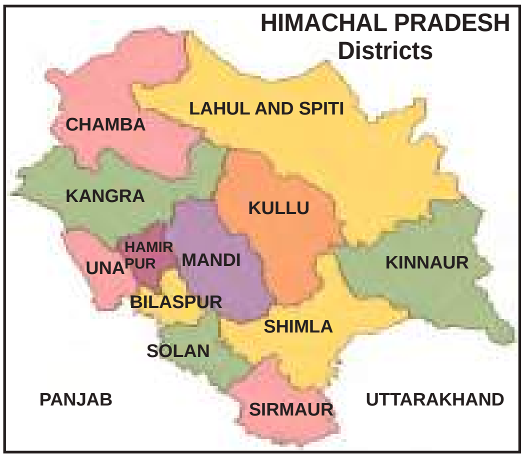
1 INTRODUCTION

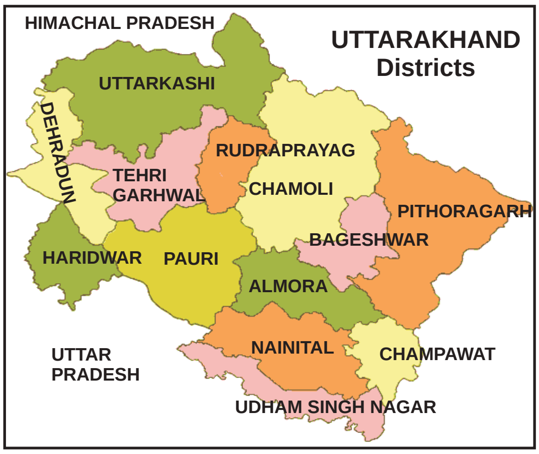
Uttarakhand is surrounded by the snowy peaks of the majestic Himalayas, and is one of the most popular pilgrimage and tourist destinations of India. Himachal Pradesh presents an intricate mosaic of mountain ranges, hills, and valleys and is known for its natural beauty.

Introduction To Area

Location

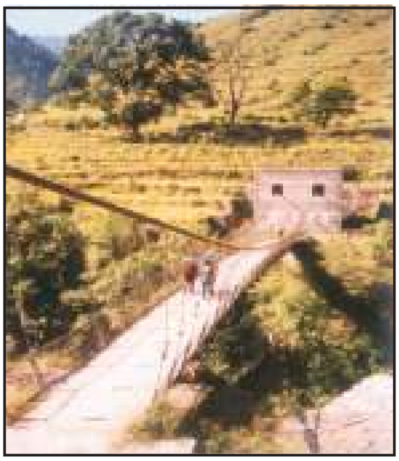
Uttarakhand and Himachal Pradesh situated in the northern reaches of India are well-known around the world for the high snow-capped mountains, their natural beauty and major Hindu pilgrim places. Himalayan mountains flank the northern boundary of Uttarakhand and the eastern boundary of Himachal Pradesh, separating them from Tibet.





Access

From other parts of India, Uttarakhand (UK) and Himachal Pradesh (HP) can be reached by air, rail and road. Rail service, however, barely touches them at Dehradun and Kathgodam in Uttarakhand, and at Kalaka in HP. Air connectivity is even more limited. Beyond this, access is mainly by roads. Although, the main urban centres and the tourist centres and pilgrim places are connected by paved all-weather roads, the remote places are reached by unpaved steep roads. and even on foot. In rainy season the access to the hilly areas frequently gets blocked for several days due to landslides.



Travel from one village to another often involves (a) either negotiating steep hilly tracts along narrow footpaths, often involving elevation gain or loss of several hundred meters, or (b) access from the nearest motorable road to the village that may be across a river that is crossed by a pedestrian bridge.

The house construction activity, most always involves complicated logistics since the materials are carried on a mule or on human back. This adds substantially to the time and the cost of construction.

Introduction To Natural Hazard Risks

Earthquake and wind Hazard Maps

The maps on the following pages of Himachal Pradesh (HP) and Uttarakhand (UK) show the areas under the Earthquake Zones IV and V and Wind Speed Zones II, III and IV within their boundaries. Any one concerned about the safety from natural disasters in this area should be aware of the possible risks of potentially destructive earthquakes that exist in most of the areas. In some parts of these states the wind speeds can reach around 55m/s which pose risks of moderate to very high damage.

Damage Risk to Housing Under Various Hazard Intensities									
		Eqk. Intensity MSK				Wind Velocity m/s			
Category	**Type of Wall and Roof**	**> IX**	**VIII**	**VII**	**< VI**	**55&50**	**47**	**44&39**	**33**
A1	Mud wall (All roofs)	VH	H	M	L	VH	H	M	L
A2.a	Unburned Brick Wall (Sloping roofs)	VH	H	M	L	VH	H	M	L
A2.b	Unburned Brick Wall (Flat roofs)	VH	H	M	L	VH	H	M	L
A3.a	Stone Wall (Sloping roofs)	VH	H	M	L	VH	H	M	L
A3.b	Stone Wall (Flat roofs)	VH	H	M	L	H	M	L	L
B.a	Burned Brick Wall (Sloping roofs)	H	M	L	VL	H	M	M	L
B.b	Burned Brick Wall (Flat roofs)	H	M	L	VL	M	L	L	VL
C1.a	Concrete Wall (Sloping roofs)	M	L	VL	NIL	H	M	M	L
C1.b	Concrete Wall (Flat roofs)	M	L	VL	NIL	L	VL	VL	VL
C2	Wood Wall (All roofs)	M	L	VL	NIL	VH	H	M	L
C3	*Ekra* Wall (All roofs)	M	L	VL	NIL	VH	H	M	L
X1	GI and other metal sheets (All roofs)	M	VL	NIL	NIL	VH	H	M	L
X2	Bamboo, Thatch, Grass, Leaves, etc. (All roofs)	M	VL	NIL	NIL	VH	VH	H	L

Note: VH: Very High, H: High, M: Medium; L: Low, VL: Very low, NIL: Nill

Seismic Intensity vs Damage to Buildings				
Category	**Building Type**	**Intensity VII**	**Intensity VIII**	**Intensity IX**
A	Mud and Adobe houses, RR Constructions	About 75% will have large deep cracks, About 5% will suffer partial collapse	About 75% will suffer partial collapse	About 75% will suffer complete collapse
B	Ordinary brick buildings, building of large blocks and prefab type, poor half timbered houes	About 50% will have small cracks in walls	About 75% will have large and deep cracks	About 50% will show partial collapse, About 5% will completely collapse
C	Reinforced masonry buildings, well built wooden buildigns.	About 50% will have fine plaster cracks	About 75% may have small cracks in walls. About 5% may have large deep cracks	About 50% may have large deep cracks, About 5% may have partial collapse.

Source: Arya A.S., Bullietin ISIT, Sept. 1990

Land-slide Risk:

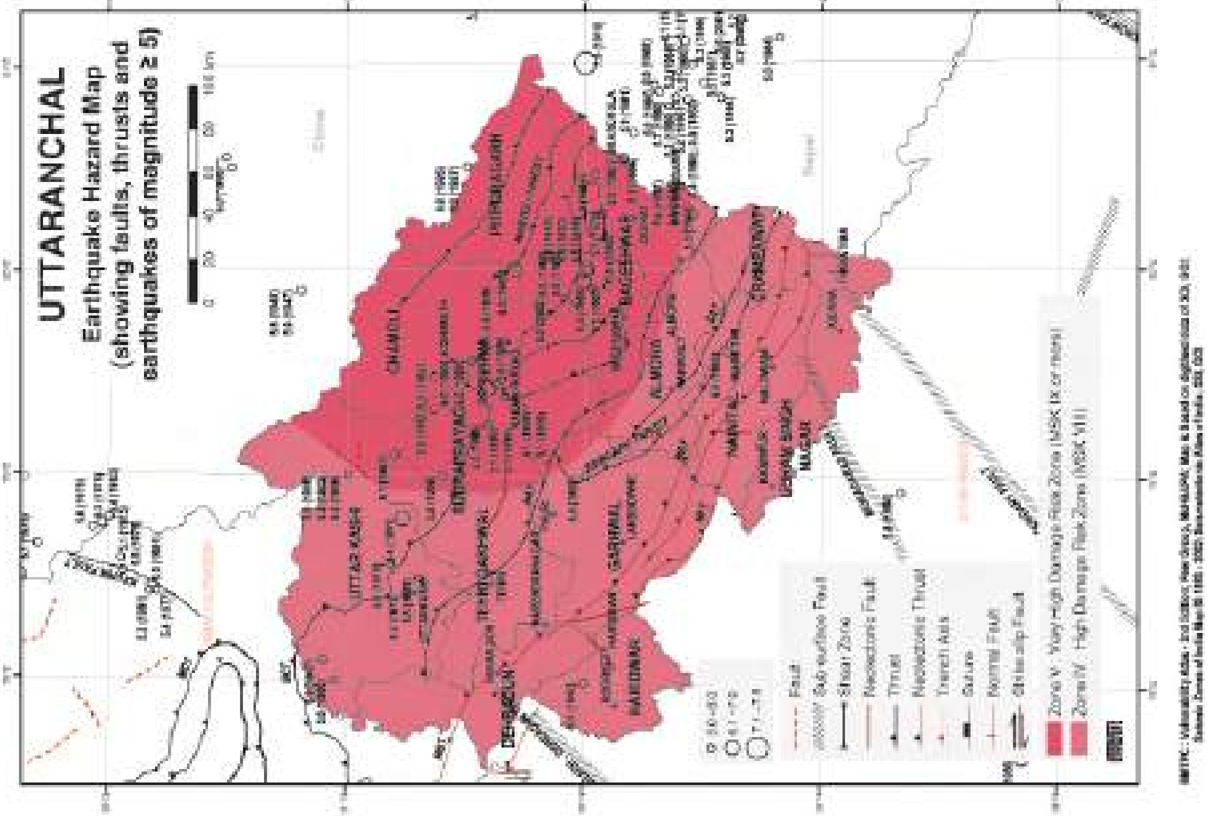
The hill areas of the states are liable to suffer land slides during monsoon, and also during high intensity earthquake. The vulnerability of the geologically young and not so stable steep slopes in various Himalayan ranges have been increasing at a rapid rate in the recent decades due to human activities like deforestation, cutting of mountain sides for road, terracing and changes in agriculture crops requiring more intense watering etc. The land slide prone areas should be avoided while locating new settlements and buildings, and those which are already occupied should either be resettled elsewhere or slope protection measures be undertaken based on scientific assessment, to make them stable and safer.

1

INTRODUCTION

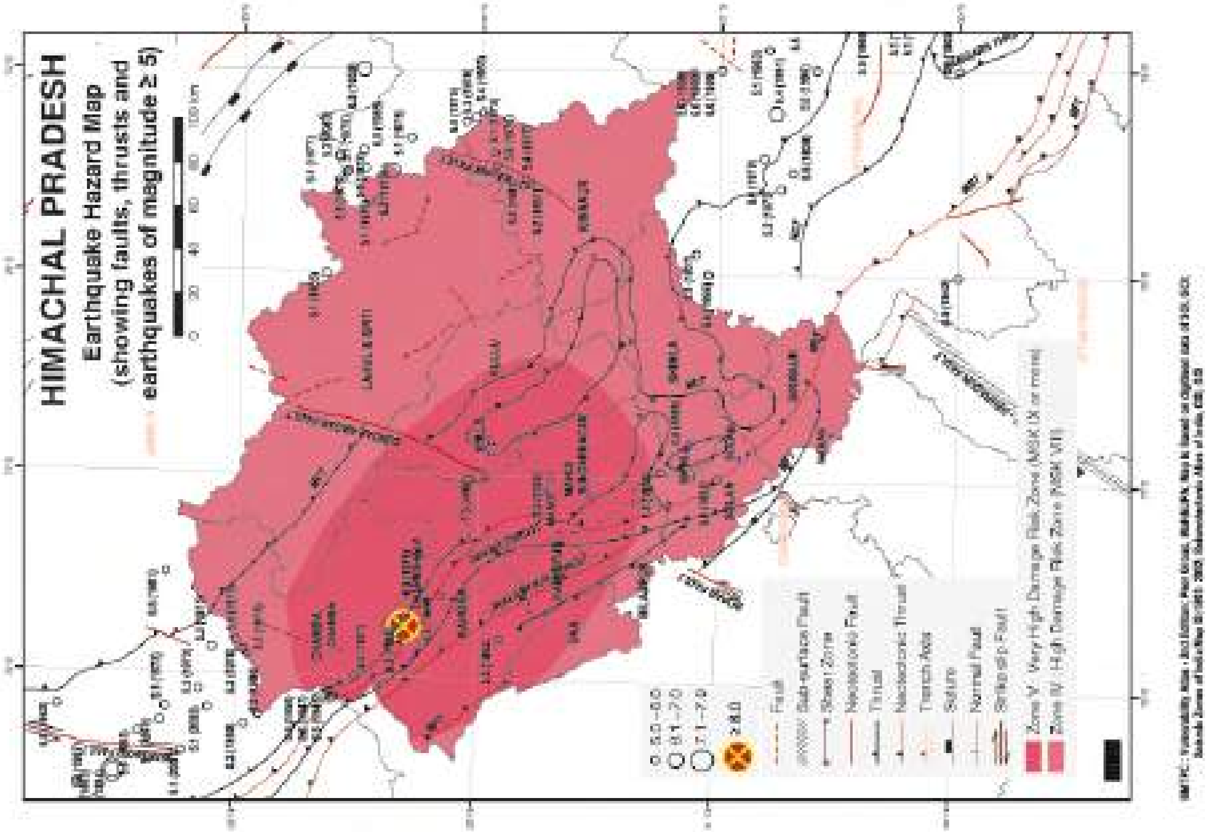
Introduction To Hazard Risks

Earthquake Hazard Maps



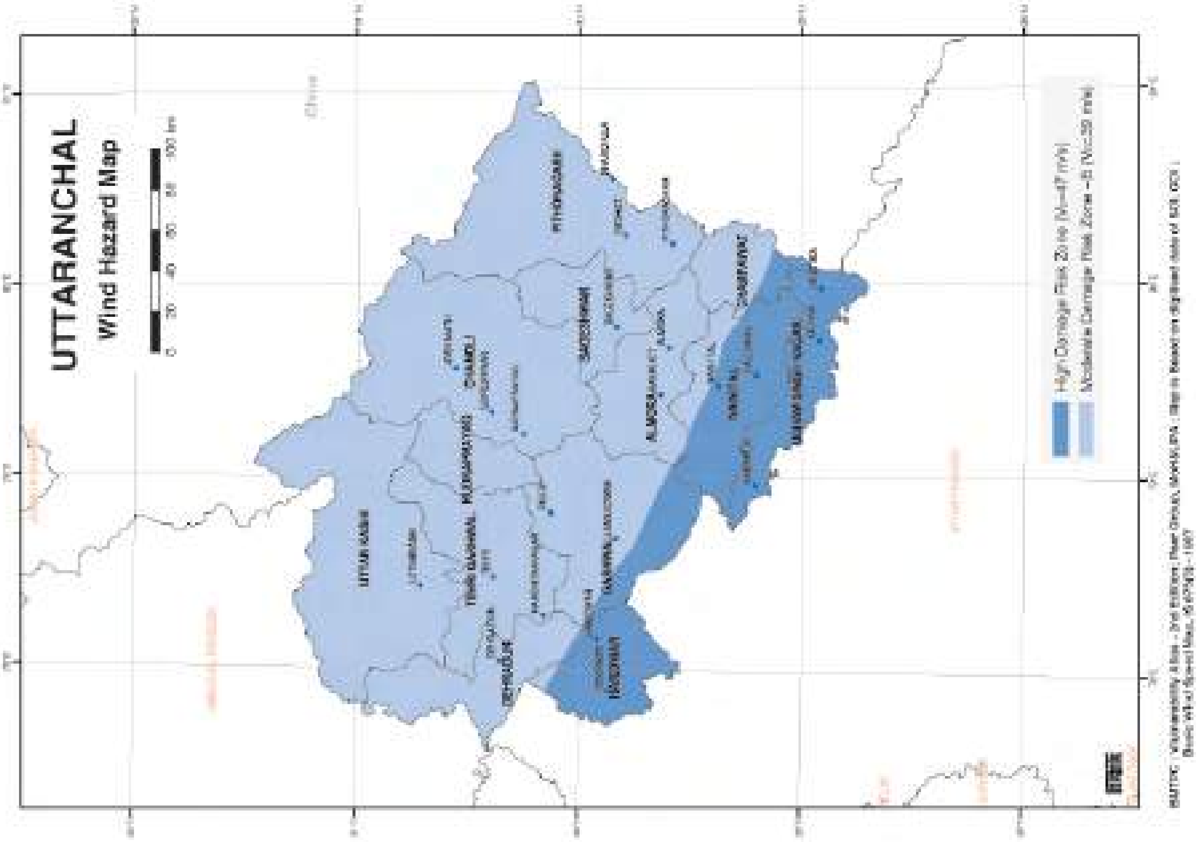
SEISMIC ZONES

- Zone V : Very High Damage Risk Zone (MSK IX or more)
- Zone IV : High Damage Risk Zone (MSK VIII)
- Zone III : Moderate Damage Risk Zone (MSK VII)
- Zone II : Low Damage Risk Zone (MSK VI or less)



Introduction To Hazard Risks

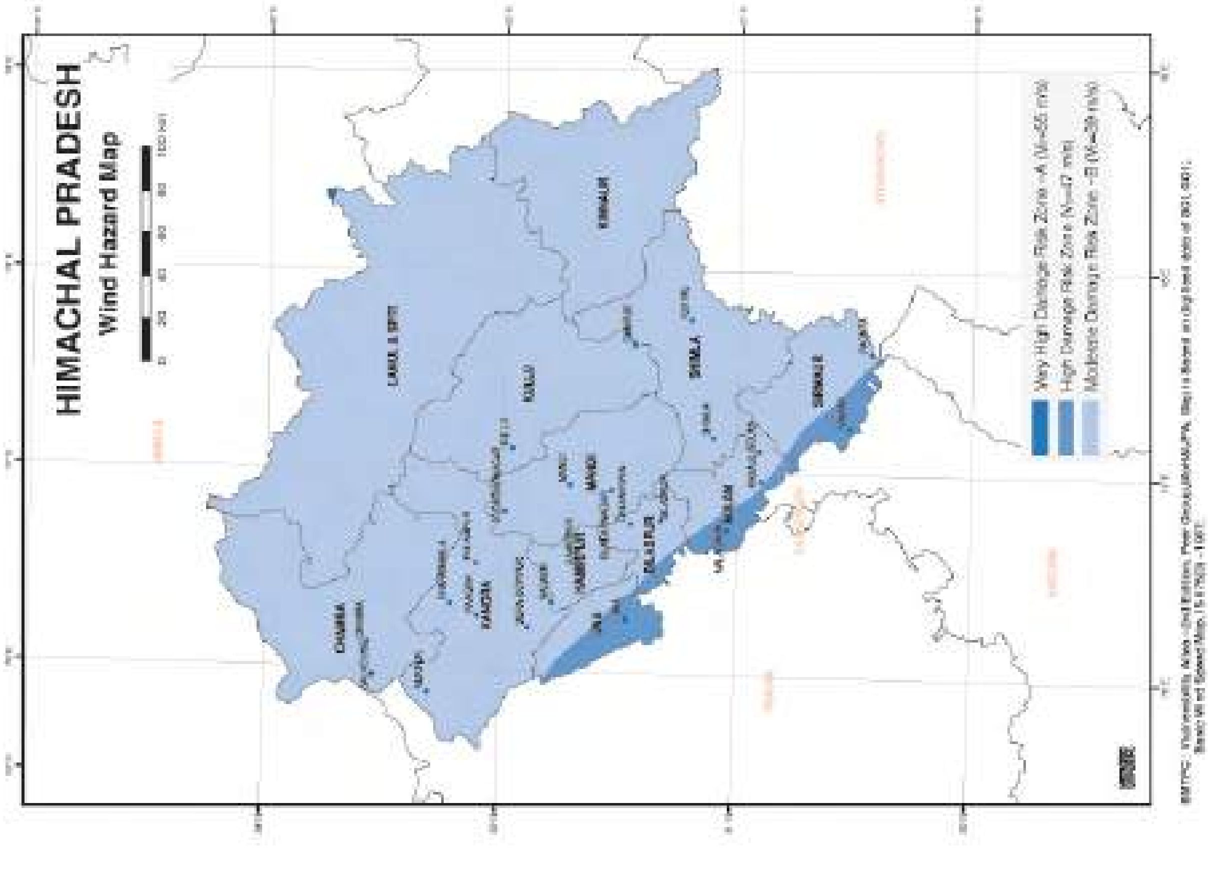
Wind Hazard Maps



WIND SPEED ZONES

For simplification wind speed areas are Categorised as Zones IV to I, in this manual

- Zone IV - Wind speed up to 50-55m/s
- Zone III - Wind speed up to 47m/s
- Zone II - Wind speed up to 33-44 m/s



Introduction To Recent Earthquakes

Acronyms used: Mw = Moment Magnitude, Ms = Surface Wave Magnitude, ML = Local Magnitude, Mb = Body Wave Magnitude

Time, Location and Magnitude	Brief Damage Details
12 September 1950 Chamba-Udhampur, HP. Mw 6.0	Information not available
28 December 1958 Rameshwar Devi Dhura area, Uttarakhand, Mw 6.1.	More than a dozen buildings collapsed. Fissures and landslides were generated in an area within 150 kilometres of Kapkot. Many people died in the region.
17 June 1955 Lahul-Spiti, HP. Mw 6.0	Information not available
17 June 1962 Chamba-Udhampur, HP. Mw. 6.0	Information not available
27 June 1966 Athpali Dhung area of Nepal - Dharchula Uttarakhand border area, Mw 6.2.	This earthquake was centred in Far western Nepal along the border with Uttarakhand.
28 August, 1968 Dharchula, Uttarakhand Intensity 7.0	Between 150 to 200 persons were killed and several hundreds injured. Extensive damage to several villages in western Nepal. The quake also caused damage in Dharchula, Pithoragarh area of Uttarakhand. 13 persons were killed here and 40 were injured.
19 January 1975 SW Dutung, HP. Ms 6.8	It caused havoc in parts of the Kinnaur, Lahual and Spiti regions of India. 60 people were killed in this sparely populated region.
29 July 1980 Bajhang-Ghoghda area, Nepal, Mw 6.5	768 people were killed and nearly 5,000 injured in this earthquake in Uttarkashi district. Some 18,000 buildings were destroyed in the Uttarkashi Chamoli region. Landslides and rockfalls were widespread in the Gharwal Hills.
19 October 1991 Pilang-Bhatwari area, Uttarakhand, Mw 6.8	Was felt strongly in many parts of Uttarakhand, including Nainital, Kumaon and the Terai areas. Many people ran outdoors in panic, and window-panes were broken in many localities.
05 January 1997 Dharchula area, Uttarakhand, Mw 5.6	115 people killed in the Gharwal region. The quake was felt very strongly in Uttar Pradesh, Chandigarh, Delhi and Haryana.
28 March 1999 Chamoli-Pipalkoti area, Uttarakhand, Mw 6.4	115 people killed in the Gharwal region. The quake was felt very strongly in Uttar Pradesh, Chandigarh, Delhi and Haryana.
30 March 1999 Chamoli Pipalkoti area, Uttarakhand,ML 4.9	50 people were injured in this tremor which was an aftershock of the Eqk. of 28 March 1999. Several buildings developed further cracks and many damaged houses at Maithana village collapsed. At Barai in Chamoli district, 20 houses collapsed and 11 developed cracks, while at Kotiyal 4 houses collapsed and 85 developed cracks. Some damage was also reported from Rudraprayag district.
11 Noverbmer 2004 Bharmour, Kangra H.P. Mb5.1	It was felt strongly in the Kangra-Dharamsala region and event caused minor damage to buildings in the region.
Noteworthy earthquake in Himachal Pradesh had struck on 4 April 1905 at Kangra. It was of Mw7.8 where 28,000 people were killed and large scale damage had occurred.	

Introduction To Retrofitting

The table on previous page shows that the northen Himalayan belt, especially in Uttarakhand and Himachal is very active seismically. Here the **earthquake can occur any time, anywhere and of a very high intensity.** Because of this, it is important that people get prepared to face the impact of this. One must also know that earthquakes do not kill people but buildings do. This is why this manul will become very valuable for vulnerability reduction of existing buildings through retrofitting. In this manner there will be less damage and less death toll, if the earthquake strikes.

What is Retrofitting?

There are simple ways to reduce the vulnerability of existing buildings through a process called Retrofitting. Apart from being cost-effective through lesser cost than rebuilding, it offers other important advantages that make it very much viable, effective and attractive option. These include the following: (a) The expense of demolition and debris removal is completely eliminated. (b) The need for a temporary shelter is eliminated. (c) It can be done in phases depending upon the availability of funds. In the first phase itself, at least a part of the house can be made safer for immediate occupation. (d) The cost of redoing the non structural items including built-in conveniences and decoration is eliminated.

This Manual will be useful to engineers, architects, contractors, masons and people, who are thinking of retrofitting existing houses and public buildings to reduce their vulnerability against future earthquakes. There are indeed, a large number of houses that appear to be safe but their masonry walls can delaminate or collapse with the roofs. In the absence of the knowledge of retrofitting option, most house-owners will think of dismantling these houses at a large cost and try to rebuild at even larger cost. This will mean a huge economic loss for the area that can never be recovered. People may also end up with houses that are smaller, and, quite likely, unsafe.

The Manual ensures that the measures recommended to reduce the vulnerability against a future earthquake through retrofitting are both compatible and sustainable to the most commonly observed existing building systems in rural areas.

Even the newly built houses which do not conform to the codal requirement for the earthquake safety could be made less vulnerable to future earthquakes through the application of the measures recommended in this Manual.

Introduction to Manual

Who is it made for?

The Manual is made for engineers, architects, contractors and masons who want to repair, restore or retrofit a building in Uttarakhand or Himachal Pradesh to reduce their vulnerability against future earthquakes. Even an educated person who has some understanding of construction can use this manual to take decision on repair and retrofitting of his own property.

Which type of hazards does it covers?

The Manual focuses on natural hazards that can be tackled through application of appropriate vulnerability-reducing measures on a structure. Both Uttarakhand and Himachal Pradesh are mountainous, and hence, not flood prone, except for some isolated locations in river valleys. The wind speeds that pose less than moderate damage risk are experienced in most parts of the states. On the other hand, both the states face serious earthquake hazard as is evident from the past history, and also as indicated in the BIS building codes as well as in the Vulnerability Atlas of India. Hence, the Manual covers methods to reduce the effect of seismic hazard. Landslides too are a major hazard in the mountains. Unfortunately, there is very little that one can do to reduce the effect of this hazard through mere retrofitting of an existing building. Hence, this hazard is not covered in this manual.

Which type of buildings it cover?

First and foremost, the Manual does not cover the RC buildings. It also does not cover building technology that is used in one or two small pockets by a very small number of people. The manual, essentially, covers the popular building technologies that (a) a significant percentage of the population is using, (b) that are viable, and (c) are expected to remain in use in the foreseeable future. These could be listed as follows based on the materials used in walls and roof.

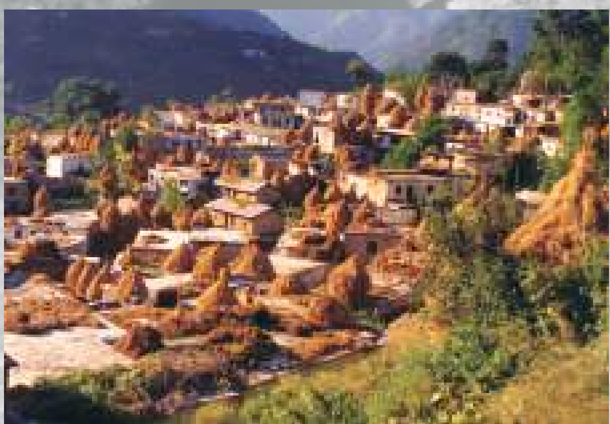
Walling: Random Rubble (RR), Burnt Bricks (BB), Concrete Blocks (CB)

Roofing: *Pathal* (Stone tile), CGI sheeting, RC/RB slab

How to use this Manual?

After the preliminary introduction to the states, the predominant hazards and the major building typologies, the Manual places focus on the damage. It is important for all those working on an existing building to understand how different types of damages occur before going in how to repair them or how to prevent them. Next, it shows how the vulnerability of a building can be assessed, since that is the first step to retrofitting. This is followed by how the damaged building is repaired to restore the original strength of the structure, and the next is retrofitting measures that are required to tackle different vulnerabilities in the structure. For better understanding of the subject two case studies of old, damaged school buildings that were repaired, restored and retrofitted are given with all technical details including the project drawings. It would be incomplete if the topic of new construction is left out. Hence, it is covered under the chapter of "good practices". This will enable the reader to relate many of the technical issues better. For any one who wants to actually undertake retrofitting, he must have numbers concerning the consumption of various materials, and cost of labour. Hence, this too has been included.

2 BUILDING TYPOLOGIES



Vernacular Architecture is the popular architecture that is practiced by the people without the help of architects. It is evolved over generations by the people and their artisans for their own use. It relies on materials and skills that are available in the area.

Vernacular Architecture of Uttarakhand and Himachal Pradesh

Why vernacular Architecture?

The factors that govern popularity of the vernacular architecture are (a) **economics** in relation to the spending capacity of the people, (b) ease of **maintenance** by common man, and (c) effective response to the **local climatic factors,** such as heat and cold, or earthquake risk, or heavy rainfall etc.

Economics

This is best manifested by the bricks which are most economical in the planes and by the rubble in the hills on account of their easy availability in respective areas. Large valleys and plains have soil that is most suitable to make bricks, burnt or unburnt. The mountains, on the other hand, have little soil to offer, but have lots of stone and rock. Now that the people in the hills have started thinking about switching over from stone to bricks, these factors (of availability of rubble) and economics of bricks become very relevant. The cost per brick which is Re.2.75-3 in Haridwar or Ambala town can be Rs.5.50 at a road-side village 60 kms. away in the hills, or as high as even Rs.6-7 in a village mere 2 kms. away if transported on mule-back . In regards to roofing, even today the CGI sheets can't make inroads where timber and slate/*pathal* (stone roofing tile) are cheaply available (nothing to do with the market rate but everything to do with the accessibility) and where access to the area is only by foot over a long distance and steep terrain. RC roof is gaining popularity because of other reasons (Government regulation regarding the mining of slate and using local timber). Aspiration for modern materials like RC further pushes people away from the slate roof.

Maintenance

Maintenance requires materials and skills. Since both these are no different from that used for construction, the maintenance of the vernacular structures is easy and within the reach of an ordinary individual. If materials from outside were to be used, the maintenance of the structure would become expensive. The case in point is RC slab, which when cracks, becomes exceedingly difficult to repair in a manner that it lasts. When bars in it begin to corrode, people find it difficult to stop that process.

Local Climate & Thermal Comfort

Winter season, including its cold and snow, is one factor that dictates the choice of materials and technology the most, especially in the hills. The thick walls of stone with mud plaster are most effective in keeping the cold out and heat in, and so is thick mud-timber roof or stone tile /slate-timber roof. Flat mud-timber roof is used in areas with less precipitation, whether in the form of rain or snow. The lighter pitched roof made from CGI sheets works well only in combination with the attic floor that keeps out the cold in winter and heat in summer. Pitched roof allows little snow accumulation. The RC roof alone does not give the desired thermal comfort, in winter as well as summer, but offers the flat space which is hard to get in the mountains.

Vernacular Architecture of UK and HP (cont.)

Architecture practiced by a majority of people is an integral part of the **cultural heritage** of any area. It reflects the strength of the community to house itself independent of any outside intervention. It is a manifestation of a system that is **optimal** for particular local context in every way, and the one that is **sustainable**. It is a system that has evolved over the centuries and continues to evolve even today, with the input from the generations of the local wisdom involving prolonged trial and error, and is a system that has little to do with the architects and engineers.

Pathal roofing on timber with lower storey of RR walls laced with timber elements and top storey of timber walls.

Stone tile / Slate / *Pathal* roofing on timber with RR walls without timber lacing

Flat mud roof on timber understructure with RR masonry walls

Uttarakhand and Himachal Pradesh are no exception to all this. A number of building systems have evolved over a long period in various parts depending on the local factors. These systems are part of the cultural heritage of these Himalayan states, and they add to its beautiful landscape. Historically these systems had depended totally on the **local materials** such as **rubble, soil, and timber for walls, and timber, slate /** ***pathal*** **/ stone-tile and mud for roofing ,** since the non-local materials were not only expensive, but their use added logistical complications in construction. In addition the local materials lead to forms that help the structure face the forces of various natural phenomena that commonly occur in the region. In recent times new materials also have made inroads on account of their favorable economics as well as peoples' aspiration for modernity. In other words, the **Vernacular architecture is constantly changing and evolving. It now goes beyond the narrow confines of the traditional architecture that used local materials only, and has become the Popular Architecture.**

Vernacular Architecture of UK and HP (cont.)

Building Typologies in the Plains

The main factors that dictate the local architecture in this zone are (a) ample availability of building quality soil, (b) ample agricultural residue, (c) moderate precipitation and warm temperatures, and (d) easy access to non-local materials.

Low elevation plains have ample agricultural waste. So the building technology used makes uses of this. The **most elementary and low cost technology** uses things like **wheat and corn stalks** etc. left over from harvest in making walls. The roof is made of **thatch** which too is either residue from sugarcane harvest or some wild grass. This is supported on **secondary timber**. The walls are finished with **mud plaster**. Such a house is constructed when it is made in a hurry, or as an additional space.

The major improvement over this is the walls made of **sun dried mud blocks** of the same size as burnt brick, or walls made by using **mud of stiff consistency** by simply shaping it with hands, called **Cob** wall. These walls are **load bearing** and support the thatch roof. But thatch lasts barely a year or two, and since it is becoming scarce its replacement is not cheap for a poor person as it is rather frequent.

CGI sheeting is a major up-gradation in the roof and **burnt bricks** in the walls since they last much longer than thatch and mud respectively. **RC roof** is seen as the ultimate sign of permanence and status!

The predominant building typologies of this region are:

	System 1	System 2	System 3
Walling	BR	Mud	Vegetal
Roofing	CGI, RC	Thatch, CGI, AC	Thatch,


Wattle and daub walls with thatch roof


Unburnt brick (mud) walls with thatch roof


Cob walls with CGI roof


Poor person's "permanent" housing unit: A box made of burnt brick walls with RC roof

Vernacular Architecture of UK and HP (cont.)

Building Typologies in Low Level Hilly Region

The main factors that dictate the local architecture in this zone are (a) easy access to building-quality stone, (b) limited availability of top soil, (c) greatly varying availability of water, (d) varying availability of timber, and (e) moderate precipitation, with no snow in winter.

The most common wall type is **load bearing Coursed Random Rubble masonry**. Since the availability of soil suitable as mortar and as plaster is limited, and water is also not in abundance, the walls are built with or without mud mortar, often without mud plaster.

Historically, the **flat mud roof** had been the most popular on account of relatively less precipitation. Even today this type of roof is visible in low elevation hilly stretches along the western boundary of HP.

Today, however, the escalating cost of timber along with the easy availability of modern materials like cement, steel and CGI sheets, a major shift is observed towards **RC roof** over stone walls, with few cases of **CGI roofing**. Those with more resources are constructing even load bearing **brick walls** in cement mortar.

The predominant building typologies of this region are:

	System 1	System 2
Walling	RR	BR
Roofing	Mud - wood, CGI, RC	RC

Mud roof on Coursed RR walls

Mud roof on Coursed RR walls

Mud roof on Coursed RR walls with partial conversion to CGI roof.

Mud roof fully replaced by RC roof.

Vernacular Architecture of UK and HP (cont.)

Building Typologies in Mountainous Region

The main factors that dictate the local architecture in this zone are (a) easy access to building-quality stone, (b) limited availability of top soil, (c) greatly varying availability of water (d) varying availability of timber (e) extreme cold and snow in higher reaches in winter, and (g) possibilities of occurrence of earthquake.

The most common wall type is Coursed/ un-coursed Random Rubble masonry with/ without mud mortar, since availability of mud and water vary a lot. Generally walls are plastered with mud or cement mortar. The most common roof consists of *pathal* supported on timber under structure. The roof is generally two-way or four-way pitched with varying shapes, size and quality of stone tile / slate /*pathal*. The thickness of stone tile can vary from as little as 10mm in HP to as much as 50mm in UK.

In recent times with increasing cost of timber, lighter roof like CGI sheets have become popular even though it is not as good for winter cold. Flat RC slab roof also has become more popular, since it offers additional flat space which is always in short supply in mountains

The predominant building typologies of this region are:

	System 1	System 2
Walling	RR	BR
Roofing	Stone tile / Slate / *pathal*, CGI, RC	RC

Doubly-pitched slate / *pathal* / stone tiles roof on RR walls

Four-way pitched roof with rounded slate / *pathal* / stone tiles

Four-way GI sheet roof

Combination of stone tiles and RC roofing

Vernacular Architecture in Rain-shadow Region in HP

The typical buildings in this region have flat mud roof on timber decks supported on RR or Cob-mud walls. At present, people are fast shifting to RC slabs placed on RR or brick masonry walls. The mud roof buildings of this region constitute mere 1.4% (2001census) of the total housing stock of HP. Hence, this type of buildings are not covered in this manual.

Vernacular Architecture of UK and HP (cont.)

Earthquake-Resistant Vernacular Architecture

Both, UK and HP have an old tradition of constructing earthquake-resistant masonry buildings using entirely local materials and skills. The earthquake resisting features used in such buildings are elements of timber in horizontal and vertical directions. In addition it also includes timber struts and ties that help anchor roof and floor to the walls. In UK this tradition has dwindled to a great extent, but still one can find recently constructed buildings having such elements, although to a greatly reduced extent. In HP this tradition is still alive and many recent buildings also are known to have such elements.


An old house in UK with horizontal and vertical earthquake-resisting elements


A religious centre in HP with earthquake-resistant structure including retaining walls.


An old house in UK with horizontal and vertical earthquake-resisting elements


An old house in UK with horizontal and vertical timber elements.


A recently built house in HP with horizontal and vertical timber ties


A recently built house in UK with horizontal timber bands

Vernacular Architecture of UK and HP (cont.)

Himachal Pradesh: Districts and Building Typologies

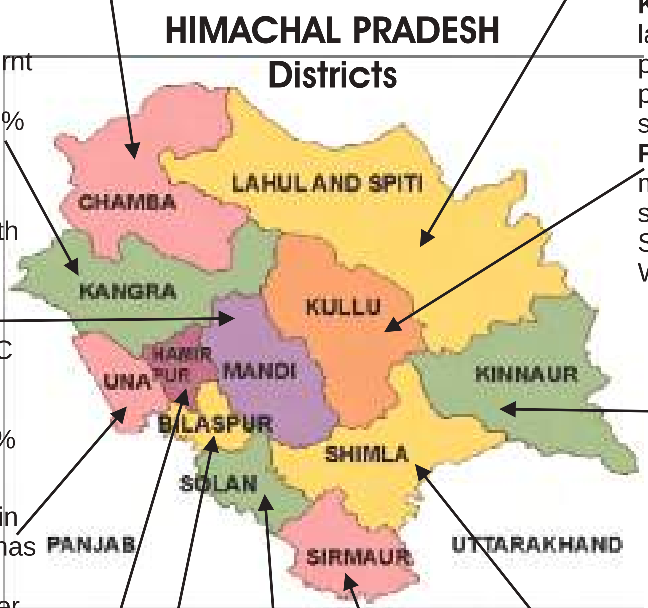
Hazard Information for each district consisting of the percentage area of the district in different Seismic Zones and Wind Speed Zones is given in the following abbreviated format.
Seismic Zones - Sm. Zn.: V-4%, IV-96%
Wind Speed Zones - Wn. Zn.: IV-1%, II-99%

Chamba: Wholly mountainous, elevation ranging from 2000' to 21000', climate from semi-tropical to semi-arctic.
Roof: timber-mud and slate.
Walling: RR
Sm. Zn.: V-58%, IV-42%
Wn. Zn.: III-100%

Lahul and Spiti: Big district full of natural scenery with the rugged awe-inspiring snow clad mountains, and villages with prayer flag fluttering over the Buddhist monastery, elevations ranging from 10,000' to 21,000'.
Roof : wood-mud, GI and some RC.
Wall: unburnt bricks or RR
Sm. Zn.: V-4%, IV-96%
Wn. Zn.: IV-1%, II-99%

Kangra: Marvelously scenic, one of the most pleasant, relaxing and spiritual places, and is well wooded with oak, cedar, pine and other timber-yielding trees
Roof: Slate, RC.
Walls: unburnt or burnt BR.
Sm. Zn.: V-98%, IV-2%
Wn. Zn.: II-100%

Kullu: Marvelous landscapes, hospitable, peaceful and co-operative people having distinct life style and culture.
Roof: Slate, some wood-mud and RC. **Walls**: RR, some timber walls
Sm. Zn.: V-67%, IV-33%
Wn. Zn.: II-100%



Mandi: The greater part mountainous with the elevations raning from 1,800' to 13,000 feet.
Roof: Slate, some RC
Walls: RR, some unburnt brick.
Sm. Zn.: V-96%, IV-4%
Wn. Zn.: II-100%

Kinnaur : Beautiful district with three high mountain ranges, river valleys of Sutlej, Spiti, Baspa and their tributaries.
Roof: Wood-mud, some GI **Walls**: RR, some timber walls
Sm. Zn.: IV-100%
Wn. Zn.: IV-100%,

Una: well developed in the industrial sector, has railway line. Winter climate: cool, Summer climate: hot.
Roof: Slate, RC
Walls: Unburnt or burnt BR
Sm. Zn.: V-54%, IV-46%
Wn. Zn.: III-56%, II-44%

Shimla : Elevation 1000' to 8000'. The topology: rugged and tough.
Rural- Roof : Slate, wood-mud, GI,
Walls: RR, some unburnt and burnt BR.
Urban - Roof: RC, some GI, **Walls**: BR
Sm. Zn.: IV-100%
Wn. Zn.: II-100%

Hamirpur: Roof: slate, RC, **Walls**: unburnt brick, some BR
Sm. Zn.: V-100%,
Wn. Zn.: II-100%,

Bilaspur:
Roof: slate , RC.
Walls: unburnt and burnt BR, RR
Sm. Zn.: V-49%, IV-51%
Wn. Zn.: IV-11%, II-89%

Solan:
Roof: RC. GI, wood-mud.
Walls: Unburnt and burnt BR, RR
Sm. Zn.: V-4%, IV-96%
Wn. Zn.: III-16%, II-84%

Sirmour:
Roof: Wood-mud, slate, RC.
Walls: RR, unburnt and burnt BR
Sm. Zn.: IV-1006%
Wn. Zn.: III-21%, II-79%

Vernacular Architecture of UK and HP (cont.)

Uttarakhand: Districts and Building Typologies

Hazard Information for each district consisting of the percentage area of the district in different Seismic Zones and Wind Speed Zones is given in the following abbreviated format.
Seismic Zones - Sm. Zn.: V-4%, IV-96%
Wind Speed Zones - Wn. Zn.: IV-1%, II-99%

Uttarkashi:
Mountainous terrain
Roof: *Pathal*, and RC, some GI. **Walls**: stone and some BB.
Sm. Zn.: V-17%, IV-83%
Wn. Zn.: II-100%

Rudraprayag:
Mountainous terrain
Roof: *Pathal*, some RC.
Wall: RR.
Sm. Zn.: V-98%, IV-2%
Wn. Zn.: II-100%

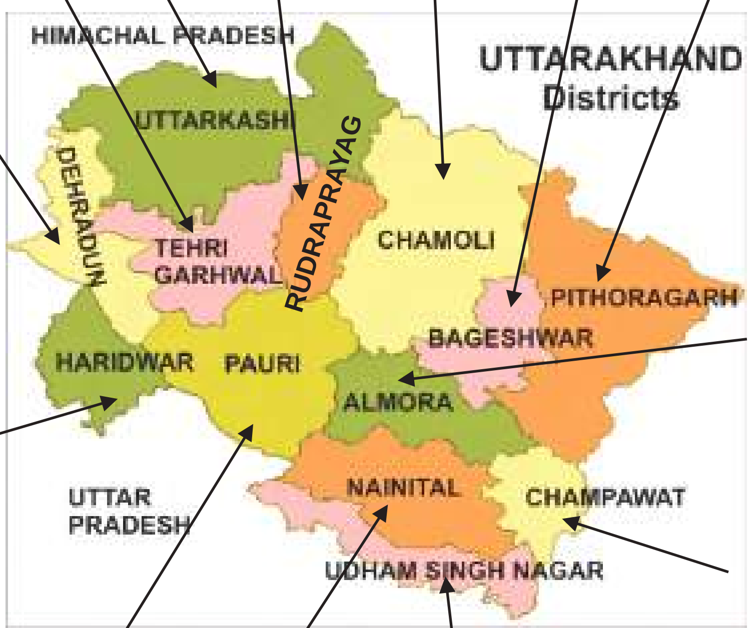
Chamoli:
Mountainous terrain
Roof: *Pathal*, some RC, **Wall**: RR.
Sm. Zn.: V-100%
Wn. Zn.: II-100%

Bageshwar:
Hilly terrain
Roof: *Pathal*, some RC.
Walls: RR.
Sm. Zn.: V-100%
Wn. Zn.:II-100%

Tehri: Mountainous.
Roof: *Pathal*, some RC.
Walls: RR, few BB.
Sm. Zn.: V-3%, IV-97%
Wn. Zn.: II-100%

Pithoragarh:
Mountainous terrain
Roof: *Pathal*, some RC.
Walls: RR.
Sm. Zn.: V-95%, IV-5%
Wn. Zn.: II-100%

Dehradun: Plains and hilly.
Rural - Roof: RC, RB, GI, some slate, wood-mud-thatch,
Walls: BB, RR, mud.
Urban - roof: RC, RB, GI.
Walls: BB
Sm. Zn.: IV-100%
Wn. Zn.: III-3%, II-97%



Almora:
Mountainous terrain.
Roof: *Pathal*, RC. **Walls:** Stone.
Sm. Zn.: V-18%, IV-82%
Wn. Zn.: III-1%, II-99%

Haridwar- Low level plains stretched up to foot of the hills.
Rural- **Roof**: RB, RC, wood-mud-thatch, **Walls**: BB, mud
Urban- Roof: RB.
Walls: BB.
Sm. Zn.: IV-100%
Wn. Zn.: IV-97%, II-

Champawat:
Hilly terrain,
Roof: *Pathal,* some RC.
Walls; RR, some BB.
Sm. Zn.: IV-100%
Wn. Zn.: III-18%, II-82%

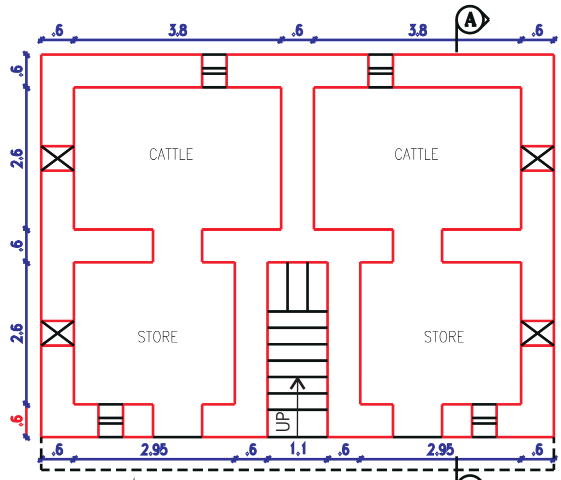
Pauri: Hilly terrain,
Roof: *Pathal* , RC.
Walls: RR, BB.
Sm. Zn.: V-3%, IV-97%
Wn. Zn.: III-24%, II-76%

Nainital:
Mountainous terrain.
Roof: RC, *Pathal*, GI and wood-mud-thatch. **Walls**: RR, BB.
Sm. Zn.: IV-100%
Wn. Zn.: III-78%, II-22%

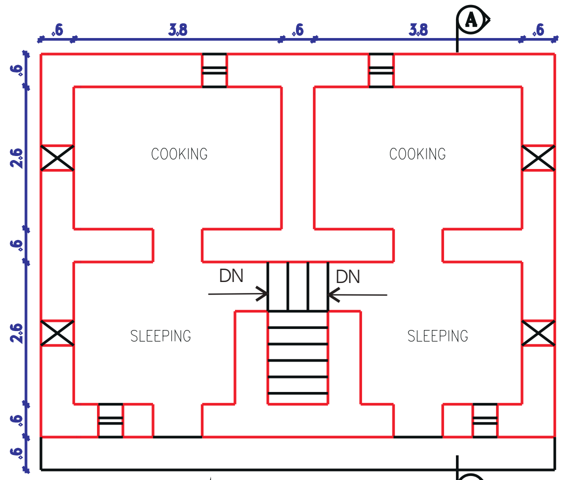
Udham Singh Nagar:
Low level plains stretched up to foot of the hills
Rural - Roof: RB, wood-mud-thatch, some RC
Walls: BB, mud, grass-thatch.
Urban - Roof: RB, RC,
Walls: BB.
Sm. Zn.: IV-100%
Wn. Zn.: III-100%

Vernacular Architecture of UK and HP (cont.)

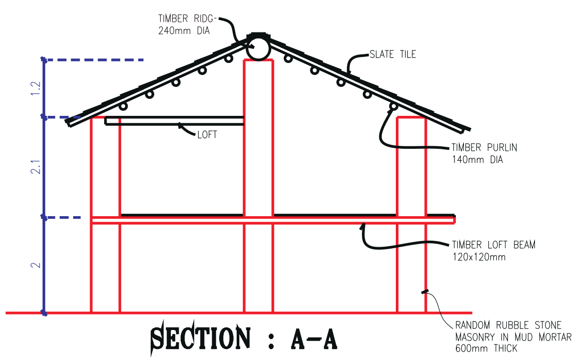
Predominant Building Typologies - Typical Building plans and Sections



GROUND FLOOR PLAN



FIRST FLOOR PLAN

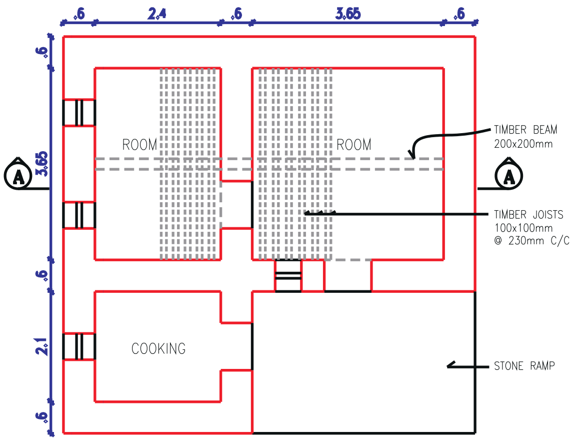


SECTION : A-A

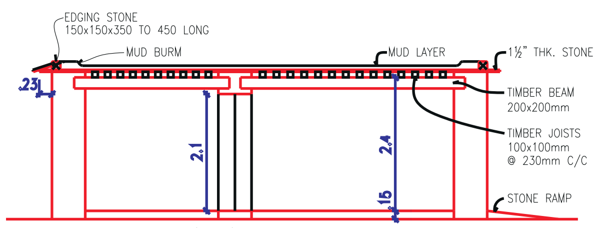
Typical house in rural areas of UK and HP:
A typical house is a two storey structure with 450mm (18")thick RR walls, plastered or un-plastered from outside with a slate / *pathal* / stone-tile roofing. The understructure of roof is of Deodar timber with Deodar planks just below the roofing. On the ground floor, typically, there are four rooms which are used as storage, kitchen or for animals in winters. Upper floor rooms are used as living spaces. The western areas of UK have large verandahs on the first floor. The stairs can be inside the house or totally on outside.

Typical house in rural areas of UK and HP:
In the olden days people made flat mud roof over RR walls where ever the good quality mud was available. There are large number of houses still existing with such roof in the areas away from the road. The house has one or two storeys, and can have any where from a single room to five or six rooms. The roof consists of Deodar understructure with a layer of twigs, bundles of thatch or logs, over which the mud is laid. In recent times many such structures have been converted in to animal shelters.

These building typologies are environment friendly. All the materials used are locally available. Their thermal performance is excellent, thus doing away with artificial means to control temperature. These systems have high self-help component, and they do not drain away the local wealth to the urban areas.



GROUND FLOOR PLAN



SECTION : A-A

3

DAMAGE FROM NATURAL HAZARDS

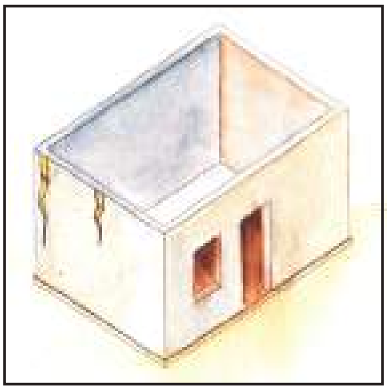
Earthquakes, cyclones and floods leave behind a trail of damage and destruction of buildings. This affects the lives of the people through loss of life, loss of house, economic losses, physical hardships, and mental agony.

A. Earthquake Damage in Walls : Types and Process

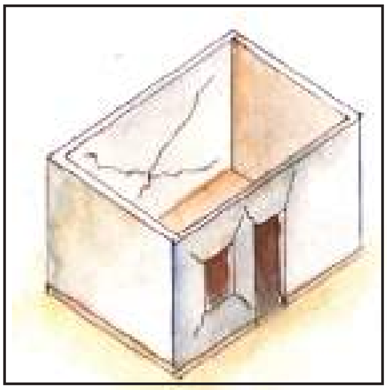
Damage to a structure is not an instantaneous event. The damage occurs during a span of several seconds as a continuous process during that period of earthquake shaking. The degree of damage can vary from a low level to a successively higher level that ultimately leads to partial or total collapse. This range of damage is first presented in the accompanying diagrams through various **stages** to demonstrate the process, and later presented in terms of **grade** of damage that conforms to a standard **damage grading system**.

In **high speed winds** the damage to walls is very similar to that in an earthquake.

Damage Stage I - Cracks



Vertical cracks at middle of long walls and at corners

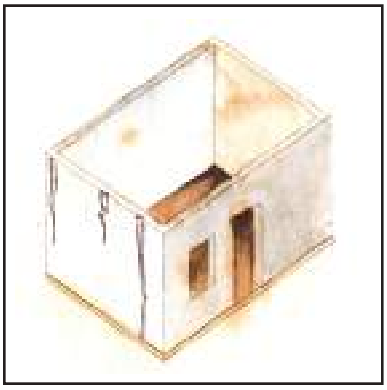


Diagonal cracks in shear walls and at opening corners

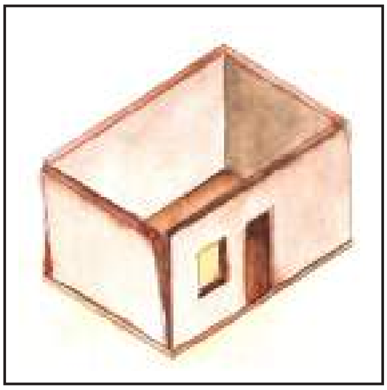
Crack at the base of the gable wall

When the intensity of the force is mild and / or the duration of shaking is short, the damage may remain limited to Stage I type damage.

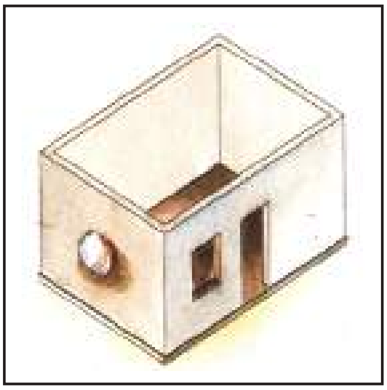
Damage Stage II - Walls going out of plumb or bulging - In a State of Impending Partial Collapse



Very wide,full length, through-and-through crack



Wall going out of plumb

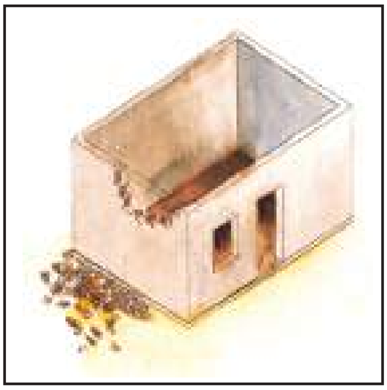


Bulging of stone wall or thick brick wall

When the intensity of the force is higher and/or the duration of shaking is longer, damage may reach Stage II of damage. The damage is intensified when the construction is of poor quality.

A. Earthquake Damage in Walls : Types and Process (cont.)

Damage Stage III - Delamination, or Partial Collapse



Collapse of large part of wall in the middle of long walls or delamination

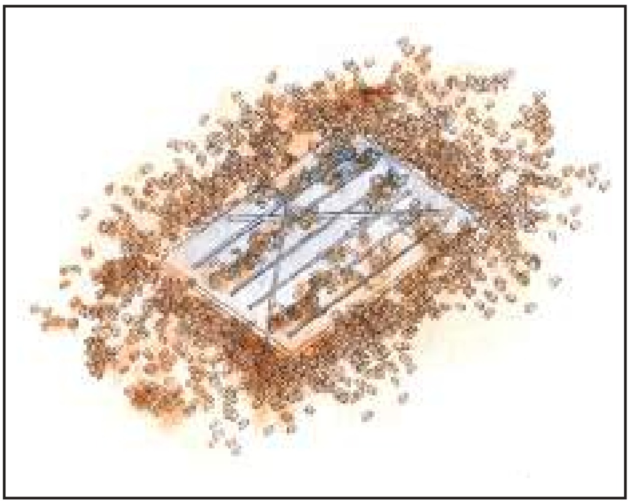
Collapse of corner

Gable collapse

When the intensity of the force is very high and the duration of shaking is even longer, the damage may reach Stage III of damage.

Damage Stage IV - Total Collapse

Further increase in intensity of the force and its duration could lead to total collapse of structure.



Earthquake Damage - Causes

During an earthquake when a structure is shaking, it gets damaged if it is not adequately strong . Extent and degree of damage depends on how weak it is. Damage type depends on the direction of the earthquake forces, the shape of the structure, the type of building technology employed, etc. In high winds the damage to walls is similar to that caused by an earthquake.

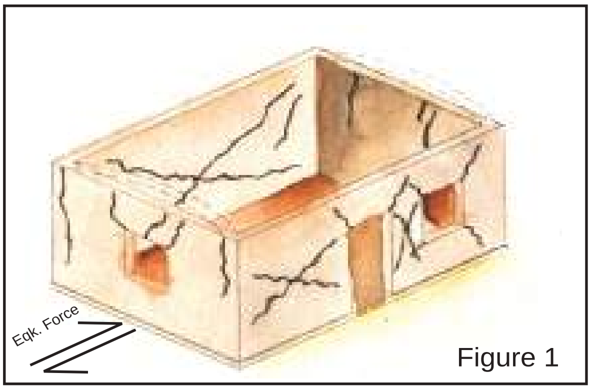


Figure 1

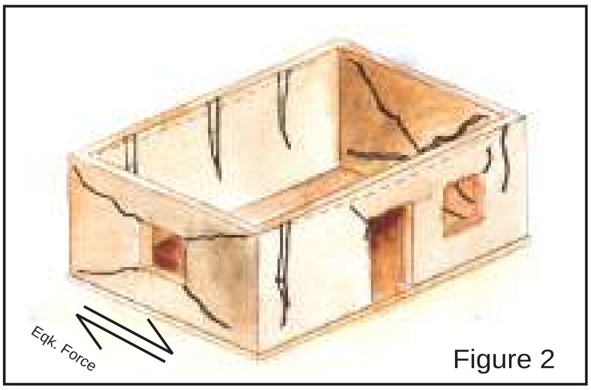


Figure 2

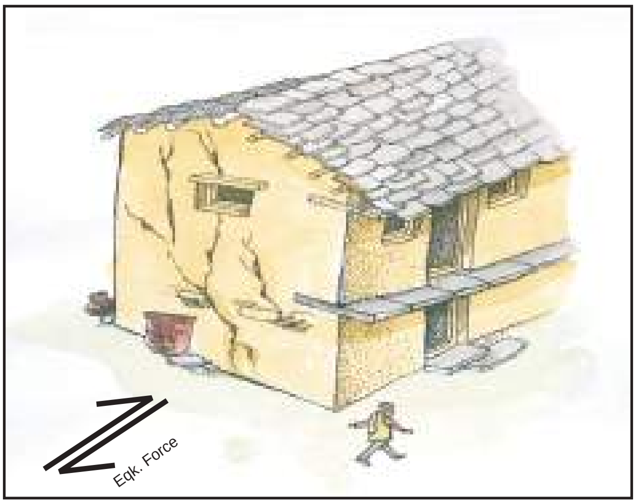
The type of damage in a masonry wall depends upon the direction of earthquake forces with respect to that of the wall. Figure 1 and 2 show how the direction of forces affects various walls in the building. Where the forces are perpendicular to a wall, vertical cracks develop in that wall. Where the forces are parallel to a wall, diagonal cracks develop in that wall. Thus an earthquake force in a particular direction will cause different types of damage on different walls.

B. Earthquake Damage in Walls : Types and Causes

Why does a structure get damaged?

Damage Causes : Stage I

Vertical cracks in the middle of long or high walls

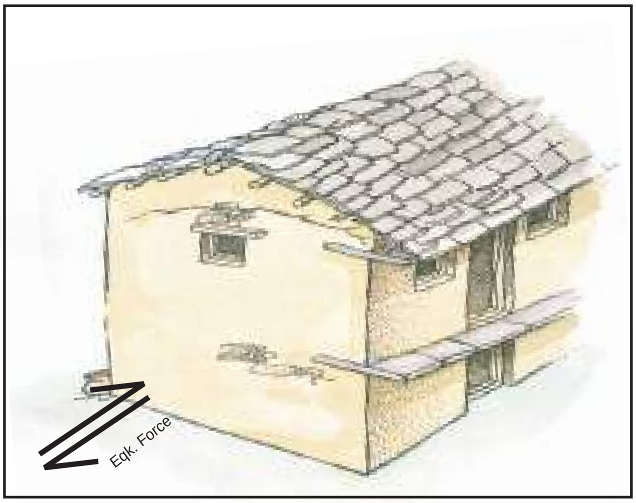


Walls are held at corners by the adjacent walls. Hence, in an earthquake when the shaking is perpendicular to a wall, its portion away from the corner will shake the most. Such shaking can result in vertical cracks near the mid-length of the wall. The longer the wall, more will be the shaking, and greater will be the chances of cracking and suffering higher degree of damage. Similarly if a wall is extra high it will shake more. Such a wall will develop horizontal cracks when shaken.

Cracks under the floor and ridge beams (concentrated load points) when supported directly on masonry

Since the earthquake force is an inertia force, its magnitude on a particular part of a structure will depend directly on the mass of that part plus the mass supported by that part. Hence, when a beam from a floor or a roof is supported on masonry wall, it exerts a high concentrated lateral load on the wall. This often results in developing a vertical crack starting downward from the point of beam support embedment.

Horizontal crack at gable wall base



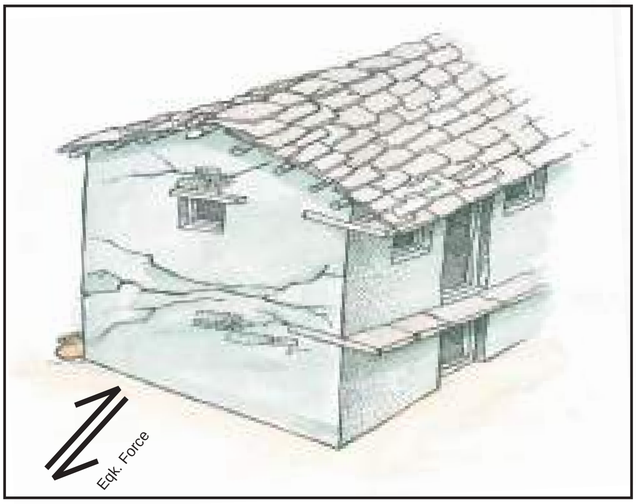
In case of gable wall, the triangular part of wall has no restraint in direction perpendicular to its plane. Hence, when the force is in direction perpendicular to wall's plane, it shakes excessively. Under such pull and push a crack develops along the base of gable walls. In heavy shaking, it can also collapse, and may lead to roof collapse if any roof beam is supported on gable.

These types of damages can occur in random rubble, brick or concrete block walls supporting roof that could be slate / *pathal*, or CGI sheet or RC slab.

B. Earthquake Damage in Walls : Types and Causes (cont.)

Damage Causes : Stage I

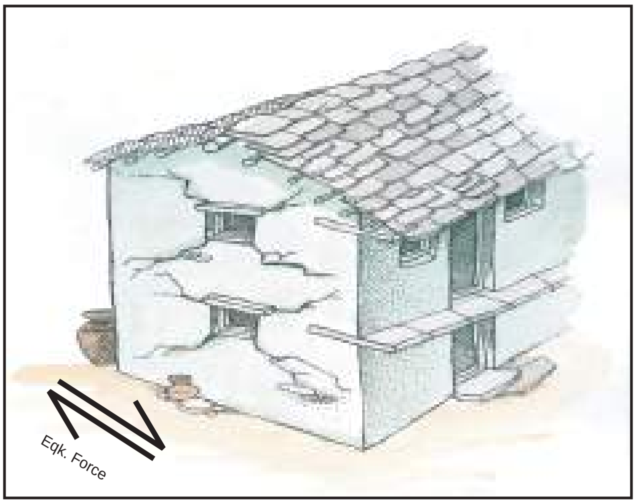
Horizontal Cracks in walls



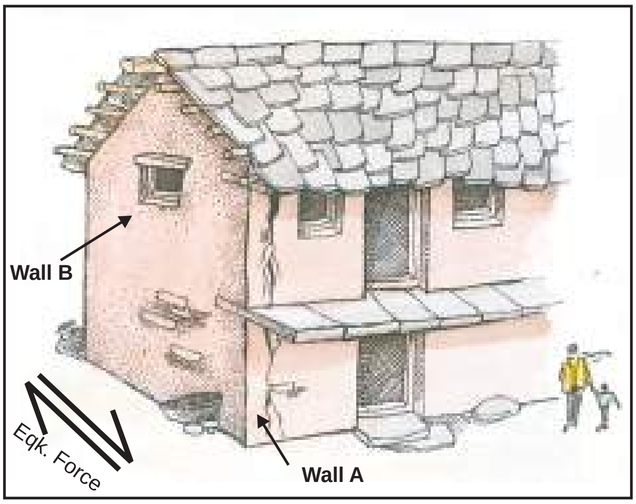
When the earthquake force is perpendicular to the wall, the wall bends about a horizontal axis causing tension on one face. Since the masonry wall is weak in tension, this bending tends to cause horizontal cracks at different levels.

Diagonal Cracks

When the earthquake force is parallel to the wall, it results in tension along the diagonal direction in the wall within its plane, which in turn results in slant cracks perpendicular to the diagonal. If the wall has openings, they create areas of extra weakness. Hence, when the walls are pulled, the tearing in diagonal direction begins from the corners of the opening.



Vertical cracks at room corners



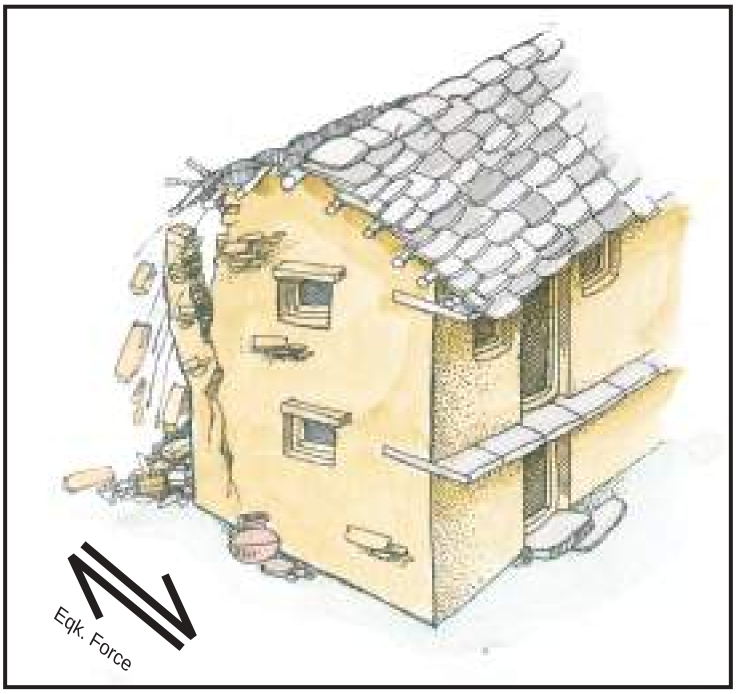
When the earthquake force is perpendicular to the wall 'A', it (the wall) is pushed and bent. At the corner, this wall deforms more than the wall 'B' which is parallel to the force. As a result wall 'B' tends to hold back wall 'A' from bending. This causes tension in wall-to-wall joint. If this joint is weak because of one wall being built first with toothing left out for facilitating a connection later on with the adjacent wall when it is built, vertical crack develops at the junction of the two walls, as they separate from each other.

These types of damages can occur in random rubble, brick or concrete block walls supporting roof that could be slate / *pathal*, or CGI sheet or RC slab.

B. Earthquake Damage in Walls : Types and Causes (cont.)

Damage Causes : Stage II

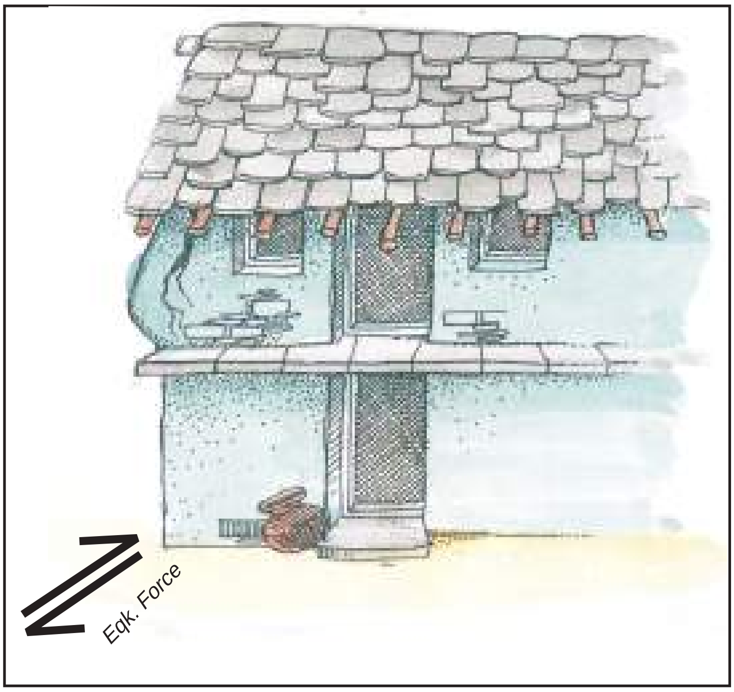
Walls going out of Plumb



When shaking increases the cracks widen and a part of the wall adjacent to the crack goes out of plumb. This happens, especially at weak areas in the wall since they are not able to withstand the forces generated by shaking. In such a case weaker portion shakes more, and then goes out of plumb. This often happens at cracked corners since walls have lost support of each other. It also happens in the upper portion of a long wall near the mid-length since this part of wall has minimum restraint.

Bulging of Thick Walls - Only in masonry walls thicker than 220mm.

This happens in stone walls when the outside face of the wall begins to separate from the inside face resulting in a bulge when shaken by an earthquake. This is because of inadequacy of interlocking among the wythes of the wall resulting from improper placement of stones as well as absence of bond stone or through stones or headers in the masonry, which provide a stitching between the outside and the inside faces of a wall.



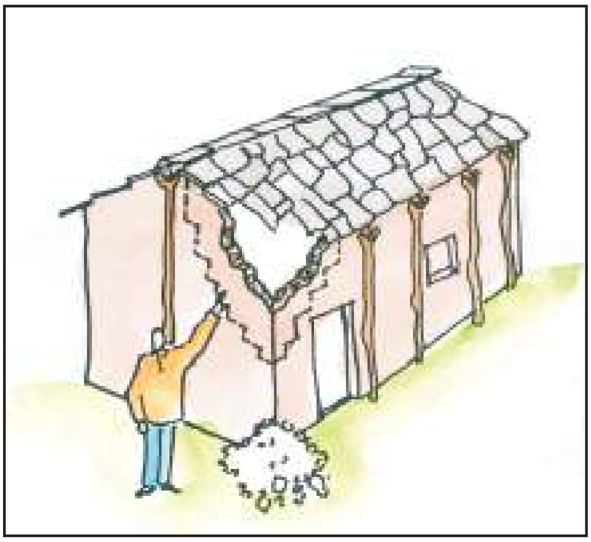
In brick walls 350mm and thicker, the bulging can be caused due to separation between the outer and the inner faces. This occurs when the mortar is weak, or if the joints are inadequately filled with mortar, and also when the bricks are improperly arranged such that there is poor interlocking between the faces.

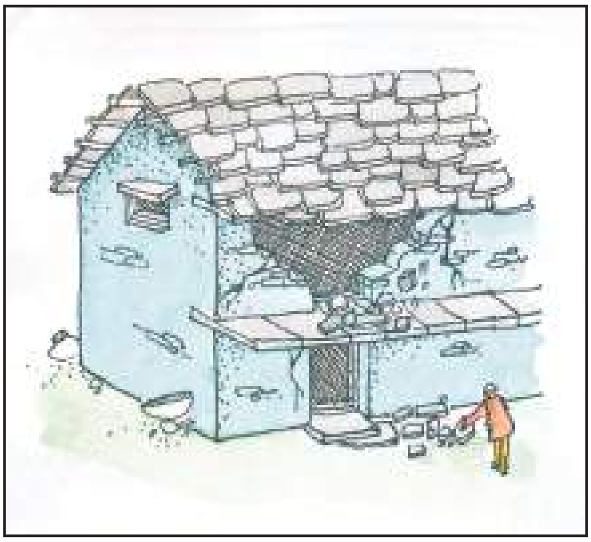
These types of damages can occur in random rubble, brick or concrete block walls supporting roof that could be slate / *pathal*, or CGI sheet or RC slab.

B. Earthquake Damage in Walls : Types and Causes (cont.)

Damage Causes : Stage III

Collapse of a portion of wall due to excessive shaking


Corner collapse


Collapse of middle portion of long walls at mid-length or Collapse of upper portion of extra high walls


Gable collapse

With excessive shaking, the portion of the wall that has first cracked and then has gone out of plumb, can collapse if the shaking continues. In other words, in the areas where weaknesses are induced due to initial shaking, the stresses generated by further shaking leads to collapse. This can be at …

1. Corner
2. Middle portion of long walls at mid-length or Upper portion of extra high walls
3. Gables

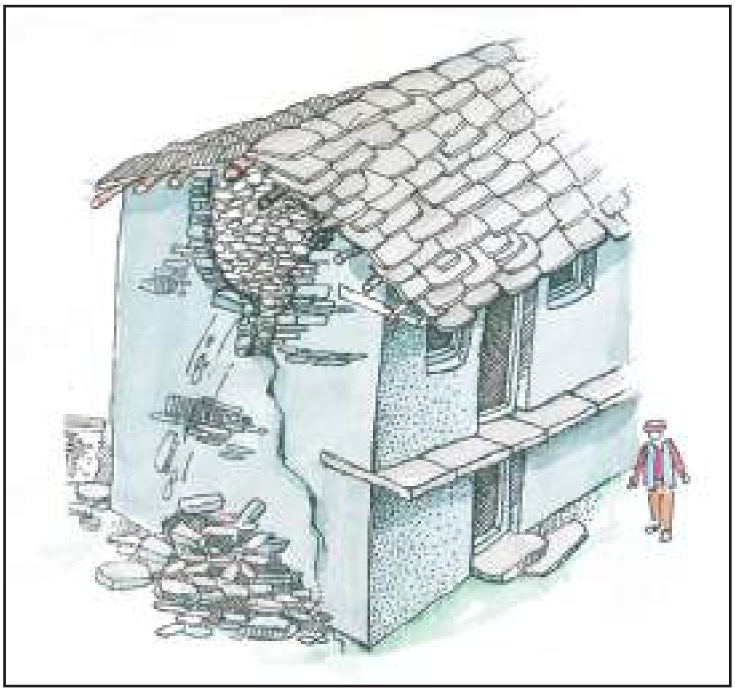
Note : Portions of roof have been removed to give an unobstructed view of the damage

These types of damages can occur in random rubble, brick or concrete block walls supporting roof that could be slate / *pathal*, or CGI sheet or RC slab.

B. Earthquake Damage in Walls : Types and Causes (cont.)

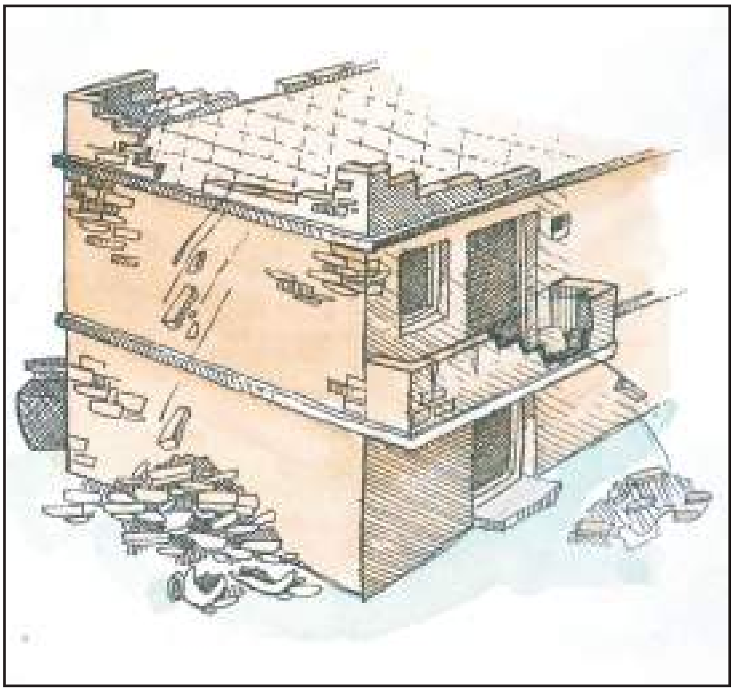
Damage Causes : Stage III

Delamination of a portion of thick wall - In Random Rubble and Brick masonry



In the portions of walls that are bulged in the initial shaking, the face of wall that has separated collapses with one face still standing, if the shaking continues. This is called Delamination. This happens in stone and thick brick walls.

Collapse of masonry parapet wall in terrace or in balcony



The masonry parapet wall being unrestrained can easily get damaged due to lateral seismic forces perpendicular to the face of the wall. Stronger shaking can even lead to its collapse.

These types of damages can occur in random rubble, brick or concrete block walls supporting roof that could be slate / *pathal*, or CGI sheet or RC slab.

C. Earthquake Damage in Walls : Categorisation

All stages of damage are categorised from Grade G1 to G5

Grade G-1 (Stage I): Slight Non-structural damage.

Thin hairline cracks in plaster, falling of some plaster.

These are fine cracks in plaster and are one-dimensional, where only length is measured.

Grade G-2 (Stage I +): Slight structural cracks.

Small cracks max. 5mm (1/4") wide in walls, falling of plaster over large areas, damage to non-structural parts like chimneys, parapets, etc. The load carrying capacity of the structure is not appreciably reduced.

These cracks are often right through the full thickness of the wall. These are two-dimensional. Hence, length

Grade G-3 (Stage I ++): Moderate structural damage.

Large and deep cracks 6mm to10mm (1/4" to 1/2") in walls, wide-spread cracking of walls, columns, and piers, and tilting or failing of chimneys. The load carrying capacity of the structure is partially reduced.

These cracks are generally across the full thickness of wall. They are three-dimensional. Hence, all the three dimensions- length, width and depth are measured.

C. Earthquake Damage in Walls : Categorisation (cont.)

All stages of damage are categorised from Grade G1 to G5

Grade G-4 (Stage II & III): Severe structural damage.

Portions of wall are about to collapse due to tilting, bulging, delamination or major cracks, or are already collapsed. Building is unsafe and can further collapse further.

Grade G-5 (Stage IV): Collapse.

A large part of, or the whole building, has collapsed.

Ref : NCPDP shock table test programme at Radhanpur (Gujarat, India), year 2002.

D. Earthquake Damage in Walls : Categorisation Examples


G 3 Damage: Racking Shear Cracks in RR wall.


G 4 Damage: Racking Shear Crack in Concrete Block wall.


G 4 Damage: Collapse of a RR wall.


G 4 Damage: Racking Shear cracks in brick wall.


G4 Damage: Severely damaged RR walls with partial collapse.


G4 Damage: Gable wall collapse.

D. Earthquake Damage in Walls : Categorisation Examples (cont.)

G 4 Damage: Delamination of RR Gable wall.

G 4 Damage: RR wall collapse. Roof undamaged.

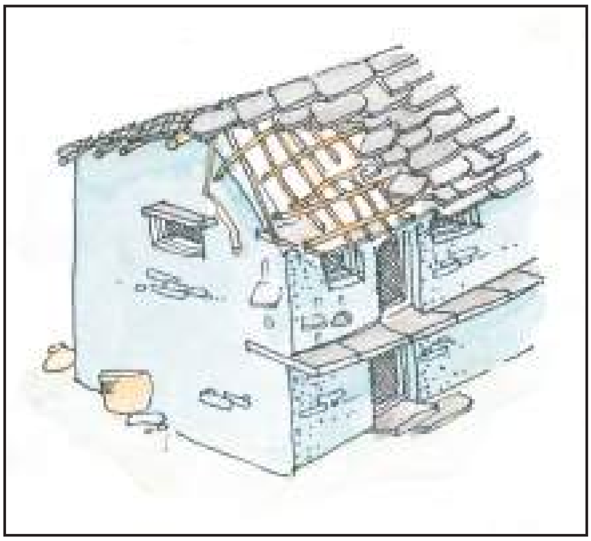
G 4 Damage: Partial collapse of RR wall and *pathal* roof.

G 4 Damage: Delamination and partial collapse of RR walls.

G 5 Damage: Collapse of *pathal* roof because of wall collapse.

E. Earthquake Damage in Roofs: Types and Causes

1. Pitched Slate / *Pathal Stone tile* roof



Stone tile roof being moderately heavy exerts large horizontal thrust on the wall in an earthquake. Under this impact...

- The stone tiles can slide down,
- Timber under-structure can disintegrate if it is poorly connected to each other, as is commonly seen in Uttarakhand,
- Timber elements in the under-structure can break, especially if degraded,
- Roof can collapse, if one or more supporting walls gets severely damaged.

Sliding of slate / pathal / stone tile roofing.

Damaged understructure and falling of stone tile roofing.

Damage to roof consisting of purlin dislocation due to principal rafter embedment failure.

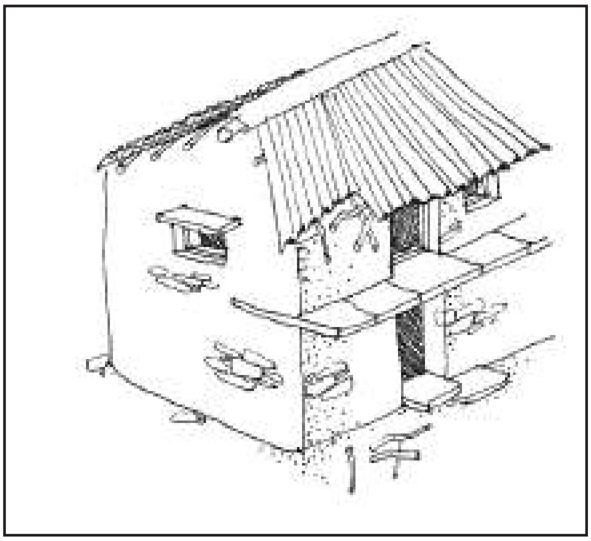
Damaged roof because of wall collapse.

E. Earthquake Damage in Roofs: Types and Causes (cont.)

2. Pitched CGI Roof

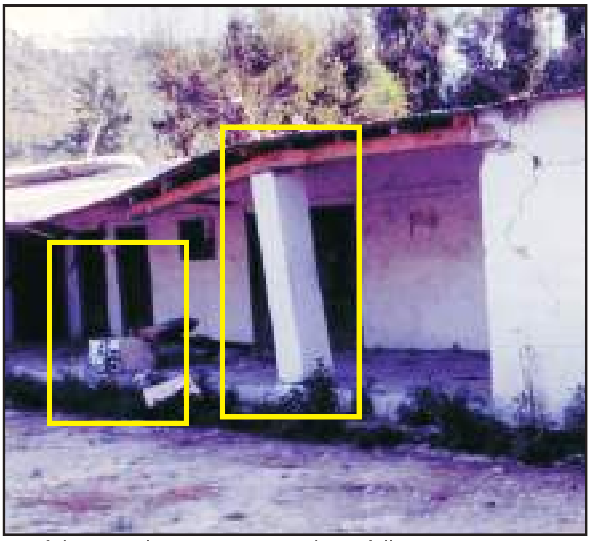
Most of the CGI sheet roofs, being light, survive well through earthquake if understructure is strong. The damage occurs when the understructure is weak, or the support walls or columns fail in earthquake. This results in ...

- Sagging of roof along with the understructure on one side and its lifting at the other end, or
- Collapse of a portion of roof accompanied by snapping of timber understructure.



Collapse of a portion of roof.

Roof slid down because of total wall collapse.



Roof damage due to masonry column failure.

3 Flat Mud Roof

The most common damage in Mud Roofs is the failure of wooden understructure. Although, resulting from the dynamic load of earthquake, it happens primarily on account of timber degradation caused by rainwater or snow-melt leaking through the mud veneer. The other cause of damage is the damage to the supporting walls.

Snapping of joists and collapse of flat mud roof.

Snapping of timber understructure and collapse of flat mud roof.

E. Earthquake Damage in Roofs: Types and Causes (cont.)

3. RC Roof and Floor Why it cracks?

Mistakes are often committed in construction because masons do not understand the behavior of RC slab. The most common mistakes are...

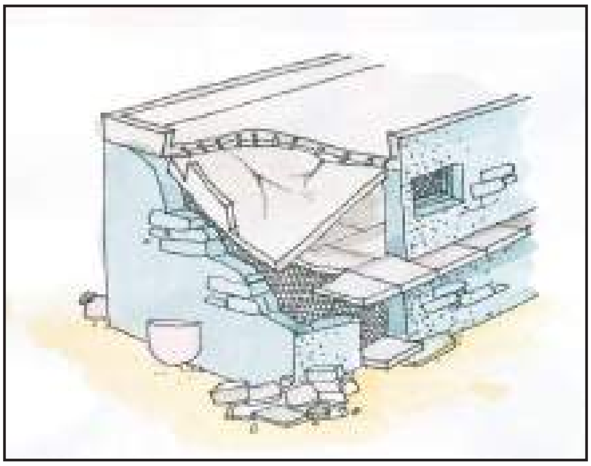
a. No cranking- up of bars in the vicinity of the supports.

b. Continuing of the bottom reinforcement bars into the cantilever portion.

c. Poor curing of slab.

d. Inadequate concrete cover around reinforcement bars.

In all the above cases, cracks can develop even in the absence of earthquake.



Fine crack G1 (Hairline)/ G2 (Little wider) near the support. Note inadequate cover below reinforcing bar.

Cracking (G3/G4) of slab due to support collapse.

Partial collapse (G5) of slab due to collapse of support walls.

RC slab with minor damage resting on severely damaged walls.

What happens in earthquake?

a. When the wall vibrates or when the wall settles because of the earthquake forces , G1/G2 type minor cracks develop in the RC slab.

b. When the walls are damaged more, the slab bends a little on one side resulting in wider and longer cracks. In some cases the chunks of concrete fall off from underside of slabs. This is a G3/G4 type structural damage.

c. When one or two walls supporting the slab collapse, a part of slab collapses. This results in bending and exposure of bars with chunks of concrete falling off. This is a G5 type structural damage.

d. Sometimes the walls supporting the RC roof are damaged badly. RC roof may be damaged or undamaged. However, the structure having G4 damage is in precarious condition.

F. Earthquake Damage in Timber Floors: Types & Causes

1. Timber Floor

The damage occurs as follows:

A. Collapse of supporting walls, or of the walls and roof of the upper storey results in the snapping of timber joists causing collapse of the whole or part of the floor.

B. Joists pulling out from the walls or sliding away from the stone bed damages the floor..

Snapping of timber floor planks.

Damage to floor due to collapse of roof and walls.

Collapsed support wall causing snapping of timber floor elements.

Joists pulled out of the wall.

Damage to roof deck.

Snapping and collapse of timber floor joists.

4 VULNERABILITY ASSESSMENT

Vulnerability of a structure is its weakness against the forces of the natural hazards expected in the region.
A structure with higher vulnerability is likely to suffer greater damage. Vulnerability reduction of existing structures demands retrofitting.

Vulnerability Assessment of Buildings

Why Assess Vulnerability of an Existing Building?

Uttrakhand and Himachal Pradesh, there are many types of construction practices that use different materials for construction. These include local materials such as mud, straw, wood, stone, bricks and concrete blocks, and even industrial materials like cement and steel. Among many factors, the hazard vulnerability of a building depends upon the choice of building materials and construction technology adopted. Generally the industrial materials conform to established norms and standards that ensure certain minimum strength. But in the local non-engineered materials the variations can be very large. For example mud used for mortar can vary a great deal from place to place, and so can the wood and stone. Hence, the building vulnerability can be high with the local materials, especially when built in a non-engineered manner. On the other hand, the vulnerability is low with the use of engineered materials, especially when built in an engineered manner.

In reality, the non-engineered vernacular technologies are time-tested, since they are developed through centuries of experience. But they are vulnerable today since many of the traditional practices have got diluted in recent decades. This is on account of a number of reasons. Materials such as wood which is critical to resist forces of earthquake, cyclones etc. has become scarce today and, hence, very expensive.

Traditionally, the skill of master craftsmen was always passed on down the family lineage, from father to son. Today that tradition has dwindled as the demand for the craftsmen has increased. Today many craftsmen who build houses are yesterday's laborers. As a result their knowledge for house building, more often than not, is incomplete. When they construct houses, they make many mistakes, and many of them simply do not take into consideration the forces of natural phenomena likely to occur in the region. It is, hence, very important to check the vulnerability of all the existing non-engineered buildings, whether damaged or undamaged, against the future natural hazards that are likely to occur, especially since both the states fall in either Seismic Zones IV or V. If found vulnerable, then the measures to reduce the vulnerability of the building must be taken. This way the hardships that the people would face in the event of a future earthquake are eliminated or significantly reduced.

Methodology

A simple method to carry out Vulnerability Assessment involves visual evaluation of the building from the view point of damage that it can suffer in the event of a probable earthquake. This will help in deciding the retrofitting requirements for the building. The assessment is aided by a series of questions shown below which will determine the need for appropriate retrofitting measures.

Vulnerability Assessment of Buildings (cont.):

Procedure for Vulnerability Assessment of an existing house.

1. Foundation and plinth:

Generally the masonry foundation does not get damaged in earthquake or high winds, unless plinth height is in excess of 0.9m. In that situation Seismic Band is required at Plinth level. In a building with plinth level higher than 0.9m, if **Plinth Level Band** is absent then the plinth masonry is vulnerable. It requires **Seismic Belt at Plinth level**.

2. Walls made out of RR:

In RR wall, if **Through-Stones** are absent or inadequate, then walls can delaminate and collapse. Hence, install **Cast-in-Situ RC Bond Elements** at appropriate locations.

3. Weak Wall-to-Wall Connections:

Construction of corners with toothing followed by construction of walls results in poor wall-to-wall connections In the absence of Seismic Bands, this results in cracking. This vulnerability can be reduced by installing **Seismic Belt**.

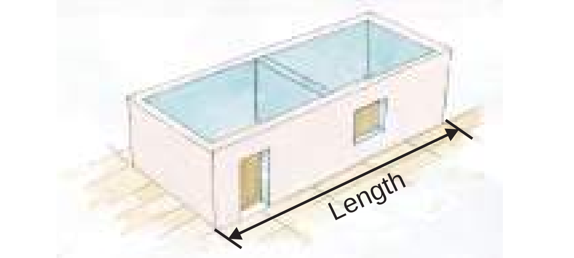
4. Wall thickness:

Wall must have thickness no less than that given in tables below for adequate load-bearing capacity. Pilasters should be added in the existing walls that are vulnerable. In a multi-storeyed building if walls are **excessively thick** on the top floor, they should be removed and replaced with **lighter walls**.

No. of Storeys	Materials for walls		
	Random Rubble	Burnt Bricks	Concrete Block
Single Storey	15" (375mm) min., 18" (450mm) max.	9" (230mm)	8" (200mm)
Double Storey	Ground st.:18" (450mm), first st. 15" (375mm)	Ground st:14" (350mm), first st. 9" (230mm)	Ground st:12" (300mm),first st. 8" (200mm)
Triple Storey with Flat Roof	Ground st.: 18" (450mm), first st.15" (375mm) and second st. 9" (225mm) BB only	Ground st.:14" (350mm), first & second st. 9" (230mm)	Ground st.:12" (300mm), first & second st. 8" (200mm)

Vulnerability Assessment of Buildings (cont.):

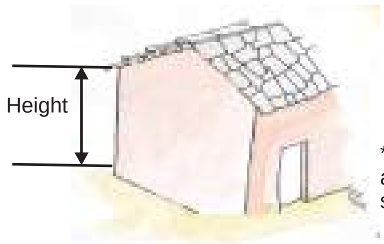
5. Wall length between cross walls:



Is the wall length greater than that shown below? If yes, then provide **buttress** or **vertical Seismic Strap** on both faces of the wall at 5m. spacing .

Wall Type	Max. Length
18" (450mm) thick RR wall	8 m
9" (225mm) thick BB wall	7.85 m
8" (200mm) thick CB wall	7 m

6. Height of wall from floor to ceiling:



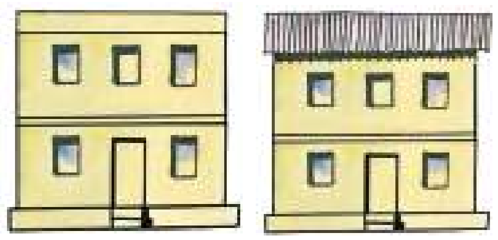
*Max. height applies to all the storeys

Is the wall height of a storey more than that shown below? If yes, then provide an additional **Seismic Belt** between lintel level and floor level.

Wall Type	Max. Height*
18" (450mm) thick RR wall	4 m
9" (225mm) thick brick wall	3.38 m
8" (200mm) thick CB wall	3 m

7. No. of storeys:

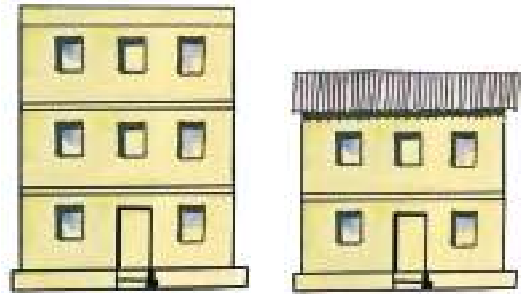
Is number of storeys more than that prescribed below? If yes, then dismantle the extra storeys. Modify the top storey to reduce its weight.



Flat Roof
Gr. + 1 Storey

Pitched Roof
Gr. + 1 Storey + Attic

RR Masonry



Flat Roof
Gr. + 2 Storeys

Pitched Roof
Gr. + 1 Storey + Attic

BB & CB Masonry

8. Openings for doors, windows and closets in walls:

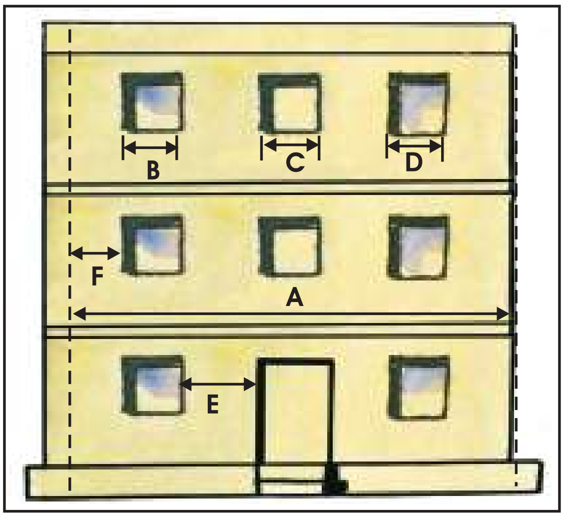
Openings bring weakness in wall. Are any of the following rules violated? If yes, then either **close off** one or more openings or, install **Seismic Belt all around**.

Sum total of width of all openings (B+C+D) on any storey not to exceed the following:

Max. No. of Storeys	% of Wall Length 'A'
One Storey	50%
Two Storeys	42%
Three Storeys	33%
Four Storeys	33% (not permitted in Seismic Zone V)

Gap between two adjacent openings 'E' = 22" (560mm) or more

Gap between inside wall corner and opening 'F' = 18" (450mm) or more



Vulnerability Assessment of Buildings (cont.):

9. Masonry columns :

Are there masonry columns without having any reinforcement? If yes, then encase these columns using reinforcing bars or rebuild with a bar.

10. Falling Hazards:

Are there masonry elements on top of the building such as parapet, chimney or small structures? If yes, then install hazard-resisting features in these elements, and anchor them well to the floor/roof.

Stone masonry columns

Masonry parapet

Stone masonry chimney

11. Hazard-resisting features:

Are any of the following (or other) hazard-resisting features incorporated in your building?

Answer the questions given below to assess the vulnerability and follow the instructions.

A. Seismic Bands in Walls:

a. **Lintle level:** Is there a band on every wall at lintle level? If not, then install Horizontal Seismic Belt at lintle level where the band is missing.

b. **Eave level and Floor Level:** Is there a band at Eave level in Pitched Roof, and one just below intermediate floor level in case of floor made of wooden elements in every wall? If not, then install Horizontal Seismic Belt where the band is missing.

c. **Gable and Ridge Wall:** In case of pitched roof, is there a Gable top band, and if extra high wall under ridge exists, then is there an additional band on top of that wall? If not, then add a belt along the top of gable, and a belt at a little below the top of ridge wall.

d. **Sill level:** Is there a band at Sill Level if the building is in Seismic Zone V, or it has 3 or 4 storeys and is in Zone IV? If not, then install a belt at Sill level.

B. Vertical Bar at Wall Junctions:

Is a vertical reinforcing bar installed within masonry at every wall-to-wall junction from foundation to the top of walls? If not, then install a bar or a Seismic Strap at every junction.

C. Vertical bar at Jambs of Door and Window:

Are there vertical bars in the jambs of door, window and built-in cupboards? If not, then install seismic straps around the openings.

D. Connection of timber floors to Walls:

Are the floor-joists anchored securely to the Floor Level band in the walls? If not, then anchor them to the Floor Level Band or if that does not exist, then to the Seismic Belt.

E. Diagonal bracings and struts under the timber floor:

Have diagonal bracings and struts been installed under the floor? If not then install the timber struts and bracings.

F. Connection of pitched roof to Walls:

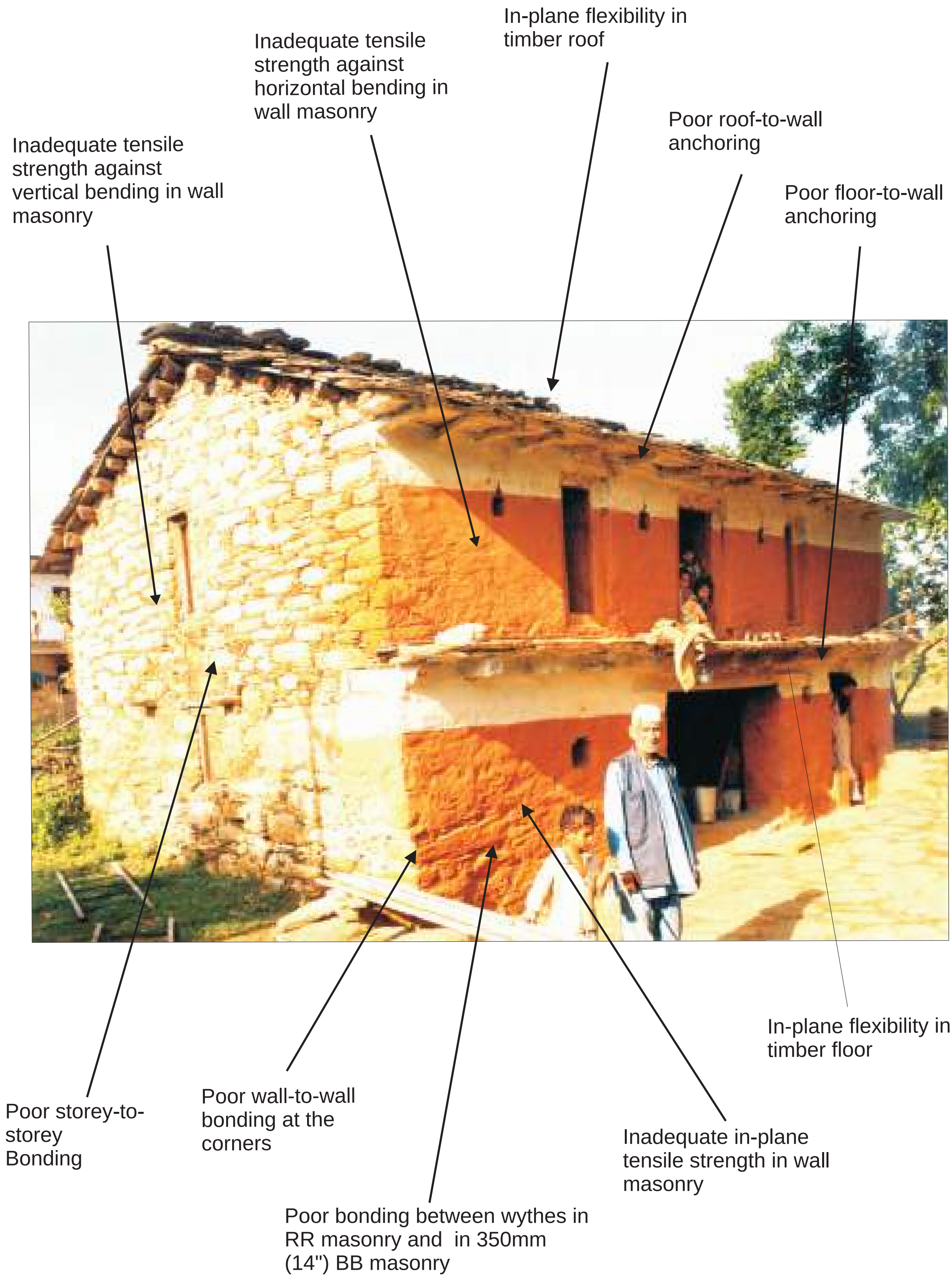
Are the roof elements anchored to the eave and gable bands? If not, then anchor all the elements including purlins, rafters, principal rafters, and beams to the respective bands or, in their absence, to Seismic Belts at eave and on gable wall.

G. Diagonal bracings and struts in roof with sheeting or stone tile covering:

Are there diagonal bracings and struts installed on the underside of the pitched roof? If not, then install struts and bracings using compatible materials.

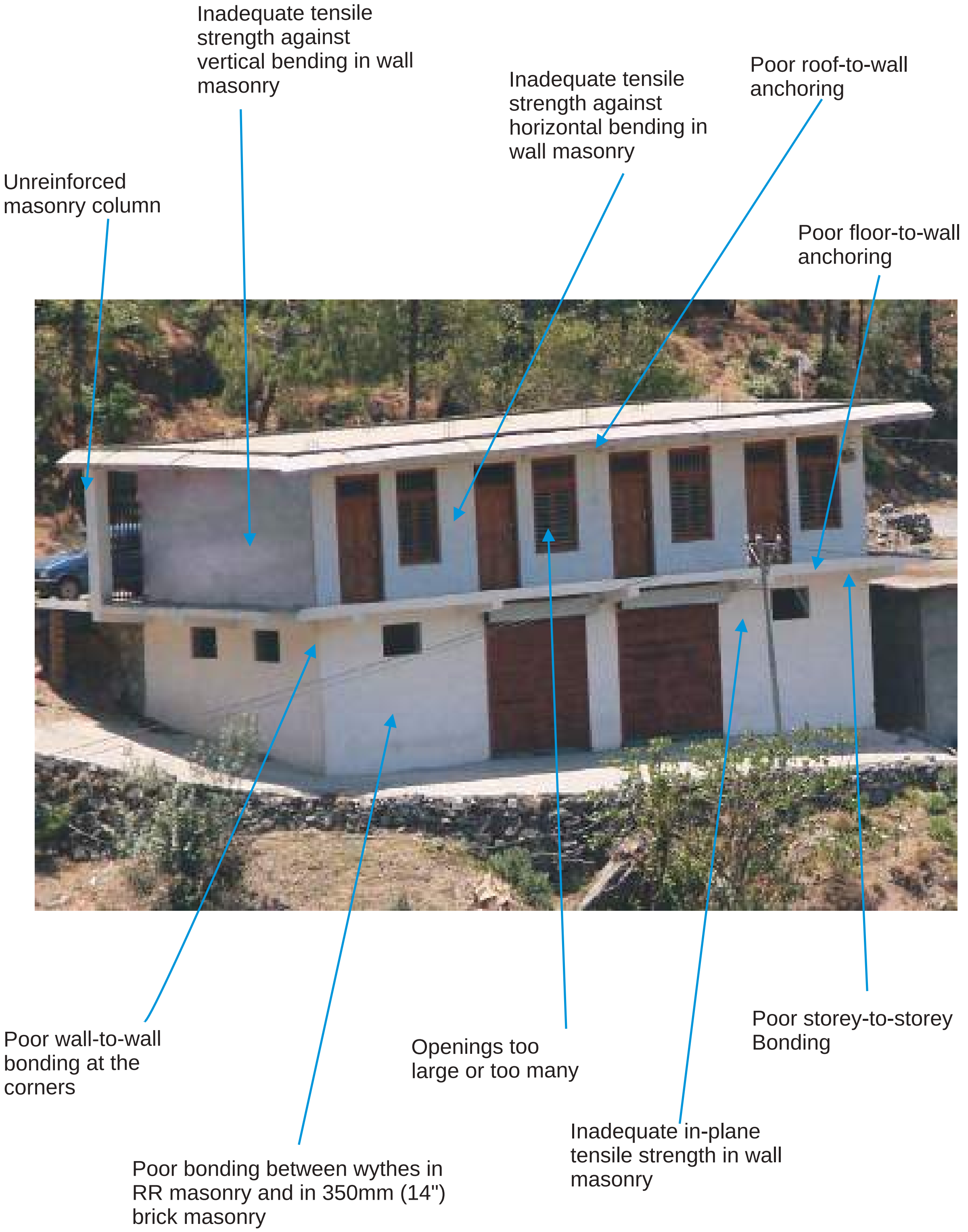
Typical Vulnerability At A Glance:

Vulnerability Commonly Observed in Buildings with Pitched Stone Tile / *Pathal* / *Slate* Roof on Random Rubble Wall



Typical Vulnerability At A Glance(cont.):

Vulnerability Commonly Observed in Buildings with RC Slab Roof on Brick or Random Rubble Wall



Vulnerability Scenario of Various Building Typologies :

The Vulnerability Atlas of India, 1997, BMTPC categorises various building typologies as follows and describes the vulnerability as follows:

Category A: (1) Buildings with **RR walls** without Hazard-resisting features in the hilly areas.

: (2) Buildings with **mud walls** in the plains.

Category B: Buildings with **BB walls** without Hazard-resisting features.

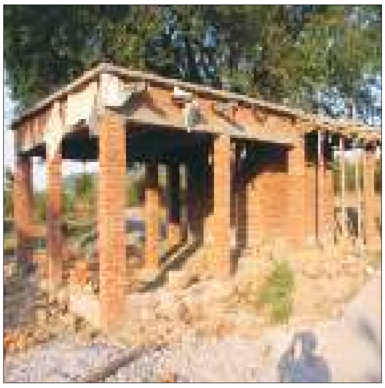
These buildings are likely to face the following risks in a future earthquake of specified intensity:

Intensity IX: All **Category A buildings** are liable to totally collapse, and **Category B buildings** are liable to heavy cracks in all the walls and may even suffer partial collapse with total collapse in many cases. Loss of lives could be in thousands.

Intensity VIII: Most **Category A buildings** are likely to collapse and **Category B buildings** likely to suffer heavy cracking with some partial or total collapses. Loss of lives could reach a few thousands.

Intensity VII: Most **Category A buildings** could suffer heavy damage, and few collapses, while **Category B buildings** could have minor to moderate damage. Loss of lives could reach a few hundred.

Vulnerabilities commonly observed in buildings with RC Roof supported on Brick or Random Rubble masonry wall



Brick masonry pillars supporting the RC roof

4” brick partition walls supporting the RC roof.

Band not continued on all walls

Poor corner joint with two different materials, and vertical joints in brick masonry not filled with mortar.

Band not continued on all walls. Too many openings in the walls just under the RC roof

No cranking of bars near the support walls and bars at the bottom in the cantilever portion of slab.

Examples of duly filled “visual assessment form” as recommended in IS 13935 are given in the case studies. This form should be included in the vulnerability assessment.

5

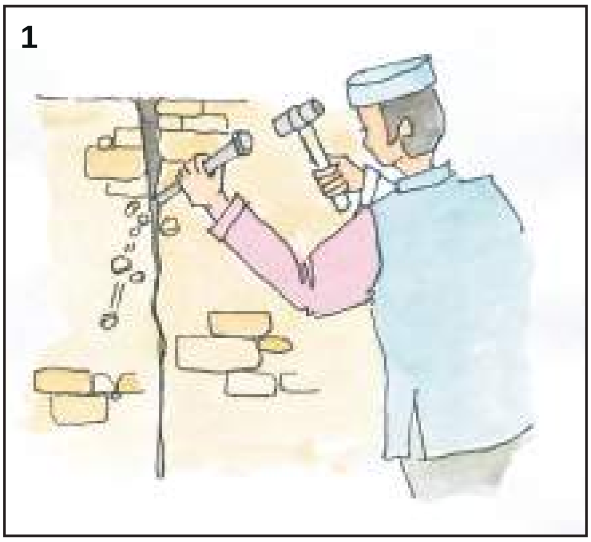
RESTORATION OF DAMAGED STRUCTURES

Bringing back a damaged structure to its pre-disaster or the original state is called Restoration. This results in the restoration of its original strength. Restoration forms the first step of building-rehabilitation. Painting, plastering, adding water-proofing or changing floor tiles is not considered restoration.

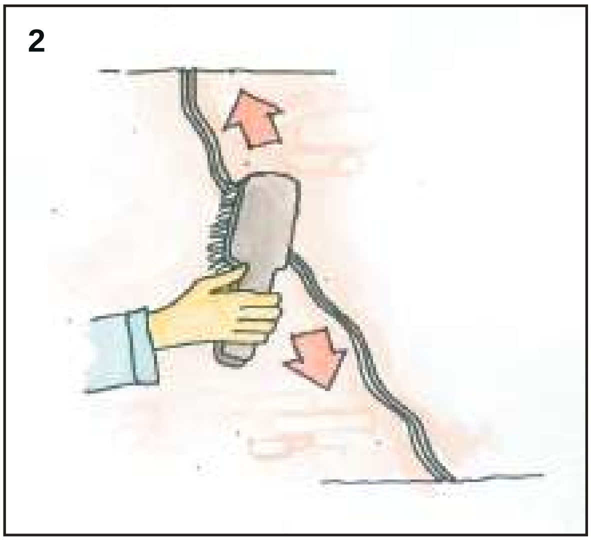
A. Restoration procedure for Wall Damage:

Grade G-1 crack: Hairline crack

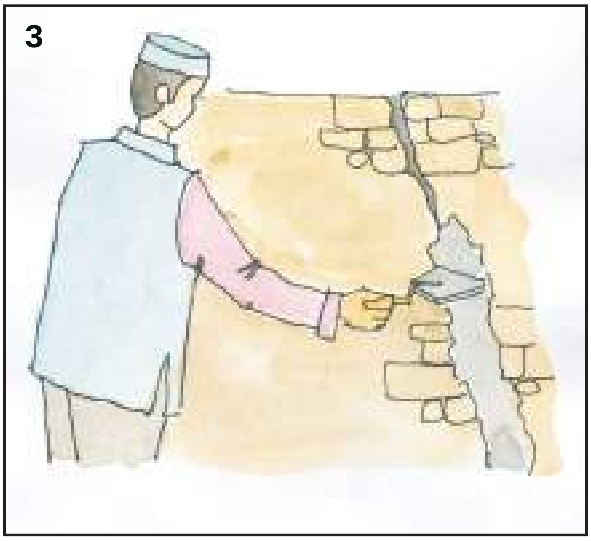
Sealing of cracks :



Making 'V' notch



Cleaning crack with wire brush



Sealing crack with cement mortar

1. Make a 'V' notch along the crack.
2. Clean it with wire brush.
3. Fill up the gap with 1:3 Cement mortar.
4. Cure it for 15 days.
5. Let it dry for min. of 3 days.
6. Finish the restored parts to match the surrounding wall surface.

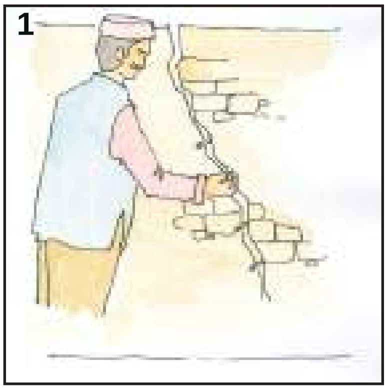
A. Restoration procedure for Wall Damage (cont.):

Grade G-2 crack - width upto 5mm (1/4") and
Grade G-3 cracks - width more than 5mm (1/4") but less than 10mm (½")

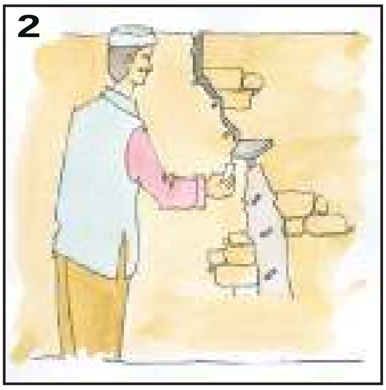

Wall having G-2 cracks


Wall having G-3 cracks

Sealing and Grouting of Cracks:

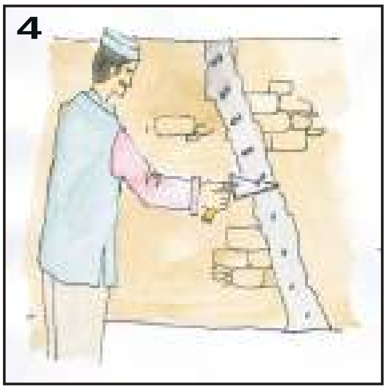


Fixing grouting nipples



Sealing crack with cement mortar

Injecting cement slurry



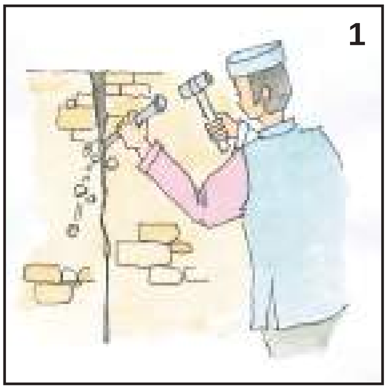
Cutting of nipple for finishing

1. Make a 'V' notch along the crack, clean it with wire brush.
2. Fix grouting nipples, approximately 50mm long, in the 'V' groove sticking out of the crack, on both faces of wall at a spacing of 150mm to 200mm.
3. If compressed air is available, then use it through the nipples to remove the fine, loose particles from the crack,
4. Seal the crack at the surface with 1:3 cement mortar with nipples sticking out and allow it to harden for some time.
5. Inject water in the crack through the topmost nipple, and then move downward to lower nipples one after another.
6. Make cement slurry with 1:1 (non-shrink cement : water) and begin injecting it into the nipple, starting from the lowest nipple upward, until the slurry comes out of the next higher nipple. Next inject it in the next higher nipple, following it till the end.
7. Cut off the protruding ends of the nipples, seal the holes with 1:3 cement mortar and finish the surface to match the adjacent surface.

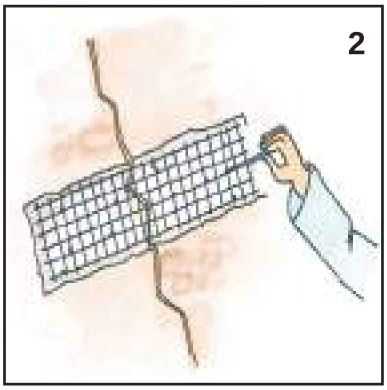
A. Restoration procedure for Wall Damage (cont.):

Grade G-3 cracks - width more than 5mm (1/4”) but less than 10mm (½”).

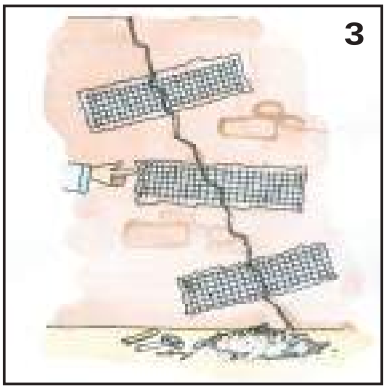
G-3 cracks



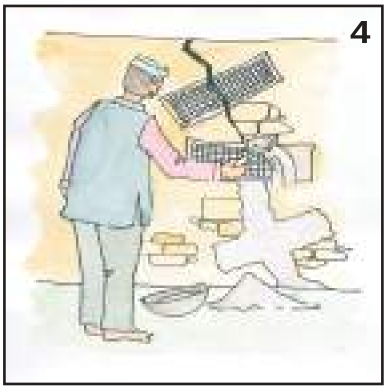
Making 'V' notch



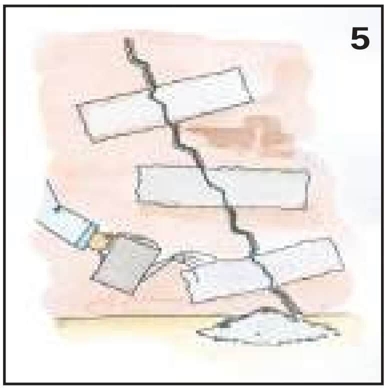
Fixing WWM with thick nails with washers



Ferrocement splices accross cracks



Applying cement plaster on splices



Curing

Sealing and Stitching of Cracks:

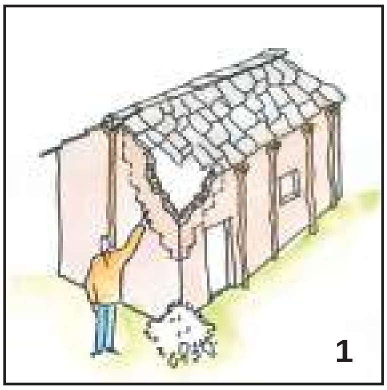
1. Make a 'V' notch along the crack, clean it with wire brush.
2. Clean crack with water to remove the fine, loose particles inside the crack.
3. Prepare masonry surface on both faces of the wall for fixing 200mm wide ferro-cement splices extending on both sides of the crack to a minimum of 450mm (18”) length as shown in diagram by removing the plaster, raking the joints up to 12mm depth, and cleaning it with water.
4. Fill the crack with 1:3 cement mortar (non-shrink cement : fine sand) with just enough water to permit pushing mortar as far in as possible, from both faces of the wall.
5. Install the 150mm (6”) wide 25x25 14 gauge galvanized welded wire mesh (WWM) (2.03mm dia.) with 100mm (4”) long thick nails inserted with washer at spacing no greater than 300mm (12”) in a staggered manner.
6. A gap of 10mm must be maintained between the mesh and un-plastered wall.
7. Plaster over the mesh with two 12mm coats of 1:3 cement plaster.
8. Cure it with water for 15 days.

A. Restoration procedure for Wall Damage (cont.):

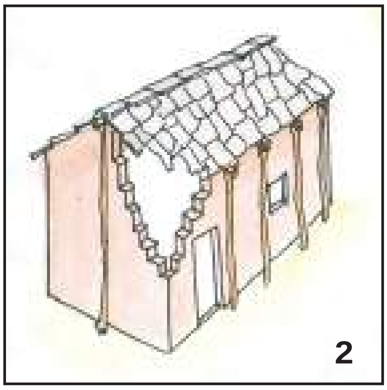
Grade G-4 Damage : Cracks wider than 10mm (½”) or a part of wall that has gone out-of-plumb, or has collapsed.


Part of a wall out of plumb

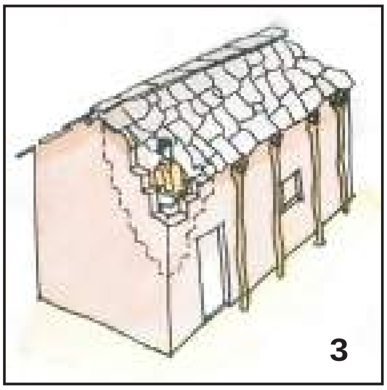

Collapsed corner



Propping up roof



Removing damaged portion of the wall



Rebuilding the wall

Restoring the damaged portion of wall:

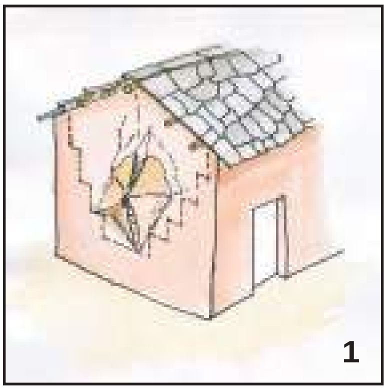
1. Mark the damaged portion of the wall.
2. Mark 600mm (2'-0”) extra on all sides from the damaged portion for removal.
3. Support with timber or steel props the roof or the floor above the portion of the wall that has to be removed. Provide additional supports to prevent any accidental collapse of structure.
4. Slowly remove the marked portion of the wall in stepped manner.
5. Separate and stack reusable material properly. Discard all materials like small round stones that is unsuitable for construction.
6. Rebuild the wall with the salvaged material or new material. Use mortar that is the same as that used in the existing construction, or stronger. If the existing wall is built with stone in mud mortar, then it is best to use stone in mud mortar in restoring, or stone in cement or lime mortar, but not bricks.
7. Adhere to the basic rules of earthquake-resistant masonry construction while rebuilding the wall. If the wall is built in stone, use one Through-stone in every 0.8 smt. (8sft.) both ways and staggered vertically.
8. If cement is used in construction or plaster, then cure it for at least seven days.
9. Remove the props once the rebuilt portion has adequate strength .
10. Finish the wall to match the adjacent parts of existing house.

A. Restoration procedure for Wall Damage (cont.):

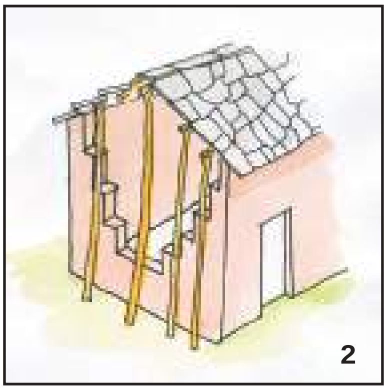
Grade G-4 Damage: Bulging or Delaminated wall or Partially Collapsed wall.


Bulged wall

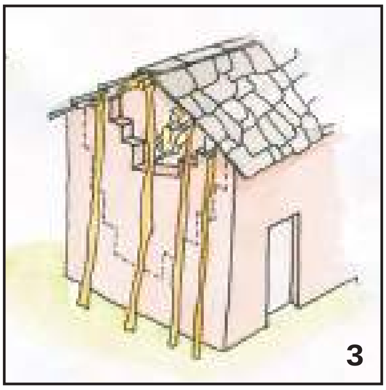

Delaminated wall



Bulged wall



Propping up roof and removing damaged portion of wall



Rebuilding the wall

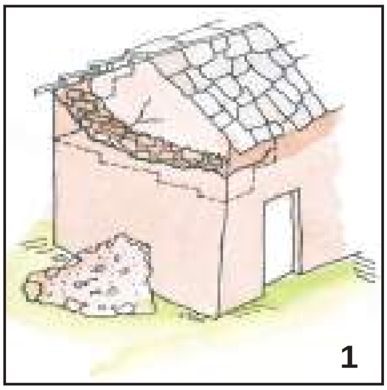
Finishing to match the existing wall

1. Mark the damaged portion of the wall.
2. Mark 600mm (2'-0") extra on all sides from the damaged portion for removal.
3. Support with timber or steel props the roof or the floor above the wall that has to be removed. Provide additional supports to prevent any accidental collapse of structure.
4. Slowly remove the marked portion of the wall in stepped manner.
5. Separate and stack reusable material properly. Discard all materials like small round stones that is unsuitable for construction .
6. Rebuild the wall with the salvaged material or new material. Use mortar that is the same as that used in the existing construction, or stronger. If the existing wall is built with stone in mud mortar, then it is best to use stone in mud mortar in rebuilding, or stone in cement or lime mortar, but not bricks.
7. Adhere to the basic rules of earthquake-resistant masonry construction while rebuilding the wall. If the wall is built in stone, use through stones at every 0.9 smt. (9sft.) both ways and staggered vertically.
8. If cement is used in construction or plaster, than cure it for at least seven days.
9. Remove the props once the rebuilt portion has adequate strength.
10. Finish the wall to match the adjacent parts of existing house.

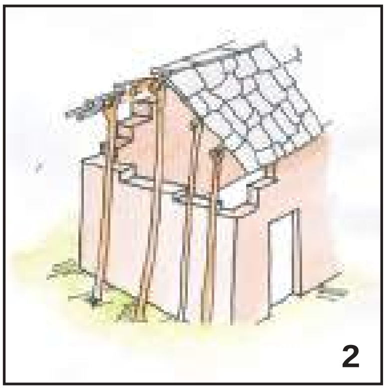
A. Restoration procedure for Wall Damage (cont.):

Grade G-4 Damage: Partially Collapsed Gable Wall.

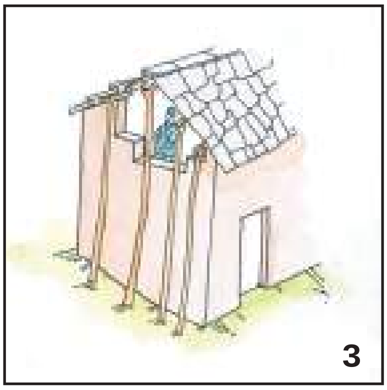
Collapsed gable wall



Collapsed gable wall



Propping up roof and removing damaged portion of gable wall



Rebuilding the gable wall

Finishing to match the existing wall

1. Mark the damaged portion of the gable wall.
2. Mark 600mm (2'-0") extra on all sides from the damaged portion for removal.
3. Support with timber or steel props the roof or the floor above the wall that has to be removed. Provide additional supports to prevent any accidental collapse of structure.
4. Slowly remove the marked portion of the wall in stepped manner.
5. Separate and stack reusable material properly. Discard all materials like small round stones that is unsuitable for construction .
6. Rebuild the wall with the salvaged material or new material. Use mortar that is the same as that used in the existing construction, or stronger. If the existing wall is built with stone in mud mortar, then it is best to use stone in mud mortar in rebuilding, or stone in cement or lime mortar, but not bricks.
7. Adhere to the basic rules of earthquake-resistant masonry construction while rebuilding the wall. If the wall is built in stone, use through stones at every 0.9 smt. (9sft.) both ways and staggered vertically.
8. If cement is used in construction or plaster, cure it for at least seven days.
9. Remove the props once the rebuilt portion has adequate strength.
10. Finish the wall to match the adjacent parts of existing house.

A. Restoration procedure for Wall Damage (cont.):

Restorable buildings:
Many buildings at first glance seem unsalvageable. The fear-psychosis in most people, and, even in some engineers, makes them opt for demolition. But if planned properly, these buildings can be restored. Damaged portions can be rebuilt but all undamaged walls and roof can be salvaged. All the buildings shown here can be restored and retrofitted with systematic planning and action.


Collapsed walls need to be rebuilt


Roof needs to be jacked up and propped, followed by rebuilding of collapsed walls and repairing of damaged ones


Roof needs to be jacked up and collapsed portion of walls need to be rebuilt


Damaged portions of walls need to be repaired and rebuilt. slightly damaged ground floor with the middle RC floor can be saved from demolition.


Cracks need to be sealed, grouted and spliced for restoration

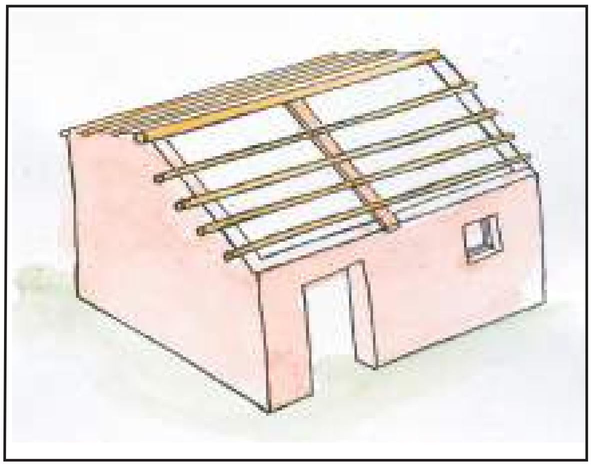

The roof, intermediate floor and ground floor walls including the foundation can be saved from demolition, while rebuilding the collapsed walls and restoring damaged ones

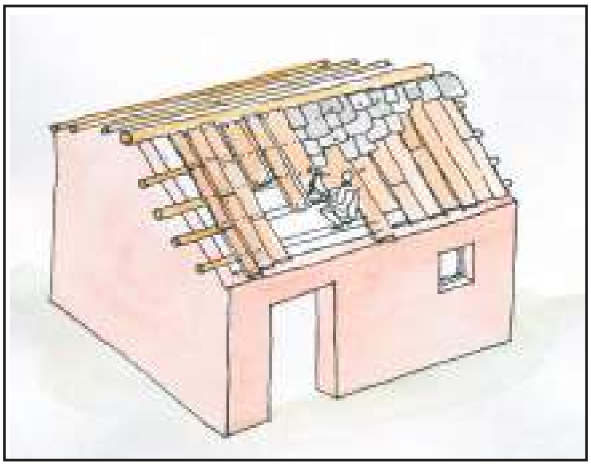
B. Restoration procedure for Roof Damage:

1. Restoration of Damaged Stone Tile / Slate / Stone Roof:


Damaged understructure and dislodged slate.

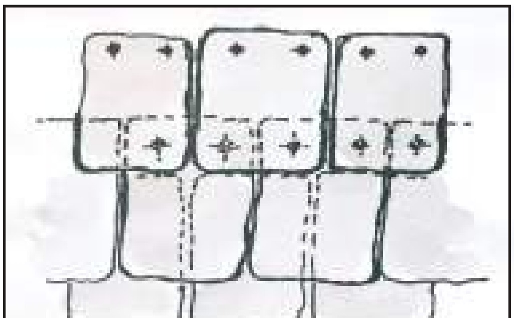

Collapsed roof due to collapsed walls.

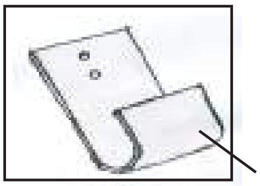

Remove all stone tiles and replace damaged timber


Replace and fix stone tiles.

It has been observed that much of the roof damage has been caused because of severe damage to the support walls. In such cases, the following steps must be taken:

1. Remove all the stone tiles / *pathal* roofing carefully, followed by the planks under them.
2. Clear the damaged portion of roof.
3. Clear the severely damaged portions of the walls and reconstruct them while adhering to the principles of good practice.
4. Repair the cracks and other minor damages.
5. Replace the severely damaged timber elements including rafters, purlins, and planks.
6. Repair the cracked elements other than the planks by nailing or splicing with the help of metal straps or MS flats. Pre-drill holes in old timber to prevent damage from cracking.
7. Replace stone tiles / *pathal*, nailing them well to the planks using at least **two nails** on each stone.
8. Install steel hooks at eave level to support the stone tiles along their bottom edge to prevent sliding.


Securely fix stone tiles / *pathal* with nails



B. Restoration procedure for Roof Damage(cont.):

1. Restoration of Damaged Stone Tile / *Pathal* / Slate Roof. (cont.)

Installation procedure for Stone Tile / *Pathal* / Slate Roof:

Remove all the stone tiles / *pathal* roofing, and discard the damaged ones

Replace damaged timber purlins and planks

Place mud over timber planks

Place stone tile starting from the lowest edge of roof

Make two hole in each stone tile for fixing it to planks

Fix stone tile / *pathal* with two nails and install steel hooks at the Eave Level

B. Restoration procedure for Roof Damage(cont.):

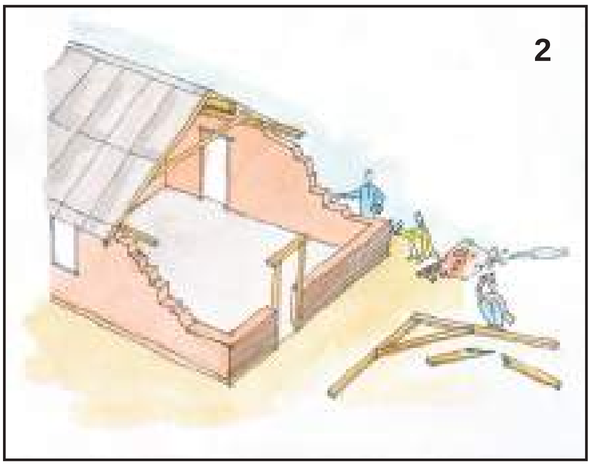
2. Restoration of Damaged CGI Sheet Roof:

Damaged roof

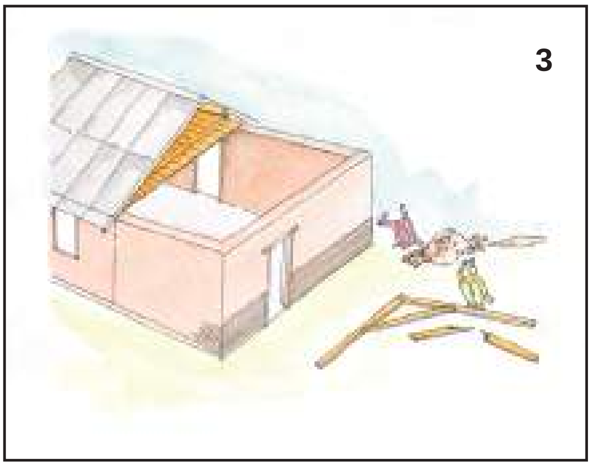
It has been observed that much of the roof damage has been caused because of severe damage to the support walls. In such cases, the following steps must be taken:

1. Remove all the sheets carefully.
2. Clear the damaged portion of roof.
3. Clear the severely damaged portions of the walls and reconstruct them while adhering to the principles of good practice.
4. Repair the cracks and minor damages.
5. Replace the severely damaged timber elements including truss top chords, rafters, purlins, and planks.
6. Repair the cracked elements other than the planks by nailing or splicing with the help of metal straps or MS flats. Pre-drill holes in old timber to prevent damage from cracking.
7. Reinstall CGI sheets, unless they are damaged or deformed.

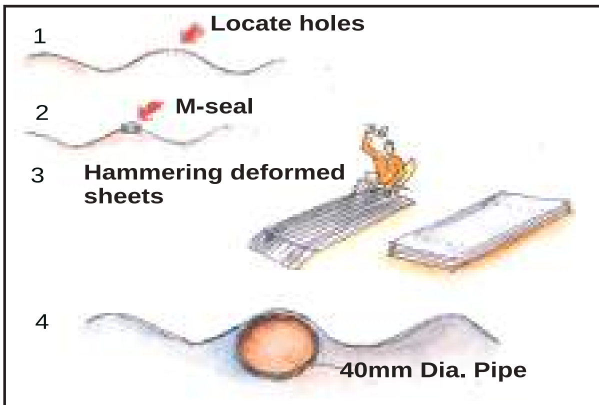
Removing CGI sheets from damaged portion of roof



Removing damaged portion of wall



Rebuild the wall



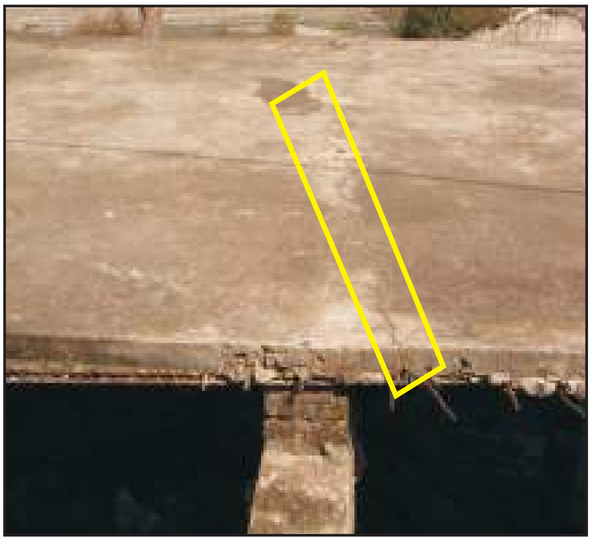
B. Repairing deformed CGI sheets

1. Remove any rusted edges around the existing nail/bolt holes with a file or a hammer.
2. Seal all open holes with M-seal (sealant).
3. Straighten out bent sheets using wooden hammer.
4. While hammering, place 40mm dia pipe under the sheeting to ensure proper corrugation.

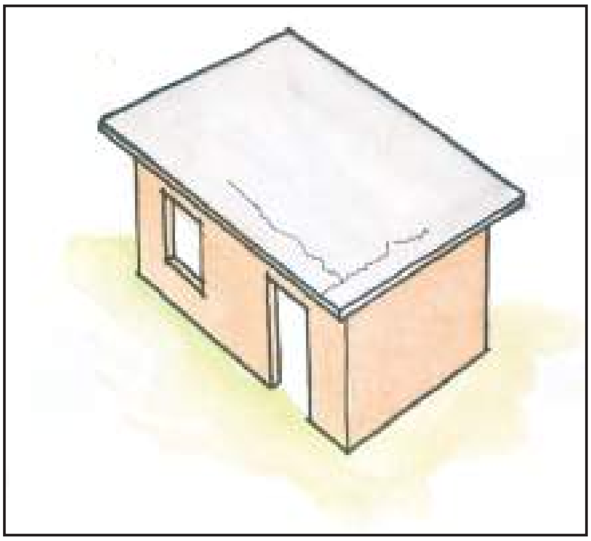
B. Restoration procedure for Roof Damage(cont.):

3. Restoration of damaged RC slab:

A. Crack in RC roof.



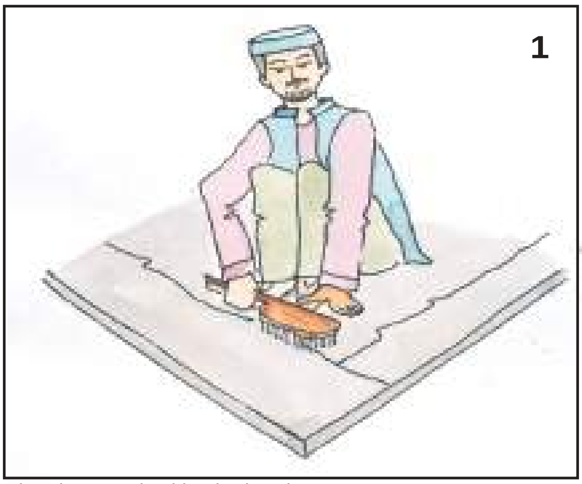
G-1/G-2 Crack in RC roof/floor



G-1/G-2 crack

I. Sealing of fine (G1) crack.

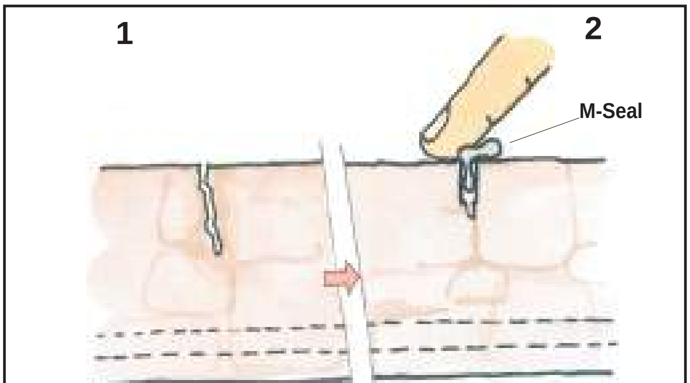
1. Clean the crack with wire brush.
2. Fill the crack with cement slurry. The cement : water ratio must be kept at 1:3.
3. Cure the cement slurry for at least 15 days.



Cleaning crack with wire brush.

Filling widened crack with cement slurry.

ii. Sealing of Moderate (G2) non-structural crack



G-2 crack

Sealing crack with M-Seal

1. Rake the crack with chisel and widen the crack.
2. Clean the crack with wire brush.
3. Seal it with M-seal. Before applying the M-seal, make sure the crack is absolutely dry. Using thumb, apply it with pressure so that no space is left out.
4. Remove excess sealant. Let the applied sealant harden.

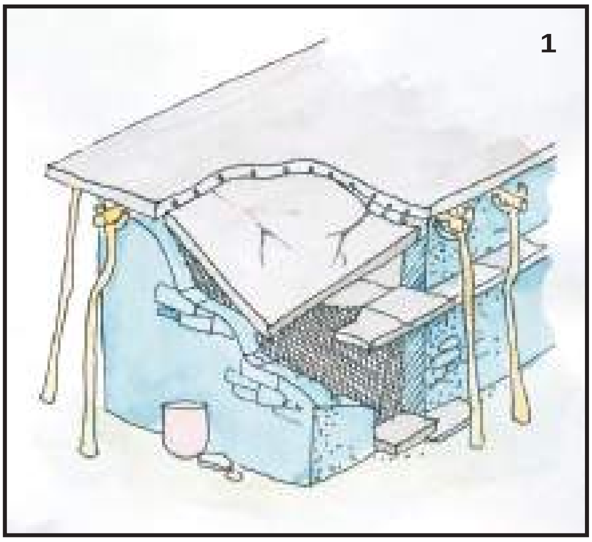
B. Restoration procedure for Roof Damage(cont.):

3. Restoration of damaged RC slab (cont.).

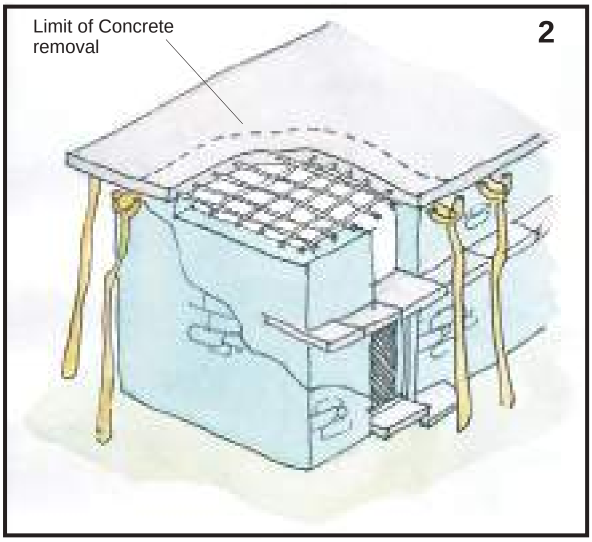
B. Restoration of Partially Collapsed RC Roof :

Consisting of wide crack with a portion of the slab bent resulting in bending and exposing of reinforcing bars.

1. Support the undamaged portion of the slab with timber poles and wooden planks to prevent further cracking in slab.
2. Mark off a line on the undamaged part of the slab at 600mm (2'-0") from the damaged area periphery.
3. Break off concrete from the collapsed portion to reduce the weight and also from the undamaged portion up to the marked line, and expose the steel bars.
4. If the walls are damaged or collapsed, restore them following the basic rules of earthquake resistant construction.
5. Straighten out the bars to the correct alignment.



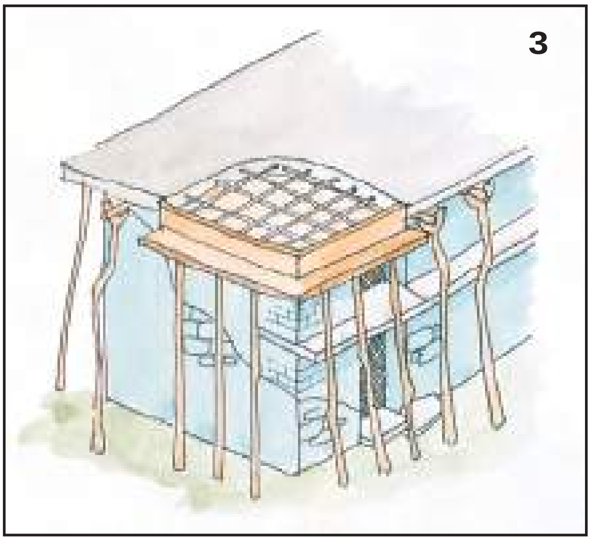
Support undamaged portion of slab with props.
Mark the area for concrete removal.



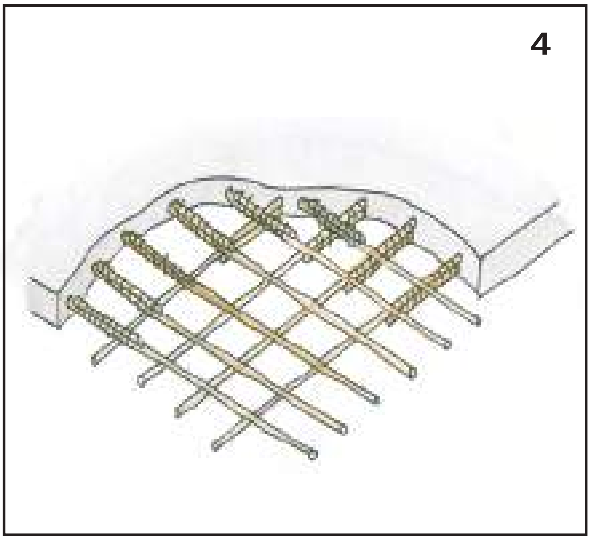
Remove the concrete, expose the bars, and straigthen the bent bars.

B. Restoration procedure for Roof Damage(cont.):

B. Restoration of Partially Collapsed RC slab (cont.):



Installing shuttering



Tying dowels to exposed rebars

6 Install shuttering for recasting of damaged portion of slab.

7. Repair the damaged steel reinforcement following one of the two options given below.

   a Cut off the damaged bar at the point from where it is bent.

   b. Connect a new bar of the same diameter such that it overlaps the portion of the cut bar projecting out of the existing concrete along a length equal to 52 times the diameter of the bar

   c. Use binding wire at min. three points.

OR

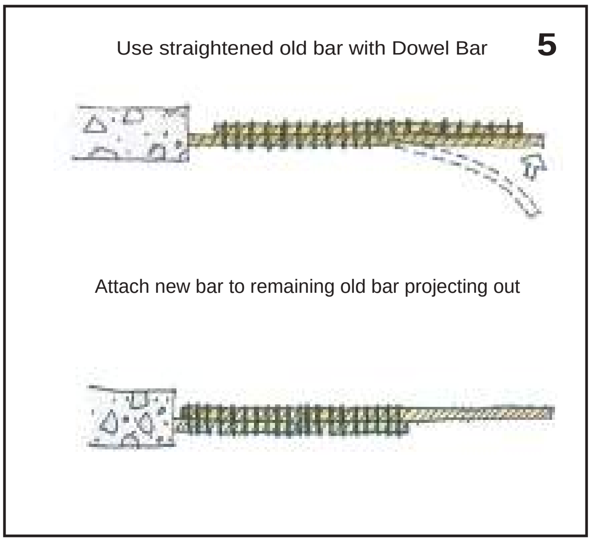
   a Take rods of the same diameter as that of the slab reinforcement. Cut dowel from it of a length equal to 52 times the bar diameter.

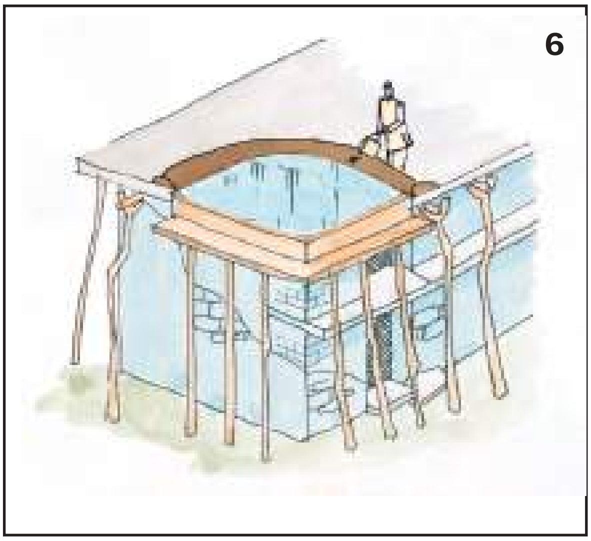
   b. Install dowel on the damaged bar such that it overlaps on its damaged portion, keeping the mid-point of dowel at the point of bending in the reinforcing bar.

   c Connect dowel to the reinforcing bar in the slab by means of binding wires at several points.

8. Apply bonding agent on the exposed edge of the undamaged slab.

9. Pour concrete and finish it to match the existing slab, and cure for 15 days.

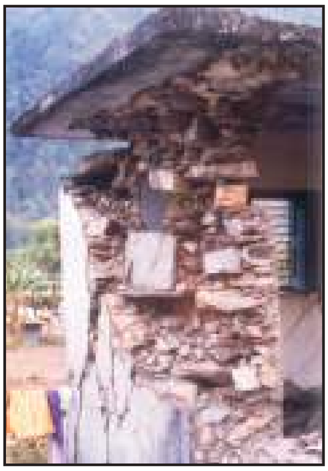




Cast slab and cure it

B. Restoration procedure for Roof Damage(cont.):

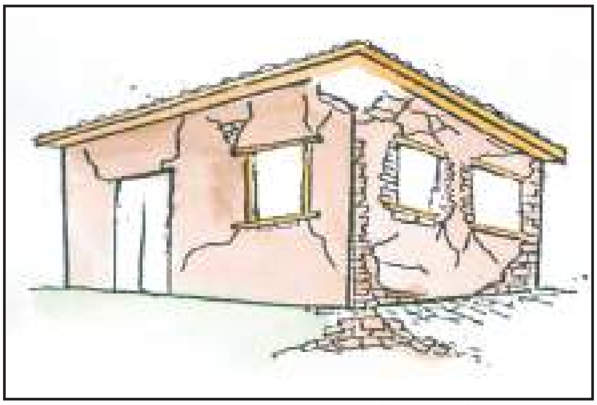
C. Restoration of an undamaged RC slab supported on severely damaged supporting walls.



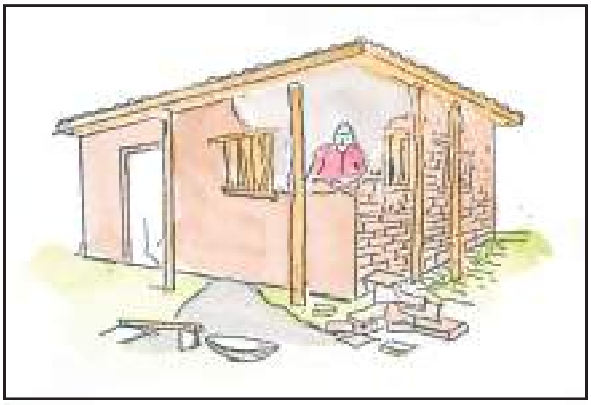
Undamaged RC slab on severely damaged wall

The damaged walls have to be restored carefully in a systematic manner so that the stability of the whole structure is not undermined.

1. Prop up the slab all along its supporting walls by horizontal planks supported with vertical and sloping posts on both sides of the walls as seen in the photographs and sketches here.
2. Supports must be strong and wedged to make sure that the slab is resting well on them. The slant supports will help in preventing the lateral sway of the slab. Do not to push up the slab at a point away from the wall to prevent cracking in top surface.
3. Mark the portion of the damaged wall that has to be removed. Starting from a corner, begin removing the portion of the wall not exceeding more than ¼ of total length of the damaged wall or 3m (10'-0"); whichever is less.
4. Begin removal of the marked portion of wall with extreme caution.
5. Start construction of the new wall from the corner following rules of earthquake resistant construction. Build it in a stepped-like manner to ensure proper bond with the next portion to be constructed.
6. Remove additional 2m (6'-6") length of next portion of the damaged wall.
7. Continue the process till all the damaged walls have been restored.
8. If cement mortar is used for construction, cure it for 15 days.
9. If the slab has developed cracks, follow the instructions given earlier to restore it.
10. When all the walls are restored, remove all the supports, and retrofit the entire structure as required. Follow the instructions for retrofitting from the chapter on retrofitting .



Undamaged RC slab on severely damaged wall



Systematically propping up slab, removing portions of damaged walls, and rebuilding them

C. Restoration procedure for Timber Floor Damage:


Sliding out timber joists

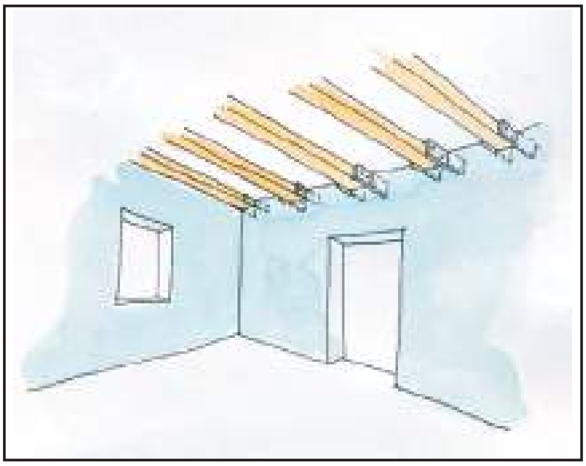

Joists sitting on cantilever bearing stone

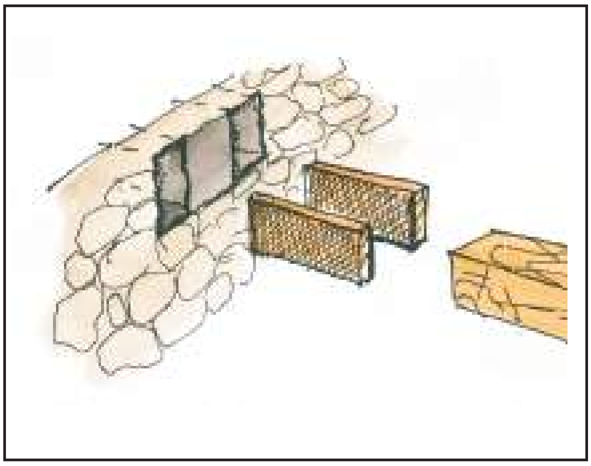
Damage is caused by following causes:

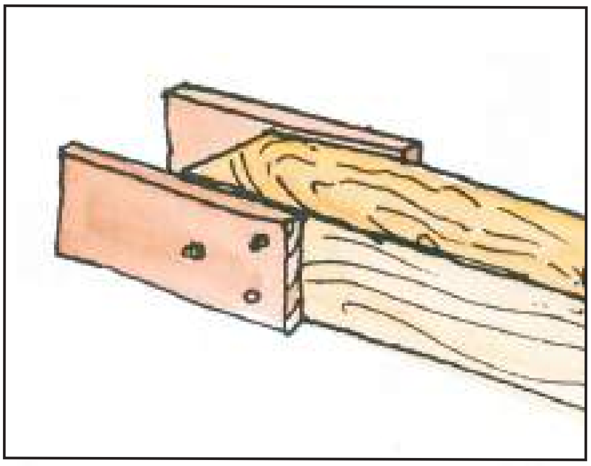
- Sliding of timber joists from the bearing stone projecting out from the walls.
- Pulling out from wall.
- Floor joists breaking
- Debris falling from the upper storey or roof.

The following steps should be taken for restoration.

1. Prop up damaged floor, and clear all the debris on it, if any.
2. Open up the floor planks and remove timber joists from the damaged area.
3. Also remove rotten timber, if any.
4. Restore the damaged wall on which the floor joists are resting.
5. Restore the cracked timber elements other than the planks by nailing or splicing with the help of metal straps or MS flats. Pre-drill holes in old timber to prevent damage from cracking.
6. To extend the joists that are not long enough for ensuring adequate bearing in wall, attach two timber pieces 150mm to 220mm long at the end of the joists with min. two nails.
7. Where the joists have slid from their place, bring them back to their original location.
8. Reinstall all the timber planks with min. of two nails at each end.
9. Remove all the supports.
10. Once the floor is restored, retrofit it with diagonal bracings and struts as instructed in the chapter on retrofitting .




Assembly for safer bearing of joists having inadequate length


Extended joist for safer bearing

6

RETROFITTING MEASURES

Retrofitting for Vulnerability Reduction means enhancing the capacity of the structure in a scientific manner to resist the forces of natural disasters likely to occur in future through application of remedial measures for every weakness.

A. Retrofitting of Existing Masonry Walls

1. Cast-In-Situ Bond Elements - For Random Rubble (RR) Wall.

Weakness in RR Wall: Bulging or Delamination of wythes in thick walls.


Bulging

Remedial Measures:
Installation of Cast-In-situ RC Bond Elements in RR wall.

Cast In-situ RC bond elements installed through the existing RR walls can prevent delamination.

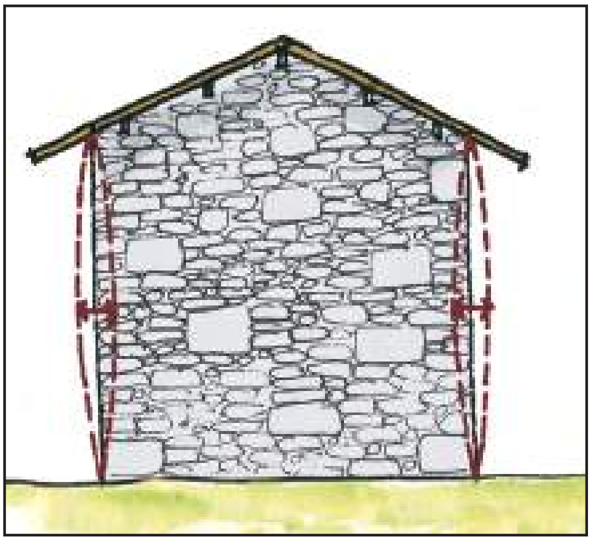
How does Cast In-situ Bond Element work?

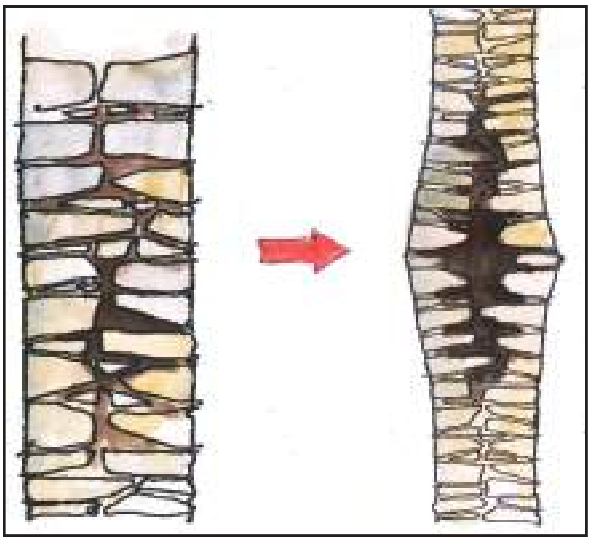
a. It binds together both the wythes in a wall, thus preventing bulging and delamination.

b. It helps reduce vulnerability of Random Rubble wall.


Bulging

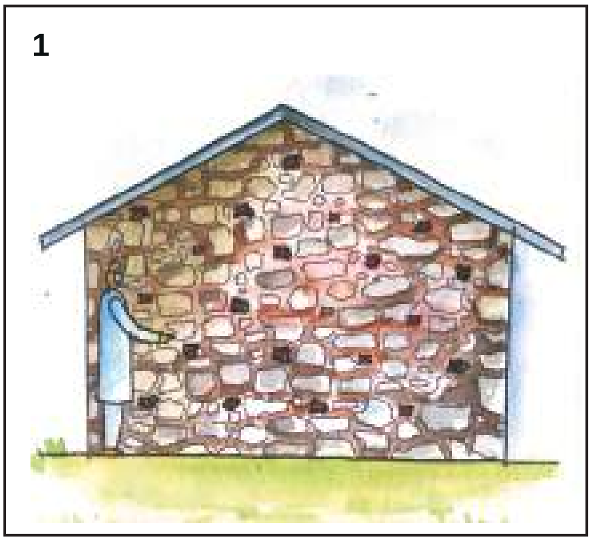

Delamination of a wythe

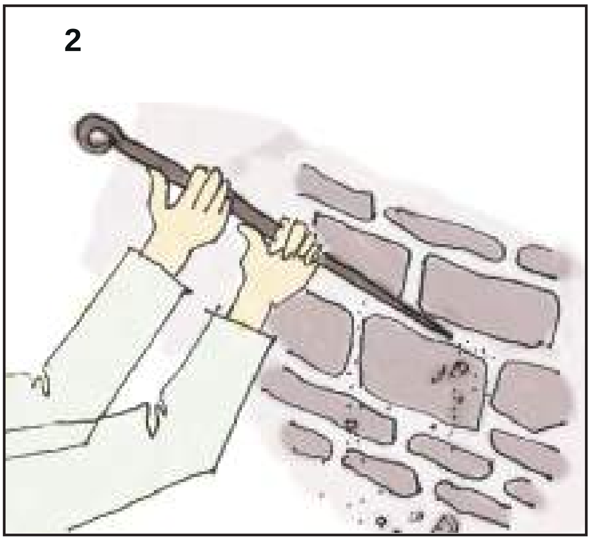

Sideway shaking of walls due to earthquake

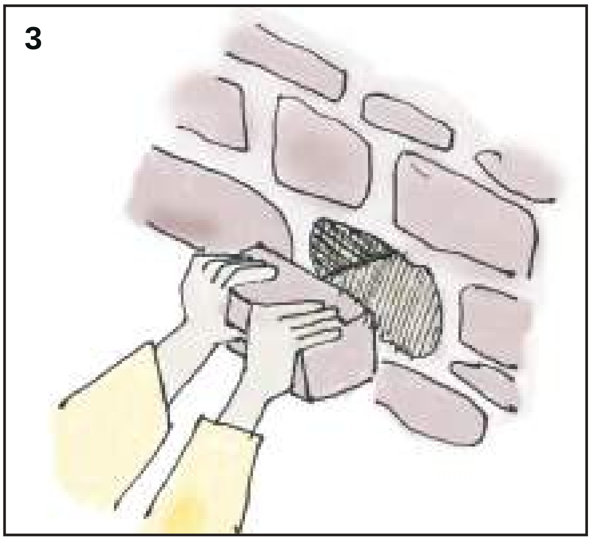

Separation of wythes due to sideway shaking

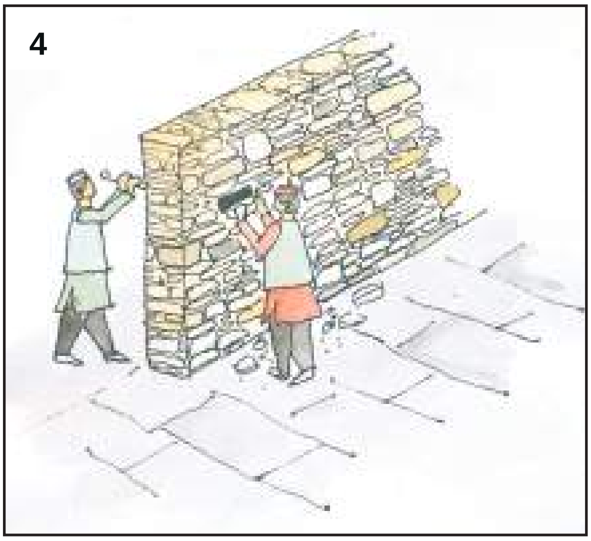
A. Retrofitting of Existing Masonry Walls (cont.):

1. Cast-In-Situ Bond Elements - RR Wall - Installation

1

Marking points for bond elements.

2

Removing mortar around stone to loosen it.

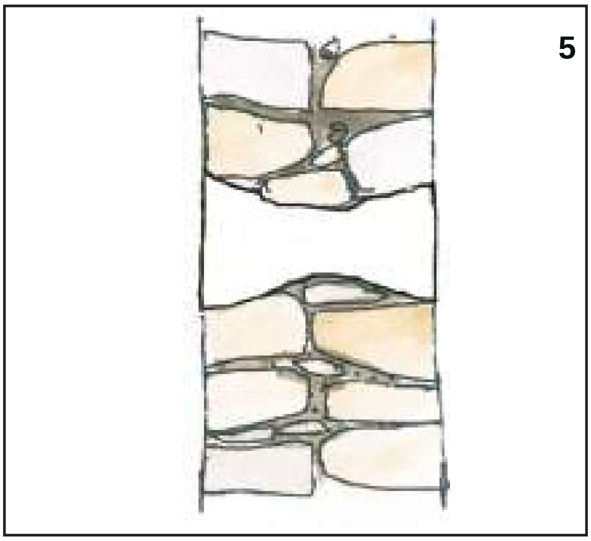
3

Pulling out the loose stone.

4

Removeing loose materials from behind the stone to make through hole.

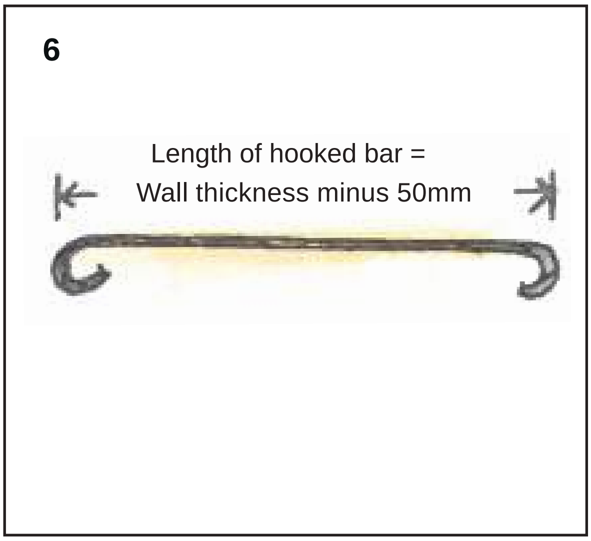
1. Mark points at horizontal and vertical spacing of 0.8m, with a stagger of 500mm., thus having one point in every 0.8 smt. (8 sft.) of the wall area.
2. Remove the patch of surface plaster of approximately 220mm x 220mm (9"x9") at each point and expose the stones. Remove the mortar around the stone to a sufficient depth gently so as to expose the sides of the stone to loosen it.
3. Loosen the stone, gently yanking it from side to side and up and down carefully by means of a small rod with tapered end, so that the other stones in vicinity are not disturbed. This rod should be of 12mm. dia. and 750mm (2' 6") length with one end flattened and one end pointed.
4. Pull out the stone slowly, holding it by both hands.
5. Remove the material behind the stone gradually to make a 75mm (3") diameter hole through the wall till the stone on the other face is reached.
6. Tap that stone to identify it from the far side. Remove this slowly by same gentle process from the other side.

A. Retrofitting of Existing Masonry Walls (cont.):

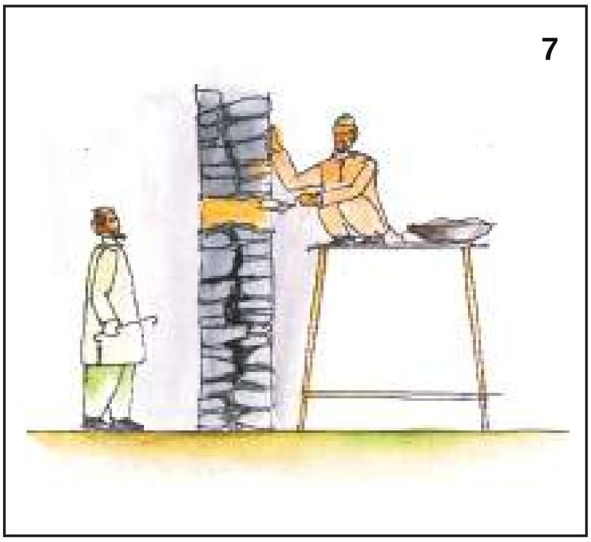
1. Cast-In-Situ Bond Elements - RR Wall - Installation (cont.)



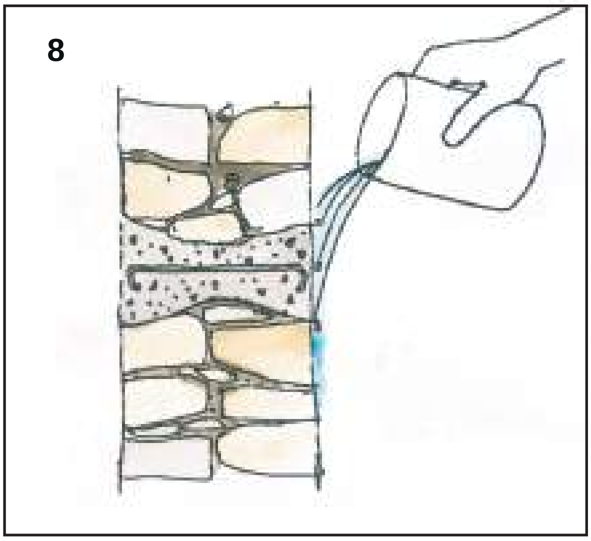
Make dumb-bell shaped hole through the wall.



Prepare a bar with hooks at both ends of correct length.



Placeing concrete and bar in the hole.



Curing concrete thoroughly.

7. The hole should be bigger in size at both faces and narrower in wall core resembling a dumb-bell. It dose not matter if the hole is inclined instead of level
8. Splash water in the hole to clean off loose materials from the surface of the stones.
9. Place concrete of 1:2:4 mix to fill the bottom half of the hole from both sides. Place 8mm dia. HSD bar hooked at both ends in the hole. Fill the hole completely with concrete to fully encase the bar. Suitable polymer additive should be used to make the concrete non-shrink.
10. Make sure the entire length of the bar is covered with concrete. The length of the hooked bar should be equal to wall thickness less 50mm.
11. Cure for minimum 10 days by sprinkling water on the exposed surfaces on both sides. Finish the wall to match the existing wall. Follow the same procedure to make all the bond elements in all the walls.

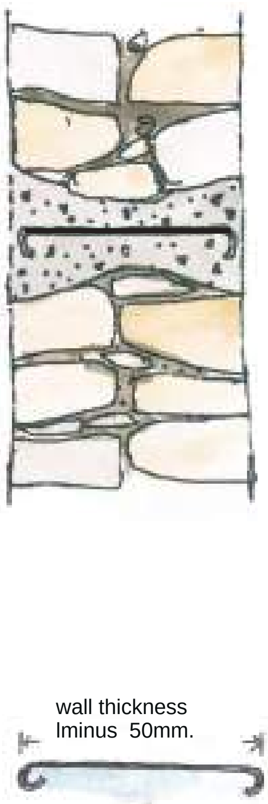
Note : Do not make more than 6 holes at a time for bond elements in a single wall, and fill them up with concrete <u>on the same day.</u>

A. Retrofitting of Existing Masonry Walls (cont.):

1. Cast-In-Situ Bond Elements - RR Wall - Installation (cont.)

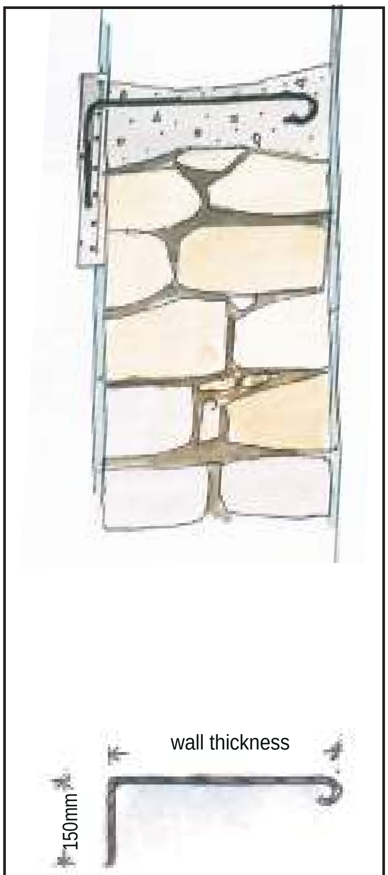
The details and method depend on the end-use (as shown below):

1. Bond element :
Used for stitching together the wythes of a thick wall.



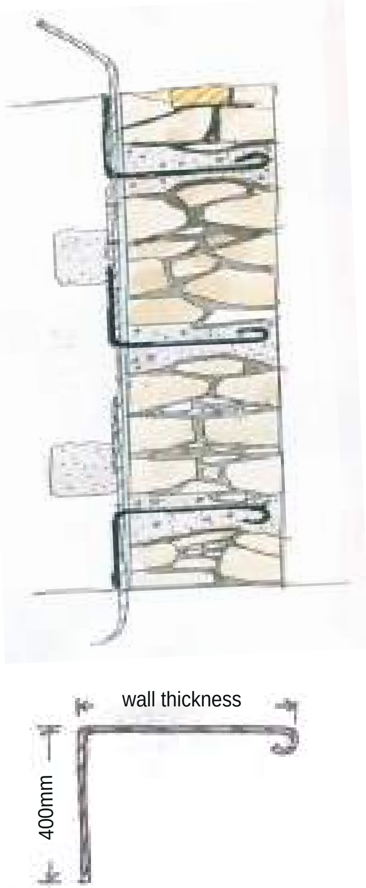
Both ends of the bar must have hook. Length of the bar after bending must be 50mm (2") smaller than the thickness of the wall.

2. Shear Connector for Seismic belt :
Used for anchoring WWM Belt on the masonry wall.



One end of the bar must be bent like a hook and the other like 'L' to which WWM is tied. The length of the bent portion must be 150mm (6"). The length of the bar after bending must be the same as the thickness of the wall.

3. Shear Connector for Vert. Corner bar:
Used for anchoring vertical reinforcing bar on the wall corner.



One end of the bar must be bent like a hook and the other end be bent like 'L' to which the vertical rod or WWM is tied. The length of the bent portion must be 400mm (16"). The length of the bar after bending must be the same as the thickness of the wall.

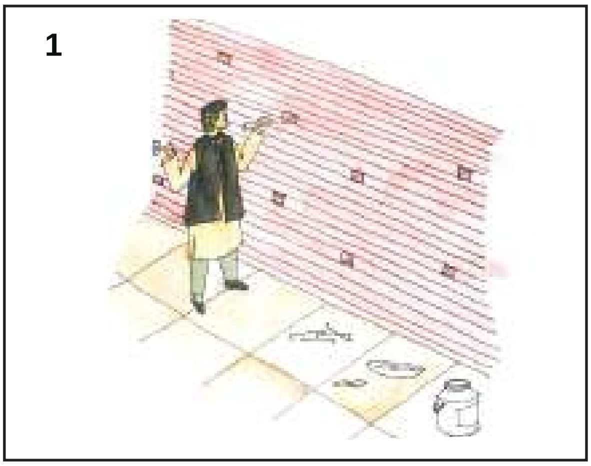
Caution: While making holes, exercise extreme care not to damage the wall and never use full size crow-bar. Use non-shrink concrete, and ensure full encasement of the rod.

A. Retrofitting of Existing Masonry Walls (cont.):

2. Cast-In-Situ Bond Elements - 350mm (14") or Thicker BB Wall: Installation

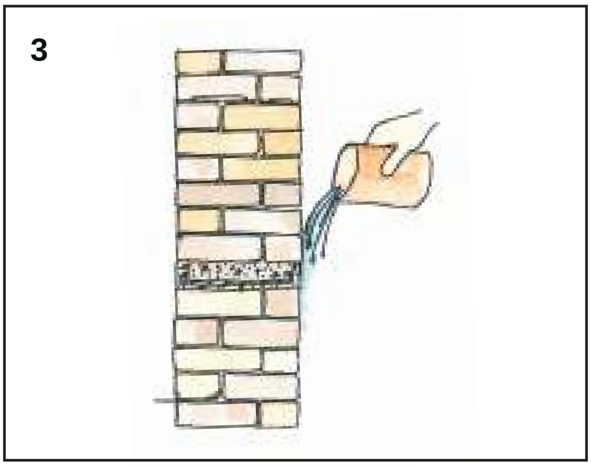
Weakness: Delamination of inner and outer faces of thick wall.
Remedial Measures: Installation of Bond elements in 350mm thick or thicker brick wall.

Delamination in Brick Masonry.



Marking point and rakeing the joints.

Pulling out brick carefully.



Curing bond elements.

1. Mark points at 1m spacing horizontally and vertically, with a stagger of 500mm., thus having one point in every 0.8 smt. (8 sft) of the wall area.
2. In a wall built with cement mortar, use a 350mm (14") long piece of a 35mm dia. GI pipe with slit end as a punch to make a through hole. In case of a wall built with mud mortar mark the header to be removed and rake off mud from the joint all around it. Loosen the brick slowly to remove it.
3. Splash water in the hole to clean off loose materials from the surface of the bricks.
4. Fill bottom half of the hole from both sides using non-shrink micro concrete of 1:1½:3 proportions and place 8mm dia. HSD bar in the hole and fill remaining void in the hole completely. Suitable polymer additive (CICOP Non-Shrink Polymeric Waterproof Grouting Compound or other equivalent) should be used to make non-shrink grout.
5. Make sure the entire length of the bar is covered with mortar. The bar must be 50mm less than the wall thickness to ensure full encasing.
6. Cure for minimum 10 days by sprinkling water on the exposed surfaces on both sides. Finish to match the existing wall. Follow the same procedure to make all the bond elements .

Bond Element variants can be used as Shear Connectors also as indicated earlier.

A. Retrofitting of Existing Masonry Walls (cont.):

3. Horizontal Seismic Belt :
Weaknesses in masonry walls: Poor wall-to-wall bonding, inadequate in-plane tensile strength, vulnerability of extra high and extra long walls resulting in a variety of cracks.

Remedial Measure:
Installation of Horizontal Seismic Belt.

Installing Seismic belt will help prevent such cracks.


Damage in extra high wall


Damage due to inadequate in-plane tensile strength


Damage in unrestrained Gable wall


Damage due to poor wall-to-wall bonding

How does the seismic belt work?

a. Like a string tied around a box, this belt binds all walls together and helps reduce cracking in corners.
b. It helps prevent walls from going out of plumb.
c. It also reduces bending of wall due to forces perpendicular to the plane of the wall, and thus helps prevent vertical cracks in the middle of the wall.
d. It resists tension caused by earthquake forces parallel to the wall, thus helps prevent the diagonal cracks, especially those emanating from corners of doors and windows.

Thus Seismic Belt improves the capacity of walls to resist the earthquake forces.

A. Retrofitting of Existing Masonry Walls (cont.):

3. Horizontal Seismic Belt - Installation (cont.).

At what locations in a building should Seismic belts be installed?

Uninterrupted seismic belts are to be provided on all walls at...

(a) Immediately below eave level for pitched roof,

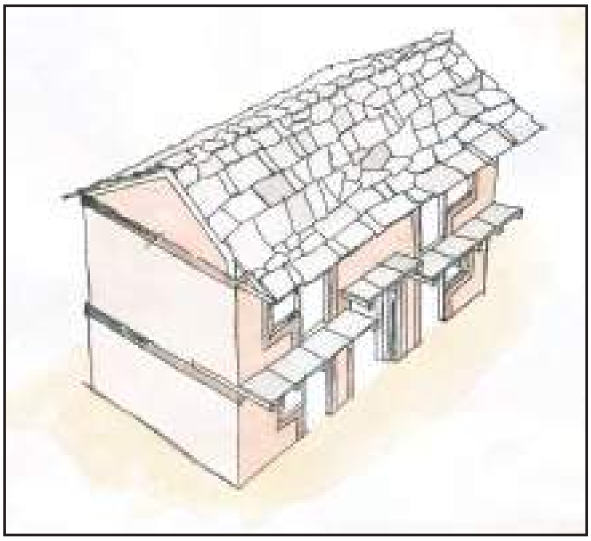
(b) Immediately above lintels of doors and windows unless the gap between eave level and lintel is less than 900mm, in which case lintel belt is not needed,

(c) Immediately below floor level, when floor is made of timber or prefabricated elements,

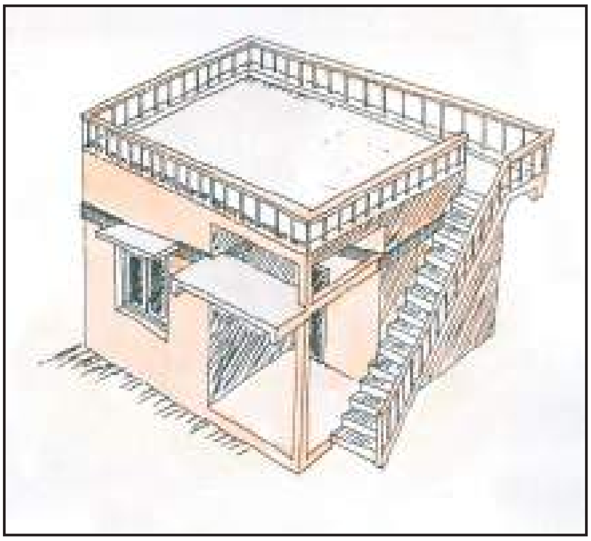
(d) Immediately below the sloping top of the gable walls, and immediately below the ridge on the ridge wall.

Some additional rules are:

- In case of flat RC roof, the eave level belt is not required.
- In case of RC floor, the floor level belt is not required.
- All belts are to be on both faces of wall.
- In a room if for some reason belt can be installed on only three walls, then to ensure continuity, a tie rod must be installed on the fourth wall at the same alignment.



Seismic belts for pitched roof building.



Seismic belt for RC slab roof building.

Specification of Seismic belt:

Belt is made with reinforcement consisting of galvanized welded wire mesh (WWM) and HSD/MS bars that are anchored to wall, and fully encased in cement mortar or micro-concrete. The width of belt should be 30mm wider than the width of WWM.

Reinforcement Requirements for Different Building Categories
(Note: For rooms with wall length <u>not exceeding 5m</u> ***)

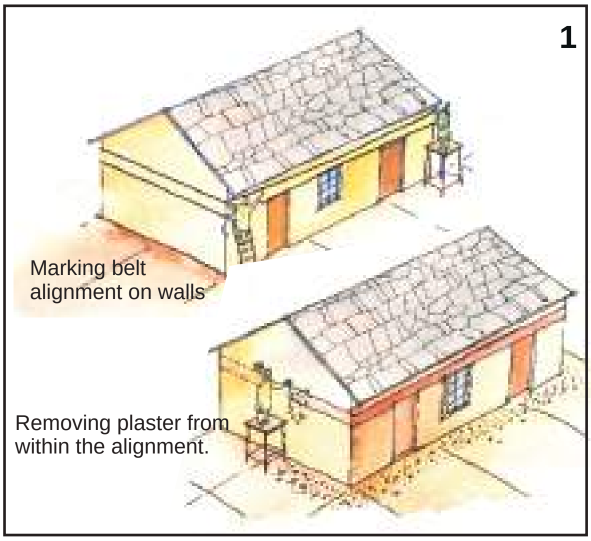
Building Category	Galvanized Welded Wire Mesh (WWM)	MS Roads
D: House in Zone IV	13ga.- 250mm wide with 8 longitudinal wires	2- 6mm dia. Bars
E: House in Zone V	13ga.- 250mm wide with 10 longitudinal wires	2- 6mm dia. Bars
E: Police Station, School, PHC etc. in Zone IV & V	13ga.- 250mm wide with 10 longitudinal wires	2- 6mm dia. Bars

Note: (i) In WWM the transverse wires should not be spaced at more than 75mm.
(Ii) 13 ga. WWM is easier to handle and install as compared to 10 ga.

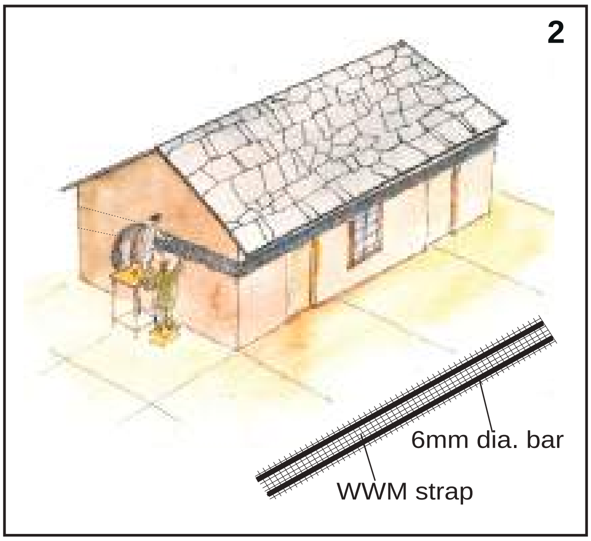
***** : For all other situations refer to Bureau of Indian Standards "Repair and Seismic Strengthening of Buildings" - Guidelines IS:13935-2008***

A. Retrofitting of Existing Masonry Walls (cont.):

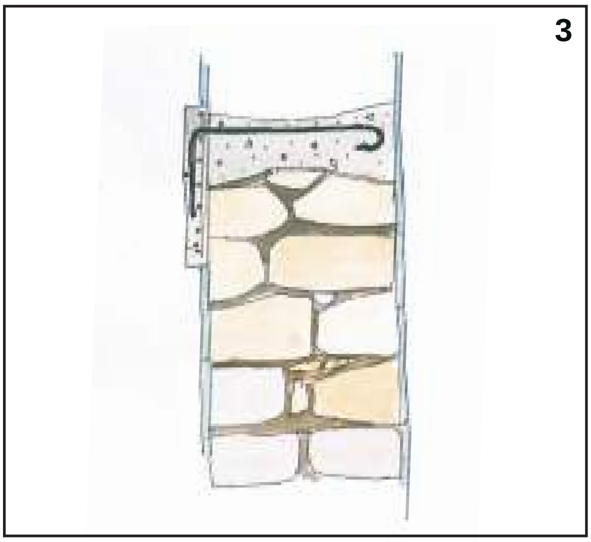
3. Horizontal Seismic Belt - Installation (cont.).



Preparing for seismic belt installation.



Installing seismic belt.



Shear connector for seismic belt.

Procedure:

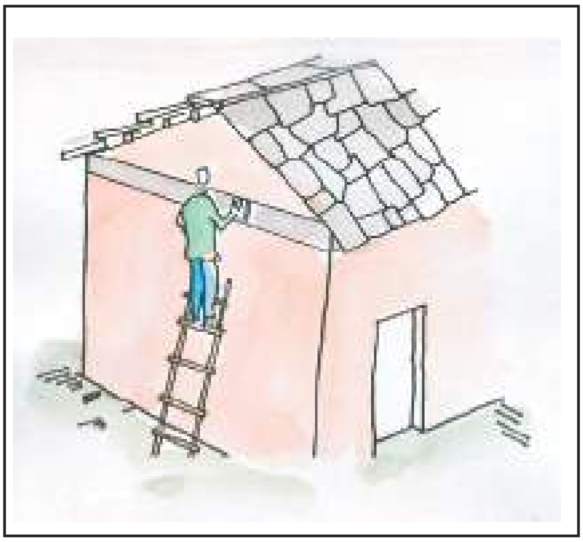
1. Study the building and decide the alignment of the belt, taking into consideration the presence of obstructions such as openings, non-masonry elements etc.
2. Mark the alignments of top and bottom edges of belt on wall using string and tube level.
3. Where the wall is plastered, use electric grinder, if available, to cut the plaster precisely along the top and bottom limits of the belt and to prevent the excessive plaster removal.
4. Remove the plaster from within the marked area and expose the masonry surface.
5. Rake all the mortar joints to the depth of 12mm (1/2”) by chisel or by electric grinder. Clean the surface with wire brush and water.
6. Cut WWM straps of the required length and width from the roll. Prepare the reinforcement assembly by attaching the precut 6mm bars, that are bent as required, to the strap using binding wires.
7. Install assembly on the prepared wall surface. In brick or concrete block wall, use 100-150mm (4”-6”) long masonry nails at about 300mm (12”) spacing in a staggered fashion in two rows to fix the assembly to the wall. Nails must be driven in mortar joints. Provide 15mm (0.5”) thick spacers of any suitable material between the wall surface and the mesh to ensure full encasement in plaster.
8. In case of rubble walls, install cast-in-situ RC shear connectors with 'L' shaped dowel bar at every 1.25-1.5m (4’-5') distance. Once the concrete hardens, attach reinforcement assembly to the bar using binding wire. In addition, use 100mm long square- headed nails at 150-300mm (6”-12”) spacing for anchoring. If a nail bounces back, then shift and reinstall it.
9. Ensure continuity of WWM and bars by making lap joints minimum 300mm (12”) long.

Caution: Make sure that the WWM is continuous around the corners.

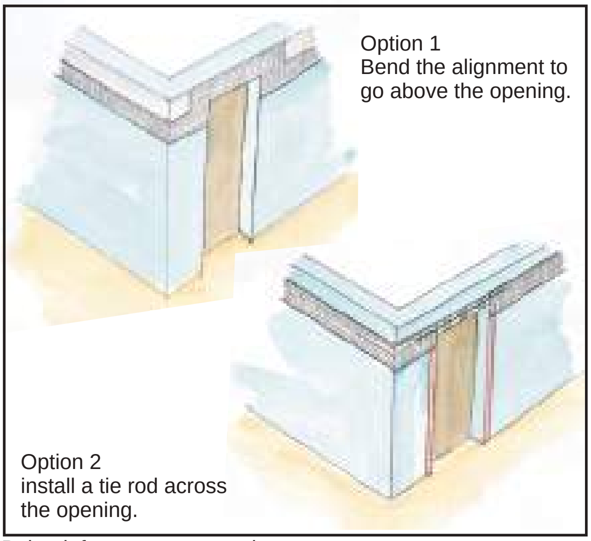
A. Retrofitting of Existing Masonry Walls (cont.):

3. Horizontal Seismic Belt - Installation (cont.).

10. Splash the exposed wall surface with water to remove all dust and also to wet it properly,
11. While still wet, apply neat cement slurry followed by first coat of cement:sand (1:3) plaster of 12mm (0.5”) thickness. After 1 to 2 hours, apply second coat of plaster with same mix and with enough thickness to provide 16mm (0.63”) cover over the reinforcement.
12. When the thickness of the coat is excessive, the plaster tends to fall off shortly after it is applied . Hence, <u>the thickness of a coat should never exceed 16mm</u>.
13. Cure the plaster for 15 days.



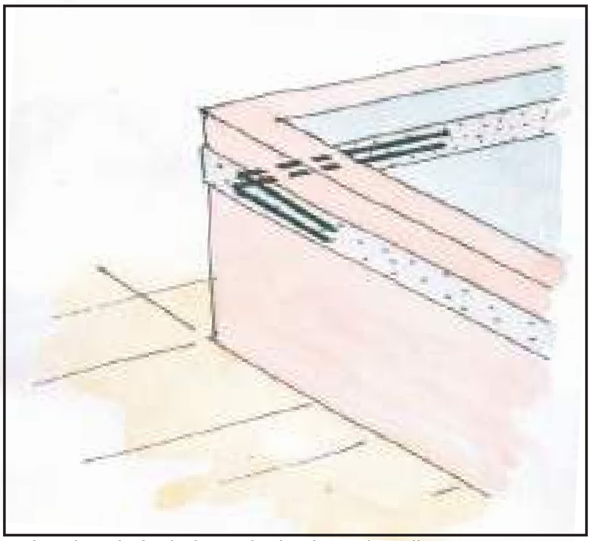
14. Where the belt alignment crosses an opening, there are two options that depend on the clearance between top of the belt and top of the wall.



Belt reinforcement at opening.

Option 1: <u>Clearance adequate to accommodate the belt</u>: Bend the belt alignment to go around the opening. Install a special shear reinforcement consisting of closely spaced zig-zag shaped 6mm MS bar with spacing no greater than 50mm. See detail in Chapter 8 - Case Studies.

Option 2: <u>Clearance being too small</u>: Install a 12mm rod across the opening with adequate overlap at both ends. Ensure that the rod is anchored at several points to the door frame.


Using dowels for belt continuity through wall.

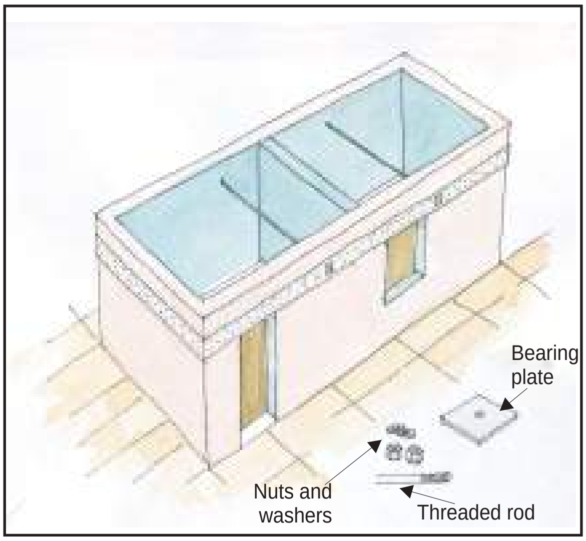
15. **Through the wall connection between belts on adjacent walls**

1. Make a hole through the wall, connecting the two belts.
2. Place through the hole, 2-8mm dia. HSD bars, either 'L' shaped or straight as the situation demands , with 450mm overlap with the WWM on both walls, and tie them with binding wires.
3. Fill the hole with 1:1.5:3 micro-concrete so as to fully encase the rods.

A. Retrofitting of Existing Masonry Walls (cont.):

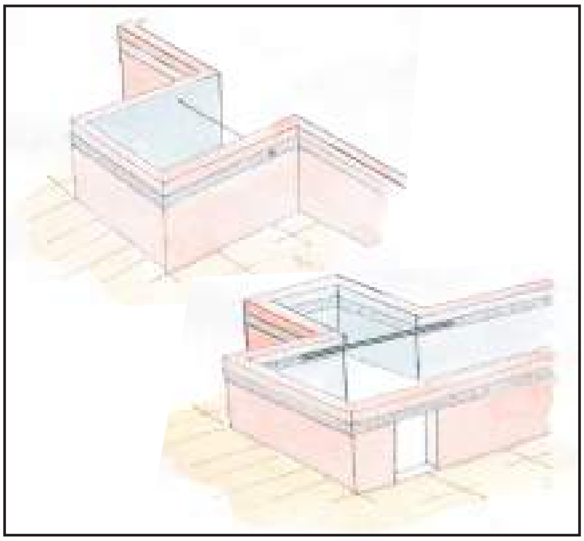
3. Horizontal Seismic Belt - Installation (cont.).

16. **Tie rod**: Tie rod shall be installed to ensure continuity of the belts in the following situations. It shall be 12mm dia MS bar with each end threaded over an adequate length along with two nuts and a 100mmX100mm MS bearing plate. Tie rod shall be installed horizontal from belt on one wall to the belt on the opposite wall. It shall go clear through a conduit placed in both walls and the belts. The rod shall be made taut with the help of the two nuts adequately tightened at each end.



Tie rod installation.

17. **Ensuring Belt Continuity across small masonry projections in walls.**

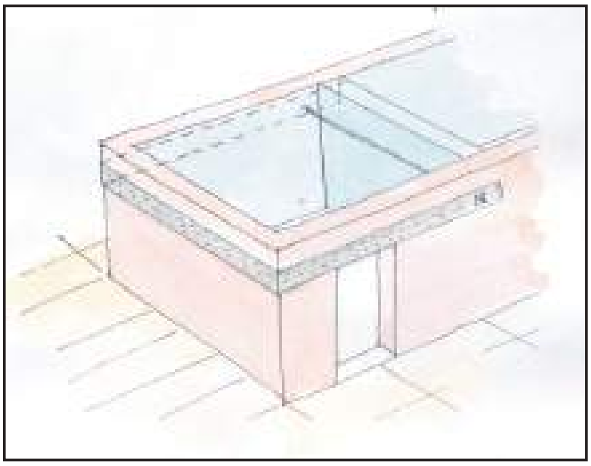

Ensuring continuity across small wall projections

This situation arises in the narrow masonry structures projecting out from the main structure. e.g. small passages or enclosures like bathroom or toilet.

1. Continue the Seismic belts around the structural projection.
2. Install tie rod across the beginning of the projection.
3. Tie rod should be installed through the opposite walls.
4. Alternatively, if the Seismic belt is on the inside wall-face of the main structure, then the continuity across the passage may be provided by simply placing a tie rod over the ends of the belt at the projection with adequate overlap on the belt.

18. **Ensuring Belt Continuity when Belt is installed on only three walls**

1. Install the belt reinforcement, including the WWM on three walls. Extend the reinforcement of the belts as close to the fourth wall as possible.
2. Make through holes (similar to that of Bond Element) within the belt alignment on both the walls as close to the fourth wall as possible.
3. Install a 12mm dia. MS tie rod through these holes in order to restrain the free end of the seismic belts.


Ensuring continuity with tie rod on 4th wall.

A. Retrofitting of Existing Masonry Walls (cont.):

4. Vertical Reinforcement - Installation

Weaknesses in masonry walls : (i) Poor storey-to-storey bonding, (ii) poor wall-to-roof bonding, and (iii) inadequate strength against vertical bending in masonry.

These weaknesses result in horizontal cracks, collapse of wall, and also the sliding of roof on top of support walls.

Collapse due to inadequate bending strength in masonry.

Poor storey-to-storey bonding.

Poor wall-to-roof bonding.

Poor wall-to-roof bonding.

Remedial measures: Installation of Vertical Reinforcement.

Vertical reinforcement attached to masonry wall will help reduce such failures.

How does the vertical reinforcement work?

a. It improves the bending strength and ductility of the wall, which in turn help control the horizontal cracking, and hence, reduces the possibility of the walls going out of plumb or collapsing.
b. It helps bond the roof with the walls, thus providing support to the wall and controlling its shaking in earthquake.
c. It helps improve the bond between successive storeys, which also strengthens the walls.

Location of Vertical Reinforcement.

Vertical reinforcement attached to masonry should be installed in all the buildings in the region as follows:

1. At all junctions of walls.
2. At 'T' junction, only on one side of the junction.
3. Through all storeys.

A. Retrofitting of Existing Masonry Walls (cont.):

4. Vertical Reinforcement - Installation (cont.)

Types of Vertical Reinforcement.

a. Single reinforcing bar.
b. Vertical Strap with Welded Wire mesh and Reinforcing bars.

a. Single Vertical Bar.

A bar should be installed at the inside corner of the wall-to-wall 'L' type junction. In case of 'T' junction, it could be installed on any one of the two corners of the junction.

Reinforcing Bar Requirement for Different Situations for Seismic Hazard ***				
		House		Public Building
		HSD Bar Dia. in mm.		HSD Bar Dia. in mm.
No. of Storeys	Storey	Zone IV	Zone V	Zone IV & V
One	Ground	10	12	12
Two	First	10	12	12
	Ground	12	16	16

b. Vertical Reinforcement Strap of Welded Wire Mesh and Reinforcing Bars.

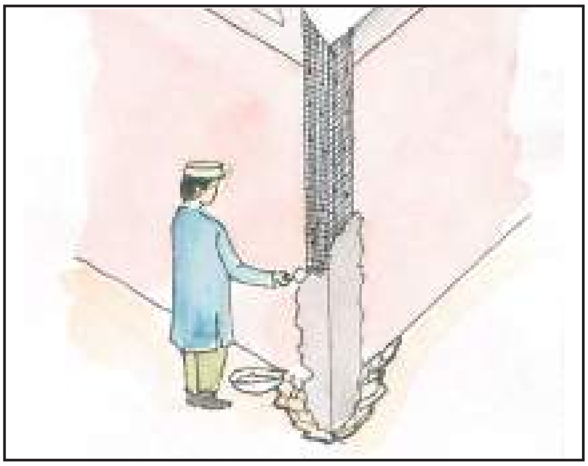
A strap of WWM is installed in 'L' configuration on the outside of 'L' type wall-to-wall junction, and in flat configuration on the outside of the of 'T' type junction.

Weld Mesh Requirement for Different Situations for Seismic Hazard ***					
		House Zone IV		Public Building Zones IV & V	
		WWM 13ga.*		WWM 13ga.*.	
No. of Storeys	Storey	N	B	N	B
One	Ground	10	300	14 Plus 2 bars of 6mm dia.	400
Two	First	10	300	14	400
	Ground	14	400	14 Plus 2 bars of 6mm dia. and 1 bar of 12mm dia.	400

N: No. of longitudinal wires in mesh, B: Width of finished vertical belt.
***:** WWM made of 13 ga. WWM is recommended here since the greater stiffness of 10 ga. WWM is difficult to handle. The number of wires of 13ga. and reinforcing bars together provide cross section area that is equal to that available with 10 ga. WWM.

**** : For all other situations, refer to IS 13935 (2008) Guidelines.*

Single vertical bar.



Vertical Strap made of WWM and Reinforcing bars.

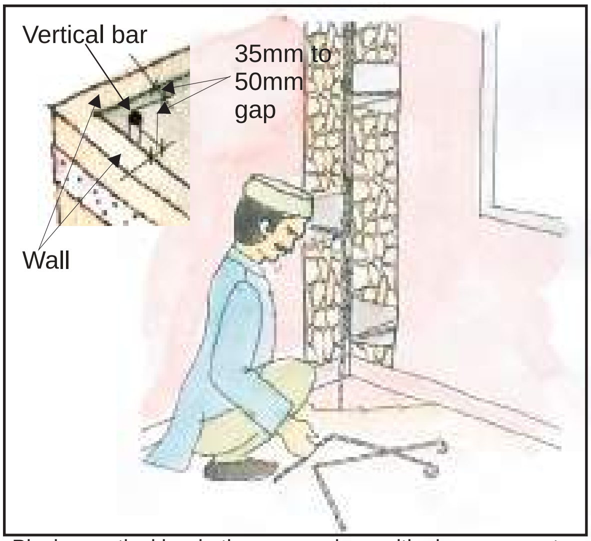
A. Retrofitting of Existing Masonry Walls (cont.):

4. Vertical Reinforcement - Installation (cont.)

(a) Installation of Single Vertical Reinforcement Bar.

Step-by-step installation procedure:


Marking boundaries for vertical bar concreting.



Placing vertical bar in the corner along with shear connectors.

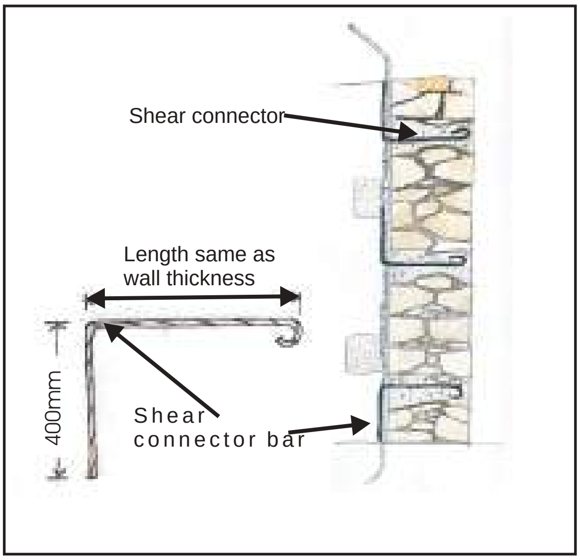

Breaking flooring and dig hole for vertical bar anchor.

1. Identify the inside corner for installation of vertical bar. Select appropriate location to maintain vertical continuity between storeys in case of multi-storeyed structure.
2. Mark the area where the bar is to be installed. Using plumb-bob demarcate 100mm (4”) wide patch at the corner on both walls as the limits of concreting for encasing the rod.
3. Using electric grinder or chisel cut the plaster neatly along vertical boundary of both sides, avoiding damage to plaster beyond the alignment of vertical bar.
4. Remove the plaster from the marked area and expose the walling material. Rake all the mortar joints to the depth of 12mm (1/2”). Clean the surface with wire brush.
5. Remove flooring within 300mm x 300mm patch at the corner and excavate to 450mm depth.
6. Make holes alternately in both walls for shear connectors. Starting at 150mm (6”) from the floor in one wall, continue making holes approximately at every 600mm (2') on alternate walls, ensuring that the topmost hole in the storey height is made 150mm (6”) below the ceiling level (in structures with more than one storey) or the eave level. Clean all the holes with wire brush to remove loose material.
7. Place appropriate diameter bar in the bottom excavation with bottom end bent 150mm (6”) in 'L' shape. In a structure with CGI roof, the top end could be connected to one of the principal elements of the attic floor or the roof. In case of the RC slab, bend it in ‘L' shape and connect to the slab reinforcement. The rod will pass through each intermediate floor.
8. Place in the holes 8mm HSD bar shear connectors shaped as described earlier, and connect them to the vertical bar making sure that the vertical bar is 35 to 50 mm (1.5” to 2”) away from each wall.

A. Retrofitting of Existing Masonry Walls (cont.):

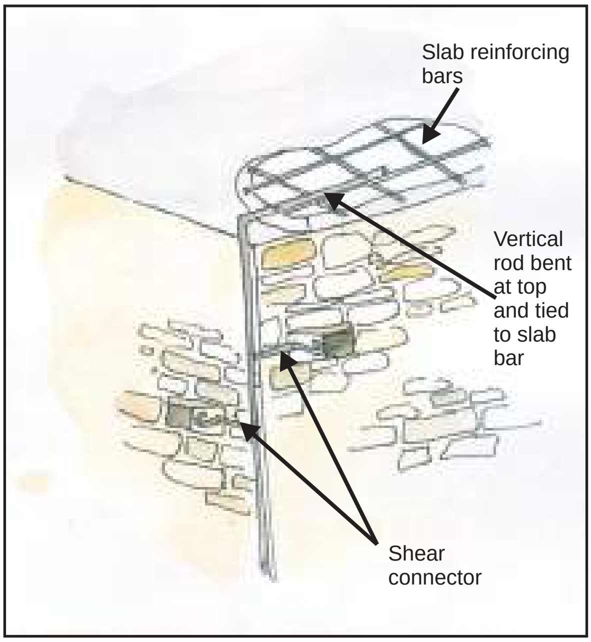
4. Vertical Reinforcement - Installation (cont.)

(a) Installation of Single Vertical Bar Reinforcement (cont.).



Shear connector and vertical bar details.

Encasing vertical bar in concrete.



Connecting top bent end of vertical bar to slab reinforcement.

9. With vertical bar plumb and 35 to 50 mm (1.5" to 2") away from each wall, pour concrete in 1:2:4 proportion with continuous rodding in the hole in the ground to completely encase the bottom of steel rod in concrete.
10. Clean all the shear connector holes by splashing water and wetting thoroughly the surface of the holes. Fill up the holes with non-shrink cement grout or micro-concrete. Make sure that the grout/concrete completely encases the shear connector bar.
11. Once all the shear connectors are grouted, clean the exposed surfaces of the wall with wire brush and water.
12. Install centering for concreting around the vertical bar. This can be done with GI sheet or timber plank. The concreting must be done in stages with their height not exceeding 900mm (3'-0"). Pour 1:1½:3 micro concrete behind the form-work with continuous rodding to prevent honeycombing. Once the concrete is set, move the form-work upwards and continue concreting. Encase the entire length of the vertical bar in this manner. The bar must have the minimum concrete cover of 15mm.
13. Where the roof is of RC slab, break the bottom concrete cover in the vicinity of the vertical bar, to expose the slab reinforcing bars. Connect the top bent portion of the vertical bar to the exposed bars of the slab using binding wires while providing a minimum of 300mm (12") overlap. Wet the exposed surface of the slab and then apply neat cement slurry. Finally apply cement mortar in 1:4 proportion and finish the joint to match the surrounding area.
14. Cure all the concrete work for 15 days.

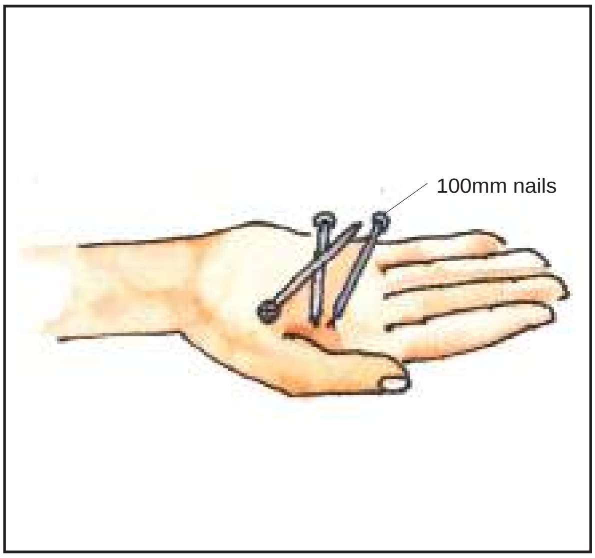
A. Retrofitting of Existing Masonry Walls (cont.):

4. Vertical Reinforcement - Installation (cont.)

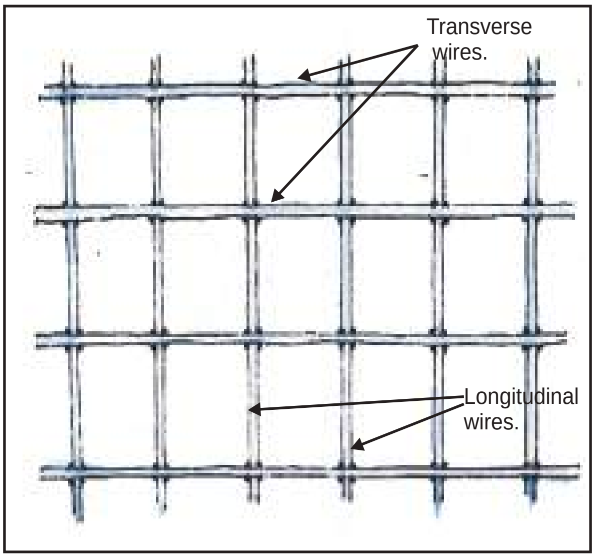
(b) Installation of Vertical Reinforcement Strap


Removing plaster for vertical strap installation


Anchoring vertical strap 300mm below plinth level



Use nails for anchoring vertical belt to wall



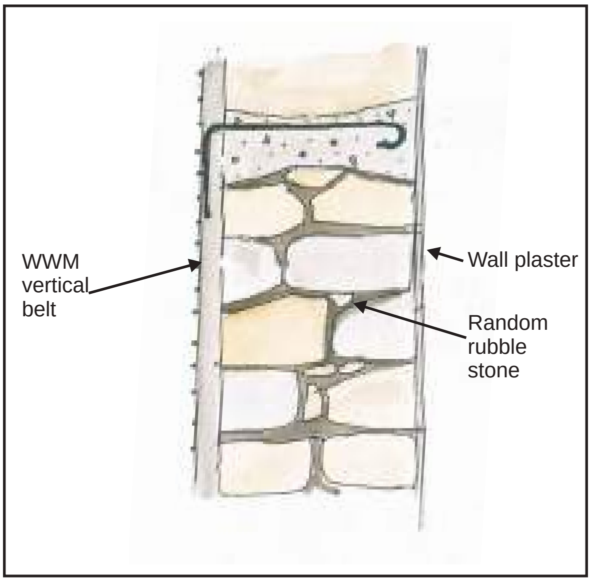
WWM for vertical strap

1.Identify the corners where flat configuration straps are to be installed and where “L” configuration straps are to be installed.
2. Mark the strap alignment on the wall using string and plumb-bob.
3. Using electric grinder, if available, or chisel, cut the plaster along the limits of the strap while avoiding damage to the plaster beyond this limit.
4. Remove the plaster from the marked area and expose the walling material.
5. The strap will start from 300 mm below plinth level and continue through to the top of the wall at roof level.
6. Rake all the mortar joints to the depth of 12mm (1/2”) by hand or by electric grinder. Clean the surface with wire brush.
7. Prepare the reinforcement assembly as per required length and attach with binding wires to it the precut 6mm bars that are bent to necessary configuration.
8. Install reinforcement assembly where the area of the wall has been cleaned. Use 100mm (4”) to 150mm (6”) long wire nails at about 300mm (12”) spacing in staggered fashion in two lines to fix the mesh to the wall. Nails must be driven in the mortar joints. Provide spacers 15mm (0.5”) thick of any suitable material between the wall surface and the mesh.

A. Retrofitting of Existing Masonry Walls (cont.):

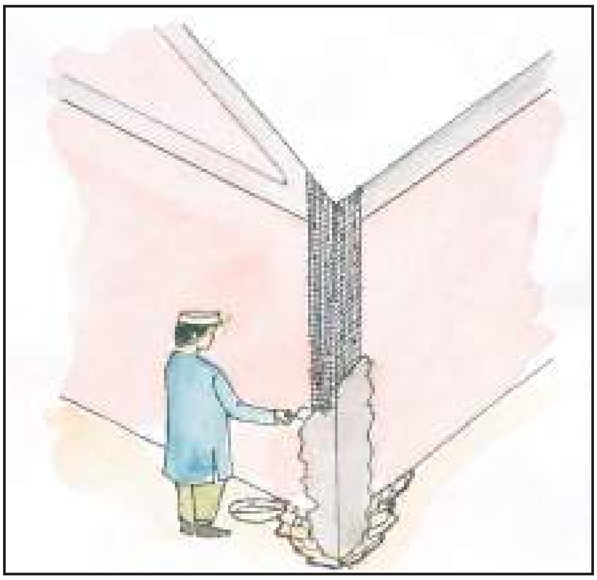
4. Vertical Reinforcement - Installation (cont.)

(b) Installation of Vertical Reinforcement Strap (cont.).



Anchoring WWM to random rubble wall with shear connectors.

Anchoring vertical WWM to the brick wall with nails.



Plastering vertical WWM strap using cement mortar.

9. In case of rubble walls, use 100mm long square-headed nails at 300mm spacing for installation. In addition, also use cast in-situ RC shear connectors with 'L' shaped dowel bar for greater reliability. Shear connectors are to be installed starting from 150mm (6") above floor level at a spacing of 600mm (2'). Successive connectors will be placed on different wall at the corner. Once the concrete hardens, attach WWM to it with binding wire. In addition, follow the instructions of installing the mesh as described above.
10. Ensure continuity of WWM and bars through overlap joints. The minimum overlap shall be 300mm (12").
11. Splash the exposed wall surface with water to remove all dust as well as to wet it properly.
12. While still wet, apply neat cement slurry followed by first coat of cement:sand (1:3) plaster of 12mm (0.5") thickness. After 1 to 2 hours, apply second layer of plaster with the same mix and with enough thickness to provide 16mm (0.63") cover over the reinforcement.
13. Cure the plaster for 15 days.

A. Retrofitting of Existing Masonry Walls (cont.):

5. Opening Encasement with Seismic Strap.

Weaknesses in Masonry Walls: Poor racking shear strength results in diagonal cracking at openings.

Remedial Measures: Encasement of openings with Seismic Strap.

This will help prevent such diagonal cracks.

How does the Encasement of opening work?

a. In simple terms, it strengthens the boundary around the opening, especially at their corners where concentration of tensile stresses occurs. Encasement helps in resisting the tearing action that begins at opening corners. This is like stitching extra patches of cloth around the boundary of an opening in the cloth.

b. When the gap between two openings is very small, the wall in that gap behaves like a pier. This pier is very weak in shear and bending. Hence, wrapping up of the pier in seismic belt greatly strengthens the pier against shear and bending forces.

The encasement strap must be uninterrupted all around the opening, and placed as close to its jamb as the nailing in the masonry permits.

Diagonal cracking: pier width too small.

Severe diagonal cracking: windows too close to corner.

Diagonal cracking in brick wall.

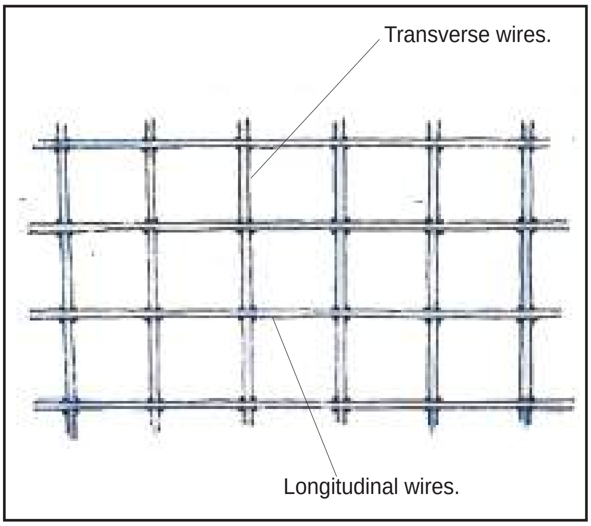
Diagonal cracking in RR wall.

A. Retrofitting of Existing Masonry Walls (cont.):

5. Opening Encasement with Seismic Strap - Installation (cont.)

Specification of strap:

- Galvanized 10ga. mesh with 8 wires in longitudinal direction spaced at 25mm with Weld Mesh width of 200mm and plastered belt width of 250mm.
- Alternatively 13ga. mesh with 6 wires spaced at 50mm and 2-6mm dia MS bars for the ease of handling. Reinforcing bars alone with equivalent area too may be used along with Chicken wire mesh if the right WWM is not available.



Galvanized Welded Wire Mesh (WWM).

Installing WWM around door opening.

Install encasement strap all around.

1. Demarcate 250mm (10") wide belt all around the openings.
2. Since the lintel belt is installed just above the openings, the encasement strap is required only on the sides of the opening and under the opening, such as windows and ventilators.
3. The procedure is exactly the same as that used for the horizontal and vertical seismic belt.
4. Belts on all sides of encasement must overlap at corners. The belts on top sides must overlap with the lintel level belt.
5. In case of an RC lintle band or *chhaja,* connect the encasement to it with 8mm HSD dowel anchored in RC element with non-shrink grout.
6. In case the spacing between two openings is less than 500mm, then the vertical portions of the encasement for both openings should merge in to each other.

WWM around window opening with overlapping at corners.

Completed encasement belt around window.

B. Retrofitting of Existing Flat Floor:

1. Diagonal braces and Struts in Timber Floor - Installation

Weakness in Timber Floor: In-plane flexibility leading to significant deformation and breakage of timber deck under lateral seismic loads.

Remedial Measures: Installation of Diagonal braces & Struts in Timber Floor.

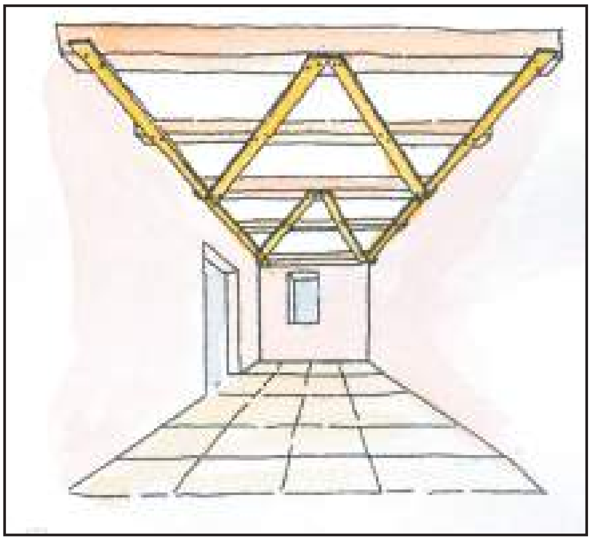
While deck deforms from rectangular shape to parallelogram, its diagonals lengthen or shorten. Diagonal bracings and the struts, if connected securely to the joists, greatly reduce the in-plane deformation of the deck and, hence, the damage. In other words, **diagonals and struts improve the diaphragm action to transfer shear to shear walls.**

Damaged Roof Elements.

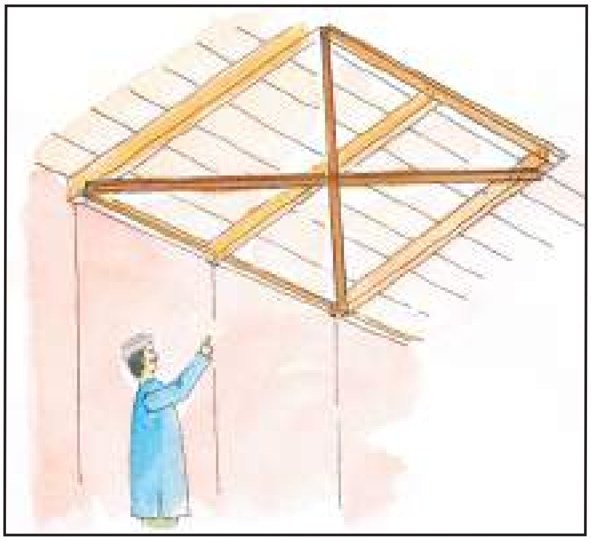
Pre-driling bracings and struts is important.

How to install timber struts and braces on floor?

1. The bracings and struts can be installed by various arrangements as shown below.
2. Install 100x25mm (4”x1”) struts (plank) on the underside of the floor joists adjacent to two long walls. **Pre-drill** these planks to prevent splitting from the holes near the ends. Also pre-drill pilot holes in the floor joists, if possible, to facilitate nail driving. Use minimum of two nails at each floor joist.
3. Install diagonal bracings starting from one end of a strut to the far end of the opposite strut. The angle between the brace and the strut should be as close to 45^0 as possible, but allowing bracings of equal length to be accommodated.
4. Install more sets of bracings in a similar arrangement to cover more floor area.
5. Bracings are installed in a manner similar to that for the struts. If, however, it is difficult to accommodate two nails at the ends, then gusset plates made of 3mm thick MS or 12mm thick plywood may have to be used with bolts.



Timber Bracings - '**K**' arrangement.



Timber Bracings - '**X**' arrangement.

B. Retrofitting of Existing Flat Floor (cont.):

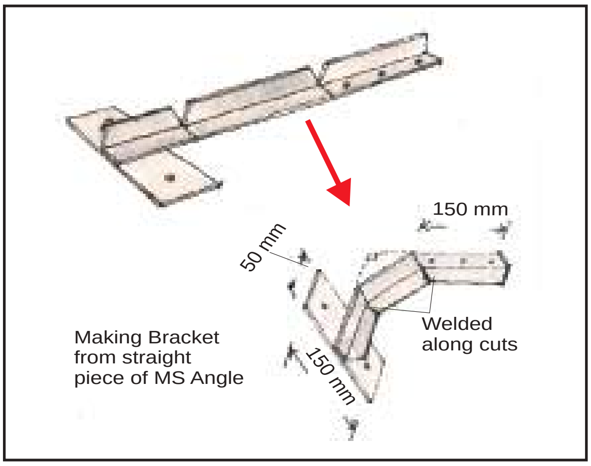
2. Anchoring of Floor deck - Installation

Weakness in Timber Floor Supported on Masonry Walls: Floor and walls are not connected to each other. So walls are unrestrained at the top, and hence, more vulnerable.

Remedial Measure: Anchoring of Floor deck to Masonry walls.

When floor deck with diagonal bracings is anchored to masonry walls, it holds the walls together and reduces their movements since it does not deform. Thus it reduces the likely damage. **The procedure for brick wall is different from that for RR wall.**

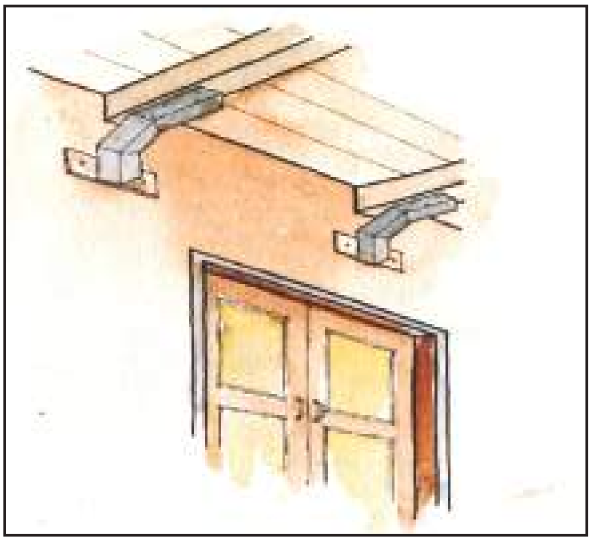
Wall damaged due to inadequate bonding between brick masonry walls and roof deck.



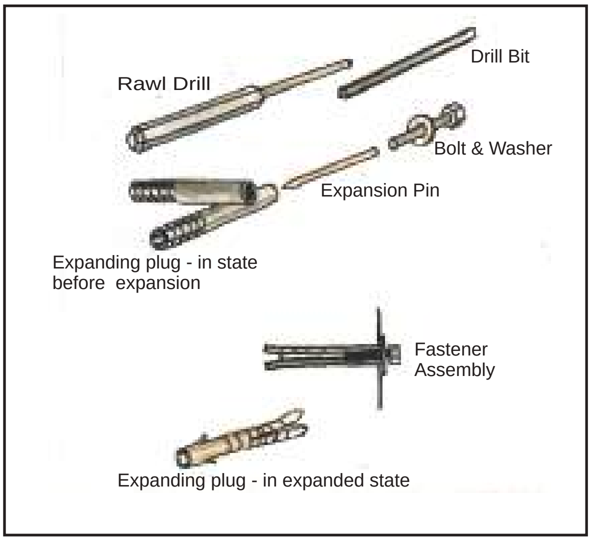
Roof-deck to brick-wall anchor.

(a) How to anchor floor deck to the Brick Masonry walls?

1. Get brackets made from MSI angles 50x50x3mm or 50x50x5. Get a 150x150mm MS plate 3mm thick with two holes welded to one end of bracket .
2. Identify the beams that must be anchored to the wall.
3. Using 15mm dia. bit, drill two holes at suitable locations in the walls at each or every alternate floor joist. Make holes either through or only 200mm (8") deep.
4. In through holes use 2 bolts of 12mm dia. with 75x75x3mm thick MS bearing plate on the other face of the wall at each bolt to install brackets on the wall .
5. In case of holes of partial depth, use polymer grout or mechanical anchors to anchor bolts.
6. Connect bracket to the underside of the wood beams with minimum of 3-10 ga.100mm long nails driven into the pre-drilled holes in them.



Floor deck anchored to brick wall.



Fasteners for anchoring in the brick masonry wall.

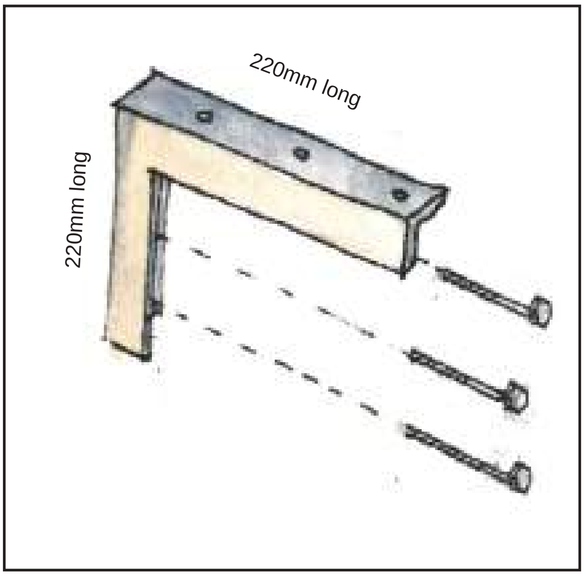
B. Retrofitting of Existing Flat Floor (cont.):

2. Anchoring of Floor deck - Installation (cont.)

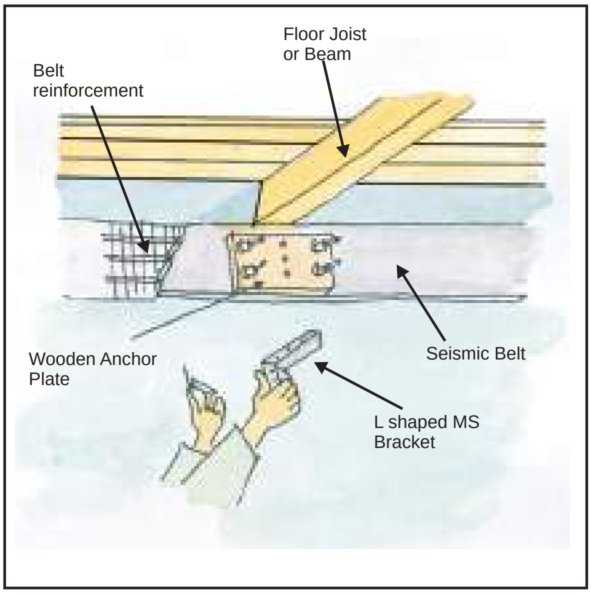
(b) How to anchor floor deck to the Random Rubble walls?

1. Get 220x220mm 'L' shaped brackets made from MS steel angles 50x50x3mm with 3 - 15mm dia. holes in each leg.
2. Identify bottom beams that must be anchored to the wall.
3. Prepare a 35x250x450mm wooden anchor plate with 4 - 15mm dia. holes in corners and 3 - 15mm dia. holes for bracket.
4. Connect bracket to the plate with 3-12mm dia. bolts.
5. Under each floor beam, install the plate with 4 - 12mm dia. bolts connected through WWM of Seismic Belt.
6. Connect bracket to the underside of the beam with 3 - 12mm dia. bolts placed through the beams. Alternatively use 3 - 8 ga. 100 to 150 mm long nails driven into pre-drilled pilot holes.
7. Instead of individual wooden plates, a full length 30x250mm plank may be installed with 12mm dia. bolts through the wall.

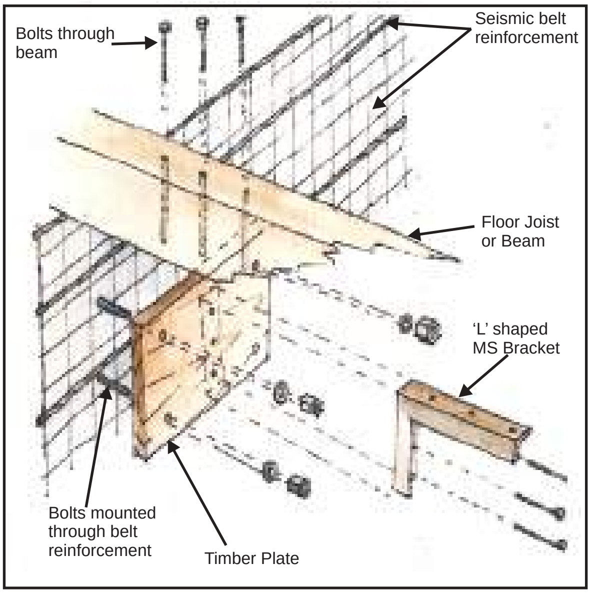
Wall damaged due to inadequate bonding between RR masonry walls and attic floor deck.



MS bracket and bolts assembly.



Installing bracket on timber plate mounted on seismic belt.



Bracket assembly installation.

C. Retrofitting of Existing Stone Tile / *Pathal* / CGI roof.

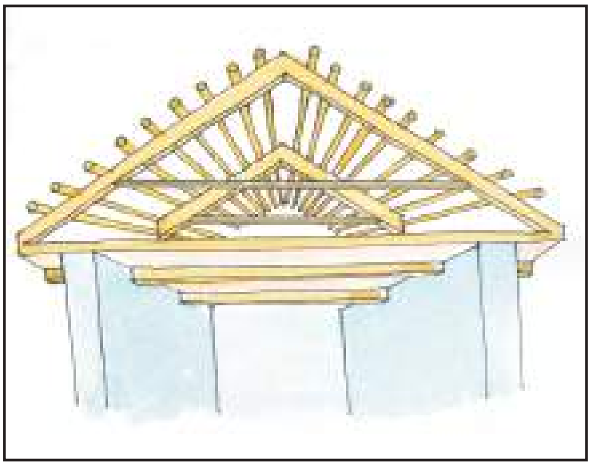
1. Principal Rafter Collar Beam - Installation

Weakness in Sloping Slate Roof : Out-of-plane flexibility leading to significant deformation of roof under lateral seismic loads, resulting in damage.

Remedial Measures: Installation of Principal Rafter Collar Beam / Horizontal Tie.

This tie will help restrain the movement of the principal rafters in outward direction, thus reducing the out-of-plane deformation of the roof. Hence, they effectively reduce the horizontal thrust from the rafter to the roof support walls or to the attic floor.

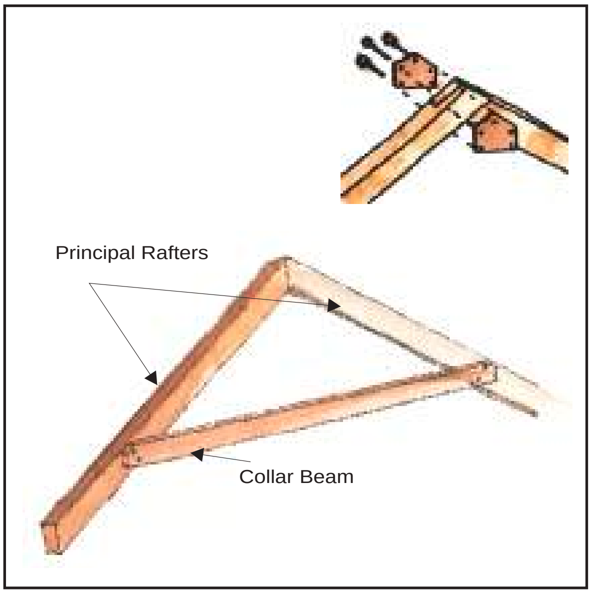
Roof damaged due to inadequate tying.



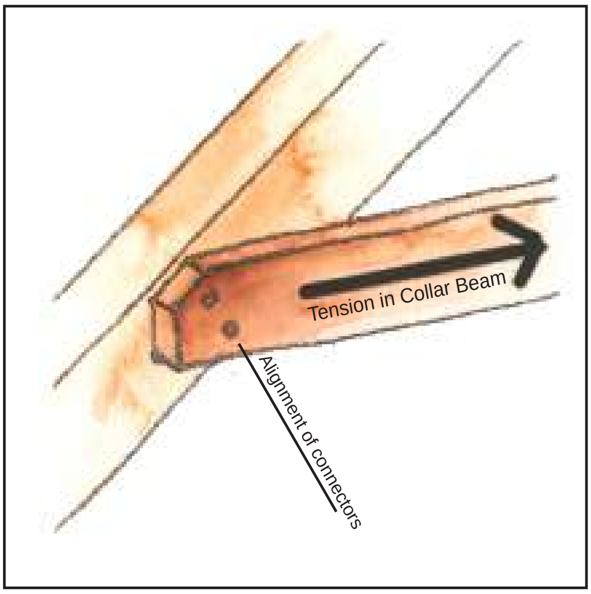
Installation of collar beams between opposite principal rafters

Installation of Collar Beam

1. Mark installation points on both vertical faces of the rafters at approximately 1/3rd rise of the roof on both sides of the ridge. Ensure proper level using tube-level.
2. Prepare a set of collar beams from a 50x100mm plank. Pre-drill the plank to prevent splitting at ends. The holes should be so aligned that the line joining them is not parallel to the length of the collar-beam. **Pre-drill pilot holes** in the rafters also, since the timber may be dry and hard. **Nailing without pre-drilling can damage it**.
3. Install collar beam with minimum 2-10ga 75mm long nails or 2-5mm dia. bolts at each end.



Collar beam for roof truss.



Arrangement of bolts with respect to tensile force.

Note: Collar beams should be installed on principal rafters in CGI roof also.

C. Retrofitting of Existing Stone Tile / CGI roof (cont.)

2. Struts and Diagonal Bracings - Installation

Weakness in Sloping Stone Tile / *Pathal* / CGI Roof : In-plane flexibility allows in-plane deformation of roof under lateral seismic loads leading to damage to the roof.

Remedial Measures: Installation of Struts and Diagonal Bracings

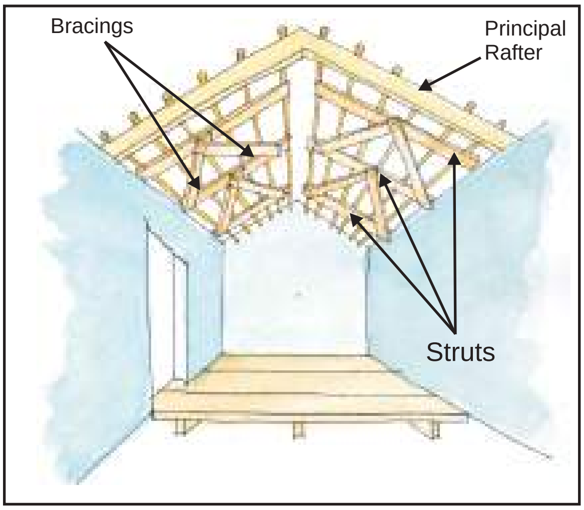
Roof damaged due to inadequate in-plane strength.

These elements installed at the underside of **the purlins that span between gable walls and principal rafters** or under **the rafters that span from ridge beam to eave level walls** will help maintain the integrity of the roof structure and help prevent the in-plane distortion of roof in the event of earthquake forces parallel to the ridge. Thus it will reduce the possible damage to roof. In other words, **diagonals and struts improve the diaphragm action to transfer shear to the shear walls.**

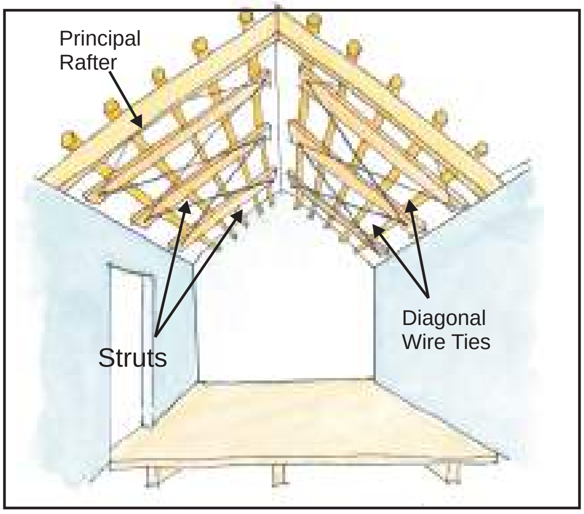
How to install struts and diagonal bracings?

1. Bracings can be installed in a variety of arrangements as shown in the diagram depending on available timber length. The continuity from ridge to eave level must be maintained.
2. Install a pair of 100x50mm struts parallel to principal rafter and connected to all the purlins, one adjacent to gable wall and one adjacent to the principal rafter.
3. The angle between the bracing and purlin should be as close to 45^0 as possible to optimise its effectiveness.
4. Bracing should be of 100x50mm (4”x2”) or heavier planks. Pre-drill the planks to prevent splitting around the holes at the ends. Also pre-drill the principal rafters to minimise the problems of driving nails in them and causing them to split because of their age and dryness. Use minimum two nails at each rafter.
5. Bracings must be installed in a symmetrical fashion on either side of the ridge.
5. If the space is not adequate for two nails at the junction with strut, then 3mm gusset plate or 12mm plywood can be used.

In some regions the roof understructure consists of rafters spanning from ridge beam to eave level walls. Hence, the struts and bracing arrangement will have to be correspondingly changed



Roof retrofitted with in-plane bracings - '**K**' Arrangement.



Roof retrofitted with in-plane bracings - '**X**' Arrangement.

In CGI roof supported on purlins, struts and bracings may be installed to reduce in-plane flexibility or to improve the Diaphragm Action.

C. Retrofitting of Existing Stone Tile / CGI roof (cont.)

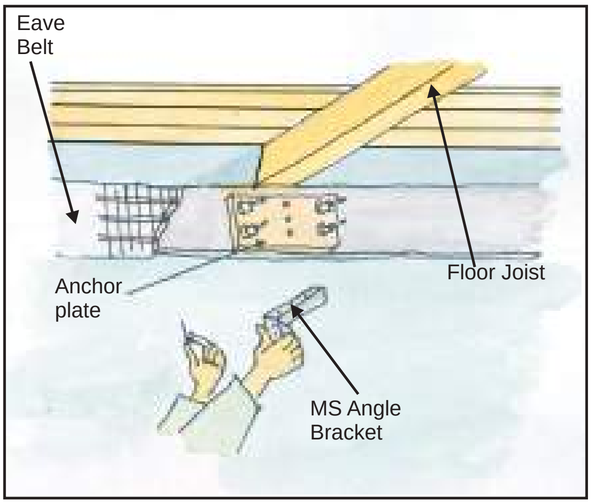
3. Securing Principal Rafters and Purlins.

Weakness in Sloping Stone Tile / *Pathal* / Slate Roof : Absence of secure connection between supporting walls, and the purlins and principal rafters results in damage in an earthquake.

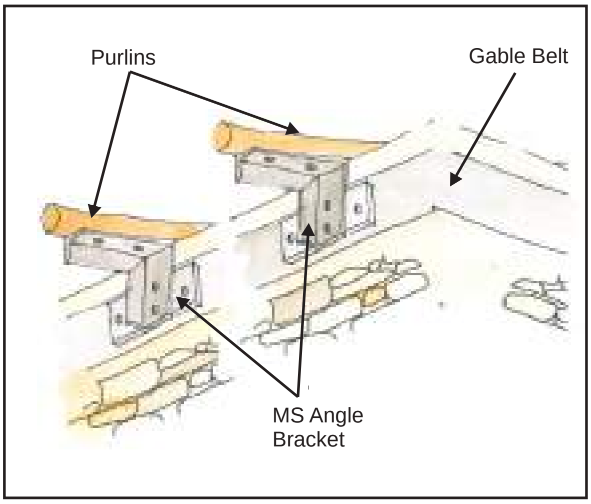
Remedial Measures: Securing Principal Rafters and Purlins to support walls

Roof damage due to inadequate connection between the walls and the roof.

If the roof has bracings and struts, and is securely connected to Principal rafters at one end and to the gable wall at the other end, then gable walls will be restrained from lateral movement. This will reduce the damage to gable walls. Similarly, if principal rafters are secured to eave level walls, then these walls too will be restrained from lateral movement. This will reduce the damage in those walls.



Arrangement for securing principal rafters.



Arrangement for securing purlins.

a. How to secure Principal Rafter

Use MS or wooden brackets as described under "Anchoring of Floor Deck" to secure Principal Rafters.

It is important to connect the brackets to eave level Seismic Belt for distribution of load.

a. How to secure Purlins

Use MS or Wooden brackets as described under "Anchoring of Floor Deck" to secure Principal Rafter.

It is important to connect the bracket to eave level Seismic Belt for distribution of load. For each purlin provide one wooden plate for ease of connection.

In CGI roof also, the Purlins and the Principal Rafters should be securely connected to the walls.

The RC slab roof would be anchored to masonry wall with the help of the Vertical Reinforcement as described under "A. Retrofitting of Existing Masonry Walls, 4. Vertical Reinforcement - Installation".

D. Retrofitting of Miscellaneous Elements

1. Encasing masonry pier.

Weakness in Masonry Piers :

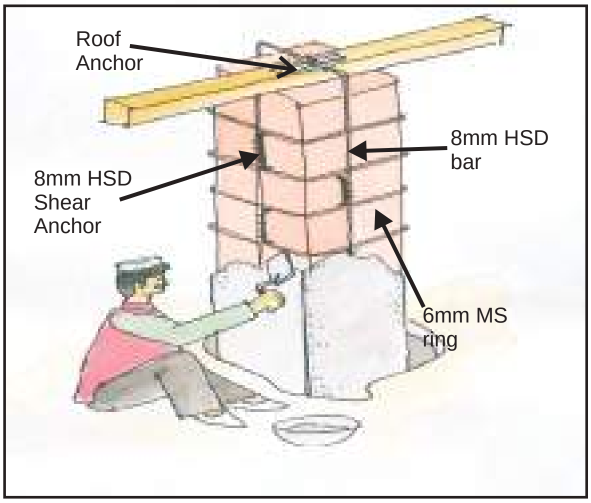
Absence of bending strength in masonry column results in cracking and failure even in low intensity earthquake.

Crack in msonry column

Remedial Measure:

Encasing masonry pier and improving its connection to roof.

- Remove plaster and rake open joints. Excavate all around to a depth of 450mm.
- Install 8mm HSD 'L' shaped shear anchor in each column face at 600mm spacing using non-shrink grout.
- Install one 8mm HSD on each face, tied to shear anchors, starting from the bottom of the excavation. Bottom 150mm of the bar must be bent in L shape.
- Fill excavation with 1:2:4 concrete and encase bars in 1:3 cement mortar.



Encase bars in 1:3 cement mortar.

2. Installing Knee-Brace.

Weakness in Column to Beam Joint:

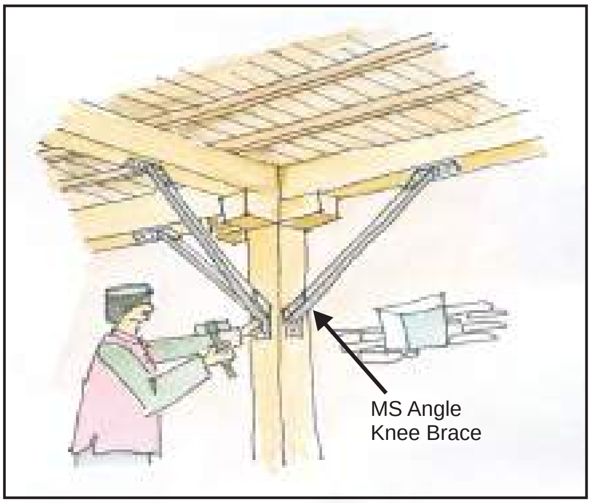
Absence of rigidity in column and beam joint results in lateral sway of timber column in an earthquake.

Sway in timber frame

Remedial Measure:

Stiffen the joint between column and beam using knee brace.

- Install knee brace made of MS angle 50x50x3mm or wood between each beam that rests on the column and the column.
- Make the end connection of bracing strong with a minimum of two 4mm diameter nails
- Pre-drill pilot hole to prevent splitting of wood.



Installing knee brace

E. Retrofitting of house while replacing the *pathal*/ stone-tile roof by RC slab

Anchoring the RC slab roof with the existing stone walls.

Weakness in new RC slab : Absence of secure connection between walls supporting the slab, and the slab can result in damage to whole structure in earthquake. The heavy slab can push the walls and the structure can collapse along with the walls and roof slab.

Remedial Measures: Anchoring RC slab to support walls

Remove the pathal/slate and all the timber including ridge beams and purlins carefully. Dismantle gable walls, and store the stones properly away from the building. Bring all the support walls up to the required height using same construction materials as the walls below, while adhering to all the rules of good construction practice.

How to strengthen the existing walls and secure RC slab to walls ?

Follow all the instruction in this chapter for retrofitting of the existing structure before installing the RC roof. Without retrofittng the building may collapse in the event of a major earthquake.

E. Retrofitting of house while replacing the pathal to CGI roof

Securing the CGI roof with the existing stone walls.
Weakness in new CGI roof : Absence of secure connection between support walls, and the CGI sheets as well as the timber understructure, results in significant deformation of roof under lateral seismic loads, causing damage to roof and walls.

Remedial Measures: Securing CGI roofing to support walls

Remove the roof completely including the understructure. Install seismic band on exposed walls at eave level continuing on over the top of gable walls with GI wire anchors in them for roof timber elements. Install seismic belt in gable walls at eave level with adequate overlap on the eave band on other walls at eave level. Anchor the timber understructure on walls and install CGI roofing using "J" botls.

How to strengthen the existing walls and secure CGI roof to walls ?
Even when the new CGI sheets are to be installed on a part of the structure, it will be best to strengthen the whole structure. When this is not possible, the part of the structure under CGI roof may be retrofitted as shown below.

Install Vertical Reinforcement at all the wall- to-wall junctions and door jambs

Install Seismic band on support walls at eave level and on top of gable walls, and the seismic belts as deemed fit.

Install Struts and Diagonal Bracings in roof and install Collar beams between opposite rafters

Anchor roof purlins/rafters to bands on top of walls

Even in the portions where the original roof is not changed, retrofitting is advisable

Install WWM Straps to encase openings in walls

Provide In-Plane Bracings and Struts under timber floor, and anchor floor joists to walls using brackets

Provide Bond Elements in RR wall

7

STEP BY STEP

Knowing how to carry out a particular retrofitting measure is not enough. The decision making for each step and coordination of various steps in execution in relation to each other are critical to successful retrofitting of a structure.

Retrofitting Step by Step:

Typical House of Uttarakhand and Himachal Pradesh

Houses are commonly double storied. The walls in these houses are predominantly made of random rubble masonry. The roof is either pitched with slate/pathal/stone tile roofing or CGI, or is flat with RC slab roof. But in low rainfall areas the flat mud roof supported on timber understructure is also found. The intermediate floor as well as attic floor, if any, are generally made of timber floor joists and planks on top of them.

Ipathal / slate roof on RR walls

Mud roof on RR walls

Planning for Retrofitting:

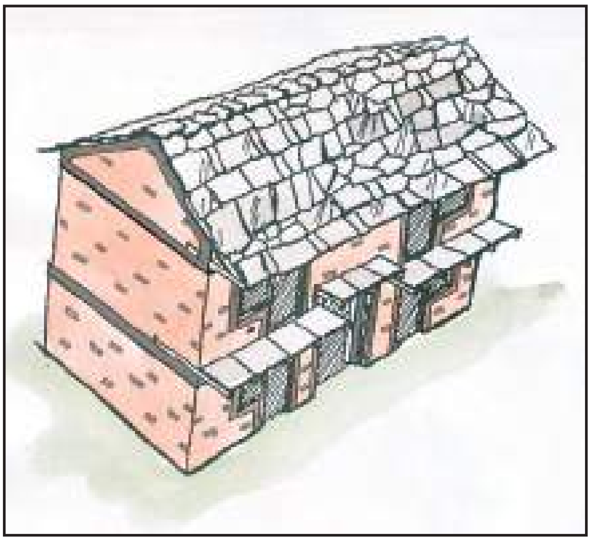
- If the house is damaged then restore it back to its original undamaged condition.
- Assess the vulnerability of the structure, damaged or undamaged, as described in Chapter titled "Vulnerability Identification."
- Evolve the retrofitting scheme for the whole building taking in to account the interface between various retrofitting measures, based on technical information given in this manual and also in BIS 13935 (2008).
- Prepare plans of the existing structure showing all the retrofitting and restoration measures to be taken along with all the dimensions so that material quantity estimate as well as cost estimate can be prepare.
- Assign priority and sequence to various retrofitting measures to be implemented. Execute the measures based on the availability of funds and time. It is not a must to execute all the measures at the same time.

RC roof on RR or Brick walls

CGI roof on stone and timber walls

Retrofitting Step by Step (cont.):

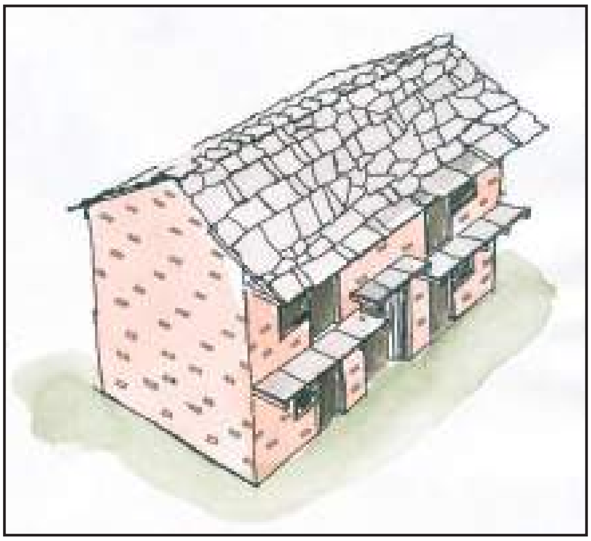
Installation of Horizontal Seismic Belt for strenghening walls.



- Plan for all the belts including those for the encasement of openings.
- Identify walls with belts on both wall faces and those with belt on only one face.
- Plan the alignment of belts to ensure proper connection between all the belts. Ensure this, especially, when some walls have belts on one face and some on both faces.
- No belt shall terminate without connection to either the other end of the same belt or to some other belt.
- If a belt terminating on one wall is to be connected to a belt on non-contiguosus face of another wall, then dowel bars are to be used for linking the two.

- Points of anchoring of floor joists must be decided, and the required provision for their installation must be made while installing the belt since they could overlap
- In case of openings if the space between two openings is less than the encasement belt width then both belts will merge in to each other.
- When it is possible to install belt on only three walls, then along the fourth wall a tie rod must be installed to ensure continuity of some sort.
- In case of an obstruction such as an opening or a structural element, the belt alignment will have to be raised through 90° bends.

Installation of Cast in-Situ RC Bond-element in Random Rubble Wall



- Based on wall area arrive at an approximate number of Bond elements that are required.
- Identify Cast in Situ RC Shear Connectors that will be installed for Vertical Reinforcement, Seismic Belt and Opening Encasement. Deduct these from the required number.
- Mark the locations for Bond element installation.
- Study the wall from both faces prior to finalizing the locations to prevent conflict with other items such as wall junctions, built-in cupboards, shelving etc.
- Exercise extreme caution not to weaken the wall while making holes.

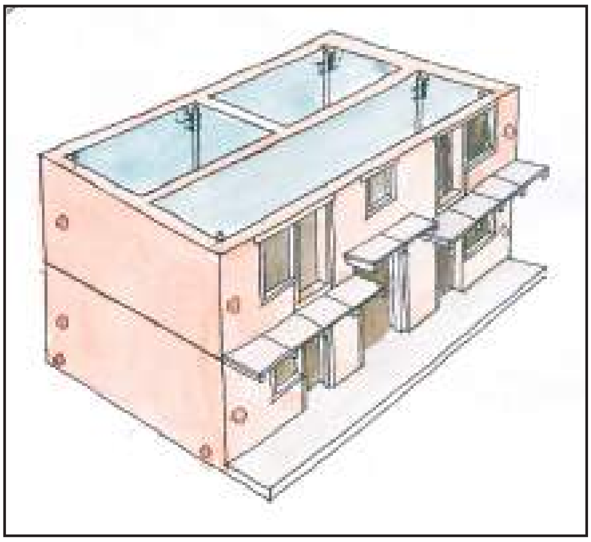
- Finish one wall at a time on each storey, starting from bottom storey.
- On the exterior face it may be best to finish the elements such that they stand out.

Note: This element may have to be installed in thick brick walls as well.

Important : These retrofitting measures are to be applied to all RR and brick wall buildings having roofs consisting of *pathal*/slate, CGI, RC slab or mud-timber.

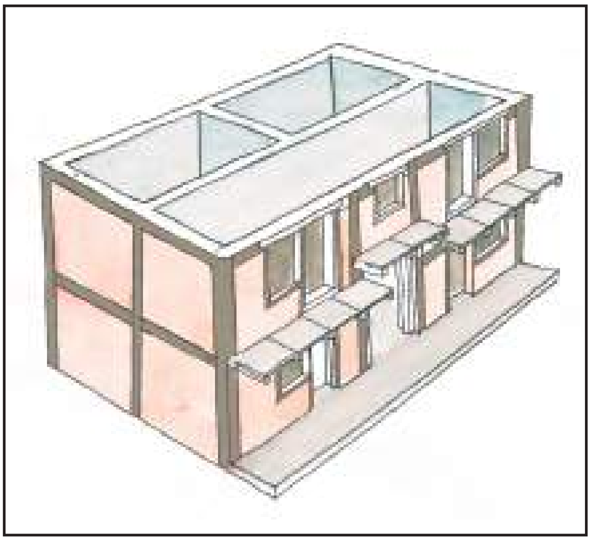
Retrofitting Step by Step (cont.):

Installation of Vertical Reinforcing Bar in Wall Junctions



- Identify all possible locations for the installation of vertical bar.
- In case of "T" wall junction, the bar needs to be placed only on one side of the junction.
- In case of a building with two or more storeys, ensure continuity of the bar from the bottom story to top story. If this is not possible because of some obstruction, then explore alternate location for the bar.
- While installing the shear connectors, ensure a common shear connector at the overlap of the alignments of the vertical bar and the Seismic Belt, thereby ensuring a connection between the two, and also saving cost by reducing the number of shear connectors.
- Make sure that at such an overlap if the belt is going to be installed after the vertical bar, then the shear connector for the belt is left exposed for later use.
- In case of obstruction by stepped footing, bend the bar as required for right positioning.

Installation of WWM Vertical Strap as an alternate to Single Vertical Bar at Wall Junctions

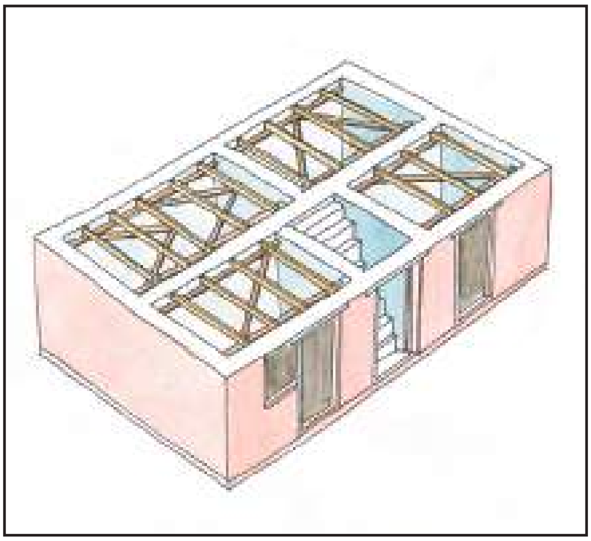


- In the event that it is not possible to install the bar on the inner face of the wall junction, the alternate option of WWM Vertical Strap may be used on the outer face of wall.
- Continuity of the vertical reinforcement must be ensured from bottom to top, be it entirely be in the form of WWM Strap or be partly in the form of WWM Strap and partly in the form of a single bar.
- Overlap between the reinforcement of Seismic Belts and the Vertical Strap must be ensured through tying, and doweling.
- Incase of brick masonry wall, simple nailing may be adequate for anchoring of strap to the wall. In case of RR masonry also the nailing would have to be used since it may not be possible to make through holes needed for shear connectors right at the wall corners.

Important : These retrofitting measures are to be applied to all RR and brick wall buildings having roofs consisting of *pathal*/slate, CGI, RC slab or mud-

Retrofitting Step by Step (cont.):

Anchoring of Floor to Walls; Additional Nailing in Floor Planks; Installing In-plane Bracing & Struts to underside of Wooden Deck.



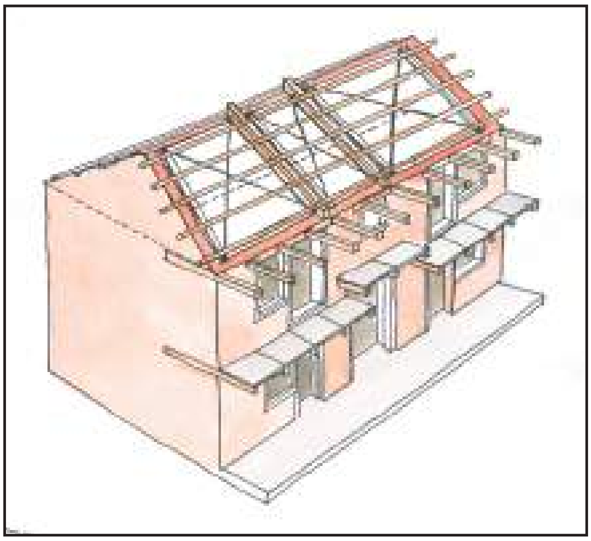
Assess one area/room at a time to decide what needs to be done.

- The anchoring of deck should be done at the underside of beams and joists. It can be done in attic also if there is adequate vertical clearances. If this requires any connection with a Seismic Belt, then it must be done before hand.
- If any plank is rotten then it should first be replaced before installing additional nails. Pre-drilling in planks (new & old) and making pilot holes in joists will help reduce the splitting.
- The arrangement of struts and bracings should be such that the angle between bracings and joists is within the range of 35 to 55 degrees.
- Bracings and struts should be nailed to every joist that they cross. Minimum two nails should be applied at each point.
- Continuity of bracings is desired within an area/ room while moving from one end of the floor to the other in both directions.

Installing Collar Beam Ties Across Opposite Top Chords of Roof Truss

- If the ridge wall is present under the ridge, then the Collar Beam will have to be provided through this wall.
- Pre-drilling should be done before installation of collar beam ties. Ensure enough vertical clearance under the ties to permit one to use the floor space.

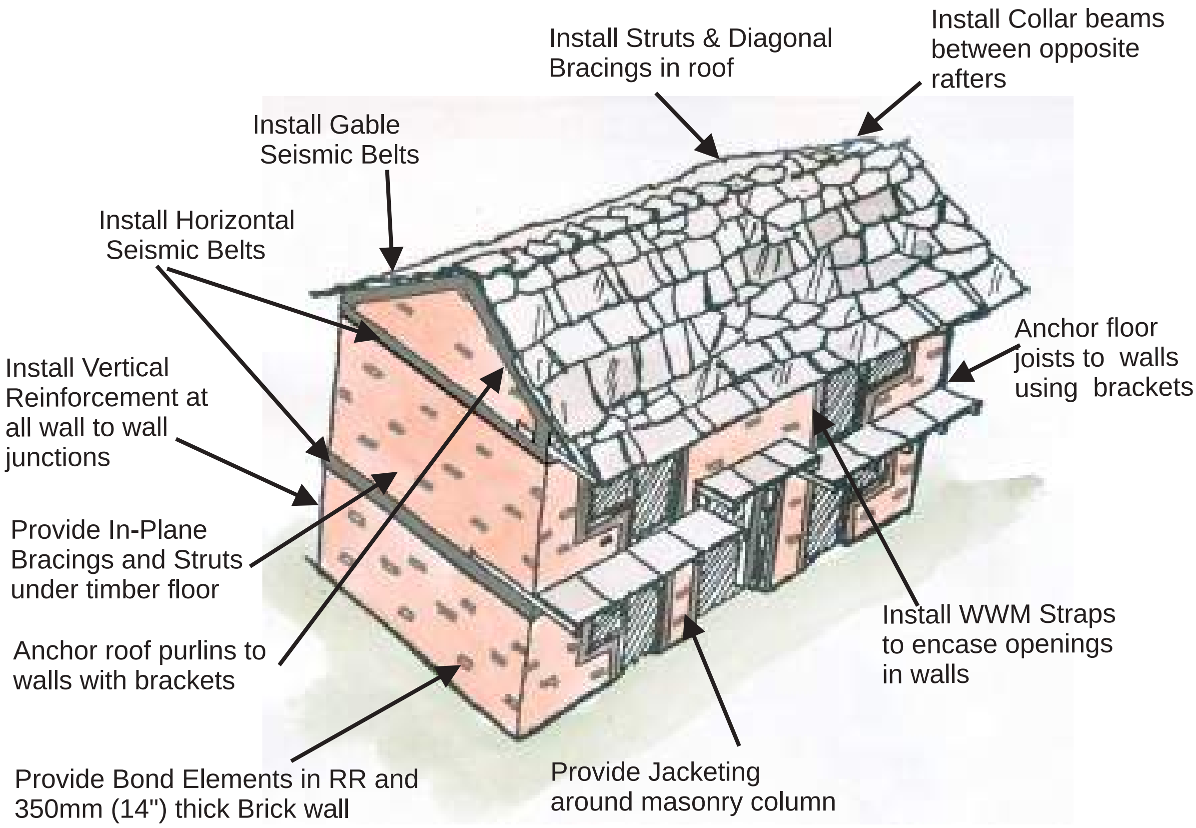
Installing Diagonal in-Plane Bracings on Underside of Roof Purlins



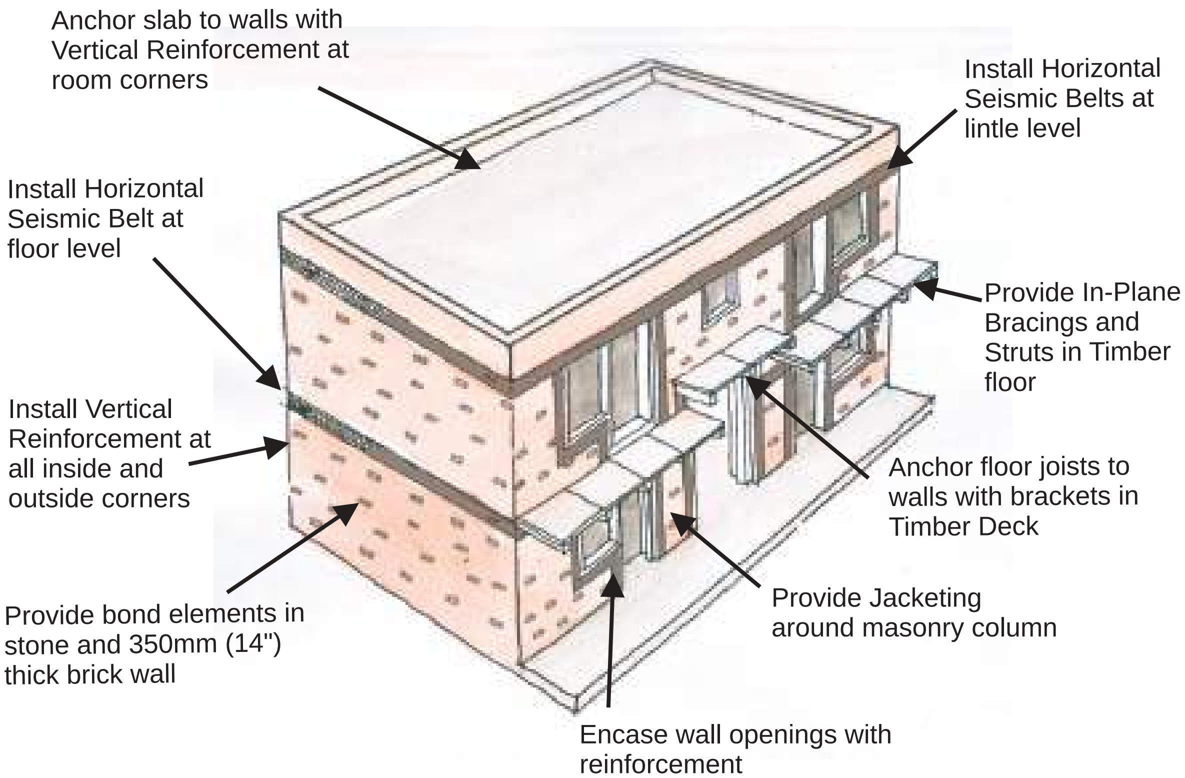
- Struts must be installed before the bracings, and they must be connected to each joist.
- To decide the layout of bracings align them at an angle of 35 to 55 degrees with the ridge of the roof.
- Ensure continuity of bracings from ridge to eave.
- The arrangement should take in to consideration the length of timber available easily.
- The arrangement should be symmetrical with respect to the ridge.
- Upon finalizing the arrangement and the points of installation, pre-drilling should precede the installation of struts and bracings.

Retrofitting at a Glance

Pitched Roof with *Pathal* / Slate / Stone tile or CGI Roofing on RR walls



RC or Mud Flat Roof on RR or Brick walls



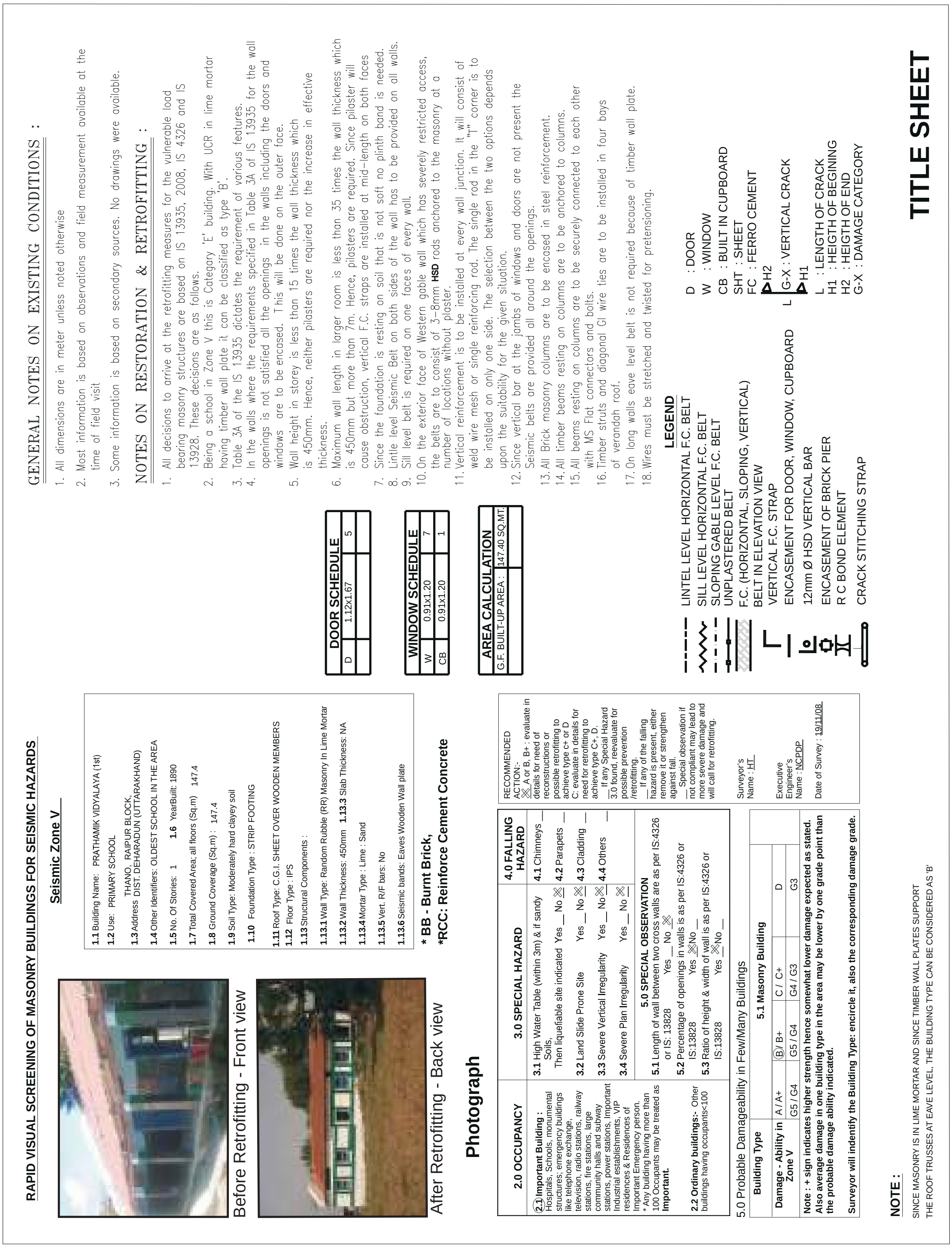
8

CASE STUDIES

Case study of restoration and retrofitting is an effective way to learn how to document the building including the damage, if any, and the vulnerability. It helps one in assessing the structure as a whole, and not just its individual components. It also explains the practical aspects of retrofitting, and provides proven engineering details that can easily be put to use in other retrofitting projects. Lastly, it inspires confidence among the engineers in retrofitting as an important solution.

A. Case Study 1
Retrofitting of School Building at Thano, UK.

The buildings covered here are both very old, and they were already under consideration for demolition by the concerned government department. These buildings were selected for retrofitting and also as a venue for exposing people to this little known concept of retrofitting. Both projects were able to generate much interest since they demonstrated the attractive economics and speed in bringing safety. All the technical decisions concerning this work were based on relevant codes of Bureau of Indian Standards.



RAPID VISUAL SCREENING OF MASONRY BUILDINGS FOR SEISMIC HAZARDS

Seismic Zone V

Before Retrofitting - Front view

After Retrofitting - Back view

Photograph

1.1 Building Name: PRATHAMIK VIDYALAYA (1st)
1.2 Use: PRIMARY SCHOOL
1.3 Address THANO, RAIPUR BLOCK, DIST. DEHARADUN (UTTARAKHAND)
1.4 Other Identifiers: OLDEST SCHOOL IN THE AREA
1.5 No. Of Stories: 1 **1.6** YearBuilt: 1890
1.7 Total Covered Area; all floors (Sq.m) 147.4
1.8 Ground Coverage (Sq.m) : 147.4
1.9 Soil Type: Moderately hard clayey soil
1.10 Foundation Type : STRIP FOOTING
1.11 Roof Type: C.G.I. SHEET OVER WOODEN MEMBERS
1.12 Floor Type : IPS
1.13 Structural Components :
1.13.1 Wall Type: Random Rubble (RR) Masonry In Lime Mortar
1.13.2 Wall Thickness: 450mm **1.13.3** Slab Thickness: NA
1.13.4 Mortar Type : Lime : Sand
1.13.5 Vert. R/F bars: No
1.13.6 Seismic bands: Eaves Wooden Wall plate

*** BB - Burnt Brick,**
***RCC: Reinforce Cement Concrete**

2.0 OCCUPANCY	3.0 SPECIAL HAZARD	4.0 FALLING HAZARD
2.1 Important Building : Hospitals, Schools, monumental structures; emergency buildings like telephone exchange, television, radio stations, railway stations, fire stations, large community halls and subway stations, power stations, Important Industrial establishments, VIP residences & Residences of Important Emergency person. * Any building having more than 100 Occupants may be treated as **Important.**	**3.1** High Water Table (within 3m) & if sandy Soils, Then liquefiable site indicated Yes __ No ☒	**4.1** Chimneys __
	3.2 Land Slide Prone Site Yes __ No ☒	**4.2** Parapets __
	3.3 Severe Vertical Irregularity Yes __ No ☒	**4.3** Cladding __
	3.4 Severe Plan Irregularity Yes __ No ☒	**4.4** Others __
2.2 Ordinary buildings:- Other buildings having occupants<100	**5.0 SPECIAL OBSERVATION** **5.1** Length of wall between two cross walls are as per IS:4326 or IS: 13828 Yes __ No ☒ **5.2** Percentage of openings in walls is as per IS:4326 or IS:13828 Yes ☒ No __ **5.3** Ratio of height & width of wall is as per IS:4326 or IS:13828 Yes ☒ No __	

RECOMMENDED ACTION:-
☒ A or B, B+ : evaluate in details for need of reconstructions or possible retrofitting to achieve type c+ or D
C: evaluate in details for need for retrofitting to achieve type C+, D.
__ If any Special Hazard 3.0 found, reevaluate for possible prevention /retrofitting.
__ If any of the falling hazard is present, either remove it or strengthen against fall.
__ Special observation if not compliant may lead to more severe damage and will call for retrofitting.

Surveyor's Name : HT

Executive Engineer's Name : NCPDP

Date of Survey : 19/11/08

5.0 Probable Damageability in Few/Many Buildings

Building Type	5.1 Masonry Building			
Damage - Ability in Zone V	A / A+	(B) / B+	C / C+	D
	G5 / G4	G5 / G4	G4 / G3	G3

Note : + sign indicates higher strength hence somewhat lower damage expected as stated. Also average damage in one building type in the area may be lower by one grade point than the probable damage ability indicated.

Surveyor will indentify the Building Type: encircle it, also the corresponding damage grade.

NOTE :

SINCE MASONRY IS IN LIME MORTAR AND SINCE TIMBER WALL PLATES SUPPORT THE ROOF TRUSSES AT EAVE LEVEL, THE BUILDING TYPE CAN BE CONSIDERED AS 'B'

DOOR SCHEDULE

D	1.12x1.67	5

WINDOW SCHEDULE

W	0.91x1.20	7
CB	0.91x1.20	1

AREA CALCULATION

G.F. BUILT-UP AREA :	147.40 SQ.MT.

GENERAL NOTES ON EXISTING CONDITIONS :

1. All dimensions are in meter unless noted otherwise
2. Most information is based on observations and field measurement available at the time of field visit
3. Some information is based on secondary sources. No drawings were available.

NOTES ON RESTORATION & RETROFITTING :

1. All decisions to arrive at the retrofitting measures for the vulnerable load bearing masonry structures are based on IS 13935, 2008, IS 4326 and IS 13928. These decisions are as follows.
2. Being a school in Zone V this is Category 'E' building. With UCR in lime mortar having timber wall plate it can be classified as type 'B'.
3. Table 3A of the IS 13935 dictates the requirement of various features.
4. In the walls where the requirements specified in Table 3A of IS 13935 for the wall openings is not satisfied all the openings in the walls including the doors and windows are to be encased. This will be done on the outer face.
5. Wall height in storey is less than 15 times the wall thickness which is 450mm. Hence, neither pilasters are required nor the increase in effective thickness.
6. Maximum wall length in larger room is less than 35 times the wall thickness which is 450mm but more than 7m. Hence, pilasters are required. Since pilaster will cause obstruction, vertical F.C. straps are installed at mid-length on both faces
7. Since the foundation is resting on soil that is not soft no plinth band is needed.
8. Lintle level Seismic Belt on both sides of the wall has to be provided on all walls.
9. Sill level belt is required on one faces of every wall.
10. On the exterior face of Western gable wall which has severely restricted access, the belts are to consist of 3-8mm HSD rods anchored to the masonry at a number of locations without plaster.
11. Vertical reinforcement is to be installed at every wall junction. It will consist of weld wire mesh or single reinforcing rod. The single rod in the "T" corner is to be installed on only one side. The selection between the two options depends upon the suitability for the given situation.
12. Since vertical bar at the jambs of windows and doors are not present the Seismic belts are provided all around the openings.
13. All Brick masonry columns are to be encased in steel reinforcement.
14. All timber beams resting on columns are to be anchored to columns.
15. All beams resting on columns are to be securely connected to each other with MS Flat connectors and bolts.
16. Timber struts and diagonal GI wire ties are to be installed in four bays of verandah roof.
17. On long walls eave level belt is not required because of timber wall plate.
18. Wires must be stretched and twisted for pretensioning.

LEGEND

LINTEL LEVEL HORIZONTAL F.C. BELT
SILL LEVEL HORIZONTAL F.C. BELT
SLOPING GABLE LEVEL F.C. BELT
UNPLASTERED BELT
F.C. (HORIZONTAL, SLOPING, VERTICAL)
BELT IN ELEVATION VIEW
VERTICAL F.C. STRAP
ENCASEMENT FOR DOOR, WINDOW, CUPBOARD
12mm Ø HSD VERTICAL BAR
ENCASEMENT OF BRICK PIER
R C BOND ELEMENT
CRACK STITCHING STRAP

D : DOOR
W : WINDOW
CB : BUILT IN CUPBOARD
SHT : SHEET
FC : FERRO CEMENT
H2
L G-X : VERTICAL CRACK
H1
L : LENGTH OF CRACK
H1 : HEIGTH OF BEGINING
H2 : HEIGTH OF END
G-X : DAMAGE CATEGORY

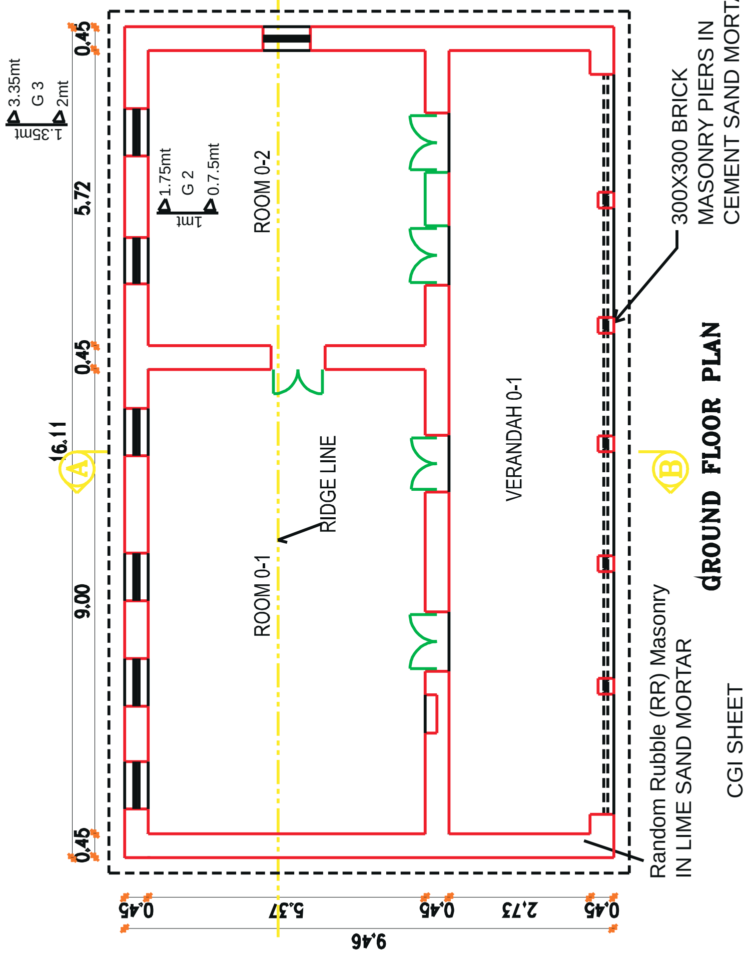
TITLE SHEET

A. Case Study 1
Retrofitting of School Building at Thano, UK (cont.).

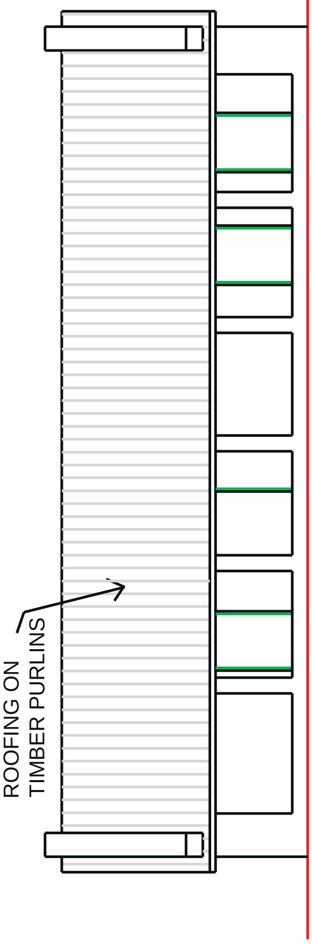
****Cost of Restoration and Retrofitting**

Sr. No.	Item	Amount	%
	Retrofitting items		
1	Horizontal Seismic belt including opening encasement	100,651	65.94%
2	Vertical reinforcements at corners	9,287	6.08%
3	Vertical seismic straps on wall length of more than 7m, in lieu of the buttresses	5,199	3.41%
4	Brick pier encasement	18,467	12.10%
5	Concrete bond elements in RR wall	10,079	6.60%
6	Improving seismic vulnerability of roof in verandah	8,961	5.87%
	Total cost and % of total cost of retrofitting only	**152,644**	**100.00%**
	Repair and restoration		
1	Crack stitching	434	0.91%
2	Crack grouting	940	1.97%
3	Re-plastering of wall replacing the weaker plaster	18,624	38.96%
4	Painting	19,800	41.42%
5	Debris removal and cleaning	8,000	16.74%
	Total cost and % of total cost of restoration only	**47,798**	**100.00%**
	Total cost of restoration and retrofitting	**200,442**	
	The estimated cost of earthquake resistant new structure of similar specification = 1480Sft @ Rs.600 per Sft	888,000	
	Cost of retrofitting as % of cost of new construction		**17.19%**

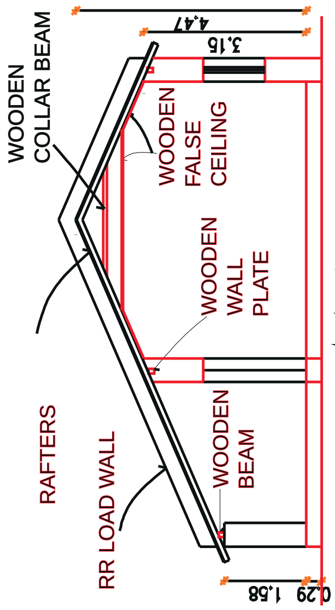
** Note: The above cost was incurred during Nov 2008 to April 2009.



GROUND FLOOR PLAN



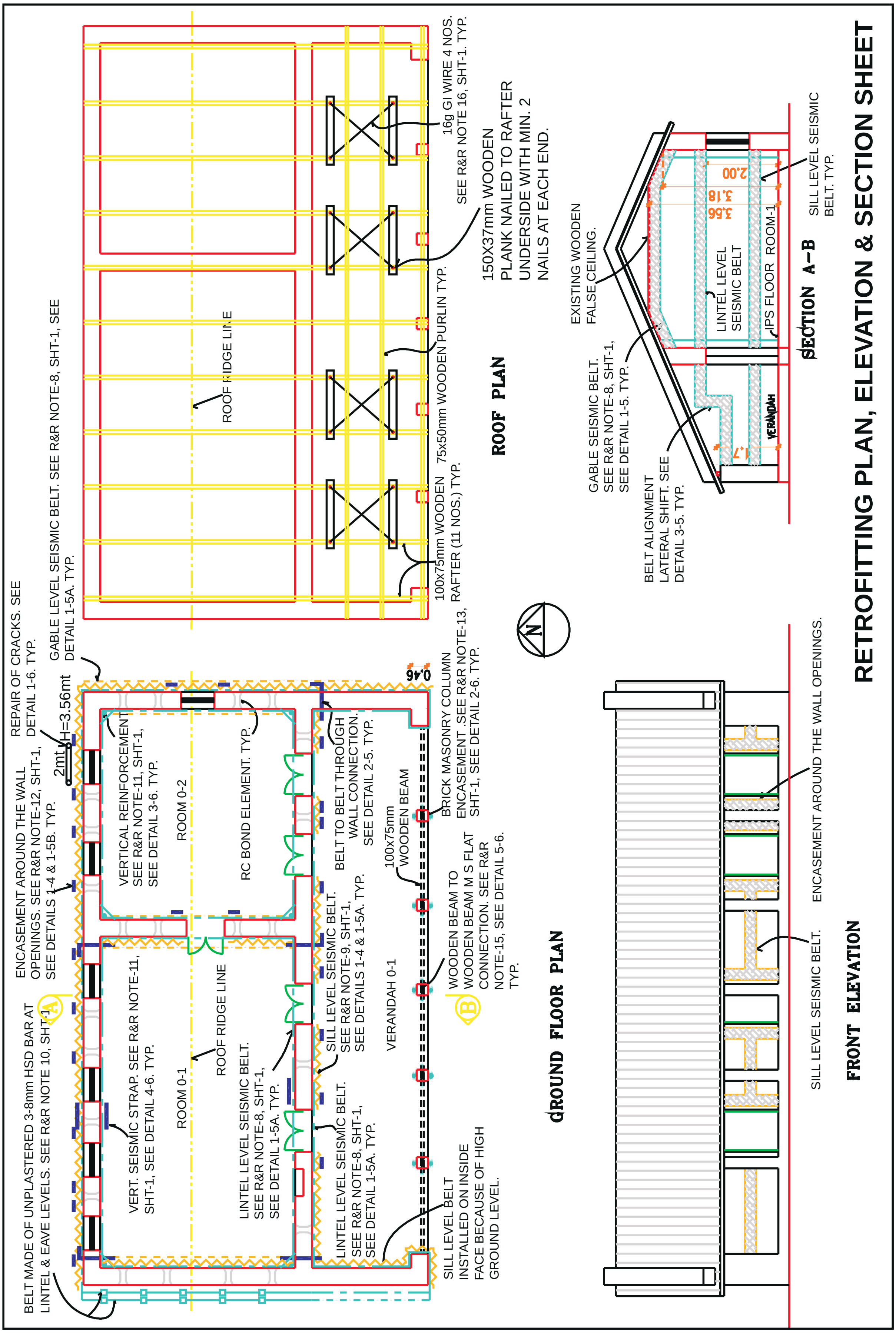
FRONT ELEVATION



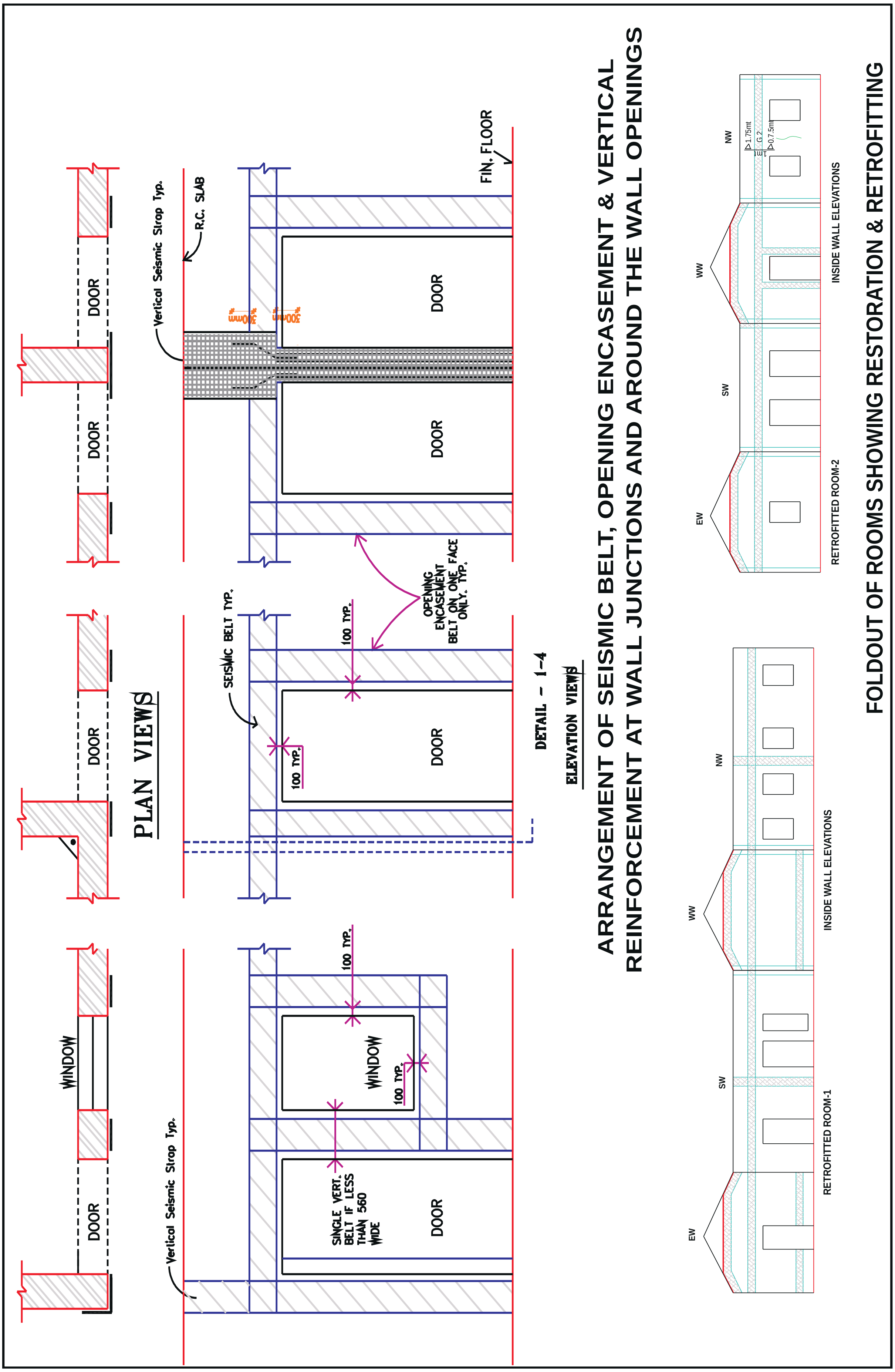
SECTION A–B

EXISTING PLAN, ELEVATION & SECTION SHEET

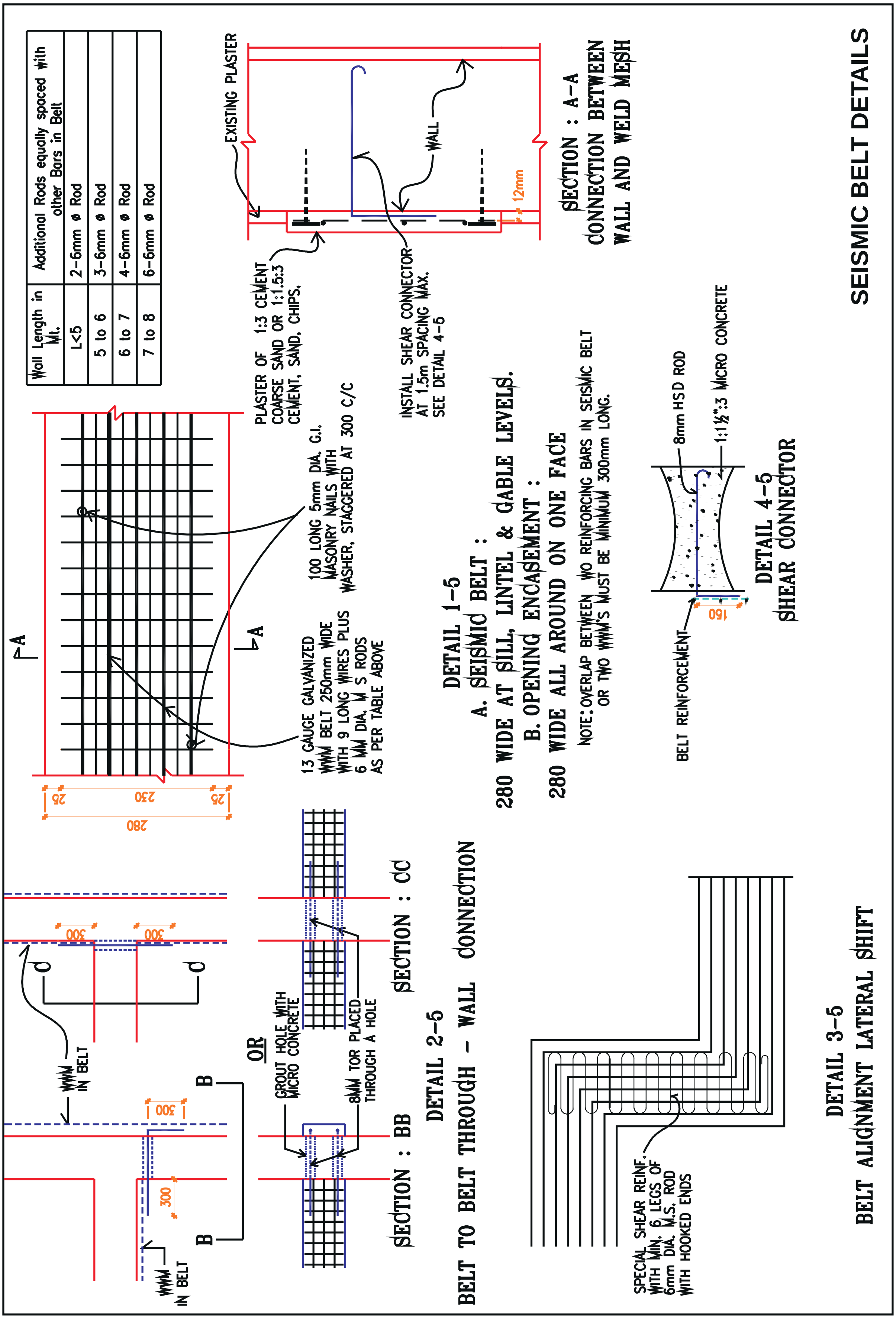
A. Case Study 1
Retrofitting of School Building at Thano, UK (cont.).



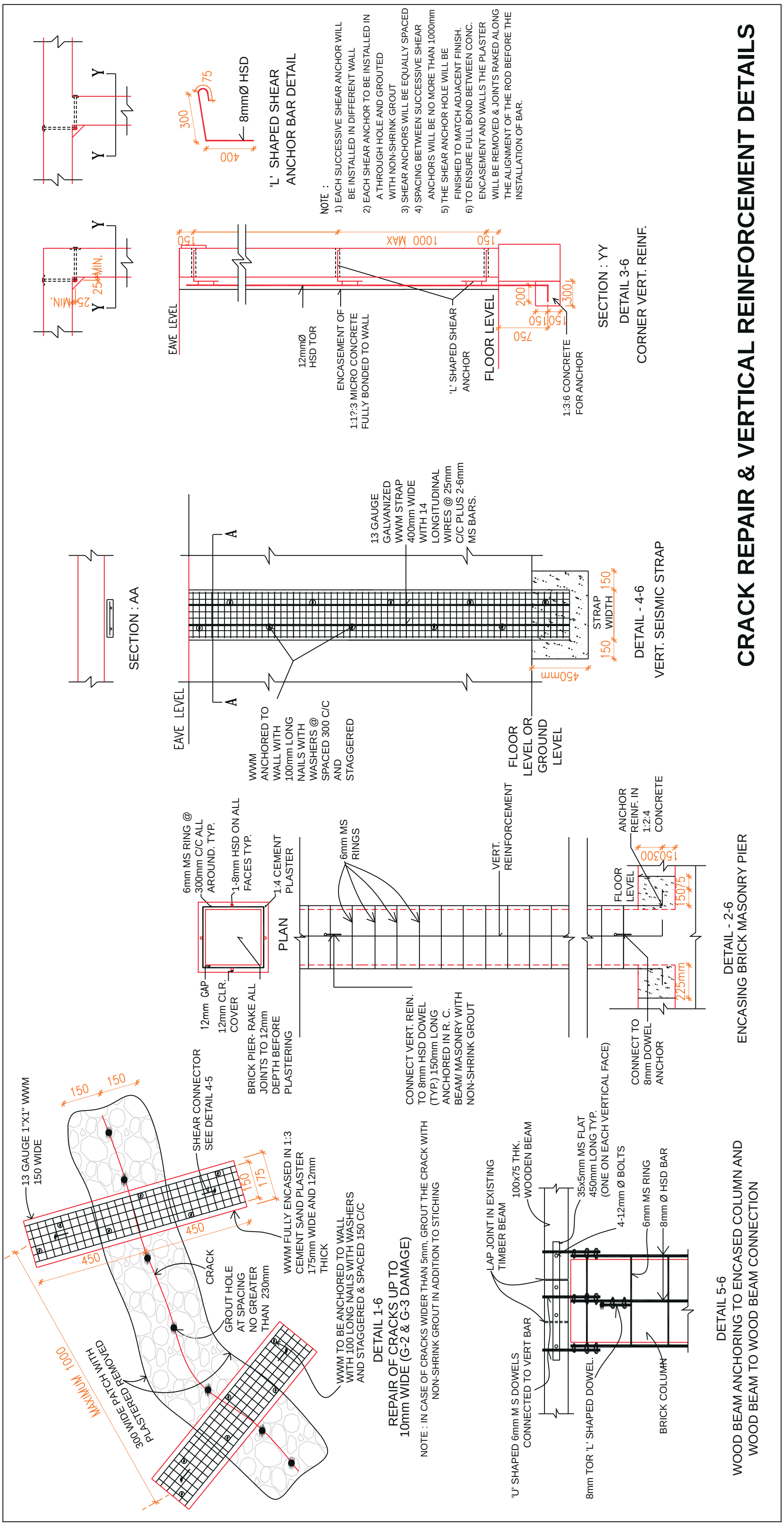
A. Case Study 1
Retrofitting of School Building at Thano, UK (cont.).



A. Case Study 1
Retrofitting of School Building at Thano, UK (cont.).



A. Case Study 1
Retrofitting of School Building at Thano, UK (cont.).



A. Case Study 1
Retrofitting of School Building at Thano, UK (cont.).

a. Before Retrofitting.

View from the front.

Front verandah.

Inside a classroom.

View from the rear.

A. Case Study 1
Retrofitting of School Building at Thano, UK (cont.).

b. During Retrofitting .


Curing shear anchor.


Installing WWM with reinforcing bars.


Attaching 6mm bars to WWM to make belt.


Anchoring belt reinforcement to wall.


Placing form-work for vertical bar concreting.


Installing window encasement with lintle belt.

A. Case Study 1
Retrofitting of School Building at Thano, UK (cont.).

b. During Retrofitting .


Cast-In-Situ RC Bond Elements with lintle and gable belts.


Vertical strap in lieu of pilaster with lintle level belt.


Drilling for shear anchor placement for column encasing.


Installing and tightening diagonal ties in verandah roof.


Retrofitted school - Rear view.

A. Case Study 1
Retrofitting of School Building at Thano, UK (cont.).
d. Retrofitted School Building .


Verandah roof beam anchored to encased brick column.


Lintle belt alignment change and roof diaphragm strut.


Lintle and Sill Belts plus door encasement by belts.


Gable and lintle level belts with corner vert. bars.


Retrofitted and restored school.

B. Case Study 2
Retrofitting of School Building at Khudbuda, Dehradun

RAPID VISUAL SCREENING OF MASONRY BUILDINGS FOR SEISMIC HAZARDS


Before Retrofitting


After Retrofitting

Seismic Zone IV Important Building Category E

1.1 Building Name: CITY GOLD PRIMARY VIDYALAYA
1.2 Use: PRIMARY SCHOOL
1.3 Address: NEAR KHUDBUDA OVER HEAD WATER TANK, INNTER COLLAGE, OPP. JAIN VIDYALAYA, TILAK ROAD, KHUDBUDA, DEHRADUN, BLOCK & DIST. DEHRADUN, UTTARAKHAND
1.4 Other Identifiers: OLDEST SCHOOL IN THE AREA
1.5 No. Of Stories: 1 **1.6** YearBuilt: 1940
1.7 Total Covered Area; all floors (Sq.m) 185.1
1.8 Ground Coverage (Sq.m) : 185.1
1.9 Soil Type:
1.10 Foundation Type : STRIP FOOTING
1.11 Roof Type : REINFORCED ONE WAY BRICK SLAB SUPPORTED ON WALLS & RC BEAM
1.12 Floor Type : IPS
1.13 Structural Components : Masonry Walls & RC Beams
1.13.1 Wall Type: Brick Masonry In Lime Mortar
1.13.2 Wall Thickness: 350mm **1.13.3** RB Slab Thickness: 100mm
1.13.4 Mortar Type : Lime : Sand
1.13.5 Vert. R/F bars: None
1.13.6 Seismic bands: None

*BB - Burnt Brick,
*RCC: Reinforce Cement Concrete

2.0 OCCUPANCY	3.0 SPECIAL HAZARD	4.0 FALLING HAZARD
2.1 Important Building : Hospitals, Schools, monumental structures; emergency buildings like telephone exchange, television, radio stations, railway stations, fire stations, large community halls and subway stations, power stations, Important Industrial establishments, VIP residences & Residences of Important Emergency person. * Any building having more than 100 Occupants may be treated as **Important.**	**3.1** High Water Table (within 3m) & if sandy Soils, Then liquefiable site indicated Yes __ No ☒	**4.1** Chimneys __
	3.2 Land Slide Prone Site Yes __ No ☒	**4.2** Parapets ☒
	3.3 Severe Vertical Irregularity Yes __ No ☒	**4.3** Cladding __
	3.4 Severe Plan Irregularity Yes __ No ☒	**4.4** Others (Toilets) ☒
2.2 Ordinary buildings:- Other buildings having occupants<100	**5.0 SPECIAL OBSERVATION** **5.1** Length of wall between two cross walls are as per IS:4326 or IS: 13828 Yes __ No ☒ **5.2** Percentage of openings in walls is as per IS:4326 or IS:13828 Yes ☒ No __ **5.3** Ratio of height & width of wall is as per IS:4326 or IS:13828 Yes ☒ No __	

RECOMMENDED ACTION:-
___A or B, B+ : evaluate in details for need of reconstructions or possible retrofitting to achieve type C+ or D
☒C: evaluate in details for need for retrofitting to achieve type C+, D.
__ If any Special Hazard 3.0 found, re-evaluate for possible prevention /retrofitting.
☒If any of the falling hazard is present, either remove it or strengthen against fall.
__ Special observation if not compliant may lead to more severe damage and will call for retrofitting.

Surveyor's Name : HT

Executive Engineer's Name : NCPDP

Date of Survey : 19/11/08

5.0 Probable Damageability in Few/Many Buildings

Building Type	5.1 Masonry Building			
Damage - Ability in Zone IV	A / A+	B / B+	ⓒ/ C+	D
	G5 / G4	G5 / G4	G4 / G3	G3

Note : + sign indicates higher strength hence somewhat lower damage expected as stated. Also average damage in one building type in the area may be lower by one grade point than the probable damage ability indicated.

Surveyor will indentify the Building Type: encircle it, also the corresponding damage grade.

DOOR SCHEDULE		
D	1.35x2.1	6
D1	1.09x2.1	4
D2	0.77x2.1	1

WINDOW SCHEDULE		
W	1.2x1.5	5
W1	2.44x1.5	1
W2	0.69x0.75	3
V	1.2x0.75	7
CB	0.77x1.45	4
CB1	0.9x1.45	4
CB2	1.06x2.1	1
CB3	1.17x1.45	1
CB4	1.69x1.45	1

AREA CALCULATION	
G.F. BUILT-UP AREA :	190.15 Sq.m

GENERAL NOTES ON EXISTING CONDITIONS:

1. All dimensions are in meter unless noted otherwise
2. Most information is based on observations and field measurement available at the time of field visit
3. Some information is based on secondary sources. No drawings were available.

NOTES ON RESTORATION & RETROFITTING:

1. All decisions concerning the retrofitting measures for the vulnerable load bearing masonry structure are based on IS 13935 -2008, IS 4326 and IS 13828. These decisions are as follows.
2. Being a school in Zone IV this is Categary 'E' building. With Brick in lime mortar having Reinforced one way Brick slab it can be classified as type 'C' building.
3. Table 3A of IS 13935 dictates the requirement of various features.
4. In the walls where the requirements specified in Table 3A of IS 13935 for the wall openings is not satisfied all the openings in walls including doors and windows are to be encased. This will be done on the outer face.
5. Wall height in storey is less than 15 times the wall thickness which is 350mm. Hence, neither pilasters are required nor the increase in effective thickness.
6. Maximum wall length in largest room is less than 35 times the wall thickness of 350mm but more than 7m. Hence, a pilaster is required. Since pilaster will cause obstruction, vertical FC straps are installed at mid-length on both faces.
7. Since the foundation is resting on soil that is not soft no plinth band is needed.
8. Lintle level Seismic Belt on both sides of the wall has to be provided on all walls.
9. Sill level belt is required on every wall.
10. The wall height is permissible for the thickness. But giving due consideration for building's age an additional belt is provided at a mid-height between lintel level belt and the roof slab .
11. Vertical reinforcement is to be installed at every wall junction. It will consist of weld wire mesh or single reinforcing rod. The single rod in the "T" corner is to be installed on only one side. The selection between the two options is made depending upon the suitability for the given situation.
12. Since vertical bar at the jambs of windows and doors are not present the Seismic straps are provided all around the openings.
13. All Brick masonry columns are to be encased in steel reinforcement.
14. Installation of RC Screed on Room 1 Roof: The IPS on the large room having popped up in some places should be removed and replaced by 50mm thick screed with 6mm dia. bars both ways at 300mm c/c for improved diaphragm action, especially since this is a very large room. This is not required over verandah and a small room in the SW corner.
15. RC slab is to be instolled in Room 0-2 and 0-3, and RC Beam in Room 0-2.
16. All parapets are to be built of low height in 1:4 cement morter, with all around plaster and vata.
17. The cracks are to be grouted with non-shrink cement grout.

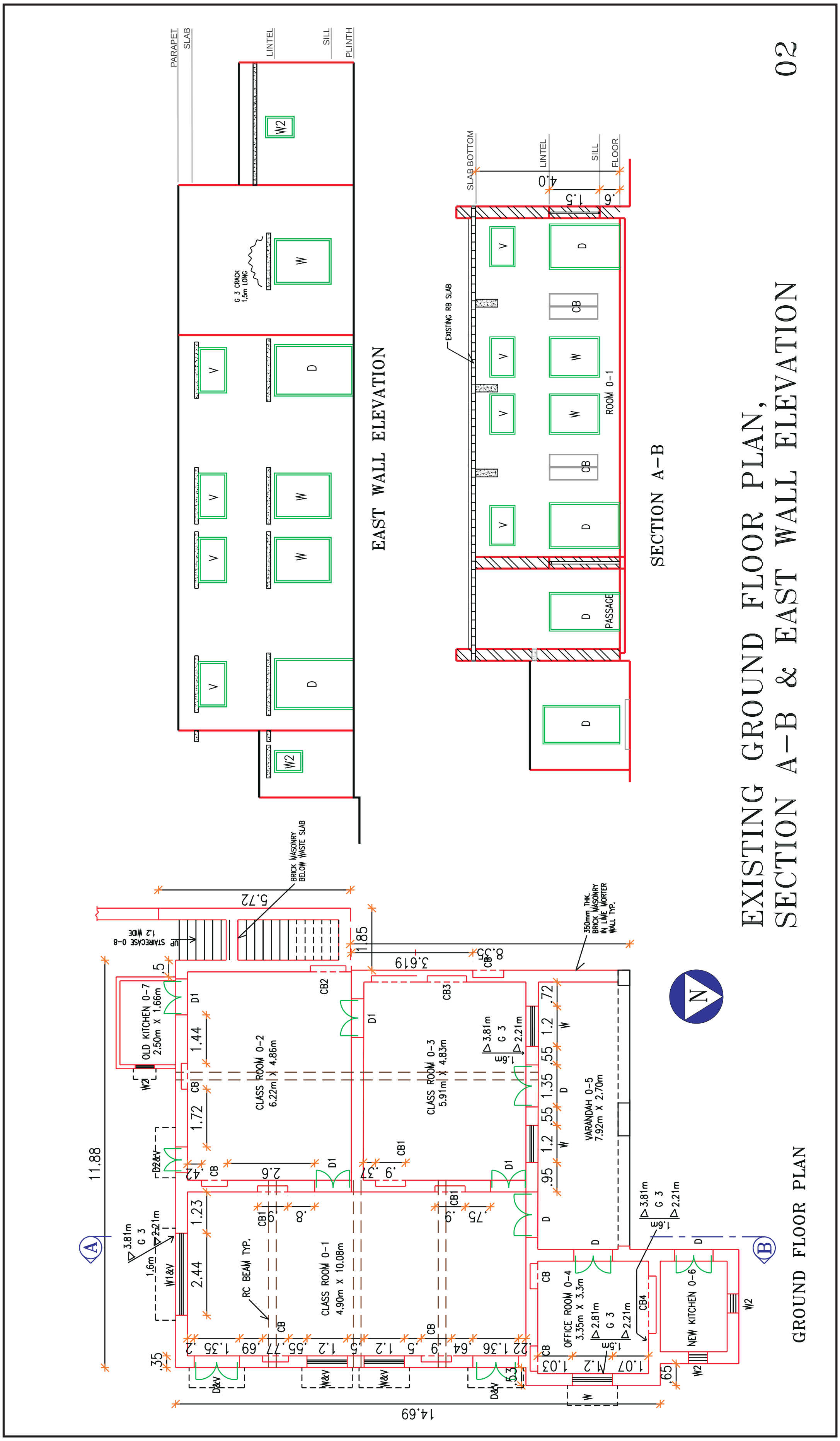
LEGEND

LINTEL LEVEL HORIZONTAL FC BELT
SILL LEVEL HORIZONTAL FC BELT
UPPER LEVEL HORIZONTAL FC BELT
FC (HORIZONTAL, SLOPING, VERTICAL) BELT IN ELEVATION VIEW
OR VERTICAL FC STRAP
ENCASEMENT FOR DOOR, WINDOW, CUPBOARD
VERTICAL BAR
ENCASEMENT OF BRICK PIER
CRACK STITCHING STRAP
RC SCREED
RC SLAB

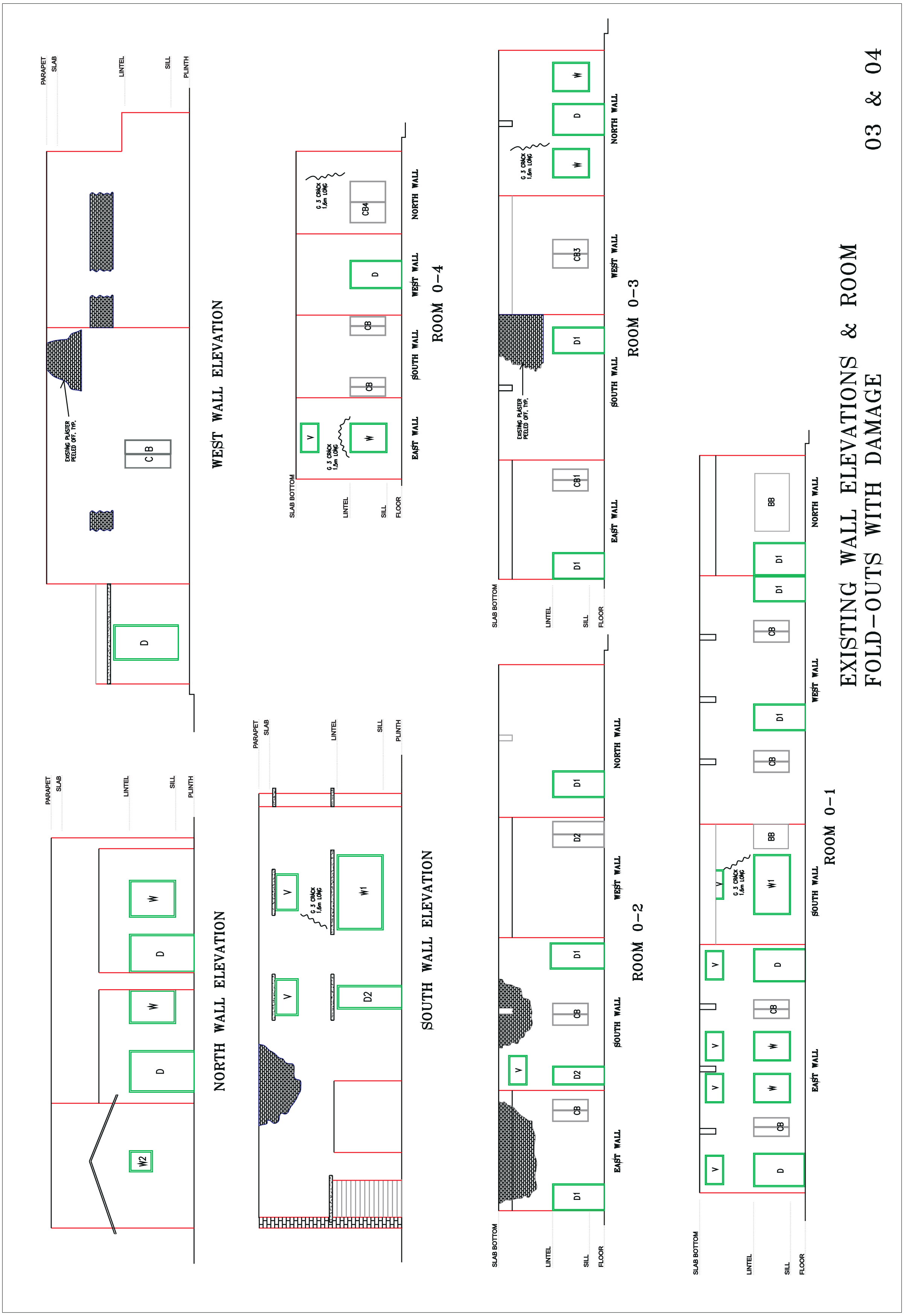
D : DOOR
W : WINDOW
CB : BUILT IN CUPBOARD
SHT : SHEET
FC : FERRO CEMENT
BB : BLACK BOARD
H2
G-X : VERTICAL CRACK
H1
L : LENGTH OF CRACK
H1 : HEIGTH OF BEGINING
H2 : HEIGTH OF END
G-X : DAMAGE CATEGORY

TITLE SHEET 01

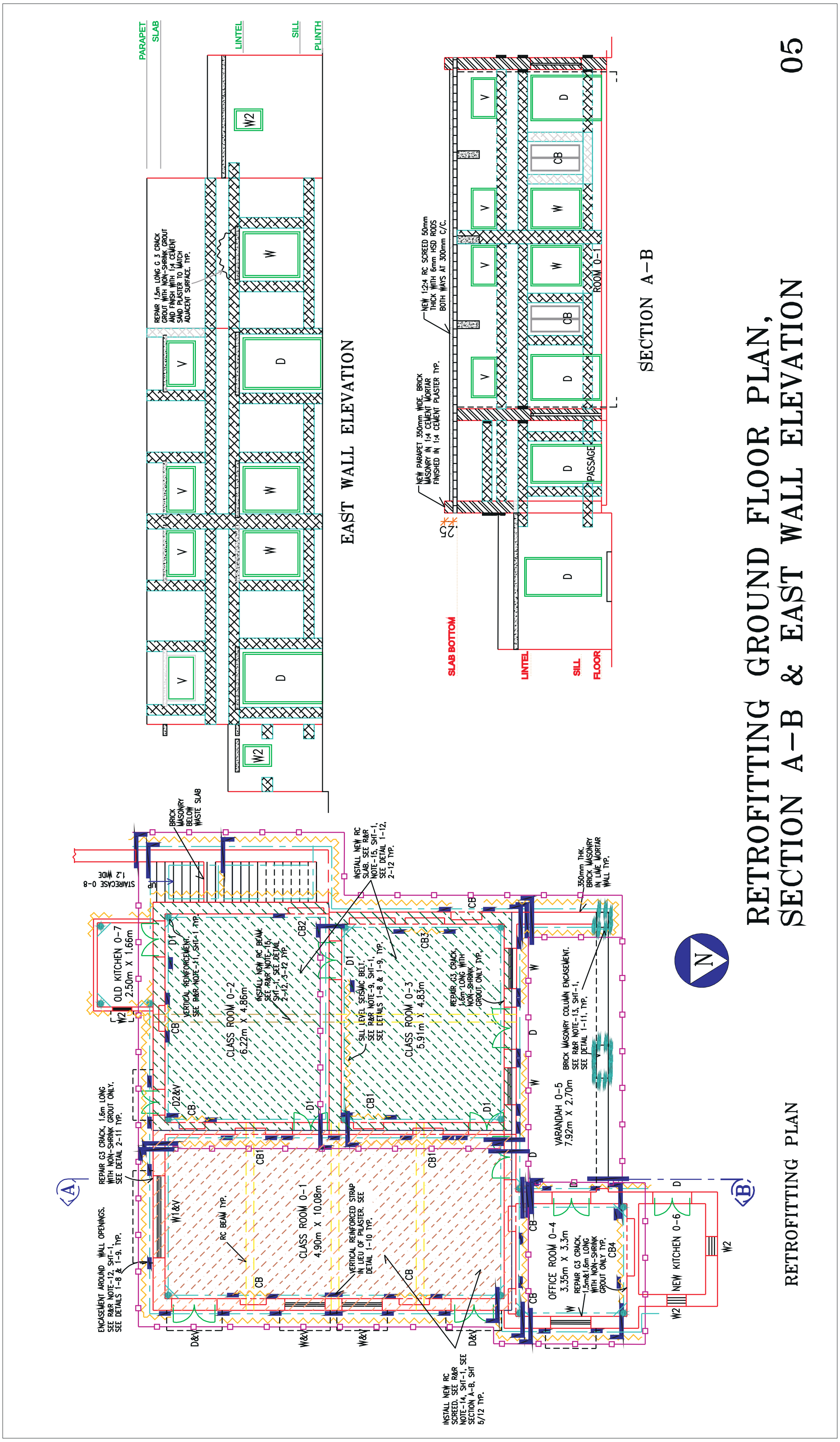
B. Case Study 2
Retrofitting of School Building at Khudbuda, Dehradun (cont.).



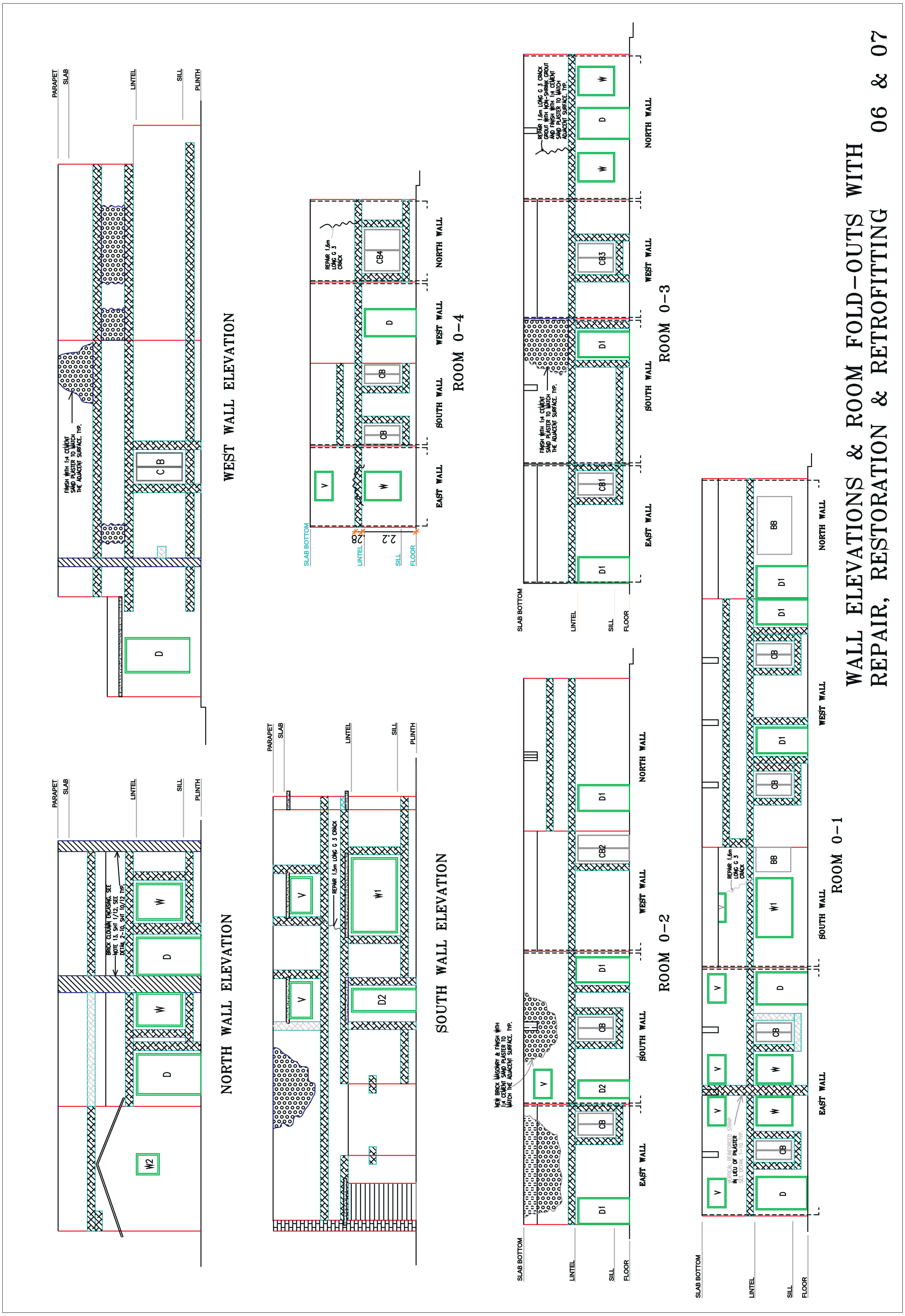
B. Case Study 2
Retrofitting of School Building at Khudbuda, Dehradun (cont.).



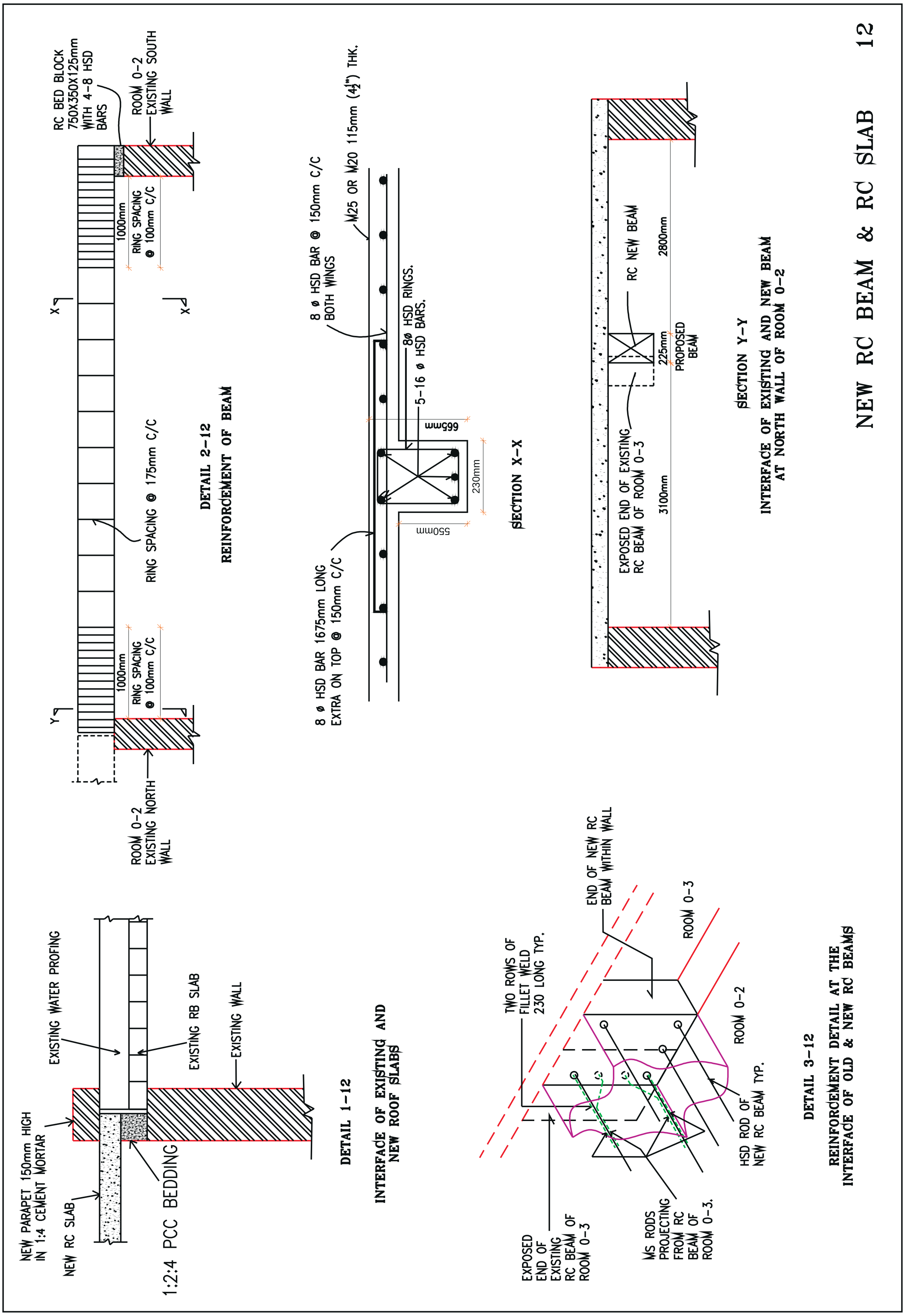
B. Case Study 2
Retrofitting of School Building at Khudbuda, Dehradun (cont.).



B. Case Study 2
Retrofitting of School Building at Khudbuda, Dehradun (cont.).



B. Case Study 2
Retrofitting of School Building at Khudbuda, Dehradun (cont.).



B. Case Study 2
Retrofitting of School Building at Khudbuda, Dehradun (cont.).

a. Before Retrofitting


Front view.


Rear view.


RC beam with large shear failure crack.


Existing brick pier with additional masonry in verandah.


Walls damaged by water seepage and roots.


Reinforced Brick roof damaged by roots and water.

B. Case Study 2
Retrofitting of School Building at Khudbuda, Dehradun (cont.).

b. During Retrofitting


Grouting of a large crack using canister.


Preparing for grouting small crack with hand pump.


Removal of damaged portion of RB roof.


Exposed masonry surface for seismic belts.


Attaching bars to WWM for making belt.


Installing upper level belt and opening encasement.

B. Case Study 2
Retrofitting of School Building at Khudbuda, Dehradun (cont.).

c. During Retrofitting

Plastering the belt and damaged walls.

Installing sheer connector for sill level belt.

Curing shear anchor for column encasement.

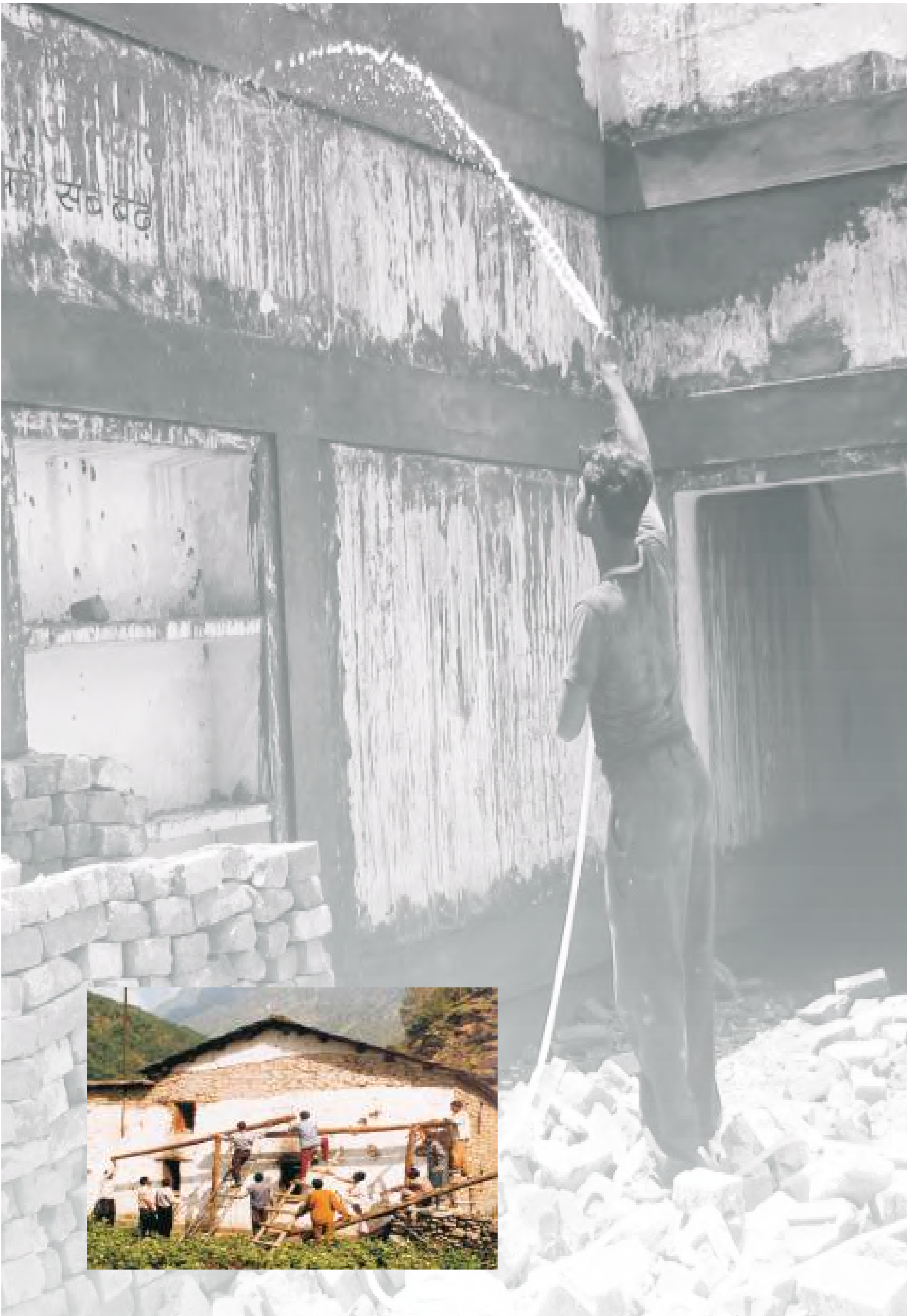
Plastering of seismic belt.

d. After Retrofitting

Finished classroom.

Finished Building.

9 GOOD PRACTICES



Following good construction practices essentially means adhering to the basic rules, ensuring quality and not taking short cuts. This can go a long way in reducing the structure's vulnerability.

A. Good Practices of Construction:

Common Precautions To Be Exercised To Prevent Commonly Observed Mistakes.

Planning and Designing of a House.

1. In an earthquake, a building with a square plan is safer than that with a rectangular plan.
2. If rectangular plan has to be provided, then length of the building should not be more than three times the width of the building.
3. Constructing a number of smaller buildings is better than constructing one very large building.
4. Symmetrical building plan around both the axes is better than asymmetrical plan. 'L', 'T', 'C' and 'H' shaped plans must be avoided.
5. If a projection of a room from the main structure is required, the length of projecting wall should be limited to 15% of the overall length of the structure in that direction.
6. Symmetry is desirable in placing of door and window openings.
7. Simplicity is the best approach for building design. Ornamentations involving large cornices, vertical or horizontal cantilever projections, stone cladding and the like should be avoided.
8. Four-sided pitched roof is better than two-sided pitched roof.
9. The height of the parapet walls in the terrace or balcony should be limited to three times the thickness of the parapet wall. It is better to build masonry wall of a lesser height and provide iron railing above.
10. Site near a hillside slope that is likely to slide during an earthquake should be avoided. Sites adjacent to a stable slope should be chosen.
11. On the sloping site, it is preferred to place several individual blocks independently on stepped terraces rather than placing the whole structure along a slope with footings at different heights.
12. A site subject to the danger of rock falls should be avoided.
13. Locating a structure on very loose sands or sensitive clays should be avoided. Hard soil and rocky ground is preferred for locating the structure.

Construction of Walls and Roof:

1. Mix all dry ingredients of concrete and mortar thoroughly before adding water.
2. Do not use fine sand in cement concrete.
3. Mud for mud mortar must be of good quality clayey soil. It must be kept wet at least for three days and <u>must be thoroughly mixed everyday</u> before using it for mortar.
4. Strictly adhere to the following Random Rubble Masonry rules:
   i. Place each stone flat on its broader face.
   ii. Place the stone in the wall such that its length goes in to the thickness of the wall, thus the interlocking of inside and outside wythes.
   iii. Provide at least one through stone in every 0.8 smt. (8 sft.) of wall.
   iv. Place long stone at corner in each course with length of the stone placed parallel to the length of that wall.
   v. Do not leave voids in masonry. Fill all voids in masonry using small chips of stone with minimum possible use of mortar.
   vi. Never use round stones for masonry. Stones must be angular. It is not necessary to dress the stones fully like in Ashlar masonry.

A. Good Practices of Construction (cont.)

Construction of Walls and Roof (cont.):

5. Use only one type of mortar in the construction of the wall.
6. Wet the masonry units, including brick, stone, concrete block etc. thoroughly in drums or tanks just before placing them on wall, so that they do not suck the water used in cement mortar. Reduction of water content in the mortar means weaker mortar.
7. In order to ensure good bond with the next course, on completing a masonry-course, its top surface must be clean with no mortar spread over it unless masonry units are going to be placed immediately on top of it. Hardened mortar weakens the joint with the next course or the band that will be placed above it.
8. Keep all vertical joints wide enough to place a finger in it and fill them properly with mortar.
9. Use tube level at every third or fourth course while using string to maintain level by placing uniform thickness of mortar.
10. Use plumb bob frequently during construction to ensure that the walls are vertical.
11. For properly anchoring attic floor to eave band install, during casting of eave band, 6mm diameter dowels with adequate length projecting out at each floor joist.
12. Use minimum two nails for a proper wood-to-wood joint.
13. Anchor RC slab to masonry wall by properly connecting the vertical reinforcement in the wall to that in the slab with an overlap having length no less than 52 times the diameter of bar.
14. Brick or stone masonry column of single storey height must have at least one 12mm TOR rod that is adequately anchored in the base of foundation and to the roof at the top.
15. Door and window openings should not be located at the room corners.
16. The lintel level of all the openings should be kept at the same height.
17. The total width of all the doors and windows in a wall must not exceed 40% of the length of that wall.

Anchoring Roof/Floor to Wall.

- Use 6mm MS or 8mm TOR rod dowels suitably located and anchored in Eave Level RC band, and projecting up adequately to anchor roof deck elements including truss bottom chords, beams and joists.

Timber Elements

- Resort to pre-drilling while using nails to minimize splitting of wood.

Installation of Hazard-Resistant Features.

1. Provide vertical reinforcements in all the corners. Bars must start from the foundation concrete and must go through all the storeys up to the roof.
2. Install plinth band with 2-8mm HSD bars tied with 8mm cross-links at 12"c/c. Properly connect the main bars with vertical reinforcement with adequate overlap.
3. Install lintle level band on all the floors similar to plinth band.
4. Install reinforcement all around the openings and on both sides in case of doors.
5. Install the floor level or eave level band if the floor is to be other than RC.
6. All timber /RC floor joists must be tied down to the band.
7. If the two sided roof is to be provided, than provide the gable top band, properly connected to the eave level band.
8. Anchor all purlins and rafter, including the ridge beam with the gable/eave level band.
9. Install collar beam to prevent the rafters from exerting a side way thrust on the walls.
10. Install diagonal bracings on the underside of the purlins.

B. Good Practices of Retrofitting

During Retrofitting pay attention to the following principles of good practices:

Seismic Belt and Vertical Reinforcement.

1. Study the possible alignment of full seismic belt before beginning its installation to avoid unexpected obstructions later.
2. Use tube level to mark out the seismic belt alignment before plaster removal for better aesthetics.
3. Use electric grinder to make a groove along the top and bottom of belt alignment in order to minimise damage to plaster during its removal and to reduce cost.
4. Rake all joints adequately and clean the wall surface with wire brush within the limits of the belt alignment and in vicinity of the vertical reinforcement to ensure good bond with the wall.
5. Ensure total embedment of WWM of belt in cement mortar by keeping a ½" gap between exposed wall surface and WWM with the use of spacers, and by ensuring that the mortar reaches behind the mesh.
6. Ensure adequate concrete cover on Vertical Reinforcement by ensuring a gap of 1½" to 2" between the rod and the wall.
7. Use minimum 4" diameter nails with washer for anchoring WWM in brick or concrete block walls, and use square headed nails in case of rubble wall. Remove and change the location of nails that are loose to ensure that they are secure.
8. Concrete for vertical reinforcement shall contain aggregates no larger than ½".
9. WWM must be galvanized for all applications.
10. No end of WWM should be left unattached to the other end of the same WWM or other WWM. Ensure that all such connections between the WWMs are either direct through their overlap or indirect through the use of overlapping dowel bars.

Shear Connector and Bond Element.

1. Make dumbbell-shaped hole for shear connector and bond element with its core just wide enough to permit the insertion of a 8mm HSD rod with hooked end in order to ensure its effectiveness in holding the wythes together and to reduce mortar consumption.
2. Prior to concreting, remove all loose material from hole and clean it with water.
3. In case of rubble masonry wall, use aggregates no bigger than ¼" in concrete. In case of brick masonry, use only coarse sand in mortar.
4. Reinforcing bar must be fully encased in concrete.

Roof and Floor.

1. In case of "In-Plane" bracings, if made of wood, use at least two bolts at each end. If made of multiple strands of GI wires, use carpenter's hammer to pull each wire tight while installing, followed by twisting all the wires together for pre-tensioning.
2. For timber-to-timber connections, use a minimum of two nails or screws for each joint. Pre-drilling is a must to prevent cracking/splitting of wood.
3. Secure the roof structure properly to the walls using MS angle brackets and bolts.

10

MATERIAL QUANTITIES

The information given in the following pages can be used to arrive at the quantity of materials required and the cost of various items which are to be carried out. These activities require special tools which are also described in this chapter.

Materials Quantity Estimate

Repair & Retrofitting work					
Sr. No.	Item Description	Quantity	Unit	Rate (Rs.)	Amount (Rs.)
1	G1 Crack sealing with 1:2 Cement Sand mortar			1 Rmt.	
	Cement	0.652	kg.	5	3.0
	Sand	0.001	cum.	777	0.8
2	G2 Crack Grouting in 1:2 cement sand mortar			1 Rmt.	
	Cement	1.691	kg.	5	9.0
	Sand	0.002	cum.	777	1.6
3	G2 and G3 Crack Grouting with Cement Sand (1:2) mortar, using appropriate grouting plasticizer			1 Cum.	
	Cement	603.86	kg.	5	3140.0
	Sand	0.83	cum.	777	647.0
	Grouting Plasticizer	1.81	Litre	275	498.0
4	G3 Crack grouting in 350mm thick Brick wall with 30% cavity in crack with Cement Sand (1:2) mortar with grouting plasticizer			1 Rmt.	
	Cement	0.942	kg.	5	5.0
	Sand	0.001	cum.	777	0.8
	Grouting Plasticizer	0.003	Litre	275	0.8
5	Crack stitching strap 280 mm wide and 1m. long with 250 mm. wide galvanised WWM having 9-13 ga. wires in longitudinal direction at 25mm spacing and 13 ga. cross wires at spacing of 75mm encased in cement sand mortar 1:3 or micro concrete 1:1.5:3			1 Rmt.	
	Galvanised 13 ga. WWM	0.23	smt.	215	49.0
	4" Nails 5mm dia. with large head	0.12	kg.	70	8.0
	Cement	4.44	kg.	5	23.0
	Sand	0.01	cum.	777	7.0
6	Cast-in-Situ Concrete Bond Element in 450 mm. thick RR wall with 8mm. HSD rod and in-fill of concrete 1:2:4			1 No.	
	Steel-8mm HSD	0.22	kg.	36	7.0
	Cement	1.11	kg.	5	6.0
	Sand	0.002	cum.	777	2.0
	Aggregates	0.003	cum.	971	3.0
7	Horizontal Seismic belt 280 mm wide for length of wall <5 mt. with 250mm. wide galvanised WWM having 9-13 ga. wires in longitudinal direction at 25mm. spacing and 13 ga. cross wires at 75mm spacing plus 2-6mm dia MS bars encased in cement mortar 1:3 or micro concrete 1:1.5:3.			1 Rmt.	
	Galvanised 13 ga. WWM	0.23	smt.	215	49.0
	Nails 5mm dia. with large head	0.12	kg.	70	8.0
	6mm MS bar	0.44	kg.	36	16.0
	Cement	4.44	kg.	5	23.0
	Sand	0.01	cum.	777	7.0
8	Horizontal Seismic belt 280 mm wide for length of wall 5 to 6 mt. with 250 mm wide galvanised WWM having 9-13 ga. wires in longitudinal direction at 25mm spacing 13 ga. cross wires at 75mm spacing plus 3-6mm dia bars encased in cement mortar 1:3 or micro concrete 1:1.5:3			1 Rmt.	
	Galvanised 13ga. WWM	0.23	smt.	215	49.0
	Nails 5mm dia. with large head	0.12	kg.	70	8.0
	6mm MS bar	0.67	kg.	36	24.0
	Cement	4.44	kg.	5	23.0
	Sand	0.01	cum.	777	7.0

Materials Quantity Estimate (cont.)

Sr. No.	Item Description	Quantity	Unit	Rate (Rs.)	Amount (Rs.)
	Repair & Retrofitting work				
9	Horizontal Seismic belt 280 mm wide for length of wall 6 to 7 mt. with 250 mm wide galvanised WWM having 9-13 ga. wires in longitudinal direction at 25mm spacing and 13 ga. cross wires at 75mm. spacing plus 4-6mm dia bars encased in cement mortar 1:3 or micro concrete 1:1.5:3.			1 Rmt.	
	Galvanised 13 ga. WWM	0.25	smt.	215	54.0
	Nails 5mm dia. with large head	0.12	kg.	70	8.0
	6mm MS bar	0.89	kg.	36	32.0
	Cement	4.44	kg.	5	23.0
	Sand	0.01	cum.	777	7.0
10	Horizontal Seismic belt 280 mm wide for length of wall 7 to 8 mt. with 250 mm wide galvanised WWM having 9-13 ga. wires in longitudinal direction at 25mm spacing and 13 ga. cross wires at 75mm. spacing plus 6-6mm dia rods encased in cement mortar 1:3 or micro concrete 1:1.5:3.			1 Rmt.	
	Galvanised 13 ga. WWM	0.25	smt.	215	54.0
	Nails 5mm dia. with large head	0.12	kg.	70	8.0
	6mm MS bar	1.33	kg.	36	48.0
	8mm HSD Steel bar	0.00	kg.	36	0.0
	Cement	4.44	kg.	5	23.0
	Sand	0.01	cum.	777	7.0
11	Cast-in-Situ Concrete Shear Connector for Seismic Belt in wall up to 450mm thick 8mm HSD bar and in-fill Concrete 1:2:4			1 No.	
	8mm HSD steel bar	0.23	kg.	36	8.0
	Cement	0.86	kg.	5	4.0
	Sand	0.0012	cum.	777	1.0
	Aggregates not bigger than 10mm.	0.0024	cum.	971	2.0
12	Through the wall (up to 450mm thick) connection between belts on different walls using 2-10mm HSD dowels encased in 1:2:4 concrete			1 No.	
	10mm HSD Steel bar	1.580	kg.	36	57.0
	Cement	1.056	kg.	5	5.0
	Sand	0.0015	cum.	777	1.0
	Aggregates not bigger than 10mm	0.0029	cum.	971	3.0
13	12mm dia MS Tie Rod in up to 450mm th. wall, threaded at both ends with 2 nuts at each and 100x100x5 MS bearing plate at each end.			1 Rmt.	
	12mm dia MS bar	0.89	kg.	40	36.0
	100x100x5mm thick MS Bearing Plates	0.47	kg.	35	16.0
	Misc. - Nuts, Threading, washers etc.	2.00	Nos.	106	12.0
	Cement	1.88	kg.	5	10.0
	Sand	0.003	cum.	777	2.0
	Aggregates not bigger than 10mm.	0.005	cum.	971	5.0
14	12mm dia HSD vertical reinforcement at wall corners encased in 4"x4" triangle of 1:1.5:3 micro concrete with top and bottom anchor bar.			1 Rmt.	
	12mm HSD Steel bar	1.36	kg.	36	49.0
	Cement	2.00	kg.	5	10.0
	Sand	0.002	cum.	777	2.0
	Aggregates not bigger than 10mm.	0.004	cum.	971	4.0

Materials Quantity Estimate (cont.)

Repair & Retrofitting work					
Sr. No.	**Item Description**	**Quantity**	**Unit**	**Rate (Rs.)**	**Amount (Rs.)**
15	16mm HSD vertical reinforcement at wall corners encased in 4"x4" triangle of 1:1.5:3 micro concrete with top and bottom anchor bar.			1 Rmt.	
	16mm HSD Steel bar	2.42	kg.	36	87.0
	Cement	2.00	kg.	5	10.0
	Sand	0.002	cum.	777	2.0
	Aggregates not bigger than 10mm	0.004	cum.	971	4.0
16	Cast-in-Situ Concrete Shear Connector for Vertical Bar in wall up to 450mm thick 8mm HSD bar and in-fill of Concrete 1:2:4			1 No.	
	8mm HSD steel bar	0.34	kg.	36	12.0
	Cement	0.94	kg.	5	5.0
	Sand	0.001	cum.	777	1.0
	Aggregates not bigger than 10mm.	0.003	cum.	971	2.0
17	Vertical bar bottom anchor in 1:3:6 concrete of 300x300x450mm			1 NO.	
	Cement	14.37	kg.	5	75.0
	Sand	0.02	cum.	777	14.0
	Aggregates	0.04	cum.	971	36.0
18	Vertical bar top anchor in RC slab - Concrete breaking - Labour Only			1.00	Nos.
19	Vertical seismic strap 400mm wide with galvanised WWM having 14-13 ga. wires in longitudinal direction at 25mm spacing and cross wires at 75mm spacing plus 2-6mm MS bars and 1-12mm HSD bar encased in cement mortar 1:3 or micro concrete 1:1.5:3.			1 Rmt.	
	Galvanised 13ga. WWM 25mmx50mm	0.51	Smt.	215	110.0
	6mm MS bar	0.82	kg.	36	30.0
	12 mm HSD steel bar	1.51	kg.	36	54.0
	Cement	6.59	kg.	5	34.0
	Sand	0.01	cum.	777	11.0
	Nails 5mm dia. with large head	0.20	kg.	70	14.0
20	Vertical seismic strap 400mm wide made with galvanised WWM having 14-13 ga. wires in longitudinal direction at 25mm spacing and cross wires at 75mm spacing plus 2-6mm MS bars encased in cement mortar 1:3 or micro concrete 1:1.5:3.			1 Rmt.	
	Galvanised 13ga. WWM 25mmx50mm	0.51	Smt.	215	110.0
	6mm MS bar	0.82	kg.	36	30.0
	Cement	6.59	kg.	5	34.0
	Sand	0.01	cum.	777	11.0
	Nails 5mm dia. with large head	0.20	kg.	70	14.0
21	Vertical seismic strap bottom anchor in 1:3:6 concrete of 400x150x300mm.			1 No.	
	Cement	3.97	kg.	5	21.0
	Sand	0.01	cum.	777	6.0
	Aggregates	0.02	cum.	971	16.0
22	Vertical Strap top anchor in RC slab - Concrete breaking - Labour Only			1 No.	

Materials Quantity Estimate (cont.)

Repair & Retrofitting work					
Sr. No.	**Item Description**	**Quantity**	**Unit**	**Rate (Rs.)**	**Amount (Rs.)**
23	Door and window encasement 280mm wide with 250mm wide galvanised WWM strap having 9-13 ga. wires in longitudinal direction at 25mm spacing and 13ga. cross wires at 75mm spacing plus 2-6mm MS bars encased in cement mortar 1:3 or micro concrete 1:1.5:3.			1 No.	
	Galvanised 13ga. WWM	0.32	smt.	215	69.0
	Nails 5mm dia. with large head	0.12	kg.	70	8.0
	6mm MS bar	0.62	kg.	36	22.0
	Cement	4.44	kg.	5	23.0
	Sand	0.01	cum.	777	7.0
24	Window encasement reinforcement anchor into RC window chhajja or lintle			1 No.	
	8mm HSD Steel bars	0.42	kg.	36	15.0
	Cement	1.38	kg.	5	7.0
	Sand	0.001	cum.	777	1.0
	Aggregates	0.003	cum.	971	2.0
25	Door encasement bottom anchor in 1:3:6 concrete of 300x150x300mm.			1 No.	
	Cement	3.97	kg.	5	20.0
	Sand	0.01	cum.	777	6.0
	Aggregates	0.02	cum.	971	16.0
26	Encasing of 450x450 brick pier including 1-8mm HSD bar on each face with 6mm MS rings at 300mm o/c covered in 1:4 cement mortar for pitched flexible roof like CGI or slate.			1 Rmt.	
	6mm MS Ring at 300mm spacing	1.52	kg.	36	55.0
	8mm HSD steel bars - 1 on each face	3.49	kg.	36	126.0
	8mm HSD Dowel	0.12	kg.	36	4.0
	Cement	7.53	kg.	5	39.0
	Sand	0.02	cum.	777	16.0
27	Brick pier encasement shear connector - 8mm HSD dowel 150mm long embedded 150mm deep in brick masonry and grouted with non-shrink grout 1:1 (Non-shrink Cement : Water)			1 No.	
	8mm HSD steel bar	0.12	kg.	36	4.0
	Non-shrink Cement	0.037	kg.	26	1.0
28	Brick pier encasing bottom anchor in 1:2:4 concrete of 800x800x450mm.			1 No.	
	Cement	86.03	kg.	5	447.0
	Sand	0.12	cum.	777	92.0
	Aggregates	0.24	cum.	971	231.0
29	Concrete breaking for pier encasement reinforcement top anchor in RC slab / beam			1 No.	
	Cement	1.80	kg.	5	9.0
	Sand	0.002	cum.	777	1.0
	Aggregates	0.004	cum.	971	4.0
30	Anchors in RC: 8mm HSD dowel 150mm long, embedded 100mm deep in RC element and grouted with non-shrink grout 1:1 (Non-shrink cement : Water)			1 No.	
	8mm HSD steel bar	0.12	kg.	36	4.0
	Non-shrink Cement	0.037	kg.	26	1.0

Materials Quantity Estimate (cont.)

Repair & Retrofitting work					
Sr. No.	**Item Description**	**Quantity**	**Unit**	**Rate (Rs.)**	**Amount (Rs.)**
31	Wooden bracing and struts on upper side of wooden attic floor (Approx.)			1 Rmt.	
	6"x1" wooden planks	1.00	Rmt.	265	265.0
	4" long 5mm dia. GI nails with washer	0.12	Kg. approx.	70	8.0
32	Timber Attic floor to UCR wall anchor made of MS Angle 50x50x5mm mounted on 450x250x35mm wooden plate with 3-12mm dia. bolts and connected to floor joist with 3-12mm dia. bolts, with plate mounted on the Seismic Belt with 4-12mm dia. bolts at its corners.			1 No.	
	Anchor Brackets made from MS Angle 50x50x5mm with each arm 12" long and with 3-13mm holes	2.28	kg.	53	110.0
	18"x10"x1.25" wooden plank	0.46	Rmt.	30	14.0
	10" Long 12mm Dia. Bolt with 2 washers and 1 nut.	1.00	kg. approx.	80	80.0
	3" Long 12mm Dia. Bolt with 2 washers and 1 nut.	0.57	kg. approx.	80	46.0
	2" Long 12mm Dia. Bolt with 2 washers and 1 nut.	0.38	kg. approx.	80	30.0

Note: All rates are indicative only and should not be taken as a standard, and are based on 2009 June local rates at Dehradun in Uttarakhand State. The rates will vary in the mountains at and away from road side.

Item Rates

Note: All rates are indicative only and should not be taken as a standard, and are based on 2009 June local rates at Dehradun in Uttarakhand State. The rates will vary in the mountains at and away from road side.

Repair and Retrofitting Iteams Rate - In Rupees					
Sr. No.	**Item Description**	**Unit**	**Labour Rate**	**Materials Rate**	**Total Rate**
1	G1 Crack sealing with 1:2 Cement Sand Mortar	Rmt.	23	5	28
2	G2 Crack Grouting in 1:2 Cement Sand Mortar	Rmt.	27	13	40
3	G2 & G3 Crack Grouting with Cement Sand (1:2) mortar using appropriate grouting plasticizer	Cum.	3228	5143	8371
4	G3 Crack grouting in 350mm thick Brick wall with 30% cavity in crack, using 1:2 mortar with grouting plasticizer	Rmt.	39	26	65
5	Crack stitching strap 280mm wide and 1m long with 250mm wide galvanised WWM having 9-13ga wires in longitudinal direction at 25mm spacing and cross wires at spacing of 75mm encased in cement mortar 1:3 or micro concrete 1:1.5:3.	Rmt.	111	106	217
6	Cast-In-Situ Concrete Bond Element in 450mm thick RR wall with 8mm HSD bar and in-fill of Concrete 1:2:4	No.	47	21	64
7	Horizontal Seismic belt 280mm wide for length of wall <5m with 250mm wide galvanised WWM having 9-13ga. wires in longitudinal direction at 25mm spacing, and cross wires at spacing of 75mm plus 2-6mm MS bars encased in cement mortar 1:3 or micro concrete 1:1.5:3.	Rmt.	143	125	268
8	Horizontal Seismic belt 280mm wide for length of wall 5 to 6m., with 250mm wide galvanised WWM having 9-13ga. wires in longitudinal direction at 25mm spacing, and cross wires at spacing of 75mm plus 3-6mm MS bars encased in cement mortar 1:3 or micro concrete 1:1.5:3.	Rmt.	155	135	290
9	Horizontal Seismic belt 280mm wide for length of wall 6 to 7m., with 250mm wide galvanised WWM having 9-13ga. wires in longitudinal direction at 25mm spacing, and cross wires at spacing of 75mm plus 4-6mm MS bars encased in cement mortar 1:3 ormicro concrete 1:1.5:3.	Rmt.	169	149	318
10	Horizontal Seismic belt 280mm wide for length of wall 7 to 8m., with 250mm wide galvanised WWM having 9-13ga. wires in longitudinal direction at 25mm spacing, and cross wires at spacing of 75mm plus 6-6mm MS bars encased in cement mortar 1:3 or micro concrete 1:1.5:3.	Rmt.	200	169	369
11	Cast-In-Situ RC shear Connector for Seismic Belt in up to 450mm thick wall with 8mm HSD bar nad infill of Concrete 1:2:4.	No.	45	19	64
12	Through the wall (up to 450mm thick) connection between belts on different walls using 2-10mm HSD dowels encased in 1:2:4 concrete.	No.	117	80	197
13	12mm MS Tie Rod in wall, up to 450mm th. threaded at both ends with 2 nuts and 100x100x5mm. MS bearing plate at each end.	Rmt.	58	337	395
14	12mm HSD vertical reinforcement at wall corners, encased in 4"x4" triangle of 1:1.5:3 micro concrete with top and bottom anchors.	Rmt.	84	78	162
15	16mm HSD vertical reinforcement at wall corners encased in 4"x4" triangle of 1:1.5:3 micro concrete with with top and bottom anchor.	Rmt.	84	124	208

Item Rates (cont.)

Repair and Retrofitting Item Rates - In Rupees					
Sr. No.	Item Description	Unit	Labour Rate	Materials Rate	Total Rate
16	Cast-In-Situ RC Shear Connector for Vertical Reinforcement in wall up to 450mm thick, with 8mm HSD bar and infill of Concrete 1:2:4.	No.	53	25	78
17	Bottom anchor 1:3:6 concrete of 300x300x450mm for vertical reinforcement	No.	110	150	260
18	Concrete breaking for vertical bar top anchor in RC lab.	No.	260	0	260
19	Vertical seismic strap 400mm wide made with galvanised WWM having 14-13ga. wires in longitudinal direction at 25mm spacing and cross wires at spacing of 75mm plus 2-6mm MS bars and 1-12mm HSD bar encased in cement mortar 1:3 or micro concrete 1:1.5:3.	Rmt.	192	303	495
20	Vertical seismic strap 400mm wide made with galvanised WWM having 14-13ga. wires in longitudinal direction at 25mm spacing and cross wires at spacing of 75mm plus 2-6mm MS bars encased in cement mortar 1:3 or micro concrete 1:1.5:3.	Rmt.	187	238	425
21	Bottom anchor 1:3:6 concrete of 400x150x300 for vertical seismic strap.	No.	198	51	249
22	Concrete breaking for vertical seismic strap top anchor.	No.	260	0	260
23	Door and window encasement 280mm wide with 250mm wide galvanized WWM strap having 9-13ga. wires in longitudinal direction at 25mm spacing and cross wires at spacing of 75mm plus 2-6mm MS bars encased in cement mortar 1:3 or micro concrete 1:1.5:3.	Rmt.	141	125	268
24	Window encasement reinforcement anchor into window RC chajja.	No.	204	35	239
25	Bottom anchor in 1:3:6 concrete of 300x150x300 mm. for Door encasement.	No.	171	39	210
26	Encasing of 450x450mm brick pier including 1-8mm. HSD bar on each face with 6mm MS rings at 300mm. o/c covered in 1:4 cement mortar.	Rmt.	368	288	676
27	Brick pier encasement shear connector-8mm HSD dowel150mm long, embedded 150mm deep in brick masonry and grouted with non-shrink grout 1:1 (Non-shrink Cement : Water)	No.	69	9	78
28	Bottom anchor in 1:2:4 concrete of 800x800x450mm for Brick pier encasing	No.	574	924	1498
29	Concrete breaking for pier encasement reinforcement top anchor in RC slab / beam	No.	200	24	224
30	Anchor in RC-8mm HSD dowel 150mm long, embedded 100mm deep in RC element and grouted with non-shrink grout 1:1 (Non-shrink Cement : Water)	No.	60	12	72
31	Wooden bracing and struts on upper or lower side for wooden attic floor	Rmt.	40	330	370
32	Anchor for Timber Attic to UCR wall made of MS Angle 50x50x5 mounted on 450x250x35mm wooden plate with 3-12mm dia. bolt and connected to floor joist with 3-12mm dia. bolts, with plate mounted on the Seismic Belt with 4-12mm dia. bolts at its corners.	No.	217	318	535

Materials and Labour Rates

Materials & Labour Rates for Dehradun			
(To be used for reference only)			
Sr.No.	**Item**	**Rupees**	**Unit**
1	4" long nails 5mm dia. with large head	70	kg.
2	AC sheet 3'x7'-0"	450	no.
3	Aggregates	971	cmt.
4	Binding Wire	60	kg.
5	Bolts MS	60 to 80	kg.
6	Cement	260	bag
7	CGI sheet 3'x10'-0"	850	no.
8	Concrete Block	13	no.
9	Galvanized Iron wire	80	kg.
10	Galvanized WWM - 13 ga. 1¼" x 1¼"	215	Smt.
11	Grouting Plasticizer	275	ltr.
12	Lime	5	kg.
13	MS plate	35	kg.
14	MS rolled section	40	kg.
15	Nails	70	kg.
16	Nuts	70 to 80	kg.
17	Wood Plank	varies	cmt.
18	Plasticizer	240	ltr.
19	RCC Slab	150	sft.
20	Rubble	varies	
21	Sand	777	cmt.
22	Steel	36	kg.
23	Steel fabrication	12	kg.
24	Timber	70,640	cmt.
	Labour		
25	Carpenter	300	day
26	Mason	300	day
27	Unskilled labour	165	day

Note: All rates are indicative only and should not be taken as a standard, and are based on 2009 June local rates at Dehradun in Uttarakhand State. The rates will vary in the mountains at and away from road side.

List of Equipment, Tools And Miscellaneous Items

Note: The items that are not commonly used at construction sites are shown in photos.

For Wall Preparation a nd Making Holes

- ✓ 1 Rotary power drill with long extension cord (if electric power is available), and drill bits of 1" and 2" dia. 12" long.
- ✓ 1 Electric grinder for plaster cutting
- ✓ 2 Brick masonry hole making tool - 1.25" dia. GI pipes 12" and 18" long
- ✓ 3 Wire brush for wall cleaning
- ✓ 4 Chisel & hammer for raking mortar joints

For Anchors and Concreting

- ✓ Bar bending set, made of wood or of steel
- ✓ Bar bending tools for different size bars or 2' long-½" and 1" dia. GI or MS pipes
- ✓ 5 kg. Sledge hammer
- ✓ Different size chisels with tongs for cutting steel rods, WWM and concrete;
- ✓ 5 Pliers with wire cutter,
- ✓ 6 Binding wire tightening tool
- ✓ Spanners for the wall anchor bolts
- ✓ Sheet metal as form-work of corner vertical reinforcement concreting
- ✓ 6" and 4" long 5mm dia. nails with large round head with washers, 6"long nails for use in walls of mud-mortar
- ✓ 7 Grouting canister and hand pump
- ✓ Scaffolding extending to min.10' to 15' length along two adjacent walls .
- ✓ Ladders (2 to 3 numbers)
- ✓ 8 Carpenters saw, hand drill, hammer etc.

For Mixing Mortar and Plastering

- ✓ Shovel
- ✓ Pans
- ✓ Sieve for coarse sand
- ✓ Trowel
- ✓ Plastering tool
- ✓ 2"x1" wooden batten min. 15' long, and an aluminum straight edge 6' long.
- ✓ 9 Tube level and plumb bob

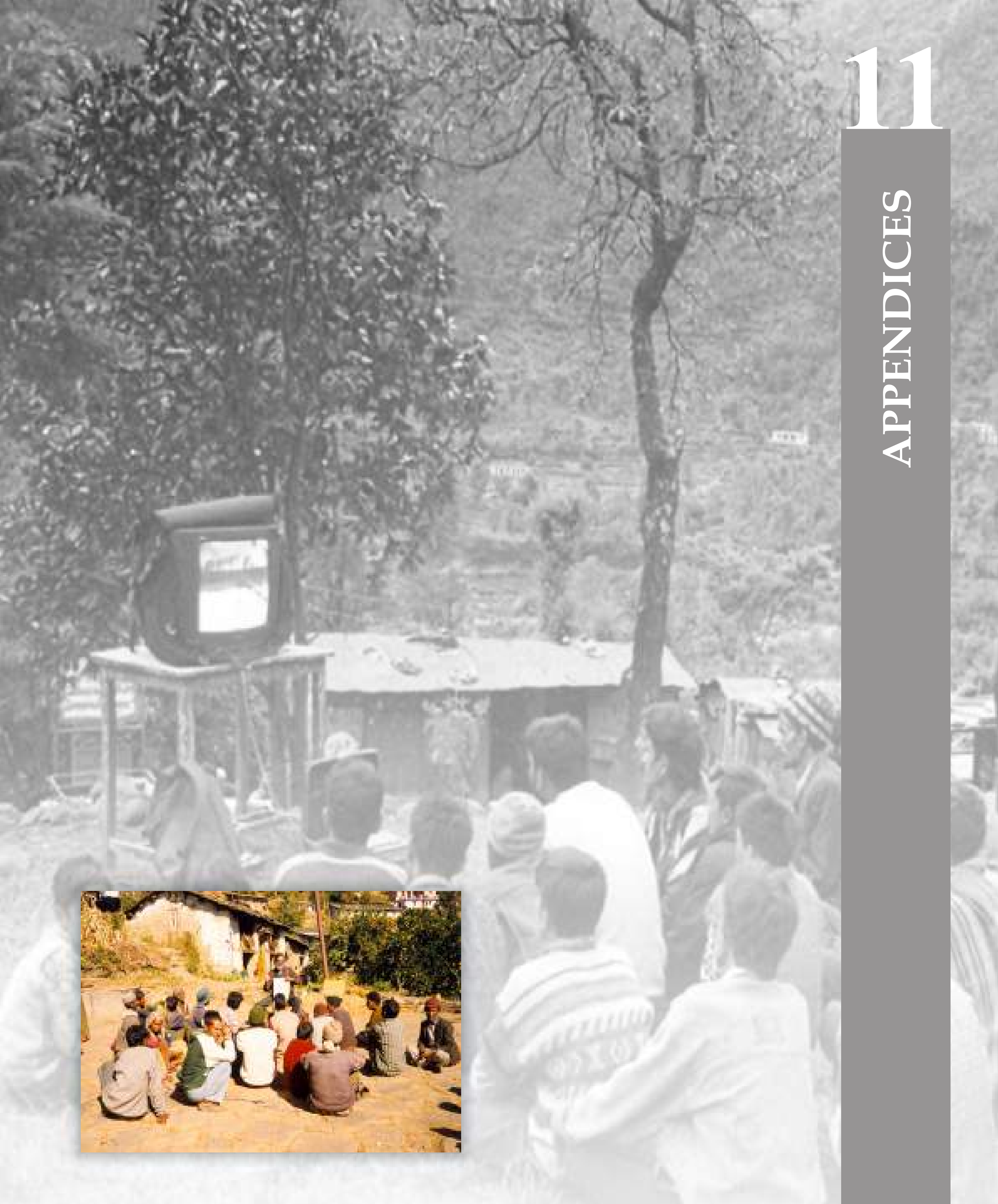
Miscellaneous

- ✓ Torch
- ✓ Cotton string for marking
- ✓ Chalk / Marker / Charcoal

Materials

- ✓ Water
- ✓ Cement
- ✓ Polymer additives
- ✓ Coarse sand
- ✓ Aggregates (1/4") and (1/2")
- ✓ Adhesive powder or solution for good bond between old and new concrete
- ✓ Steel rods 8mm HSD, 10mm HSD, 12mm HSD, or MS as required
- ✓ Galvanised WWM as per the IS 13935 or as recommended in this manual
- ✓ Binding wire, Galvanised preferred
- ✓ 10mm studs approximately 220mm long.
- ✓ 1"x4" Planks
- ✓ 4" Wood nails with washer
- ✓ 2.5mm or 3mm GI wire

11 APPENDICES



The glossary with Hindi words of various technical items can help engineers communicate with the local contractors and masons. The condensed BIS guidelines provide codal requirements for ready reference.

Glossary

English	Hindi
Damage	नुकसान
Shaking	कम्पन
Continuous	लगातार / निरंतर
Severity	गंभीरता / तीव्रता
Construction	निर्माण
Stepped	सीढ़ीनुमा
Basic rules	मौलिक नियम
Severe damage	भारी नुकसान
Earthquake	भूकम्प
To dismantle	निकाल देना
Structure	संरचना
Support wall / Load bearing wall	सहारेकी दीवार
CGI roofing sheets	नालीदार चद्दर
Totally collapsed	पूर्ण रूप से क्षतिग्रस्त
Quantity	संख्या
Restoration	पुनःस्थापित करना
Partially collapsed	आंशिक रूप से क्षतिग्रस्त
Inadequate	अपर्याप्त
Interlocking between stones	पत्थरोंको एक दूसरे में फसाना
Eventually	आखिरकार
Fill up	भरना
Carefully	सावधानी पूर्वक
Dumbell shaped	डमरुनुमा
Hole	छेद
Proportion	अनुपात
End	छोर
Different types	विभिन्न प्रकार
Seismic belt	भूकम्पीय पट्टा
Lintel	सरदल
Frame	चौखट
Level	सतह
Sloping edge	तिरछी धार
Galvanized	जस्तेदार
Raking	खरोंचना

English	Hindi
Reinforcement	सरियेके जालसे प्रबलीकरण/ मजबूत करना
Inadequate bonding	अपर्याप्त बंधन/जुड़ाव
Option	विकल्प
Satisfactory bond	संतोषजनक बंधन
Opening	छेद / खुली जगह
Anchor	बांधना / स्थिरण
Encase	ढकना
All around	चारों तरफ
Wooden Truss	लकड़ी की कैंची
Diagonal bracing	कर्ण में तान धरन
Strut	मलगा
Wood plank	लकड़ी का तख्ता
Affordable	सामर्थ्य के अंदर
Easy to execute	करने में आसान
Local	स्थानीय
Quality	गुणवत्ता
Buttress	पुख्ता करना
Resistant	प्रतिरोधक
Metal strap	लोहेकी पट्टी
Wire-nail	कील
Control	नियंत्रण
Bond / Stitch	जुड़ाव / टांका लगाना
Enclose	बाड़ा लगाना / धेरना
Plumb	साहुल
Lap	चढ़ाव
Staggered	टेढ़ी मेढ़ी रेखा
Header	खड़ा रद्दा
Stretcher	पट्ट रद्दा
Through-stone	मुनिया
Wood chisel	छेनी
Saw	आरी
Jack plane	रंधा

Glossary

English	Hindi
Hand drill	बर्मा
Spalling of concrete	कंक्रीट में फफोले निकलना
Ridge	काठी धार
Bulging of wall	दीवार का फूलना
Chicken wire mesh	मुर्गा जाली
Columns	स्तम्भ, खंभा
Crow-bar	सब्बल
Curing	तराई, गीला रखना
Delamination of wall	दीवार की एक परत ढह जाना
Diagonal cracks	तिरछी दरारें
Earthquake forces	भूकंम्प के धक्के
Earthquake Resistant	भूकंम्प प्रतिरोधी
Eave band	ओलती पट्टिका
Ferrocement bandage	लोहे की जालीवाला कंक्रीट का पट्टा
Parapet	मुंडेर
Partition Walls	विभाजक दीवारें
Foundation	नींव
Screw	पेंच
Nail	कील
Rafter, Joist	कड़ी
Purlin	बांसा
Cast-in-situ	स्थल पर ढाला गया
Pre-cast	पूर्व-निर्मित
Eave	ओलती / ढलवाँ छत का निचला किनारा
Stone chips	छपलें, चूले, कतल
Tension (Pulling)	तनाव
Welded Wire Mesh	लोहे की जाली
Wythe	दीवार की परत

Guidelines at a Glance

Guidelines at a Glance for Earthquake-Resistant Reconstruction of Masonry Buildings (Category E) For Wall Length of 5m.max.

Sr. no.	Item	Stone masonry in mud mortar	Stone masonry in Cement:sand mortar	Brick masonry in Cement:sand mortar	Concrete Block in Cement:sand mortar	Additional Information
1	Wall thickness	450 - 500 mm max	350 to 450 mm. max	230 mm	200 mm	Stones in wall thickness to be interlocked with each other
2	Mortar	Good quality mud	Fdn. 1:6, Wall 1:4	Fdn. 1:6, Wall 1:4	Fdn. 1:6, Wall 1:4	
3	Height of Masonry Courses	600 mm max.	600 mm max.	NA	NA	
4	Through Stones / Bonding Elements of length equal to wall thickness	At 600 mm vertical &1200 mm horizontal spacing	At 600 mm vert. and 1200 mm horiz. spacing	Use headers and stretchers, and break all vertical joints	Use headers and stretchers, and break all vertical joints	Alternatively for RR walls Use 50X50 CB with 8mm rod or 150X150mm CB or wooden log 100X100mm
5	Long Stones, CB or wooden log at all wall junctions.	Every alternate course	Every alternate course	NA	NA	Long Stones to be 600 mm long, CB to be 150x150x500 mm.
6	Height of one storey	2.7 m. max.	3.2 m. Max.	3.2 m Max.	3 m Max.	
7	Max. no. of storeys	One	Flat roof -2 storeys / Pitched roof - 1 Storey + Attic	Flat roof -2 storeys / Pitched roof - 1 storey + Attic	Flat roof -2 storeys / Pitched roof - 1 storey + Attic	
8	Span of walls between cross walls	5.0 m max.	7.0 m max.	7.0 m max.	7.0 m max.	
9	Pilaster/ buttress needed at intermediate point if span of wall is more than specified above					
	Spacing between pilasters	3.5 m max.	5.0 m max.	5.0 m max.	5.0 m max.	
	Top width equal to main wall thk.	450 mm	380 to 400 mm	210 mm	210 mm	
	Base width	450 mm or 1/6th of the wall height	1/6th of the wall height	1/6th of the wall height	1/6th of the wall height	
10	Control of openings in walls					
	(a) Total length of all openings in a wall	0.33 of wall (inner) length,	0.5 of wall (inner) length in single storey, 0.42 in double storey bldg.	0.5 of wall (inner) length in single storey, 0.42 in double storey bldg.	0.5 of wall (inner) length in single storey, 0.42 in double storey bldg.	
	(b) Distance of opening from inside corner	More than 600 mm.	More than 450 mm.	More than 450 mm.	More than 450 mm.	
	(c) Pier width between consecutive openings	More than 600 mm.	More than 600 mm.	More than 560 mm.	More than 560 mm.	

Guidelines at a Glance

Guidelines at a Glance for Earthquake-Resistant Reconstruction of Masonry Buildings (Category E) For Wall Length of 5m.max.

Sr. no.	Item	Stone masonry in mud Mortar	Stone masonry in Cement:sand mortar	Brick masonry in Cement:sand mortar	Concrete Block in Cement:sand mortar	Additional Information
11	Vertical reinforcement at jambs of openings					
	One storey bldg. or upper storey in two storey bldg.	12 mm HSD	12 mm HSD	12 mm. HSD	12 mm HSD	Encase in 75mm concrete 1:1½:3
	Ground storey of two storey building	NA	16 mm HSD	16mm. HSD	16mm HSD	Encase in 75mm concrete 1:1½:3
	When controls of openings are violated	Box Jambs in RCC 1:1½:3	Box Jambs in RCC 1:1½:3	Box jambs in RCC 1:1½:3	Box Jambs in RCC 1:1½:3	Thickness of box jamb - 75 mm with 2 - 10mm HSD bars.
12	Vertical reinforcement at all inside and outside corners					
	One storey bldg. or upper storey of two storey bldg.	12mm HSD or 'L' section of two timber planks 80x30 and 50x30mm	12 mm HSD	12 mm HSD	12 mm HSD	Encase rods in 75mm concrete 1:1½:3 . Nail timber planks to timber bands.
	Ground storey of two storey building.	NA	16 mm HSD	16 mm HSD	16 mm HSD	Encase in 75mm concrete 1:1½:3
13	Continuous Horizontal Seismic Bands of 75mm thickness in all internal and external walls					
	Location of bands in Flat Roof building : at plinth level in softsoil also or if plinth height >90 cm.	Sill, lintle level and at ceiling level if ceiling is of timber	Sill, lintle levels in ea. storey & under floor/ceiling level in case of timber floor/ceiling	Sill, lintle levels in ea. storey & under floor/ceiling level in case of timber	Sill, lintle levels in ea. storey & under floor/ceiling level in case of timber floor/ceiling	Use 2-10HSD Bars with 6mm MS stirrups at 150mm c/c. Overlap of bars = 500 mm. When distance betwee eave and lintle level is less than 600mm, lintle band can be integrated with eave band.
	Location of bands in Pitched Roof building : at plinth level in softsoil also or if plinth height >90 cm.	Sill, lintle and eave levels, and at triangular masonry gable top	Sill, lintle on ea. Storey, eave, masonry gable top and at timber floor level	Sill, lintle on ea. storey, eave, masonry gable top and at timber floor level	Sill, lintle on ea. storey, eave, masonry gable top and at timber floor level	
	Material for seismic band	Concrete 1:1½:3 or timber if vert. timber reinforcement is used	Concrete. 1:1½:3	Concrete.1:1½:3	Concrete.1:1½:3	For timber band use 2-75x38mm with cross links 50x30mm at 500 mm c/c
14	Corner strengthening with Dowels	L' or 'T' shaped wooden inserts	NA	NA	NA	Timber size 30x50 mm.
15	Gable wall materials	AC or CGI on timber frame	AC or CGI on timber frame	AC or CGI on timber frame	AC or CGI on timber frame	

Ref : Guidelines for "Earthquake Resistant Reconstruction and New Construction of Masonry Buildings in Jammu & Kashmir State" by Prof. A.S.Arya and Ankush Agrawal.

Guidelines at a Glance

SPECIFICATIONS AT A GLANCE

Repair, Restoration & Retrofitting of Masonry Buildings (Category E) for Wall Length 5m. Maximum

	Sr. no.	Description	Concrete/ Mortar	Grout/ Plaster Thk.	Weld Mesh (galvenised)			Size of Belt		Nails / Dowels			Bonding Element	
					gauge.	Size	Overlap	Width	Length	dia.	Length	Spacing	Hole Size	Bar Size
RESTORATION	1	Crack sealing & grouting with 12 mm dia. plastic/ aluminium nipples at 150 to 200 mm c/c	Sealing mortar cem:sand 1:3	Non shrink cem:water 1:1										
RESTORATION	2	Crack sealing and Splicing across crack	Sealing mortar non-shrink cem :sand 1:3	Plaster cem:sand 1:3 thk.12mm	Splicing with 16 to 14 gauge WWM 25X25mm size			200 to 300 mm	450mm on ea. side of crack	Nails 5mm dia.	100 to 150mm	300mm c/c		
RESTORATION	3	Reconstruction of damaged wall. Provide headers in RR wall.											Stone headers at 600mm vert., & 1.2m horiz. spacing	
		If existing wall is in mud mortar, reconstruct with 1:6 cem:sand mortar												
		If existing wall is in mud mortar, reconstruct with 1:4 cem:sand mortar												
RETROFITTING	4	Cast in-situ RCC bond elements horizonatally & vetically 1m. apart with 50 cm. horizontal stagger in RR wall.	Cem:aggra: sand, 1:2:4 concrete										Dumbbell shaped 75mm dia. Hole	8mm HSD bar hooked at both ends.
RETROFITTING	5	Horizontal seismic belt to be provided on all walls both faces	Cem:sand 1:3 or micro conc. 1:1½:3	First coat 12mm, second coat 16mm+dia. of bars.	Weld mesh 10g	Longitudinal Wires at 25mm x transverse wires at up to 150mm	300mm	280 mm with 10 Longitudinal wires	Continuous	5mm with washer	100 to 150mm	300mm c/c		
RETROFITTING	6	Vertical seismic belt at corners - 1 storey house or top storey of 2 storey house	Cem:sand 1:3 or micro conc. 1:1½:3	First coat 12mm, second coat 16mm+dia. of bars.	10g	Vert. at 25mm x Horz. at 150mm	300mm	400mm with 14 Longitudinal. Wires.		5mm with washer	100 to 150mm	300mm c/c		

Guidelines at a Glance

SPECIFICATIONS AT A GLANCE														
Repair, Restoration & Retrofitting of Masonry Buildings (Category E) for Wall Length 5m. Maximum														
	Sr. no.	Description	concrete/ Mortar	Grout/ Plaster Thk.	Weld Mesh (galvenised)			Size of Belt		Nails / Dowels			Bonding Element	
					gauge.	Size	Overlap	Width	Length	dia.	Length	Spacing	Hole Size	Bar Size
RETROFITTING		Bottom storey of 2 storey house		same as above	10 ga	same as above	300mm	Same as above with 1-12 HSD bar		5mm	150mm	300mm c/c		
	7	Vertical reinforcing bars at inside corner in leiu of seismic belt - One storey house and in top storey of Two-storey house	Cem:Sand 1:3 or micro conc. 1:1½:3	Min. 15mm cover.		12mm HSD bar	300mm						Start 450 mm below plinth and continue through to roof/eave level horizontal band	
		Lower storey of two storey house		min 15mm cover.		16mm HSD bar	300mm							
		Fix bar with wall with 'L' shaped dowel from cast-in-situ bond elements		non shrink 1:3 cem: sand						8mm 'L' shape	Vert. leg 400mm horiz. leg 150mm	1 m.	Dumbbell shape 75mm dia. hole	hooked on horiz. leg
	8	Seismic belt around openings	Cem:Sand 1:3 or micro conc. 1:1½:3	First coat 12mm, second coat 16mm+dia. of bars.	10g.	25mm x 150mm	280mm	280mm with 10 longitudinal wires		5mm	150mm	300mm c/c		
	9	Stiffening flat wooden floor / roof Install strut & diagonal brace of timber planks				100mm wide x 25mm				10g.	75mm	2 nails at each end.		

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About BMTPC

Building Materials & Technology Promotion Council (BMTPC)

BMTPC is an inter-ministerial organization under the Ministy of Housing & Urban Poverty Alleviation striving to bridge the gap between laboratory research and field level application. The Council provides technical support for strengthening the building materials sector through development and promotion of cost-effective, environment-friendly, energy-efficient building materials and disaster resistant construction technologies.

BMTPC has been playing a proactive role in the area of disaster mitigation and management. The note worthy contribution made by BMTPC are publication of Vulnerability Atlas of India and Landslide Hazard Zonation Atlas of India. BMTPC has always been in forefront in educating and creating mass awareness amongst common man and publishes Guidelines, brouchures, pamphlets etc. for Improving Earthquake and Cyclone/Wind Resistant Housing. These documents have served as important tool for safety against natural hazards for all stake holders involved in disaster management. The Council is also involved in construction of cost effective disaster resistant model houses and retrofitting of existing buildings besides helping State/UT Govts. in modifications of their Building Byelaws.

In order to sensitize stakeholders regarding retrofitting, BMTPC has been carrying out retrofitting of various life-line structures such as schools, hospitals etc. The widely circulated Earthquake Tips, a joint venture of IIT Kanpur and BMTPC in another milestone towards educting common people of India regarding earthquake aspects in simple easy to comprehend language. The same is being published in vernacular languages.

About NCPDP

National Centre for Peoples'-Action in Disaster Preparedness

NCPDP was created in October, 2000 at the time of Bhavnagar Earthquake in Gujarat state with a focus on disaster preparedness. This was an outcome of seven years of post-earthquake intervention by its two honorary directors Ms. Rupal Desai and Mr. Rajendra Desai, in regions of Latur, Jabalpur and Chomoli in India. Later, NCPDP played a major role in rehabilitation as well as capacity building for long-term preparedness in Gujarat in the aftermath of Kutchch Earthquake, and also worked on capacity building and technology demonstration in the quake affected Kashmir.

NCPDP is one of a few technology-based organizations in the country with first-hand experience of working at the grass-roots. It has a firm belief that building capacity of people from within is the only way to mitigate disasters for a safer world. Hence, we at NCPDP believe that intervention by external agencies in the aftermath of a disaster is most needed to work in this direction. Skill up-gradation of building artisans should form the backbone of this approach.

NCPDP strives to bring viable, eco-friendly and sustainable technologies to help people reduce their vulnerability against future disasters. It strives to remain prepared for timely intervention in the aftermath of major disasters. It is continuing to work on disaster mitigation through (a) training of engineers and building artisans, (b) awareness & confidence building programs in communities, (c) preparing ready to use technical information for people, (d) research on structural behavior of masonry structures, (e) conducting building vulnerability studies in different parts of India, (f) promoting retrofitting for vulnerability reduction, and (g) making policy interventions.

Taking information from this manual to the people is vital to ensuring vulnerability reduction

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