PROTECTION OF EDUCATIONAL BUILDINGS AGAINST

EARTHQUAKES

A MANUAL FOR

DESIGNERS AND BUILDERS

National Society for Earthquake
Technology-Nepal (NSET-Nepal)

OFDA/USAID

UNESCO-Kathmandu

Authors

Jitendra Kumar Bothara
Ramesh Guragain
Amod Dixit

Advisor and Reviewer

Prof. A. S. Arya

Publisher

National Society for Earthquake Technology-Nepal (NSET-Nepal)

Photographer

Mahesh Nakarmi
Jitendra Bothara
Ram Chandra Thapa
Ramesh Guragain

First Publication 2002

Graphic Artist

C. D. Rana Magar

Book Publication Series:

5

PREFACE

UNESCO has, over the past several years, paid great attention to the provision of information and guidelines for the mitigation of damage to educational buildings caused by earthquakes.

Nepal is a disaster prone country. Floods, landslides, epidemics and fires cause considerable losses to life and property in Nepal every year. Earthquakes, on the other hand are not so frequent, but has the potential for causing the greatest damage. Nepal is a seismic prone country and the risk it faces from earthquakes is very high. Past records have shown that Nepal can expect two earthquakes of magnitude 7.5-8 on the Richter scale every forty years and one earthquake of magnitude 8 + every eighty years. The last great earthquake to strike Nepal was in 1934 which had a magnitude of 8.3 Richter. It caused considerable damage to buildings along with great loss of lives. Since then, the population in Nepal has skyrocketed, urban development unplanned and construction practices have deteriorated. If a similar earthquake to that of 1934 were to strike now, it would cause a greater loss of lives and properties.

Educational buildings in Nepal would also face considerable damages, as almost all buildings have not been built to be earthquake resistant. A preliminary survey conducted by NSET-Nepal on 700 buildings of 378 public schools in Kathmandu Valley showed that nearly all figures, the buildings do not comply to the stated requirement of strength to withstand earthquake loading.

School buildings play an important role in communities in Nepal. Apart from its educational usage, they are also used as community meeting places and emergency shelters during disasters. Thus, it is doubly important that school buildings be earthquake-resistant.

It is for these reasons that NSET-Nepal and UNESCO felt the need for this manual. A similar manual was prepared by UNESCO, Bangkok office in 1987 with Prof. A.S. Arya as the author. The present manual is an updated version of the previous one in the context of Nepal and incorporates the experiences of earthquake-resistant design and retrofitting of school buildings.

This manual takes into account the prevalent construction practices in Nepal, and the use of local materials and labour. It also deals with the retrofitting and strengthening of old school buildings in a practical manner, which can be undertaken by local masons under minimal supervision. Pertinent recommendations of the Nepal National Building Code (draft) has been taken into consideration while preparing this manual.

This manual has been prepared under the guidance of Dr. A.S. Arya, Professor Emeritus, University of Roorkee and NSET-Nepal would like to acknowledge his contribution to this effort.

Although this manual is primarily meant for the technical persons engaged in the design, construction and protection of educational buildings against earthquakes, it is hoped that it would also help education policy makers, officials, community leaders, and others to build earthquake-resistant houses and other buildings, even at the village level.

NSET-Nepal will put its efforts into translating this manual to Nepali and other main languages of Nepal. Suitable forms of distribution, training etc., will be explored and implemented for bringing the knowledge of earthquake-resistant construction to the wider populace of Nepal.

Shiva Bahadur Pradhanang

President

ACRONYMS

ATC	:	Applied Technical Council
BW	:	Brick Work
CS	:	Cement Sand
EAARRP	:	Earthquake Affected Area Reconstruction and Rehabilitation Project
HFF	:	Himalayan Frontal Fault
IS	:	Indian Standards
ISZ	:	Indus Suture Zone
KVERMP	:	Kathmandu Valley Earthquake Risk Management Project
MBT	:	Main Boundary Thrust fault
MCT	:	Main Central Thrust fault
MSK	:	Medvedev-Sponheuer-Karnik earthquake intensity scale
NBC	:	National Building Code
NBCDP	:	National Building Code Development Project
NSET-Nepal	:	National Society for Earthquake Technology-Nepal
RC	:	Reinforced Concrete
RRM	:	Random Rubble Masonry
UBC	:	Uniform Building Code
UNDP	:	United Nations Development Program
UNESCO	:	United Nations Educational and Scientific Organization
mm	:	millimeter
m	:	meter
cm	:	centimeter

Table of Contents

	PREFACE	ii
	ACRONYMS	iii
1	INTRODUCTION	1
1.1	Aim of the Manual	1
1.2	Scope of the Manual	1
2	EARTHQUAKES	2
2.1	What is an Earthquake ?	2
2.2	Why do Earthquake Happen ?	2
2.3	Earthquake Locations	3
2.4	Measurement of Earthquake	3
2.4.1	Earthquake Magnitude	3
2.4.2	Earthquake Intensity	3
2.5	Seismicity of Nepal	4
2.6	Seismic Hazard of Nepal	6
3	EARTHQUAKE EFFECT	7
3.1	Ground Effects	7
3.1.1	Surface Faulting	7
3.1.2	Liquefaction Settlements	7
3.1.3	Landslide	7
3.1.4	Rock Falls	7
3.3	Effects of Earthquake on Buildings	8
3.3.1	Failure Mechanism of Building	8
3.3.1.1	Failure Mechanism of Masonry Building	8
3.3.1.2	Failure Mechanism of RC Framed Building	9
3.3.2	Building Damage	9
3.3.2.1	Masonry Buildings	9
3.3.2.2	RC Framed Buildings	10
3.3.3	General Damages	10
3.4	Causes of Failure	10
3.4.1	Deficiencies in Structural Layout	10
3.4.2	Quality of Material and Construction	11

4 SEISMIC CONSIDERATIONS FOR BUILDING DESIGN 12
4.1 Seismic Zones 12
4.2 Soil Condition 12
4.3 Importance of Building Based on Occupancy 13
4.4 Classification of Construction for Strengthening Purpose 13
5 SITE COSIDERATIONS 14
5.1 Choice of Site 14
5.1.1 Slope Stability 14
5.1.2 Flood Hazard 14
5.1.3 Fault Rupture Hazard 14
5.1.4 Liquefaction Hazard 14
5.1.5 Ground Topography 14
5.2 Site Improvement 16
6 BUILDING FORMS FOR EARTHQUAKE RESISTANCE 17
6.1 Building Configuration 17
6.2 Height and Number of Storeys 19
6.3 Distribution of Load Bearing Elements 19
6.4 Location and Size of Door and Window Openings 21
7 MATERIALS AND QUALITY OF CONSTRUCTION 22
7.1 Materials of Construction 22
7.2 Building Typology 23
7.3 Construction Materials 23
7.3.1 Concrete 23
7.3.1.1 Cement 23
7.3.1.2 Coarse Aggregates 23
7.3.1.3 Sand 24
7.3.2 Brickwork 24
7.3.2.1 Bricks 24
7.3.2.2 Mortar 24
7.3.2.3 Plaster 24
7.3.3 Reinforcing Steel Bars 24

7.4 Quality of Construction 24

8 MASONRY BUILDING USING RECTANGULAR BUILDING UNITS IN CEMENT MORTAR 26

8.1 Improving Buildings for Seismic Safety 26

8.2 Foundation 27

8.2.1 RC Strip 28

8.2.2 PCC Strip/Lime Strip 28

8.2.3 Plum Concrete 28

8.2.4 Brick/Stone Masonry 28

8.3 Walls 29

8.3.1 Openings 29

8.3.2 Reinforcement of Opening 29

8.3.3 Wall Reinforcement 30

8.3.3.1 Strengthening the Junctions 30

8.3.3.2 Bands 31

8.3.3.3 Vertical Reinforcement 32

8.4 Concrete Block Walls 33

8.5 Separation and Crumple Sections 34

9 LOW STRENGTH MASONRY IN RECTANGULAR BLOCK AND STONE 35

9.1 Definition 35

9.2 Limitations 35

9.3 Strengthening Measures 35

9.4 Materials 35

9.5 Walls 35

9.5.1 Thickness 35

9.5.2 Buttresses 36

9.5.3 Door and Window Openings 36

9.5.3.1 Rectangular Block Masonry 36

9.5.3.2 Stone Masonry 36

9.5.4 Construction 36

9.5.4.1 Block Masonry 36

9.5.4.2 Stone Masonry 36

9.5.5 Stitches 37

9.5.6 Bands 37

9.5.7 Vertical Reinforcing 38

10 DETAILLING OF RC FRAMES 39

10.1 Foundation 39

10.2 Beam 39

10.2.1 Dimensions 39

10.2.2 Longitudinal Reiforcement 39

10.2.3 Web Reinforcement 40

10.3 Column 41

10.3.1 Dimensions 41

10.3.2 Longitudinal Reinforcement 41

10.3.3 Web Reinforcement 41

10.4 Beam Column Joint 42

10.4.1 Transverse Reinforcement 42

11 FLOOR AND ROOF CONSTRUCTION 43

11.1 General 43

11.2 RC Slab 43

11.3 Wooden Floor and Flat Roof 44

11.4 Pitched Roof 45

12 ASSESSMENT OF SAFETY OF MASONRY BUILDINGS 47

12.1 Visual Assessment 47

12.1.1 Configuration 47

12.1.2 Connections 47

12.1.3 Quality of Construction 47

12.1.4 Building Condition 47

12.2 Comparison with Safety Provisions in the Building Codes 48

12.3 MSK Intensity Scale 48

12.4 Analytical Method 49

13 RETROFITTING OF MASONRY BUILDING 50
13.1 Philosophy and Approach 50
13.2 Lessons Learnt from Past Earthquake 50
13.2.1 Masonry Buildings 50
13.3 General Retrofitting Techniques 50
13.3.1 Configuration Improvement 51
13.3.1.1 Modification of Plan 51
13.3.1.2 Elevation Improvement 51
13.3.2 Floor or Flat Roof Improvement 51
13.3.2.1 Insertion of a New Slab 51
13.3.2.2 Existing Wooden Floor or Flat Roof 52
13.3.2.3 Roof Improvement 53
13.3.2.4 Improving Earthquake Resistance of Wall Structure 54
13.4 Associated Problems 61
REFERENCES 62
FIGURE ix
TABLE xi

Figure

Fig.	1	:	Different Plates of Earth	2
Fig.	2	:	Epicenter and Focus	3
Fig.	3	:	Schematic Tectonic Cross-Section Through Central Nepal	6
Fig.	4	:	Seismic Hazard of Nepal	6
Fig.	5	:	Development of Surface Faulting	7
Fig.	6	:	Liquefaction	7
Fig.	7	:	Earthquake Induced Landslide	7
Fig.	8	:	Building Damage due to Rockfall	7
Fig.	9	:	Ground Shaking	8
Fig.	10	:	Ground Motion and Inertia Force	8
Fig.	11	:	Wall Collapse	8
Fig.	12	:	Vibration of Masonry Building During Earthquake Ground Motion	9
Fig.	13	:	Roof Collapse due to Lack of Anchorge	9
Fig.	14	:	Torsion of Unsymmetrical Plans	11
Fig.	15	:	Seismic Zoning Map of Nepal	12
Fig.	16	:	Active Faults of Nepal and Surrounding Region	15
Fig.	17	:	Preparing a Building Site in a Sloping Terrain	16
Fig.	18	:	Building with Changing Elevation	17
Fig.	19	:	Plan Shapes and Improvements	18
Fig.	20	:	Distribution of Structural Walls in Plan	19
Fig.	21	:	Column Orientation	19
Fig.	22	:	Lateral Supports to Long Walls	20
Fig.	23	:	Locations for Reinforcing	27
Fig.	24	:	Footings	28
Fig.	25	:	Construction of Strip Foundation in RC	28
Fig.	26	:	Plum Concrete Strip Fooring	28
Fig.	27	:	Masonry Strip Fooring	28
Fig.	28	:	Reinforcing of Openings	29
Fig.	29	:	Reinforcing of Openings	29
Fig.	30	:	Staggered Toothed Wall Joint	30
Fig.	31	:	Stepped Wall Joint Stitching	30
Fig.	32	:	Joint Strengthening by Dowel Reinforcement Placed in One Joint	30
Fig.	33	:	Joint Strengthening by Wire Fabric	31
Fig.	34	:	Bands at Different Levels	31
Fig.	35	:	Reinforced Concrete Band	31
Fig.	36	:	Vertical Reinforcement in Brick Wall	33
Fig.	37	:	Section of Horizontal Band	33
Fig.	38	:	Vertical Bar in Hollow Concrete and Stonecrete Block	34
Fig.	39	:	Crumple Section	34
Fig.	40	:	Cross Section of Stone Wall	35
Fig.	41	:	Use of Buttress	36
Fig.	42	:	Opening Sizes in Bearing Walls Constructed of Rectangular Blocks	36
Fig.	43	:	Opening Sizes in Bearing Constructed of Random Rubble	36
Fig.	44	:	Stone Wall Delamination with Buckled Wythes	36
Fig.	45	:	Random Rubble Masonry with “Through” Stone or Other Bonding Elements	37
Fig.	46	:	Wall Junction Strengthening	37
Fig.	47	:	Detail of Timber Stitches	37
Fig.	48	:	Detail of Timber Band	37
Fig.	49	:	Vertical Reinforcement in Rubble Stone Wall	38
Fig.	50	:	Tying up Isolating Footings	39
Fig.	51	:	Provision of Special Confining Reinforcement into Footing	39

Fig.	52	:	Anchorage Beam Bars in an External Joint	40
Fig.	53	:	Lap Splice in Beam	40
Fig.	54	:	Beam Reinforcement	40
Fig.	55	:	Beam Web Reinforcement	40
Fig.	56	:	Lap Splice in Beam	41
Fig.	57	:	Transverse Reinforcement in Column	41
Fig.	57	:	Transverse Reinforcement in Column	41
Fig.	58	:	Column and Joint Detailing	42
Fig.	59	:	Hoop Stirrups for Joints in Frame	42
Fig.	60	:	Precast Slab with Reinforced Concrete Topping	43
Fig.	61	:	Cantilever Slab	43
Fig.	62	:	Anchorage of Timber Joists into RC Band Using Anchor Bars	44
Fig.	63	:	Anchorage of Timber Joists with Wall Using Wedges	44
Fig.	64	:	Floor Stiffening Using Two Layers of Planks	44
Fig.	65	:	Floor Stiffening Using RC Topping	44
Fig.	66	:	Floor Stiffening Using Bracing	44
Fig.	67	:	Use of A-Type Trusses to Reduce Thrust on Wall	45
Fig.	68	:	Anchorage of Timber Rafters into RC Band Using Anchor Bars	45
Fig.	69	:	Anchorage of Timber Joists with Wall Using Wedges	45
Fig.	70	:	Roofing Bracing	46
Fig.	71	:	Integration of New Floor with Existing Wall	51
Fig.	72	:	Details of Inserted Slab	52
Fig.	73	:	Stiffening of Wooden Floor by RC Topping	52
Fig.	74	:	Stiffening of Wooden by RC Topping	52
Fig.	75	:	Stiffening the Existing Floor/Flat Roof by Bracing	52
Fig.	76	:	Connection of Floor with Wall (a-b)	53
Fig.	77	:	Roof Bracing	54
Fig.	78	:	Inserting Internal Cross Wall	55
Fig.	79	:	Strengthening Existing Wall with Buttressing	55
Fig.	80	:	Strengthening Existing Wall with Insertion of RC Column	56
Fig.	81	:	Stitching of Transverse walls	56
Fig.	82	:	Strengthening Walls by Prestressing	56
Fig.	83	:	Jacketing of Walls	57
Fig.	84	:	Splint and Bands Strengthening Technique	57
Fig.	85	:	Column and Beam Strengthening Technique	57
Fig.	86	:	Stitching the Wyths	58

Table

Table	2.1	:	MSK intensity scale in brief	4
Table	2.2	:	Approximate relationships between Magnitude, MSK Intensity scale and felt area	4
Table	2.3	:	Major earthquake of Nepal	5
Table	4.1	:	Soil Clasification	12
Table	4.2	:	Categories of buildings for strengthening purposes	13
Table	6.1	:	Recommended maximum number of storeys and floor height	19
Table	6.2	:	Limiting distance between structural walls in different constructions systems	20
Table	8.1	:	Number and diameter of bars in bands	32
Table	8.2	:	Requirements of Vertical bars in stone masonry walls	32
Table	8.3	:	Mortar	33
Table	9.1	:	Requirement of Vertical steel bars in stone masonry walls	38
Table	12.1	:	Code Compliance	48
Table	12.2	:	Vulnerability Assessment based on MSK intensity Scale	49
Table	13.1	:	Selection of Retrofitting Methods for Masonry Building	59

1. INTRODUCTION

1.1 Aim of the Manual

This manual presents in simple illustrated form, ways to protect educational buildings from the disastrous effects of an earthquake. It is written such that the information may be used at the community level as a guide for the construction of earthquake-resistant educational buildings.

1.2 Scope of the Manual

Primarily, the manual deals with the construction techniques used for school buildings and student hostels built of brick, stone masonry and reinforced concrete (RC) framed buildings. These buildings are usually non-engineered and constructed using traditional methods.

This manual lays heavy stress on how materials normally classified as "unsuitable" or "slightly suitable" can be made "moderately suitable". It also includes methods for correct use of normally "moderately suitable" materials and includes mention of RC for situations where it is typically used without the benefit of an engineer. Steel detailing of RC framed buildings has been included as such structures are being increasingly used for the construction of school buildings although they are largely non-engineered.

The protective measures suggested for new buildings are kept simple and inexpensive intentionally and can be adopted with little modification to normal construction practice. The manual also covers seismic strengthening of existing buildings.

The recommendations regarding seismic strengthening of buildings cover buildings of one to three storeys having room with a maximum up to 9 m length. The recommendations are largely based upon the data of public school buildings collected from the three districts of Kathmandu Valley under the Earthquake Safety Program of the Kathmandu Valley Earthquake Risk Management Project (KVERMP). The data revealed most school buildings are of one to two storeys, very few three and rarely more than three storeys; class rooms' size ranged between three to five meter in breadth and four to eight meter in length. Thus the proposed recommendations cover almost all buildings except those which have four or more stories or have large assembly halls. Such buildings should be designed by professional designer. Alternatively, large one storey hall can be constructed of load bearing masonry walls with external buttress. The issue is also discussed in this manual.

The measures proposed here should be construed only as good construction practices. seering professional consultation from qualified engineers for construction of any school building is encouraged.

2. EARTHQUAKES

2.1 What is an Earthquake?

An earthquake is a sudden and violent motion of the earth caused by volcanic eruption, plate tectonics, or man made explosions which lasts for a short time, and within a very limited region. Most earthquakes last for less than a minute. The larger earthquakes are followed by a series of after shocks which also may be dangerous.

2.2 Why do Earthquakes Happen?

Earthquakes can be caused by volcanic eruption, or by plate tectonics. Blasting, quarrying and mining can cause small earthquakes. Underground nuclear explosions are also man made earthquakes. But large majority of earthquakes and especially big earthquakes are invariably caused by plate tectonics.

The earth's crust is a rock layer of varying thickness ranging from a depth about 10 km under the ocean to 65 km under the continents. The crust is not one piece but consists of portions called plates, which vary in size from few hundred to many thousands of square kilometers (ref. Fig. 1). The theory of *plate tectonics* holds the plate ride upon the more mobile mantle, and are driven by some yet unconfirmed mechanism, perhaps thermal convection currents. When the plates contact each other, stresses arise in the crust. These stresses may be classified according to the movement along the plate boundary: a) pulling away from one another, b) sliding sideways relative to each other and c) pushing against each other. All these movements are associated with earthquakes but in the Himalayas (b) and (c) movements cause earthquakes.

The area of stress at plate boundaries, which releases accumulated energy by slipping or rupturing is known as faults. A rupture occurs along the fault when accumulated stresses overpass the supporting capacity of rock mass and the rock rebounds under its own elastic stress until the stress is relieved. Usually the rock rebounds on both sides of the fault in opposite directions.

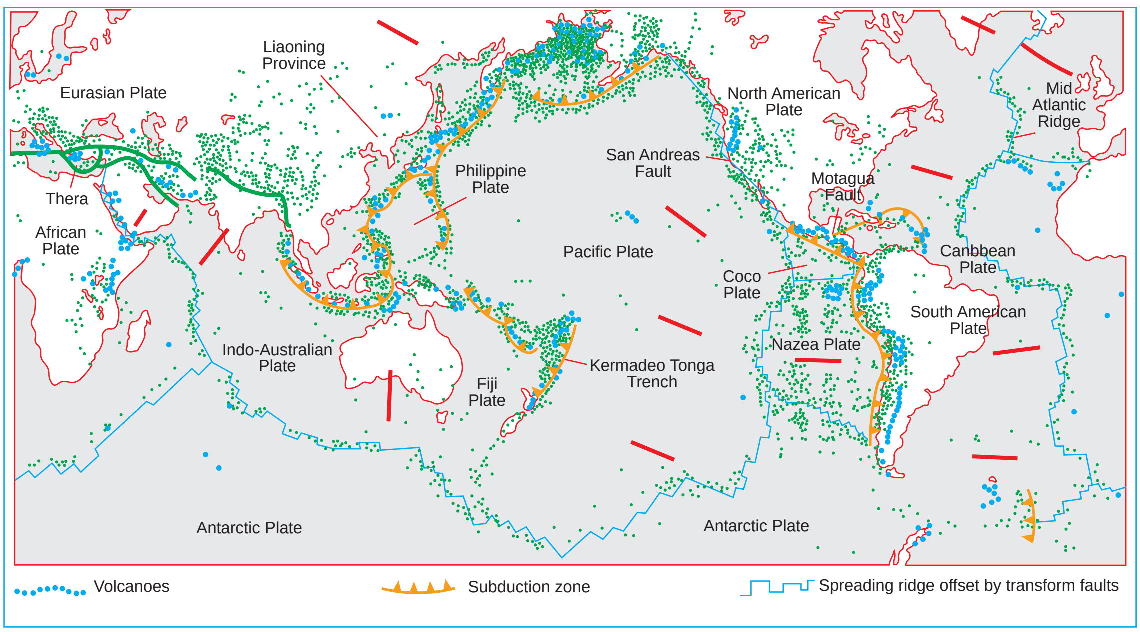


Fig. 1: Different plates of earth

The point of rupture is called the focus or hypocenter and may be located near the surface or deep below it. The point on the surface vertically above the focus is termed the epicenter of the earthquake (ref. Fig. 2). The fault rupture generates vibrations called seismic waves which radiate from the focus in all directions.

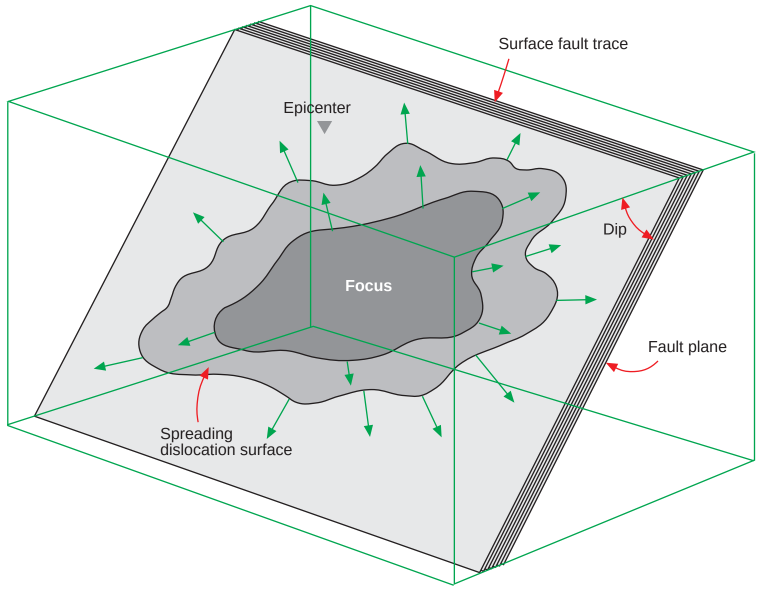


Fig. 2: Epicenter and Focus

2.3 Earthquake Locations

Earthquakes may occur almost everywhere in the world. But certain areas of the world are very susceptible to earthquakes (ref. Fig. 3). Most earthquakes occur in areas bordering the Pacific ocean, called the Circum-Pacific belt and the Alpine belt which traverse the East Indies, the Himalayas, Iran, Turkey, and the Balkans. Approximately 95% of the earthquake activity occurs at the plate boundaries. Some do occur, however, in the middle of the plate, possibly indicating where earlier plate boundaries might have been.

2.4 Measurement of Earthquakes

2.4.1 Earthquake Magnitude

The magnitude of an earthquake is a measure of the amount of energy release at the source, the focal area. It is estimated from instrumental observations. The oldest and most popular measurement of an earthquake is the Richter scale, defined in 1936. Since this scale is logarithmic, an increase in one magnitude signifies a 10-fold increase in ground motion or roughly an increase in 30 times the energy release. Thus, an earthquake with a magnitude of 7.5 releases 30 times more energy than one with a 6.5 magnitude, and approximately 900 times that of a 5.5 magnitude earthquake. An earthquake of magnitude 3 is the smallest normally felt by humans. Largest earthquake that have been recorded under this system are from 8.8 to 8.9 in Magnitude.

2.4.2 Earthquake Intensity

The intensity is a measure of the felt effects of an earthquake. It is a measure of how severe the earthquake shaking was at any location. So it could differ from site to site. For any earthquake, the intensity is strongest close to the epicenter. A single event can have many intensities differing in the severity of ground shaking at different locations.

These two terms, earthquake Magnitude and earthquake Intensity are frequently confused in describing earthquakes and their effects. While Magnitude, expressed generally on the Richter scale, is a term applied to the amount of energy released of an earthquake as a whole, Intensity is a term applied to the effect of an earthquake at the affected site that determines the severity of the effect on a structure.

The most widely used scale for measuring earthquake Intensity has been the Modified Mercalli Intensity (MMI) scale that was first developed by Mercalli in 1902, later on modified by Wood and Neuman in 1931. It expresses the intensity of earthquake effects on people, structures and earth's surface in steps from I to XII. The further more detailed and explicit scale, the Medvedev-Sponheuer-Karnik (MSK) scale (1964) is now also commonly used. Both scales are very close to each other. A brief description of the different Intensities, is given in Table 2.1.

Table 2.1: MSK intensity scale in brief

Earthquake Intensity (MKS)	Earthquake Effects at any Particular Site
I	Not noticeable
II	Scarcely noticeable (very slight)
III	Weak, partially observed only
IV	Largely observed
V	Awakening
VI	Frightening
VII	Damage considerable in poorly constructed buildings
VIII	Damage to masonary buildings
IX	Poorly built masons structures collapse
X	Most Masonary and frame structure destroyed
XI	Catastrophic danage to well built structures
XII	Total devastation with landscape changes

It will be seen that intensities I to VI indicate little or no damage. The last three intensities (X to XII) are too severe to achieve earthquake safety in traditional non-engineered buildings at economical costs. But luckily such earthquakes are infrequent, as shown in Table 2.2. Seismic zones of Intensity VII, VIII, and IX are amenable for incorporation of earthquake protection measures at reasonable cost.

Table 2.2: Approximate relationships between Magnitude, MSK Intensity scale and felt area

Earthquake magnitude Richter, M	Expected annual number	Maximum expected intensity	Radius of felt area (km)	Felt area (km^2)
4.0-4.9	6,2000	IV-V	50	7,700
5.0-5.9	800	VI-VII	110	38,000
6.0-6.9	120	VII-VIII	200	125,000
7.0-7.9	18	IX-X	400	500,000
8.0-8.7	1	XI-XII	800	2,000,000

Source: Earthquakes by Don de Nevi, Celestial Arts. Calif., May 1977, p.102.

2.5 *Seismicity of Nepal*

Nepal is located in boundary between the Indian and the Tibetan plate, along which a relative shear strain of about 2 centimeters per year has been estimated. The Indian plate is also subducting at a rate thought to be about 3 cm per year. The existence of the Himalayan range with the world's highest peaks is evidence of the continued tectonics beneath the country. As a result, Nepal is very active seismically. There have been a number of devastating earthquakes within living memory such as those in 1934, 1960 and 1988. There was a significant 1833 and the earlier earthquake recorded event in the most comprehensive catalogue to date occurred in 1255. Huge damage and casualties occurred due to these events (ref. Table 2.3). There are frequent small to medium size earthquakes in different parts of the country with localized effects. Nepal continues to face a high level of earthquake hazard and risk.

Table 2.3: Major earthquakes of Nepal

Year	Date	Earthquakes epicenter	Human		Building/Temples	
			Death	Injuries	Collapsed	Damaged
1993		Jajarkot	*NA*	*NA*	40% of the buildings were estimated to be affected	
1988	21 Aug	Udayapur	721	6453	22328	49045
1980	04 Aug	Bajhang	46	236	12817	13298
1934	15 Jan	Bihar/Nepal	8519	*NA*	80893	126355
1837	17 Jan	*NA*	*NA*	*NA*	*NA*	*NA*
1834	Sept-Oct	*NA*	*NA*	*NA*	*NA*	*NA*
	26 Sept	*NA*	*NA*	*NA*	*NA*	*NA*
	13 July	*NA*	*NA*	*NA*	*NA*	*NA*
	11 July	*NA*	*NA*	*NA*	*NA*	*NA*
1833	26 Aug	*NA*	*NA*	*NA*	18000 in total	
	25 Sept	*NA*	*NA*	*NA*	*NA*	*NA*
1823	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
1810	May	*NA*	Moderate		Heavy	
1767	Jun	*NA*	*NA*	*NA*	*NA*	*NA*
1681	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
1408	*NA*	*NA*	Heavy		Heavy	
1260	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
1255	07 Jun	*NA*	One third of the total population, including King Dbhya Malla, killed		Many buildings and temples collapsed	

Note: - *'NA'* **indicates 'description not available'.**

(Source: Development of Building Materials and Technology, NBCDP)

Many geological faults and thrusts have been created in the past as the two tectonic plates on which Nepal is astride have collided. Major fault systems of Nepal Himalayas are the Indus-Tsangpo Suture (ITS), Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Himalayan Frontal Thrust (HFT). The ITS along which the initial collision is believed to have occurred is located in southern Tibet. Fig. 3 shows the secondary active fault associated with the above mentioned Himalayan fault system.

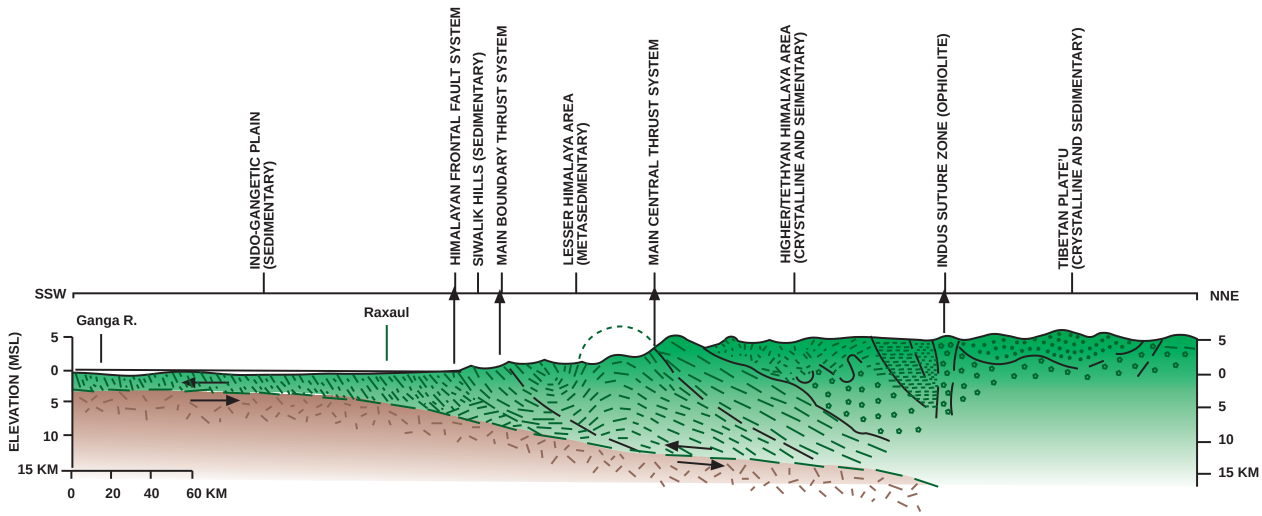


Fig. 3: Schematic tectonic cross-section through central Nepal

2.6 *Seismic Hazard of Nepal*

Fig. 4 shows the seismic hazard of Nepal, which is the study of number of earthquake events with reference to approximate recurrence interval year, in a period of 80 years.

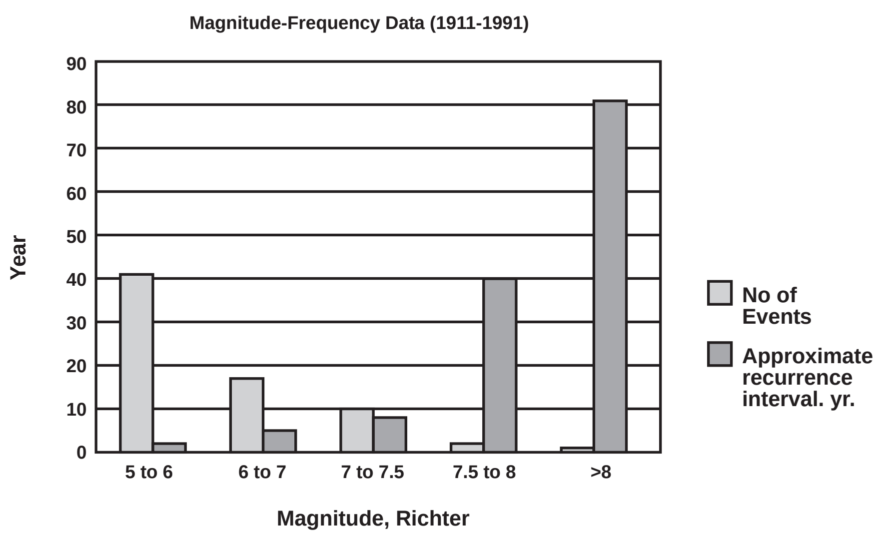


Fig. 4: Seismic Hazard of Nepal

A seismic zoning map of Nepal has been prepared to help in the design of buildings. The seismic zones are based on geologic, tectonic and lithologic features and the observed as well as potential earthquake occurrences and elaborate analysis of their mutual relationship. Seismic zoning map of Nepal is shown in Fig. 15 in Section 4.

3 EARTHQUAKE EFFECT

The effect of an earthquake can be classified as primary and secondary. Primary effects are direct effect on ground and those on the building or other structures and the secondary effects are those which occur due to the primary effects such as fires, epidemics etc..

3.1 Ground Effects

Earthquake-induced ground effects has been observed in the forms of ground rupture along the fault zone, landslides, settlement and soil liquefaction as briefly described below.

3.1.1 Surface Faulting

Surface faulting along the fault zone may be none, of very small extent, or may extend over hundreds of kilometers. Ground displacement along the fault may be horizontal, vertical or both, and may be a few centimeters or meters. Obviously a building directly traversed by such a rupture will be severely damaged or collapsed (ref. Fig. 5).

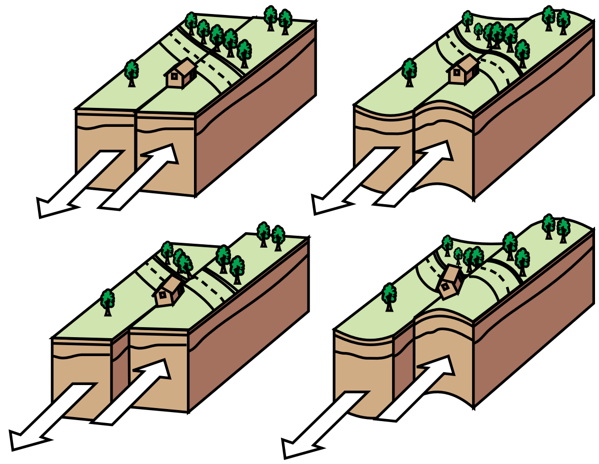


Fig. 5: Development of Surface Faulting

3.1.2 Liquefaction Settlements

Seismic shaking may cause sinking or tilting or cracking or collapse of buildings when soil is compacted or consolidated. Certain type of soils, such as alluvial or sandy soils are more likely to fail during an earthquake due to liquefaction. Liquefaction is a type of ground failure which occurs when saturated soil loses its strength and collapses or becomes liquified (ref.Fig. 6). It is more prominent if the foundation soil consists of uniform loose sands within a depth of about 8m below the ground surface and is either fully saturated by or submerged under water. The buildings resting on such ground may tilt or sink and may collapse.

Fig. 6: Liquefaction

3.1.3 Landslides

Earthquakes cause landslides where the hill slopes are unstable due to badly fractured rocks or consist of loose material (ref.Fig. 7). The effect is more pronounced in rainy season when the soil is wet than in dry season.

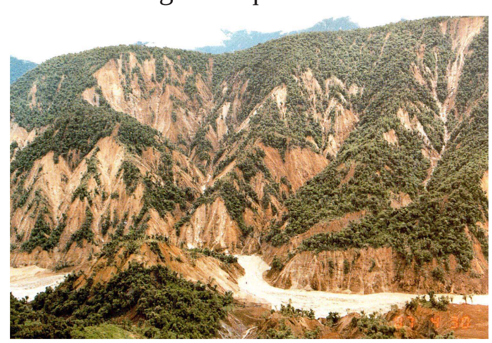


Fig. 7: Earthquake Induced Landslide

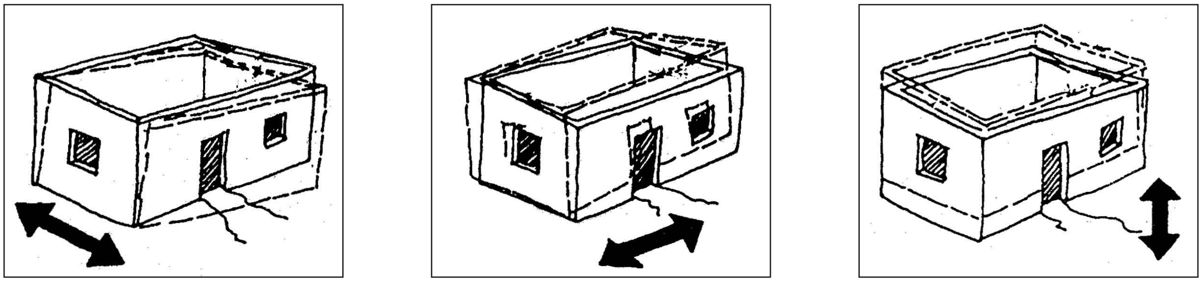
3.1.4 Rock Falls

In fractured rock areas, the earthquake can also trigger rock fall when precariously supported rock pieces or boulders are shaken loose and roll down the hill slopes and damage buildings or infrastructures (ref.Fig.8).

Fig. 8 : Building Damage due to rockfall

3.3. Effects of Earthquake on Buildings

The primary effect of an earthquake is shaking of a building or infrastructure. During an earthquake, a building is shaken in all possible directions (ref Fig. 9). The shaking loosens the joints of different components of building that leads to subsequent damage or collapse.



Fore-Back Left-Right Up-Down

Fig. 9: Ground Shaking

3.3.1 Failure Mechanism of Building

Buildings as a whole and all their components and contents are badly shaken during severe earthquakes. Since earthquakes are earth movements (which, in effect cause the ground to move under a building), the forces which occur in a building come from the inertia of its own mass. Therefore the force is proportional to the mass. Hence, the heavier the building the more will be the inertia force i.e. the earthquake load on the building. Inertia force caused on any mass (m) can be described by the formula $F = ma$ where a = acceleration effectively acting on mass m (ref. Fig. 10).

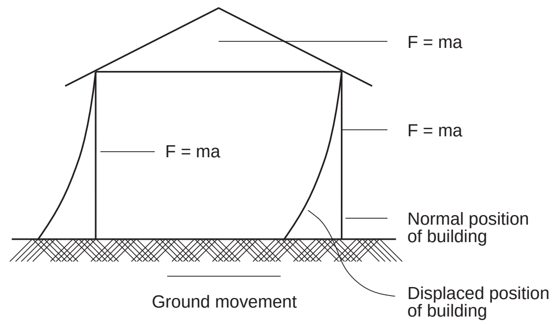


Fig. 10: Ground motion and Inertia force

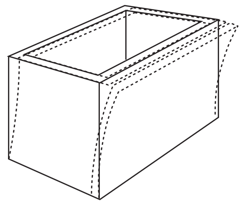
3.3.1.1 Failure Mechanism of Masonry Building

The seismic behavior of a masonry building during an earthquake generated vibration strongly depends upon how the walls are interconnected and anchored at the floor and roof level.

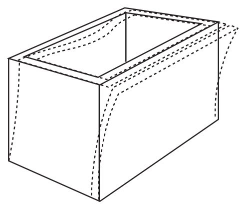
In the case of masonry buildings where the walls are not interconnected with help of timber or any other means at junctions, the individual walls tend to separate along the joints or intersections. Vertical cracks occur near the corner either in the side wall or in the adjacent end wall. Under those conditions the vibrations of the walls become uncoupled and walls might collapse. The situation is potrayed in Fig. 9, 11 and 12 (a,b).

(1988 Udaypur earthquake)

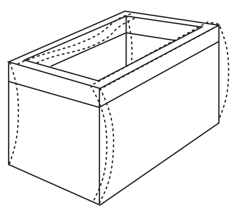
Fig. 11: Wall Collapse



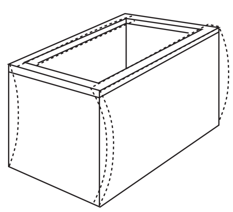
(a) structural walls are not tied together at junctions and roof level



(b) structural walls are not tied together at roof level



(c) structural walls are tied together by means of tie beams;



(d) structural walls are tied together by means of RC slab.

Fig. 12: Vibration of masonry building during earthquake ground motion

Fig. 13: Roof Collapse due to lack of Anchorage

In cases where ties are placed or reinforced concrete tie beams are cast at the floor levels, the vibration of the walls becomes synchronized (ref Fig. 12c). However, in this case, the out of plane bending of the walls takes place again, reducing the resistance of the building as a whole.

Behavior of the masonry building is improved when walls are connected together by means of rigid RC slabs. In this case, vibrations of the walls are synchronized (ref Fig. 12d), and the out of plane bending of walls is less significant. The building behaves like a box and all the walls contribute to the resistance of the building.

3.3.1.2 Failure Mechanism of RC Framed Building

RC framed buildings fail during large earthquakes due mainly to the following reasons:-

- Columns are overstressed and burst if there is not enough strength
- Failure of RC elements at the place of poor ductile detailing
- Collapse of cladding, partition walls and infill walls

3.3.2 Building Damage

3.3.2.1 Masonry Buildings

The following are the usual types of damage to the different components of masonry buildings:-

Roofs

- Falling of parapets, cornices, chimneys, cantilever balconies
- Displacement and falling of roofing tiles, cracking of asbestos cement sheet roofing, side coverings and ceilings
- Dislocation of roof trusses, wooden logs or joists and other roof beams from the walls and where the dislocations are large, they collapse (ref Fig. 13)
- Collapse of heavy roofs due to the inability of the supporting structure to carry applied horizontal force

Walls

- Plaster falling from ceiling and walls
- Fine or wide cracks in walls

- Horizontal and vertical cracks in walls due to bending of wall normal to its plane
- Gaps in walls due to collapse of portions of the walls
- Overturning of boundary walls, free standing partitions
- Diagonal cracking of wall piers between window and door openings, shearing of columns
- Shattering of random rubble masonry walls, falling of inner and outer wythes (layers) of the wall away from each other
- Falling out of infill walls, cladding walls, and gable ends

Foundation

- Sinking, tilting and/or cracking or collapse of buildings due to foundation soil failure
- Spreading of individual column footings in soft soils

3.3.2.2 RC Framed Buildings

The following are the usual types of the damage to RC framed building and its components:-

Columns

- Bursting of columns
- Soft storey effect
- Short column effect
- Splicing failure

Beams

- Anchorage failure
- Shear failure
- Confinement failure

3.3.3 General Damages

- Partial collapse of buildings
- Complete collapse of free standing staircases
- Tortional failure of unsymmetrical buildings

3.4 Causes of Failure

The most common factors that could cause building failure during earthquakes are indicated below:

- Structural layout
- Quality of materials and construction practices
- Lack of earthquake resistance features

To prevent building failure load bearing elements should be uniformly distributed along both the axes, with no sudden change in stiffness in vertical or horizontal direction, and the vertical elements are tied together at the floor by rigid floors (RC slabs). Good quality of materials and correct construction methods are essential to prevent building failure.

3.4.1 Deficiencies in Structural Layout

The following main deficiencies are observed in structural layout:

Irregular distribution of load bearing members in the plan

For improved seismic behavior of the building, it should have uniformly distributed load bearing elements (ie. walls in case of load bearing building and columns in RC framed building) in both the directions. Buildings having solid walls in one face and perforated wall in opposite face suffers torsional motions as shown in Fig. 14.

Non-uniform distribution of stiffness in plan or elevation of the building

This can result in severe damage of walls or columns at the location of sudden changes in stiffness ie. sudden change in direction, strength, and construction system (for both load bearing masonry or framed buildings).

L, E, H shaped and very long buildings are unsafe from seismic consideration. A symmetrical building with equal openings in opposite faces suffers far less damage than an unsymmetrical building with unequal openings in opposite faces.

Similarly, sudden change in stiffness ie. omission of walls in a particular storey (for eg. first storey) sudden change in column sizes over the height of building, omission of columns or implanting column in suspended beam leads to over stressing and consequent severe damage.

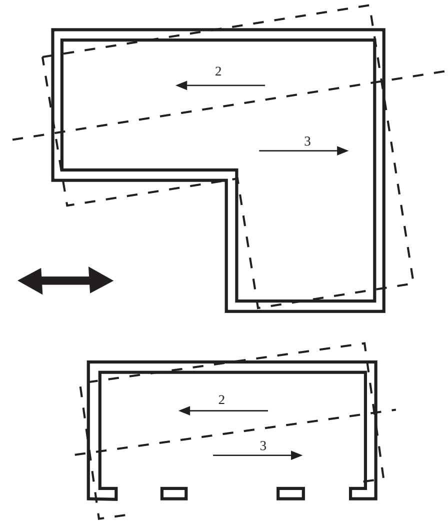


Fig. 14: Torsion in Unsymmetrical Plan building

Lack of rigid floors

This can result in vertical cracks at the joints or intersections of walls due to out of plane bending of walls. The walls separate one from another and may collapse even when the building is subjected to moderate level of shaking.

3.4.2 Quality of Material and Construction Practices

Construction materials is a primary factor affecting the vulnerability of a structure. Stone or brick laid in a weak mortar such as mud are always weaker compared to masonry built using strong binders such as a cement mortar.

Although sufficient for carrying the gravity loads, mechanical characteristics of materials used for construction of masonry buildings, are not sufficient to resist the additional bending and shearing effects, induced in the structural system by the lateral forces generated in an earthquake.

Very low or no tensile strength which characterizes the shear failure of wall elements is specially evident in the case of stone masonry and adobe buildings. Irregular shape of stones, further destabilizes the wall by their relative movements (mechanism failure).

Buildings with good construction materials but built by inferior techniques could not be expected to prevent building failure in an earthquake. Excessive thickness of horizontal mortar; vertical joints not filled with mortar; continuity in vertical joints; bricks not being soaked into water before construction; non-curing of cement based construction, are some of the examples of inferior construction techniques in masonry construction.

Similarly the use of too much water in concrete; improper compaction of concrete; honeycombing in concrete; low cover to reinforcing steel bars; improper placement of steel bars, are some of the examples in poor quality of RC construction.

4. SEISMIC CONSIDERATIONS FOR BUILDING DESIGN

The following factors, should be serously considered before constructing an educational facility.

4.1. Seismic Zones

It is important to know in which zone the facility is located. A simplified seismic hazard map of Nepal is shown in Fig. 15. In the map, the area west of Kathmandu, and confined between the Himalayas and southern terai has the highest level of seismic hazard.

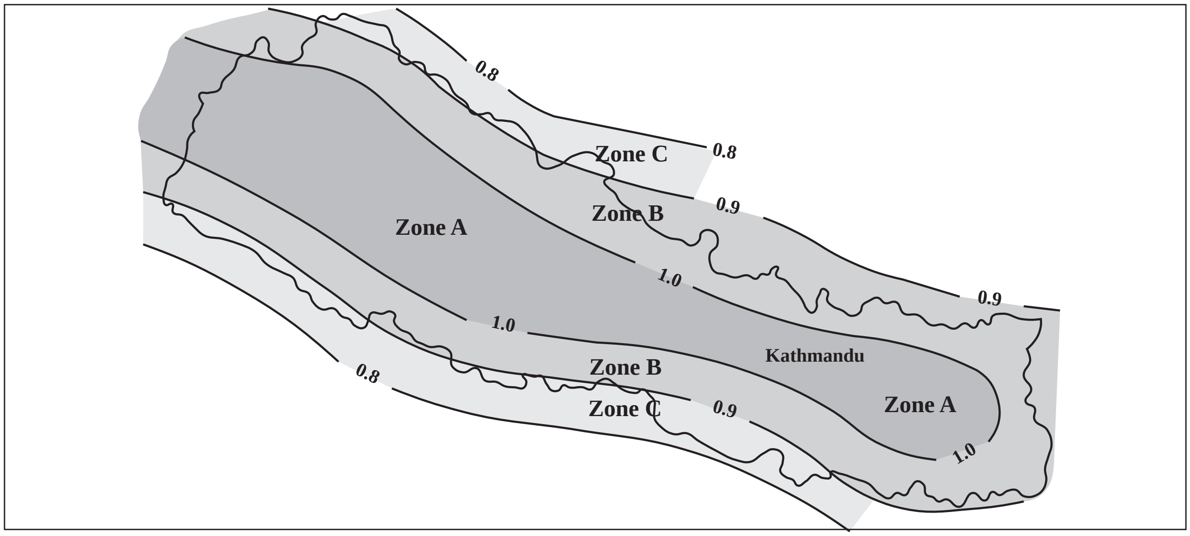


Fig. 15: Seismic Zoning Map of Nepal

4.2 Soil Condition

Soil can be classified into four types (ref. Table 4.1).

Table 4.1: Soil Clasification

No.	Type of Soils	Classification of Soils
1.	Rocks in different state of weathering boulder bed, gravel, sandy gravel and sand gravel mixture, dense or loose coarse to medium sand offering high resistance to penetration when excavated by tools; stiff to medium clay which is readily indented with a thumb nail	Hard
2.	Fine sand silt (dry lumps easily pulverized by the fingers); moist clay and sand-clay mixture which can be indented with strong thumb pressure	Medium
3.	Fine sand, loose and dry soft clay indented with moderate thumb pressure	Soft
4.	Very soft clay which can be penetrated several centimeters with the thumb; wet clays	Weak

Source: Site Consideration, NBCDP

Earthquake motions are amplified during seismic event in case of soft or weak soil, thus avoid constructing on such soil. For low-rise building (up to three storeys) soil factor is not of much importance for design purpose but for high rise building ie. buildings higher than four storeys, soil factor should be considered in design by an engineer.

For building foundation consideration, it is recommended to construct a building on a hard soil compared to soft one. There is a very high possibility of unequal settlement if the building is constructed on weak soil. It is not recommended to construct any building on weak soil

4.3 *Importance of Building Based on Occupancy.*

Protecting all buildings against damage by earthquake may be impossible. It is therefore sometimes necessary to make a distinction between buildings: which will be given higher prioriy against earthquake damages and which will be given lower priority. Schools buildings which hold large numbers of persons at one time, should be given higher priority. Classroom blocks, dormitory blocks, dispensaries and assembly halls should be given higher priority than teacher's residences, stores, lavatory blocks, and other auxiliary buildings.

4.4 *Classification of Construction for Strengthening Purposes*

Combining the conditions of seismic zones, and priority of buildings, four categories of conditions have been worked out for selecting the strengthening measures in seismic zones A, B and C (ref. fig. 15). Table 4.2 shows how these categories relating to the above conditions can be combined. Note that category I is the most severe combination of conditions requiring the highest protection measures.

Table 4.2: Categories of buildings for strengthening purposes

Protection level	**Seismic zone**		
	A	B	C
Higher	I	II	II
Lower	II	III	III

The table can be interpreted as a school building in seismic zone ‘A’ falls in building group ‘I’ whereas a store building in the same site falls in group ‘II’.

5 SITE COSIDERATIONS

5.1 Choice of Site

While selecting a site for education facility, the following considerations shall be made:

5.1.1 Slope Stability

Landslides can occur due to the strong ground shaking caused by an earthquake. All major earthquakes in mountainous terrain will result in increased instances of landslides. The vast majority of these are rock falls, although more coherent landslides, such as debris slides and soil slumps, also take place.

Areas already susceptible to landslides from storm damage, river undercutting and quarrying are also susceptible to landslides from an earthquake.

Buildings may be destroyed by landslides because they are located on the body of landslides, by the impact or by debris derived from a landslide generated uphill from the site. The building itself may also contribute to the instability of potential landslides.

Thus it is advisable to locate a school away from landslide areas.

On a sloping ground, the location of a buildings should meet the requirements shown in Fig 17, unless special slope stability measures are taken.

5.1.2 Flood Hazard

In general, flood problem is not directly related with earthquake damage unless a dam created by earthquake-induced landslide bursts. Of course an education facility may be in trouble due to flood during rainy season if it is constructed in its flood plane. It is always advisable to construct the education facility in relatively higher ground.

5.1.3 Fault Rupture Hazard

A surface fault rupture occurs when an earthquake fault breaks the earth's surface and it may result in several centimeters to several meters of differential ground displacement. The instantaneous ground displacement may occur along an approximately linear path that may extend for several tens of kilometers. If the fault traverses a house, school building or an infrastructure, it may be damaged or destroyed.

Therefore, while selecting the site for an important building or a structure, it shall be ensured that the building is not located within a distance of 500 m from surface trace of known active fault. Fig. 16 depicts the principal active faults identified so far within Nepal and can be referred to this purpose.

5.1.4 Liquefaction Hazard

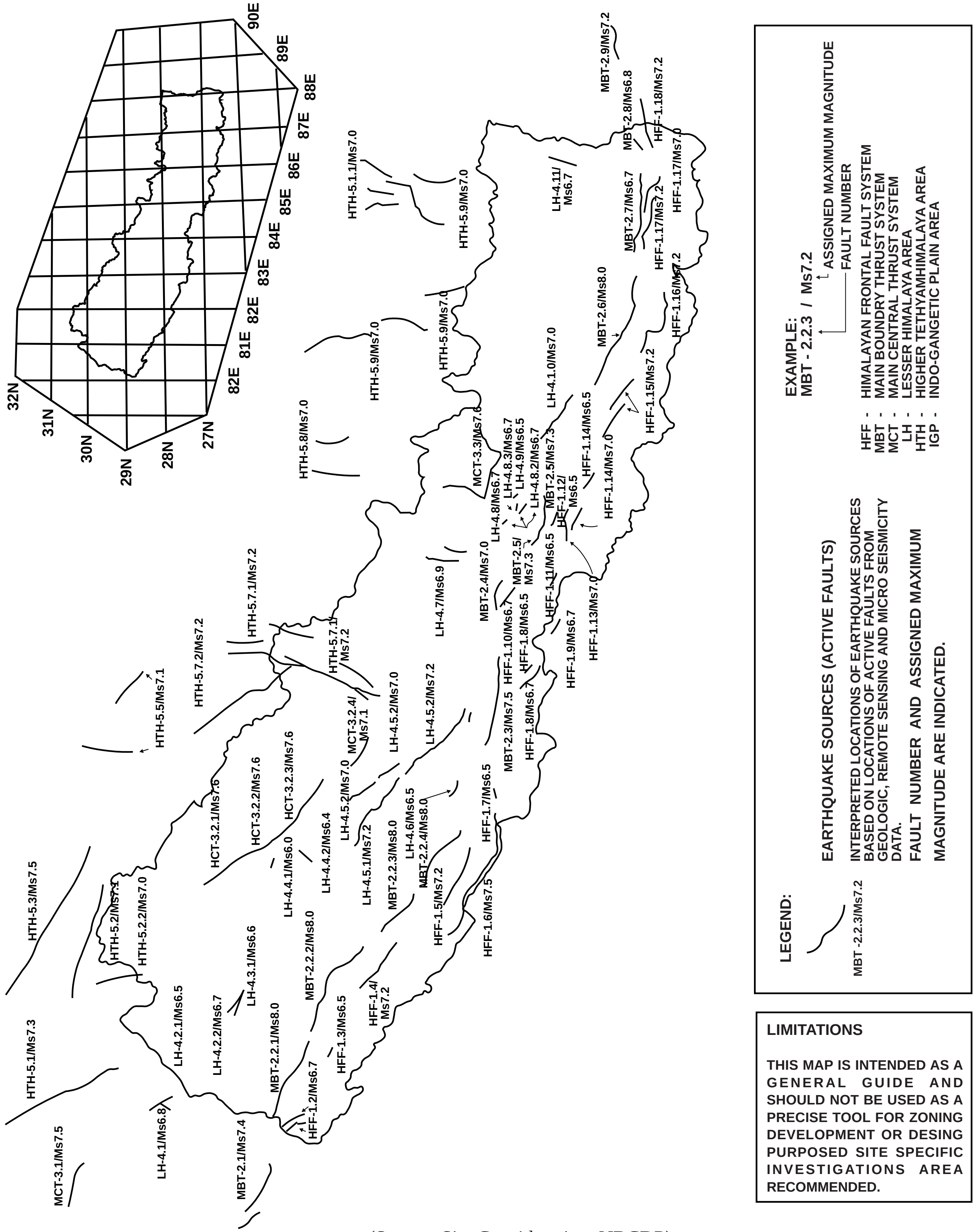
Liquefaction of subsurface soil occurs when saturated, loose, granular soil is exposed to strong earthquake shaking. It is more pronounced where ground water table is relatively high and soil is loose and uniform. It commonly results in sand boils, fissuring of the ground, settlement of the ground surface and lateral spreading of the ground surface.

Site susceptible to liquefaction should be avoided as far as possible. Such sites can be improved by compaction, stabilization, or sand pilling but all these are costly affairs and may not be viable for a school construction.

5.1.5 Ground Topography

Buildings built on sites with plain topography are usually less susceptible to damage than a building constructed along a narrow hill ridge, separated high hills, steep slopes or complicated terrain. Such sites should be avoided as far as possible.

Even if it becomes unavoidable to construct an education facility in a sloping terrain, its foundation shall be constructed at equal level and its periphery may be improved by terracing and constructing breast and retaining walls.



(Source: Site Consideration, NBCDP)

Fig. 16 : Active faults of Nepal and surrounding region

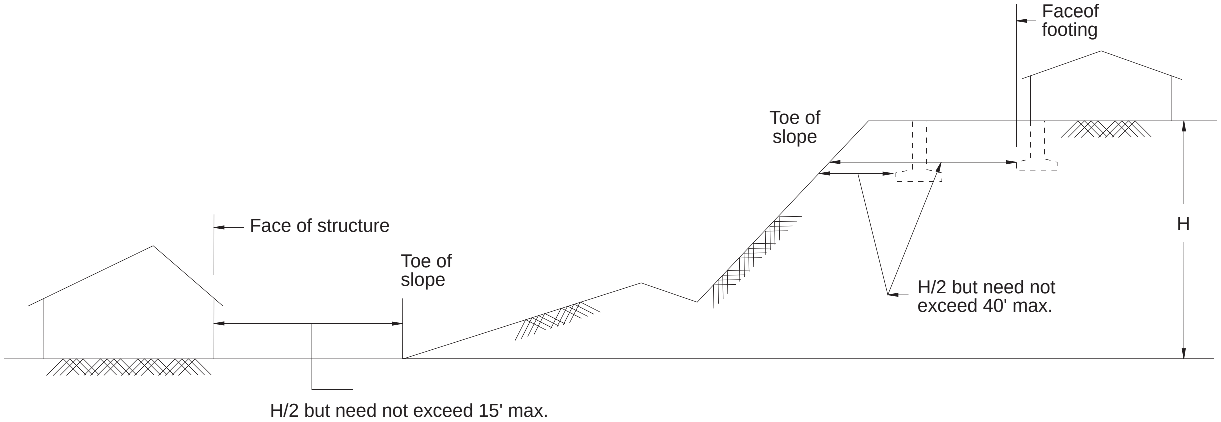


Fig. 17 : Preparing a building site in a sloping terrain

5.2 Site Improvement

In general improving site is an expensive option and may not be feasible for school building construction. Since saturation of foundation soil is dangerous from liquefaction and landslide, the site should be kept well drained. A waterproof apron may be provided all round the building to prevent seepage of water under the foundations. Water drains should be constructed away from the buildings at the edges of the apron.

In the area where it is impossible to avoid selection of a site with saturated soil, pile foundations going to depths of 8 to 10 m will generally be adequate.

6 BUILDING FORMS FOR EARTHQUAKE RESISTANCE

Important aspects of building form, include the building plan, internal partitions, size and location of openings in internal and external walls. These are explained in this section.

6.1 *Building Configuration*

The following general requirements should be taken into account when designing a building:

- The building as a whole or its various parts should be kept symmetrical along both the axes. Lack of symmetry leads to torsional effects and hence add to the concentrated damage in the critical zones. Symmetry is also desired in the location of openings.

- Simple square or rectangular designed buildings behave better when subjected to earthquake loads as compared to those with many projections. Torsional effects due to the differences in ground motions are more pronounced in case of narrow rectangular parts. Therefore, it is desirable to limit the length of a part to three times the width. If longer lengths are required, the building should be divided into separate parts with sufficient separation (ref. Fig. 19).

- Separation of a large building into separate parts is a good practice for allowing the parts to be independent during lateral loading. Such separation into parts helps to obtain symmetry and rectangularity of each part. To prevent hammering effect between the the adjacent parts, a sufficient seismic gap must be provided between the parts.

- The building should be as simple as possible. Ornamentation involving large cornices, vertical and horizontal cantilever projections, fascia stones and the likes are dangerous and undesirable from seismic point of view. Where any ornamentation is used, it must be properly reinforced and anchored.

- The distribution of stiffness both in plan and over the building height should be as uniform as possible. Buildings as shown in Fig.18 should be avoided. Mixed structural systems, combining masonry load bearing system with RC load bearing system both in plan or over the height of the building, should be avoided.

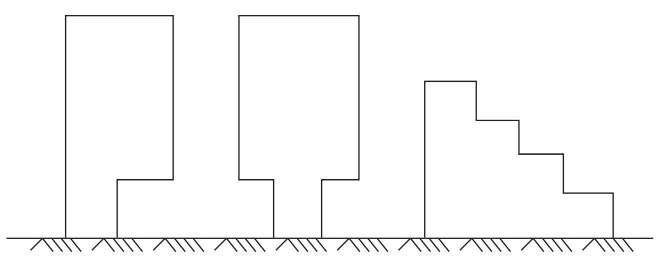
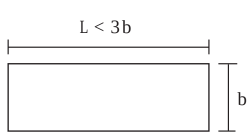


Fig. 18 : Building with changing elevation

- The locations of load bearing walls or RC columns (pillars) shall not be shifted in upper storeys. These should be truly vertical and align in a line.

Typical school buildings plan	Improvement
 A. Rectangular building	A. Modification not required

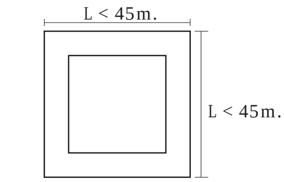
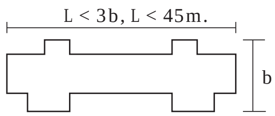
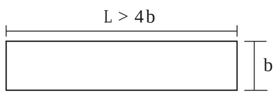
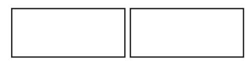
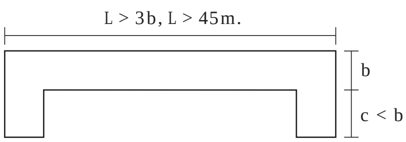
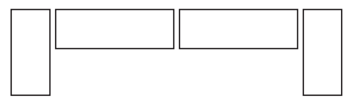
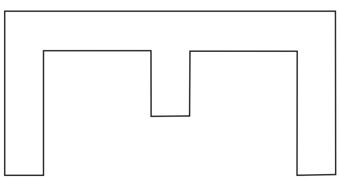
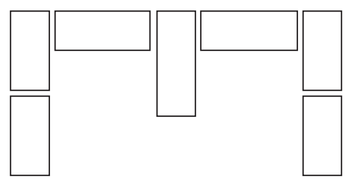
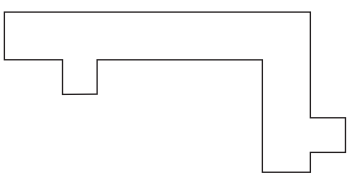
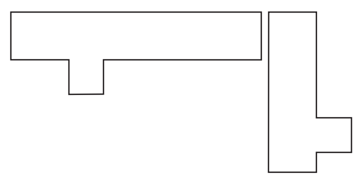
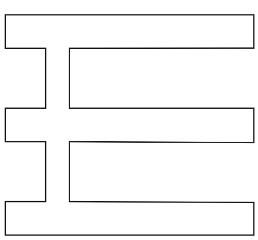
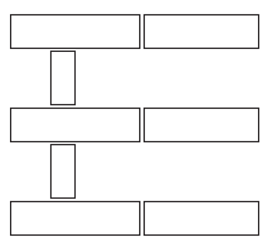
Typical school buildings plan	**Improvement**
 B. Building with courtyard	B. Modification not required
 C. Approximately symmetrical	C. Modification not required (Acceptable)
 D. Too long narrow	 D. Divide building in suitable parts
 E. Too long and narrow with some projections	 E. Divide building in suitable parts
 F. Too long, projections too large	 F. Divide building in suitable parts
 G. Unsymmetrical along both axes, too complicated shape	 G. Divide building in sutable parts and simplify the design
 G. Weak linkages between heavy blocks	 G. Divide building in suitable parts and make stiffness of each block more uniform

Fig. 19 : Plan Shapes and Improvements

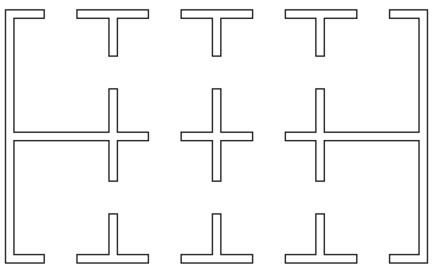
6.2 *Height and Number of Storeys*

The floor height and number of storeys should be limited according to the structural system and construction materials.

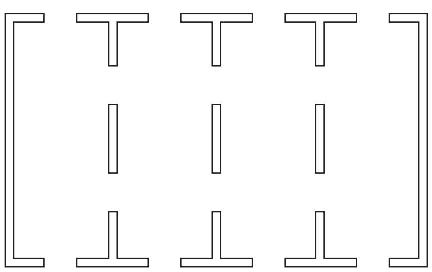
The floor height of the building is determined as the vertical distance between two consecutive floors. Table 6.1 provides values for recommended maximum number of storeys (excluding stair cover) and floor height, unless otherwise designed by a quilified engineer, for different construction system.

Table 6.1: Recommended maximum number of storeys and floor height

Construction System	Number of storey		Maximum floor height (m)	Remarks
	Ordinary Building	Important Building		
Adobe				Not recommended for school buildings
Stone in mud	2	1	2.5	Not recommended for school buildings
Brick in mud	2	1	2.5	
Brick in cement	3	3	3	



Good



Not Good

Fig. 20 : Distribution of structural walls in plan

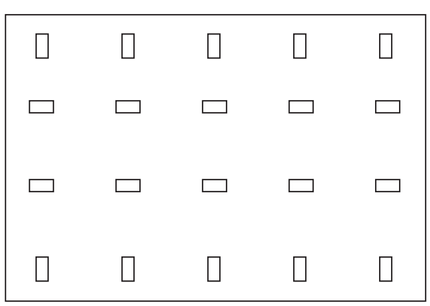


Fig. 21 : Column Orientation

6.3 *Distribution of Load Bearing Elements*

In order to have a satisfactory performance of a masonry building, its walls must be uniformly distributed in both the orthogonal directions, sufficient in number and strength to resist earthquake loads (ref. Fig. 20). Walls must be firmly connected together to the floors roofs, which must be able to act as rigid diaphragms.

Similarly columns of a RC framed building should be oriented in both the directions unless these are square (ref. Fig. 21).

The walls of the masonry building can be defined as:

- Structural walls, carrying their own weight together with the vertical and/or horizontal loads acting on the building;
- Non-structural walls, having exclusively the function of partitioning the building space. Their own weight is transferred by means of floors to the structural walls.

Considering the significance of the structural walls, these walls should have a minimum thickness of 0.38 m for stone masonry buildings, 0.35 m for brick in mud mortar, and of 0.23 m for brick or block masonry in cement mortar.

In order to obtain satisfactory performances for different masonry systems, the distances between the structural walls should be limited as given in Table 6.2.

Table 6.2: Limiting distance between structural walls in different construction systems

Construction System	**Distance between structural walls (m)**
Adobe	5.0
Stone in mud	5.0
Brick in mud	6.0
Brick in cement	9.0

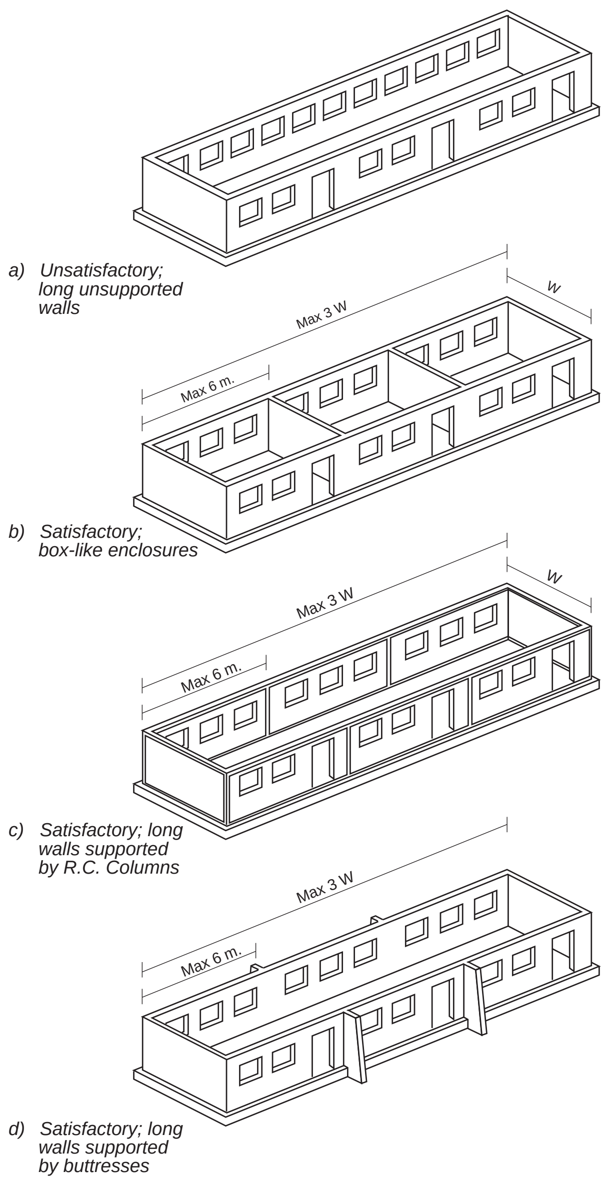


Fig. 22 : Lateral supports to long walls

Using the above recommended values, the resulting structural layout, however, should be verified by calculations. Limiting factors may be the vertical load-bearing capacity and the out-of-plane bending capacity of these walls. If wall distance is more than the recommended distance the walls should be laterally supported as shown in Fig. 22. Subdividing internal space to reduce length of walls enhances seismic behavior of buildings. But if the functional requirements do not permit the use of cross walls, longer walls have to be supported by introduction of RC columns, or external buttresses at spacing not more than 4.0m in adobe or stone-in-mud, 5.0m in case of brick in mud and 6.0m in case of brick in cement mortar.

6.4 Location and Size of Door and Window Openings

Openings in walls are a source of weakness and tend to change the behavior of the wall and consequently the building itself. Past earthquakes have revealed a strong effect of the size and the position of the openings on the earthquake-resistance of masonry as well as RC framed buildings. Unsymmetrical position of opening in symmetrical buildings may introduce structural unsymmetry which is not desirable under seismic conditions. Hence, in order to improve behavior of buildings, the following recommendations should be observed:

- Openings should be located symmetrically with respect to building configuration in plan in both directions of the building
- Openings in opposite walls should be balanced as far as feasible
- Openings should be located outside the zones of direct influence of concentrated loads at beam support
- Openings should be located at the same position in each storey
- Top of the openings should be at the same horizontal level
- Openings should not interrupt floor tie beams
- Openings should be located away from room corners
- Arches that span over openings should be avoided unless steel ties are provided

More specific requirements regarding openings with different types of building materials are given in subsequent sections.

7 MATERIALS AND QUALITY OF CONSTRUCTION

7.1 Materials of Construction

Construction material and technology affect the seismic performance of a building. A building constructed of brick in cement mortar will behave much better than brick in mud mortar, provided all other parameters remain the same.

The suitability of materials for construction is dependent on the characteristics of the materials themselves as well as their combination with other materials. To resists the internal forces caused by earthquakes it is helpful if the materials perform well both in compression and in tension. Material which perform well only in compression, are often reinforced by other materials with good tensile strength qualities.

From the earthquake safety view point, the suitability of materials of construction could be classified as follows:

- Highly suitable: steel, wood, RC
- Moderately suitable: Brick, block, dressed stone masonry with good mortar, compacted adobe construction if appropriately reinforced
- Slightly suitable: Unreinforced brick, block, stone masonry with good mortar
- Unsuitable: Unreinforced masonry with mud mortar, earthen walls without reinforcement

School buildings in Nepal are generaly one and two storeys and could be classified as follows:

- Masonry load bearing wall buildings with strip footings and flat or sloping roofs. The most commonly used masonry units are fired brick followed by stone.
- Wooden buildings with wattle and daub, or wooden planks as cladding walls, sloping roof and strip footings.
- Earthen wall buildings with flat or sloping timber roofs and little or no foundation. The classroom size in such school buildings are generally smaller than other types.
- RC framed construction.
- Buildings with vertical steel columns and steel trussed roofs.

It is thus seen that most existing school buildings will fall under slightly suitable and unsuitable categories and very few in moderate and highly suitable categories. Even though RC framed buildings fall in "highly suitable" group, but because of faulty construction technology, these are also equally vulnerable.

To overcome this situation it may be argued that schools in earthquake prone areas should be built only with highly suitable materials (i.e. steel, reinforced concrete or wood). However, in most of the localities this is not feasible in the light of the unavailability of these materials, inaccessibility, the large demand for schools and the scarce financial resources. What is needed, therefore, are suitable measures (including reinforcement) which can ensure that brick, stone, and timber can be the main materials for construction.

Simple, as well as economical, methods for strengthening buildings made of traditional materials have been developed. These methods have been scientifically developed through analytical research, observation of damage occurring during earthquakes and the physical testing of large-scale models. Thus, when applied to educational buildings these measures should prevent severe damage or collapse during earthquakes.

As pointed out in the introduction, this manual covers materials used in buildings designed without the benefit of an engineer i.e. masonry buildings. Thus steel and large RC structures are not included but detailing requirements of RC buildings is included given its growing use.

7.2 Building Typology

Based on walling materials, basic building typology available in Nepal can be classified into six broad groups:

1. Adobe or earth construction
2. Stone in mud mortar
3. Brick, block or stone in cement mortar
4. RC framed construction with masonry infill
5. Timber/bamboo framed construction
6. Steel framed buildings

Among these typologies, the first typology is generally less common, the second typology is most common in hills and mountains, whereas use of third and fourth groups are growing. The fifth typology is concentrated in terai whereas sixth typology was constructed after the 1988 earthquake in 18 districts of eastern Nepal. Among these typologies, the first two are most vulnerable during an earthquake.

Similarly, timber/bamboo structure with mud laid on it, timber structure with brick topped with plain cement concrete or mud, and RC slab are most common floor structures. The latter one is most common in urban areas or areas accessible by road.

In case of roof structure, timber/bamboo is most common with CGI sheet as roofing material. The other commonly used roofing materials are tiles, jhingati, and stone slates. Use of RC slab is growing in urban areas as well as in areas accessible by road. From seismic consideration, tiles, jhingati, and stone slate are the most vulnerable materials.

7.3 Quality of Construction Materials

7.3.1 Concrete

The concrete to be used in footings may be 15MPa, but in columns, beams and slabs, etc, should have a minimum crushing strength of 20 N/mm^2 (20MPa) at 28 days for a 150 mm cube.

7.3.1.1 Cement

Cement shall be as fresh as possible. Any cement stored for more than two months from the date of receipt from the factory should either be avoided or used only if the test results are found to be satisfactory. Any cement which has deteriorated or hardened shall not be used. All cement used shall be Ordinary Portland Cement. It is advisable to use cement which has obtained the Nepal Standard (NS) mark if independent tests are not carried out.

7.3.1.2 Coarse Aggregates

Coarse aggregates shall consist of crushed or broken stone or river gravel and shall be hard, strong, dense, durable, clean, of proper grading and free from any coating likely to prevent the adhesion of mortar. The aggregate shall be generally angular in shape though river pebbles could be used as well. As far as possible, flaky, elongated pieces shall be avoided.

The coarse aggregates shall be of following sizes:

a} For cement concrete with a thickness of 100 mm and above-graded from 20 mm downwards.

b) For cement concrete from 40 mm to 100 mm thick-graded from 12 mm downwards.

7.3.1.3. Sand

Sand shall consist of siliceous materials having hard strong, durable, uncoated particles. It shall be free from undesirable amounts of dust lumps, soft or flaky particles, shale, salts, organic matter, loam, mica or other deleterious substances exceeding five percent by weight.

Where adequate care has been taken in the following: the selection of materials; mixing; correct proportioning; proper placing; compacting and curing of the concrete, a nominal mix of 1:2:4 (cement: sand: aggregate) for 15MPa and 1:1.5:3 for 20MPa is expected to meet strength requirements.

7.3.2 Brickwork

The brick masonry shall be built with the usually specified care regarding presoaking of bricks in water, level bedding of planes fully covered with mortar, vertical joints broken from course to course and their filling with mortar fully.

7.3.2.1 Bricks

The bricks shall be of a standard rectangular shape, well burnt, hand–made or machine–made, and of crushing strength not less than 3.5 N/mm^2 for one storey and 5.0N/mm^2 for two and 7N/mm^2 for three storeyed building.

7.3.2.2 Mortar

Cement-sand mixes of 1:4 or 1:6 is recommended for one brick thick wall. Similarly, cement-sand mortar mix of 1:4 shall be adopted for a half-brick thick wall. The addition to the mortars of small quantities of freshly hydrated lime in a ratio of ¼ to ½ of the cement will greatly increase their plasticity without reducing their strength. Hence, the addition of lime within these limits is encouraged. Mortar shall be used within one hour of preparation.

7.3.2.3 Plaster

All plaster should have cement–sand mix not leaner than 1:6. They shall have a minimum 28 days cube crushing strength of 3 N/mm^2.

7.3.3 Reinforcing Steel Bars

Reinforcing steel shall be clean and free of loose mill-scale, dust, loose rust and coats of paint, oil, grease or other coatings, which may impair or reduce bond.

Note :

In this mannual steel with a strength of 415/mm2 (grade *fe* 415) has been assumed for main base in beams and Columns. The steel area shall be correspondingly increased if steel with a lower strength is used. 7 ϕ hars of steel grade *fe* 550 can be replaced by 8 ϕ hars of steel grade *fe* 415. Similarly 5 ϕ hars of steel grads *fe* 550 can be replaced by 6 ϕ hars of steel grade *fe* 250.

7.4 Quality of Construction

Performance of non-engineered buildings during past earthquakes have repeatedly demonstrated that the quality of construction of brickwork, stone masonry, block masonry or woodwork has had an undoubted influence on the extent of damage suffered; those having better quality suffered less damage. The following quality control measures are therefore emphasized:

- Materials should conform to appropriate specifications e.g. properly fired bricks of uniform sizes, seasoned or dried heart wood;
- Proper mortar should be used in construction, filling all horizontal and vertical joints. The masonry units should be laid with proper bond avoiding continuation of vertical joints particularly at the intersection of walls;

- Use of fully soaked bricks while laying in cement mortar;
- Proper curing of masonry and concrete;
- Joints in wood elements should be tight, nailed or bolted and covered with steel straps;
- Stone masonry walls should have appropriate mortar filling in the hearting and use of 'through' stones or bonding elements in the walls along with long stones at the corners and T-junction of walls for proper connection between the perpendicular walls.

Good quality of construction is insurance for a building's good earthquake behavior. Substandard material, inadequate skill in bonding or inadequate connections must not be allowed in construction.

8. MASONRY BUILDING USING RECTANGULAR BUILDING UNITS IN CEMENT MORTAR

8.1 *Improving Buildings for Seismic Safety*

The integrity between different components of a building is the most crucial aspect for survival of a masonry building during an earthquake. For improved integrity, the buildings need to have following reinforcing features:

- *Stitching of walls:* To strengthen wall junctions by stitching as these are potentially weak point;
- *Bands:* To avoid out of plane collapse of walls, these should be reinforced with RC bands at different levels;
- *Gable ends:* Reinforcement around gables with gable band and connection to purlins;
- *Floor or roof band:* Reinforcement element on top of the wall capable of transferring the inertia force of the floor/roof structure to the walls, unless floor or roof is constructed of RC slab;
- *Vertical bars:* In–plane bending and shearing resistance of masonry walls and ductility can be improved by using vertical reinforcement and control on opening sizes thus preventing crack propagation from corners of openings;
- *Floor/roof structure:* Can be improved by nailing and tie-up with straps between different components;
- *Connection between wall and floor/roof structure:* Proper integrity between floor/roof structure and wall can be enhanced by adequate holding down bolts, etc.;
- *Bracing of floor and roof structure:* Floor and roof structures should be stiffened in horizontal plane by bracing elements or RC topping to act as rigid diaphragm in the case of wooden or steel floor/roof structure.

Fig. 23 shows the critical locations for providing horizontal and vertical reinforcement in walls. The amount and actual provision of reinforcement depends upon and varies with the combination of design seismic conditions as categorized in Table 4.2 and as detailed in the following sections wherein the terms as explained below may be recognized. For category I condition, all types of reinforcement may be needed whereas for categories II and III only some of the reinforcement may be required.

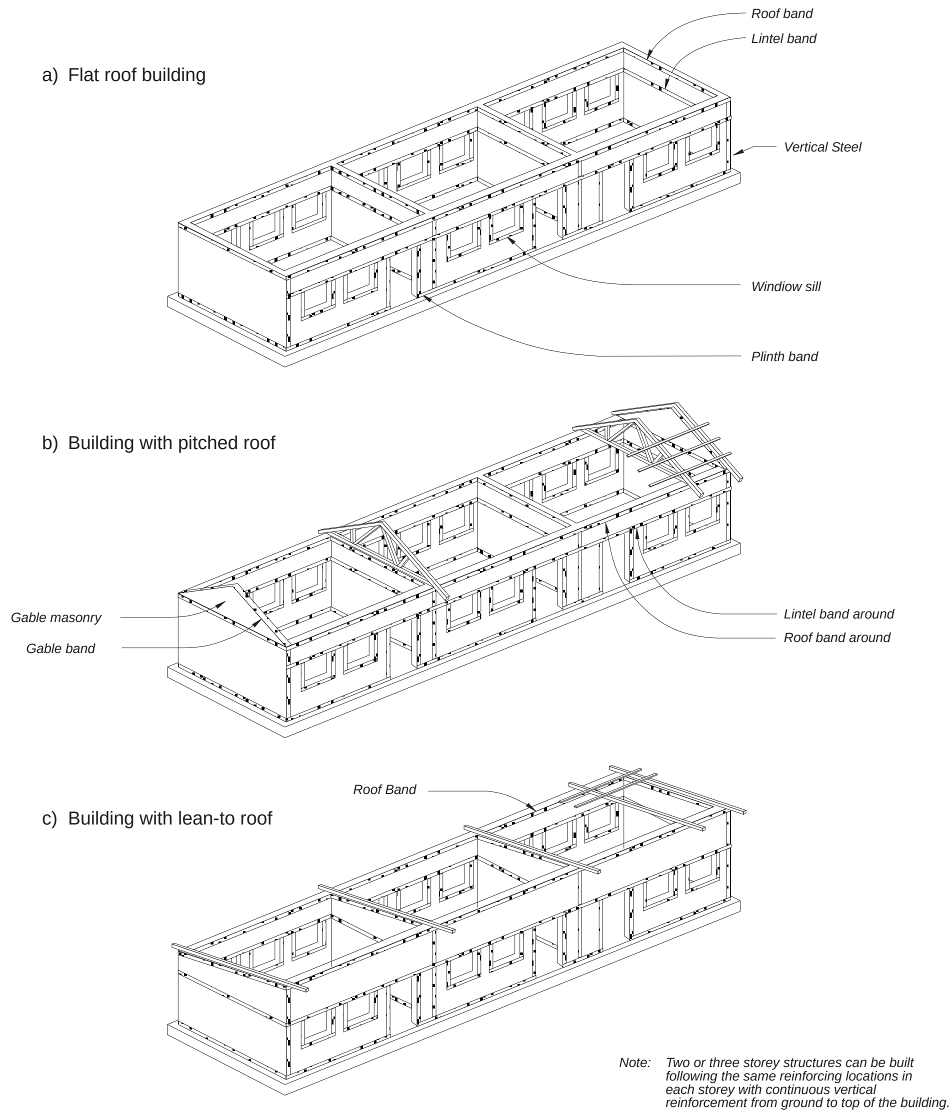


Fig. 23 : Locations for reinforcing

8.2 Foundation

For load bearing wall construction, strip footing of masonry, plain concrete or RC is commonly used. Although RC strip footing will be most effective for seismic and settlement consideration in soft as well as firm soils, masonry footings are most frequently used. The following recommendations are made for the latter:

- The depth of footing should go below the weathering zone. Usually a depth of 750 to 900mm below ground level will be adequate except in special problem soils (e.g. black cotton, highly plastic soils). It should not be placed on filled soil.

- The footing should have adequate width to meet the requirements of safe bearing pressure. Widths of 750mm for one storey, 1 m for two storey and 1.2 m for 3 storeys are frequently used and are enough in alluvial soils. These may be reduced for rocky foundations.

- The foundation should be on firm base of lime or cement concrete with minimum thickness of 150 mm over which the masonry footings may be built using gradually reducing steps to obtain the final wall thickness. Often, the footing stem is kept a half unit wider than the superstructure wall at plinth level (ref. Fig. 24).

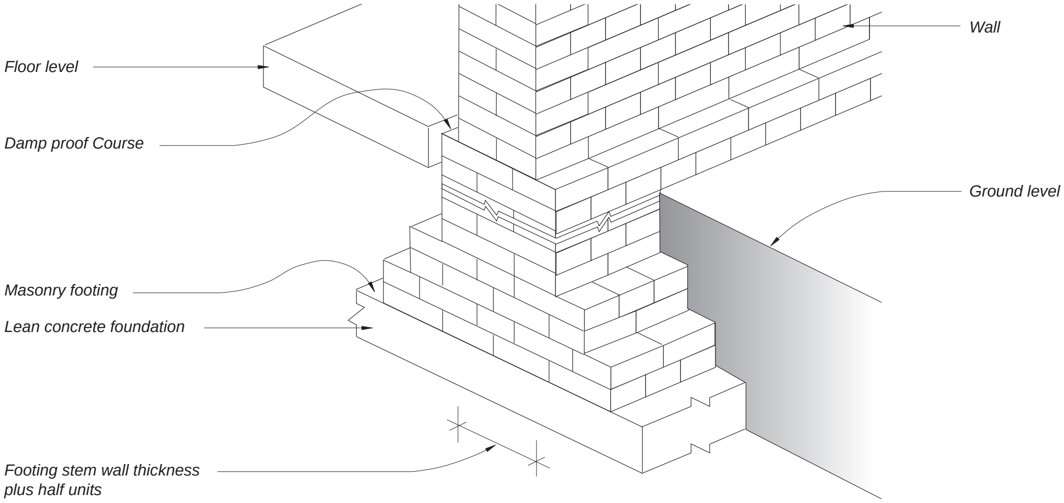


Fig. 24 : Footings

Foundation can be constructed of various materials:

8.2.1 RC Strip

This footing is most effective for seismic and settlement consideration in soft as well as firm soils. In this system, a RC strip is laid on brick or stone soling. The minimum thickness of the strip should not be less than 150mm. Wall thickness equal to that of first story structure can be erected on the strip as shown in Fig. 25.

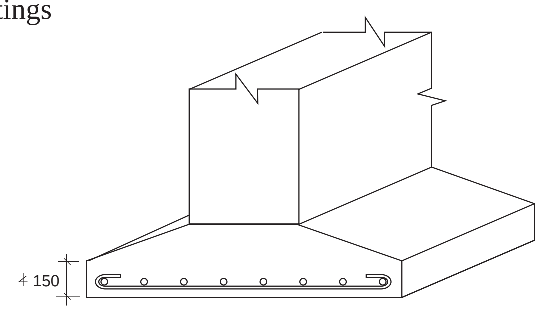


Fig. 25 : Construction of strip foundation in RC

8.2.2 PCC Strip/Lime Strip

This type of foundation is inferior to RC strip footing. Plain or lime concrete with minimum thickness of 150mm is laid on soil, brick or stone soling over which the masonry footings is built using gradually reducing wall thickness to obtain the final wall thickness. Often, the footing stem is kept a half unit wider than the superstructure wall at plinth level as shown in Fig. 24.

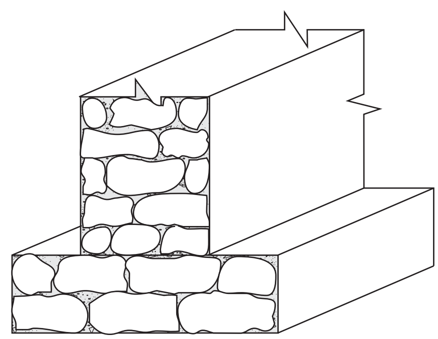


Fig. 26 : Plum concrete strip footing

8.2.3 Plum Concrete

This type of foundation is quite suitable where stone or boulders are available in abundance. Stones of 200 mm or less are suitable. It is basically stone masonry in matrix of 1:3:6 to 1:4:8 concrete which works as both binder and filler material. A section of plum concrete foundation is shown in Fig. 26.

8.2.4 Brick/Stone Masonry

It is the most common strip foundation, which can be constructed in cement or mud mortar (ref. Fig. 27).

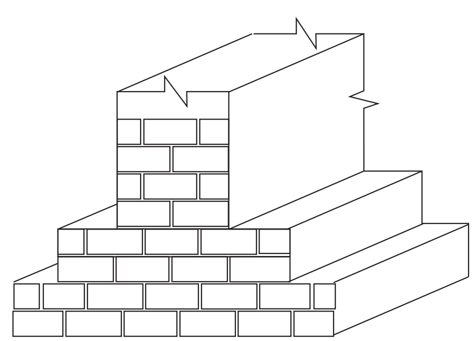


Fig. 27 : Masonry strip footing

8.3 *Walls*

8.3.1 Openings

The size and the position of the openings have a substantial affect on the resistance of masonry building to earthquake loading. Large size openings weaken the masonry walls against vertical as well as earthquake load. A control on their size and location is desirable, consistent of course, with functional requirements. Therefore, in order to improve behavior of masonry buildings, the following recommendations should be observed, as far as the location and the size of the opening is concerned:

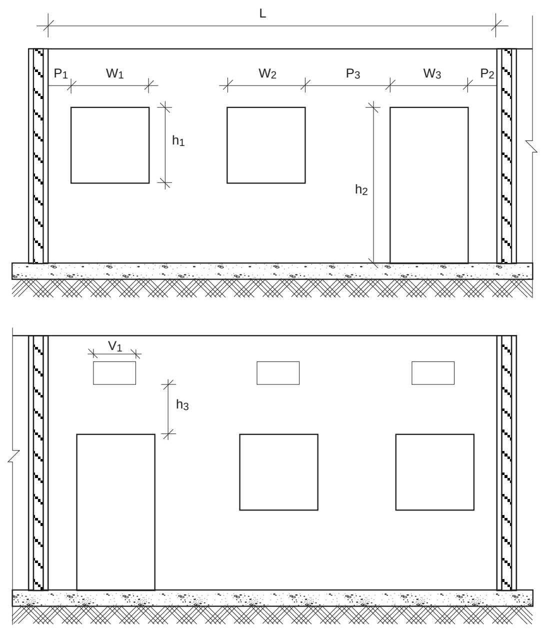
a. Opening should be located away from the inside corner of a wall by a clear distance of at least one quarter of height of the opening or one block length or 450mm whichever is greater.

b. Total combined length of openings should not exceed the following fractions of the length of walls between consecutive support or cross walls:

- 50% for one storey building construction;
- 42% for two-storey building construction; and
- 33% for three-storey building construction.

c. The horizontal distance (pier-width) between two consecutive openings shall not be less than one half of the height of the shorter opening, but not less than 450 mm.

d. The vertical distance between two openings should not be less than 600mm nor less than half the width of the smaller opening width. Fig. 28 illustrates the above points.



Rule 1: $P_1 > 0.25\ h_1$ and $P_2 > 0.25\ h_2$
Rule 2: $W_1+W_2+W_3$ < 0.5L for one storey building
< 0.42L for two storey building
< 0.33L for three storey building
Rule 3: $P_3 > 0.5h_2$
Rule 4: $h_3 > 600$mm or $> 0.5\ V_1$ (whichever is more)

Fig. 28 : Reinforcing of openings

8.3.2 Reinforcement of Opening

Where openings do not comply with the above geometrical requirements they should be strengthened as shown in Fig. 29 or the vertical bars can be started from damp proof course. The diameter of the bar may be the same as specified in Table 8.2.

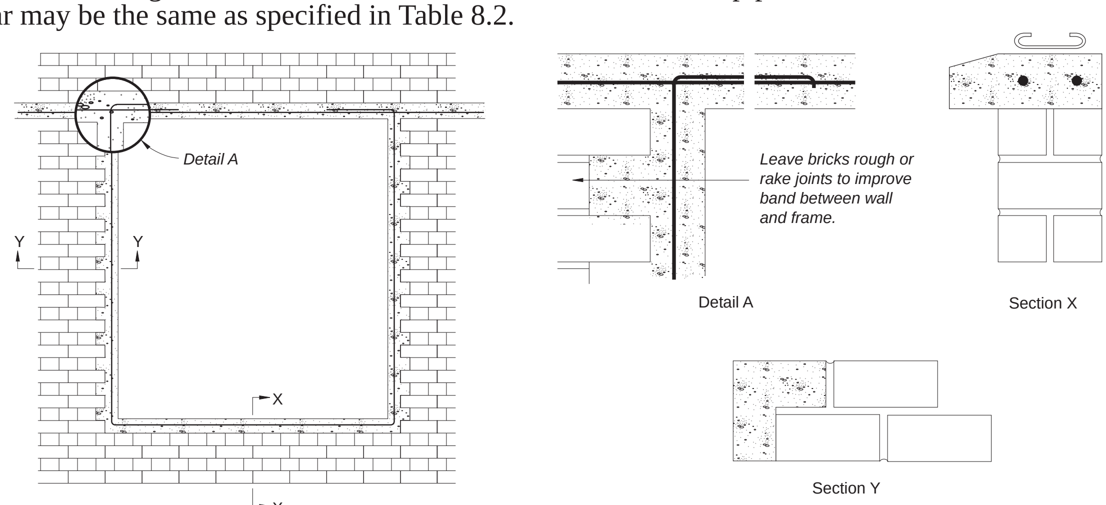


Fig. 29 : Reinforcing of openings

8.3.3 Wall Reinforcment

8.3.3.1 Strengthening the Junctions

Vertical joint between perpendicular walls (Stitching)

It is common practice to provide vertical toothed joint at wall junctions, which is generally left hollow and weak.

To strengthen the connection between perpendicular walls, it is necessary to make a sloping (stepped) joint by making corners first to a height of 600 mm as shown in Fig. 30 and then building the wall in between them. It helps to fill up all the joints with mortar. Otherwise, the toothed joint should be made in both the walls alternatively in lifts of about 450 mm as shown in Fig. 31.

To further strengthen the connection between transverse walls, steel dowel bars may be used at corners and T-junctions to enhance the box action of walls. Dowels (ref. Fig. 32A, B) are placed in every 500-700 mm interval and taken into the walls to sufficient length so as to provide full bond strength. These bars can be embedded into one brick course thick cement concrete as shown in Fig. 32C. Alternatively, these bars can be replaced with 3.25mm galvanized wires or chicken mesh (ref. Fig. 33) embedded into mortar layer. These dowels or chicken mesh do not serve to reinforce the walls in horizontal bending except near the junctions.

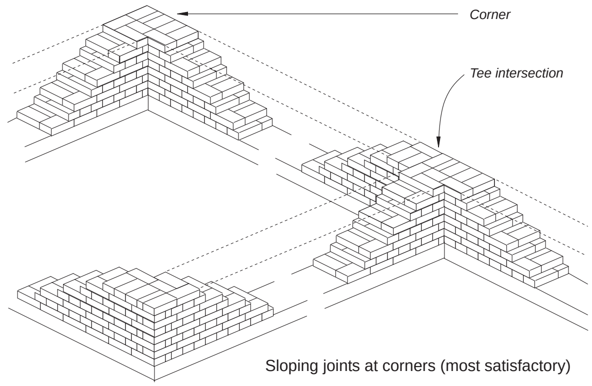


Fig. 30 : Staggered toothed wall joint

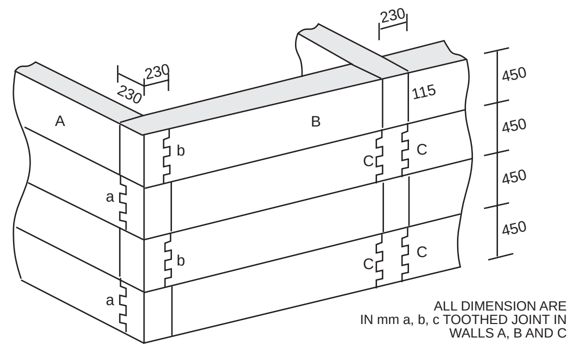
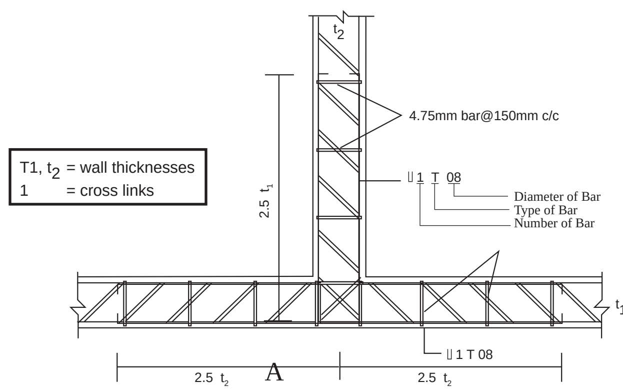
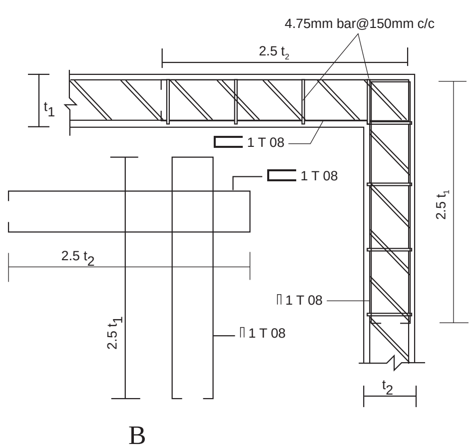


Fig. 31 : Stepped wall joint stitching





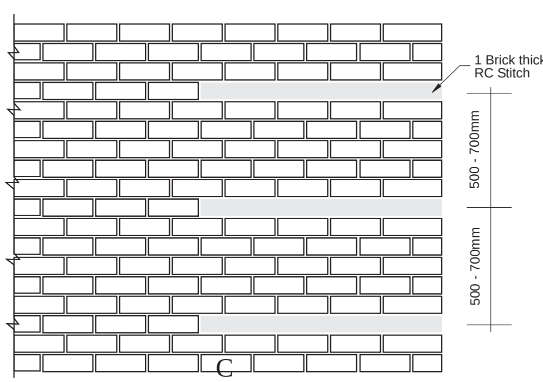


Fig. 32 : Joint strengthening by dowel reinforcement placed in one joint

8.3.3.2 Bands

A continuos band, also called 'ring beam' or 'collar beam' is a RC band or runner provided at different levels in all walls of the building for tying walls together to enhance box action. It improves horizontal bending resistance thereby preventing out-of-plane collapse of walls. It also helps to prevent shrinkage, temperature and settlement cracks. Various types of bands are shown in Fig. 34.

Plinth band

This is the band provided at plinth level which also acts as a damp proof course. This should be provided in cases where soil is soft or uneven in their properties.

Sill band

This band is provided just below the window openings. This becomes critical if the floor height is high.

Lintel band

This is the most important band and will incorporate in itself all door and window lintels. It must be provided in all stories of the building. Reinforcement required to span over openings should be in addition to band steel .

Floor and roof band

This band is required where timber or steel floor/roof structure has been used. It helps to integrate floor/roof structure with walls. Floor/roof structure should be tied with it.

Gable band

Masonry gable walls must be enclosed in a band, the horizontal part will be continious with the eave level band on longitudinal walls. The roof purlins should be tied up with sloping part of the band.

Section of bands or ring beam

The reinforcement of these bands may be kept as per Table 8.1 depending upon category of building and seismic zone. For longer spans, spans can be shortened by constructing intermediate columns or buttress.

Thickness of band shall be 75mm and 150 mm where two or four bars are used as longitudinal reinforcement respectively. The width of band shall be kept equal to that of wall or otherwise designed. The steel bars are located close to the wall faces with 25 mm cover and full continuity is provided at junctions and corners as shown in Fig. 35.

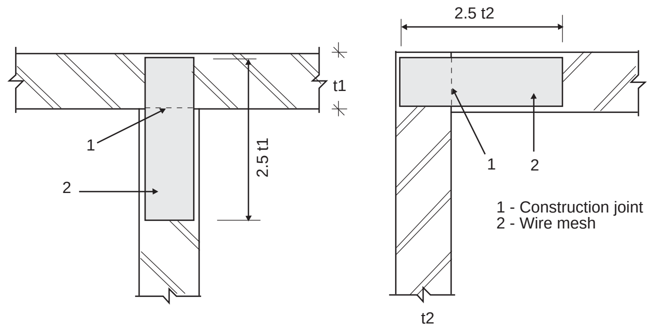


Fig. 33 : Joint strengthening by wire fabric

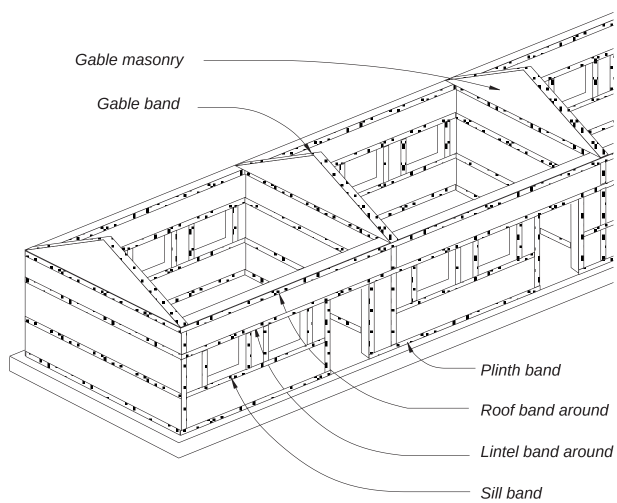


Fig. 34 : Bands at different levels

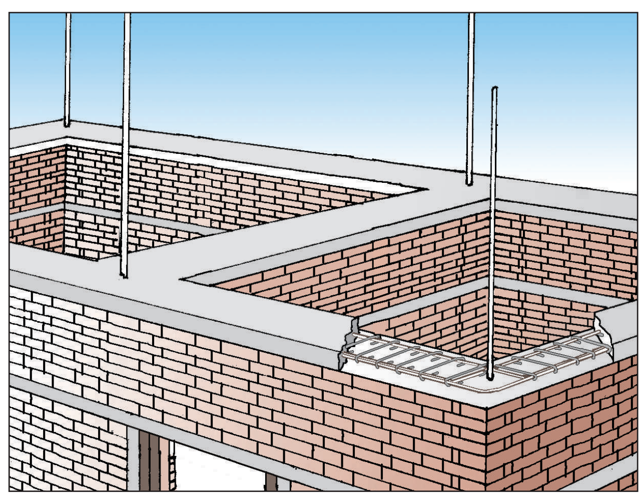


Fig. 35 : Reinforced concrete band

Table 8.1 Number and diameter of bars in bands

Span of wall between cross walls	Category I		Category II		Category III	
	No. of bars	Diameter	No. of bars	Diameter	No. of bars	Diameter
3	2	08	2	08	2	08
4	2	10	2	08	2	08
5	2	12	2	10	2	10
6	4	10	2	12	2	10
7	4	12	4	10	2	12
8	4	12	4	10	4	10
9	-	-	4	12	4	12

Notes:

- Width of the band shall be same as width of wall. Wall thickness shall not be less than 200 mm in case of structural wall.
- If band width is kept less than wall thickness, band should be redesigned. (The cross-sectional area of longitudinal steel bars and the concrete should be increased in inverse proportion to the reduced band width.)
- Longitudinal bars to be held by links stirrup made of 4.75mm or 6mm diameter bars @ 150mm.
- Concrete mix to be 1:2:4 by volume or having 15 Mpa cube crushing strength at 28 days.
- The reinforcement recommended in Table 8.1 is only for out-of-plane failure requirement. Any steel required for spanning openings, is in addition and such bars can be embedd3ed in band itself.

8.3.3.3 Vertical Reinforcment

Vertical bars should be provided at junctions of walls ie. at corners and T-junctions. For the various categories of construction, the quantity of vertical bars to be provided is given in Table 8.2. In all buildings falling in category I and II, vertical bars should also be provided in jambs of doors and large windows.

Table 8.2: Requirements of Vertical steel bars in masonry walls

No of storeys	Storey	Diameter of single bar at critical section		
		Category 1	Category II	Category III
One	-	12	10	-
Two	Top	12	10	10
	Bottom	16	12	10
Three	Top	12	10	10
	Middle	16	12	10
	Bottom	16	12	12

The arrangement for providing vertical reinforcing steel in brick wall is shown in Fig. 36 for one brick, one and half brick walls. It is not unusual to provide thicker walls in lower storeys and thinner walls in upper storeys. It is important to arrange the bars in various storeys in the same vertical line. These bars should start from the foundation and must be anchored in roof slab or roof band as shown in Fig. 36. The appropriate location of splicing is just above the lintel band and below the sill band of subsequent upper storey. An overlap length equivalent to 60 times diameter of the bar is recommended, bound well by binding wire. These bars should be covered with cement concrete or cement grout in cavities made around them during masonry construction. The concrete mix should be kept 1:2:4 by volume or richer.

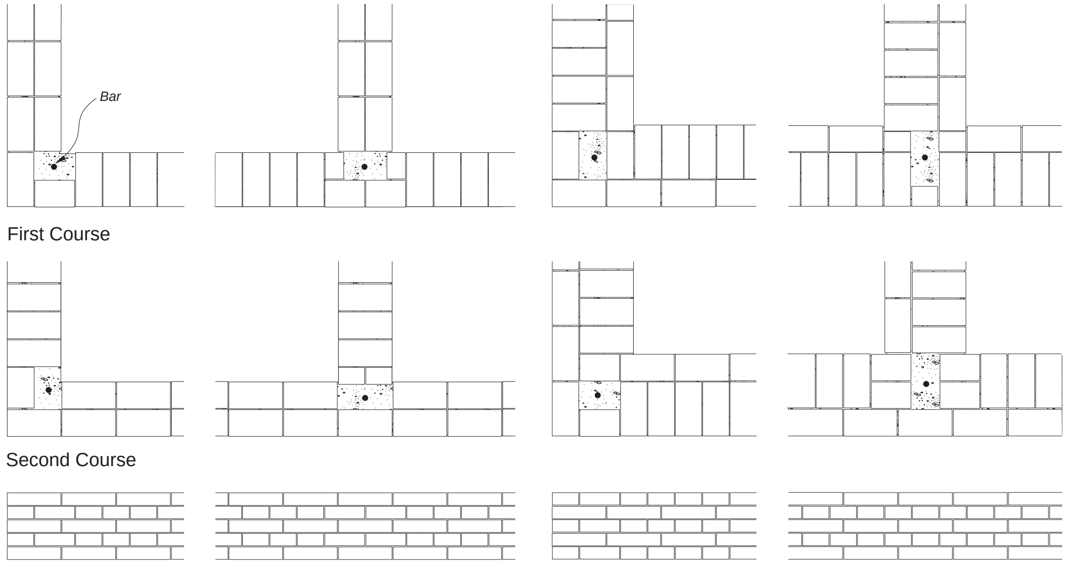


Fig. 36 : Vertical reinforcement in brick wall

Details of vertical steel placement in door/window jambs is shown in Fig. 29.

Mortar

The masonry mortar should be kept as per Table 8.3 depending upon category of building. A mortar mix (ie. cement: sand) leaner than 1:6 by volume or equivalent is not permissible.

Table 8.3: Mortar

Building Catagory	**Mixtures**
Category I	cement : sand 1:4 or cement : lime : sand 1:1:6
Category II	cement : lime : sand 1:1/4:6 or cement : sand 1:6
Category III	cement : sand 1:6

8.4 Concrete Block Walls

The recommendations made for brick masonry generally apply to solid concrete block, hollow concrete block, stonecrete masonry construction assuming that their vertical crushing strength is adequate for resisting the vertical loads, say 7 MPa (70 kg/cm^2) for three storey, 5.0 MPa for two storey buildings and 3.5 MPa (35 kg/cm^2) for one storey buildings measured on the gross plan area of the solid or hollow concrete block building.

Construction of horizontal bands

The use of channel shape concrete units will avoid the employment of framework. The horizontal reinforcement may be placed in channels and concrete cast to form the bands as shown in Fig. 37.

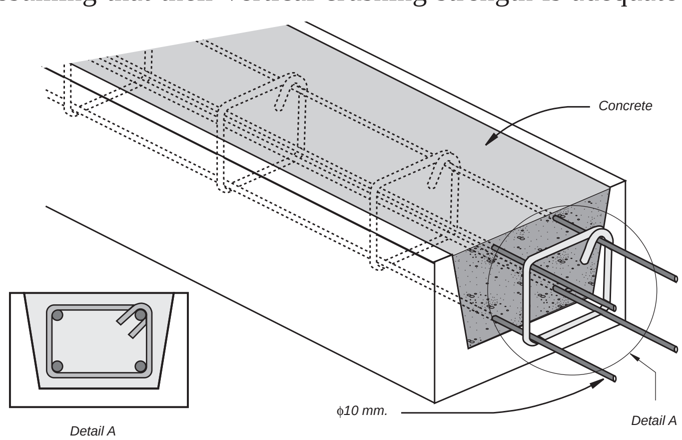


Fig. 37 : Section of Horizontal band

Vertical reinforcement

The provision of vertical reinforcement through holes of hollow concrete blocks requires splicing of vertical bars to heights of about 1.8 to 2.0 m so that the blocks need not be lifted too high. Hollow concrete blocks with ends that can be knocked are also available which do not require close splicing positions as shown in Fig. 38.

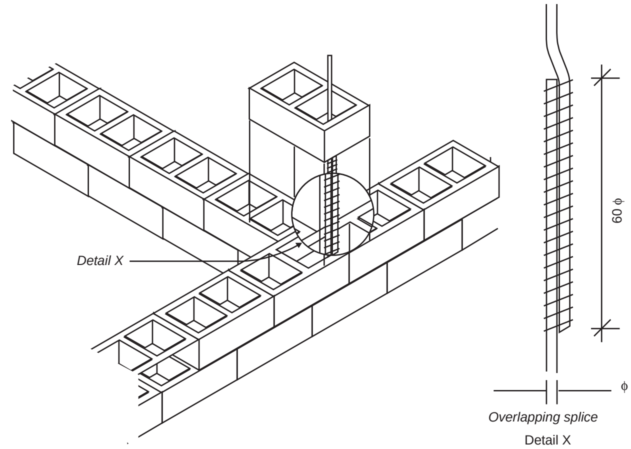
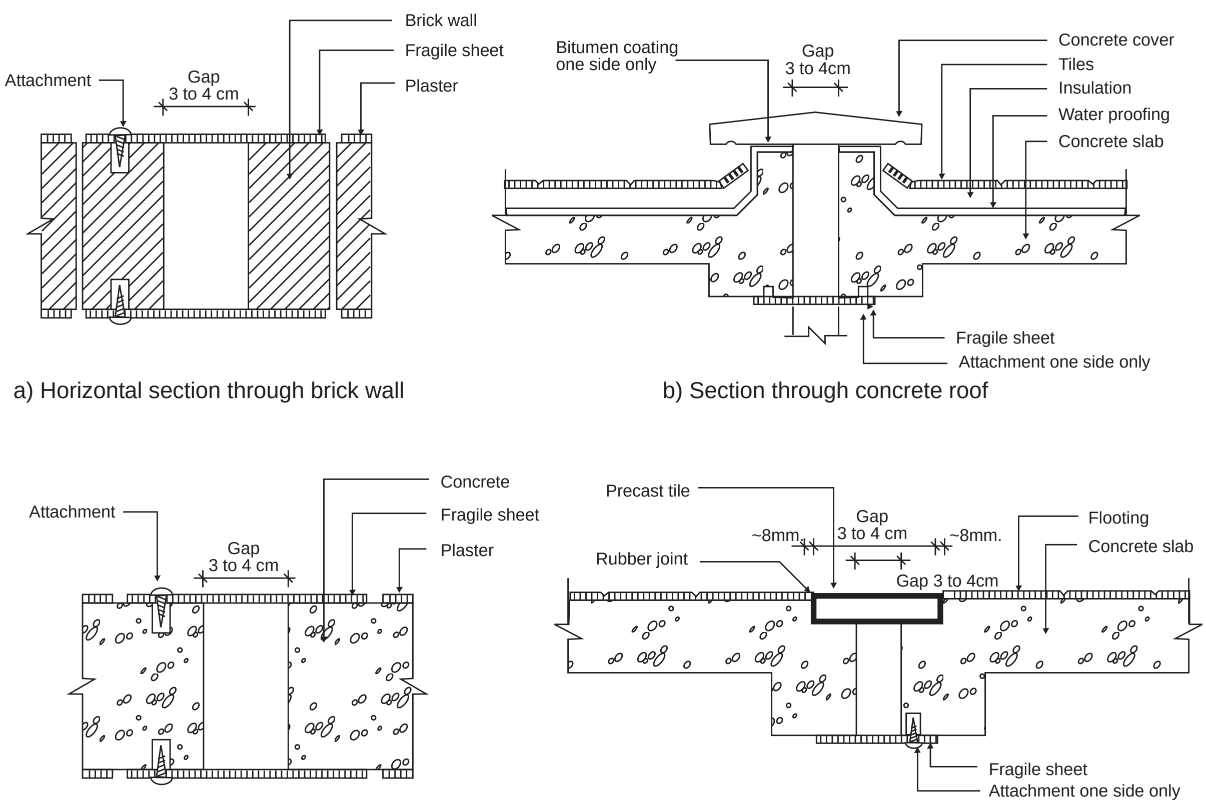


Fig. 38 : Vertical bar in hollow concrete and stonecrete block

8.5 *Separation and Crumple Sections*

Besides improving the building form seismically, physical separation of blocks prevents damage from hammering and pounding. A gap of 3 to 4 cm throughout the height of the building is desirable for buildings up to 3 storeys. Separation must be complete except below plinth level.

- In case of beam-column constuction, members may be duplicated on either side of separation section.
- Details of separation (or crumple) section may be as shown in Fig 39 (a, b, c, d).



a) Horizontal section through brick wall

b) Section through concrete roof

c) Horizontal section through concrete wall

d) Section through concrete floor

Fig. 39 : Crumple section

9 LOW STRENGTH MASONRY IN RECTANGULAR BLOCK AND STONE

9.1 Definition

Construction of brick or stone in mud mortar is called low strength masonry. Such buildings are quite vulnerable to earthquakes and unsuitable for school building construction. However, in unavoidable circumstances, these can be used by incorporating the strengthening measures described below.

9.2 Limitations

- Brickwork or squared stone masonry (rectangular block) in mud mortar may be used for construction of one storey buildings of categories I and II and not more than two storeys of categorys III. Dressed stones can be treated as rectangular blocks.
- Random rubble masonry in mud mortar is to be avoided for category I building, and used for only one storey construction in category II. It can be used for two storeys, low occupancy buildings in category III.

9.3 Strengthening Measures

The main seismic strengthening measures are as follow:

- Integrity of floor and roof and their bracing if it is constructed of timber or steel
- Provision of horizontal bands and stitches in walls
- Provision of vertical bars in junctions of walls and jambs of doors and large windows .
- Provision of vertical buttresses for enhancing stability of long walls

9.4 Materials

- The mud used for making adobe or mud mortar should be capable of being rolled in the form of a thin thread between 50 to 150mm long without cracking.
- Brick or block strength shall not be less than 3.5 MPa (35 kg/cm^2)
- Quarry stones having angular shape should be used in wall construction
- Round boulders may only be used in footing construction below ground level. If only round boulders are available, these should be partially (at least 50 percent each) dressed
- Timber should preferably be hard wood. Timber shall be well seasoned and chemically treated

9.5 Walls

9.5.1 Thickness

Brick wall: The minimum thickness of rectangular block wall shall be made 1.5 units, that is, 300 mm for 200 mm wide units and 350mm for 230 mm wide units.

Stone wall: The wall thickness may be kept 450mm as maximum to a minimum of 380 mm as shown in Fig. 40.

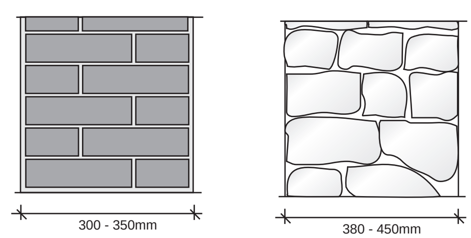


Fig. 40 : Cross section of stone wall

9.5.2 Buttresses

Buttress should be constructed by projecting walls beyond the corner and T-junctions, and wherever wall length is more than 6 m. It helps to retain the integral action of walls. The buttress at junctions also facilitate the connection of collar beams with each other (ref. Fig. 41). Thickness of buttress should be at least equal to wall thickness and width should be at least 1/6 of wall height excluding wall thickness at the bottom and at least equal to thickness of wall at top.

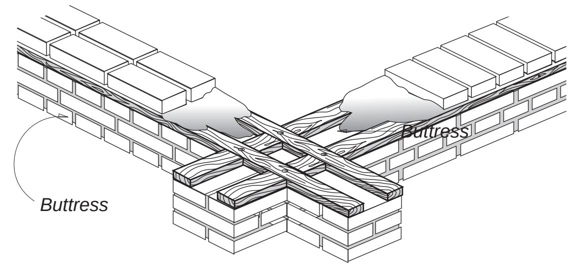
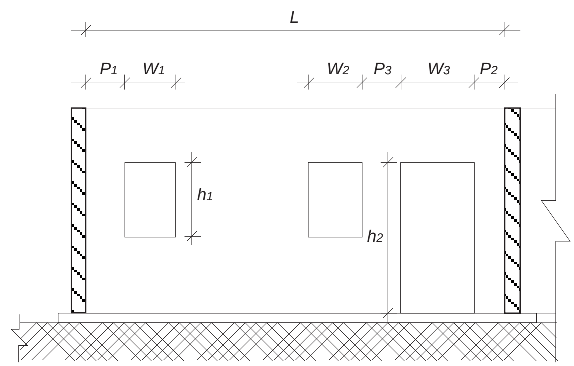


Fig. 41 : Use of buttress

9.5.3 Door and Window Openings

9.5.3.1 Rectangular Block Masonry

The controlling guidelines given in Section 6.4 will be applicable with the added restriction that the sum of width of openings shall not exceed 40% of the total length of wall between consecutive walls (cross walls, buttress etc), and the width of pier between two consecutive openings being not less than 600 mm (ref. Fig 42).

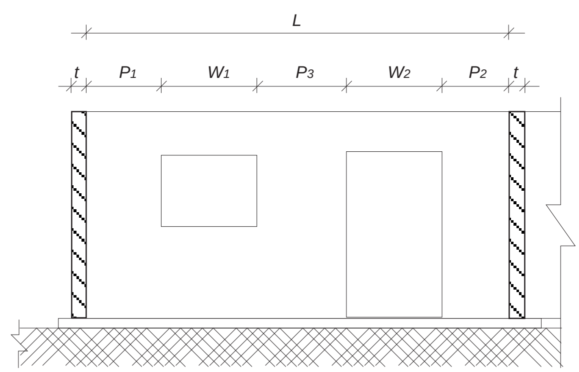


Rule 1: P1 > 0.25 h1 and P2 > 0.25 h2
Rule 2: W1+W2+W3 < 0.4L
Rule 3: 0.5h2 and P1 or P2 or P3 > 450mm

Fig. 42 : Opening sizes in bearing walls constructed of rectangular blocks

9.5.3.2 Stone Masonry

The width of an opening should not be greater than 1.20 m. The distance between an outside corner and the opening should not be less than 1.2 m. The sum of the widths of openings in a wall should not exceed 1/3 of the total wall length (ref.Fig. 43).



$P_1 + t > 1.2$ m; $P_2 + t > 1.2$m
$W_1+W_2 < L/3$; W_1, $W_2 < 1.2$m

Fig. 43 : Opening sizes in bearing walls constructed of random rubble

9.5.4 Construction

9.5.4.1 Block masonry

Problems associated with block masonry in mud mortar is very similar to that in cement mortar. For brick or masonry dressed stone construction in mud mortar, details discussed in Section 8.3.3 can be adopted.

9.5.4.2 Stone Masonry

The major problems associated with random-rubble stone wall are:

- Separation at corners and T-junctions takes place even more easily than in brick wall.
- Delamination and bulging of walls, that is vertical separation of internal and external wythes through the middle of wall thickness as shown in Fig. 44

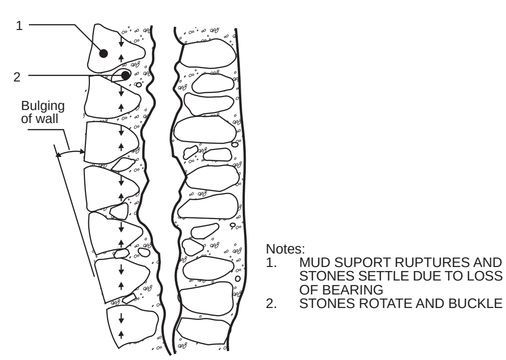


Fig. 44 : Stone wall delamination with buckled wythes

is a common problem. This occurs mainly due to absence of 'through' or bond stone and construction of wall wythes using small stones, and filling weak mud mortar between wythes. In half dressed stone masonry, the surface stones are pyramidal in shape having more or less an edge contact one over the other, thus the stones have an unstable equilibrium and easily disturbed under shaking.

The following considerations shall be made when using random rubble stone masonry:-

- Masonry should be brought to course at every 600mm
- "Through" stones of full-length equal to wall thickness should be used in every 600mm lift at not more than 1.2m apart horizontally. If full length stones are not available, stones in pairs, each of about 3/4 of the wall thickness may be used in place of one full length stone so as to provide an overlap between them as shown in Fig. 45.
- In place of "through" stone, bonding elements of steel bars of 8 to 10 mm diameter in S-shape or as a hooked link (ref Fig. 45) may be used with a cover of 25 mm from each face of the wall.
- Alternatively, wood bars of 38mm x38mm cross-section or a plain cement concrete block of 150mm x 150mm can also be used for the "through" stone.
- Long stones should also be used at corners and junctions of walls to break the vertical joint and provide bonding between perpendicular walls as shown in Fig. 46. Similarly long stones should be used along the wall in opening jambs.

9.5.5 Stitches

Stitches as discussed in section 8.3.3.1 can be used or alternatively stitches with timber as shown in Fig. 47 can also be used.

9.5.6 Bands

A continuous band, also called 'ring beam' or ‘collar beam’ as discussed in Section 8.3.3.2 could be a RC or timber band provided at different levels in all walls of the building for tying walls together and to enhance box action. It improves horizontal bending resistance thereby preventing out-of-plane collapse of walls. Details of RC bands were discussed in Section 8.3.3.2. Same details can be followed for low strength masonry.

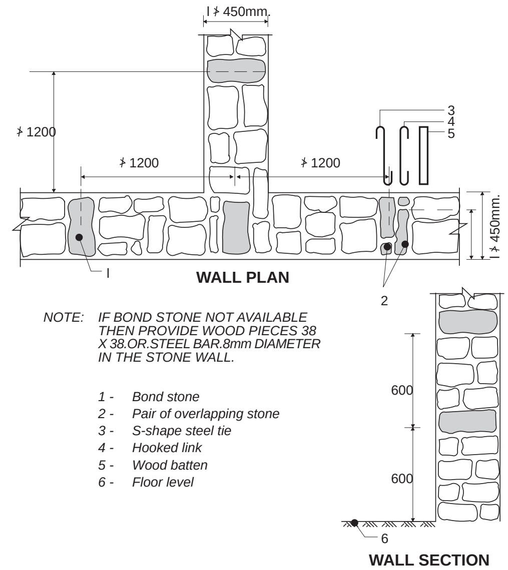


Fig. 45 : Random rubble masonry with "through" stone or other bonding elements

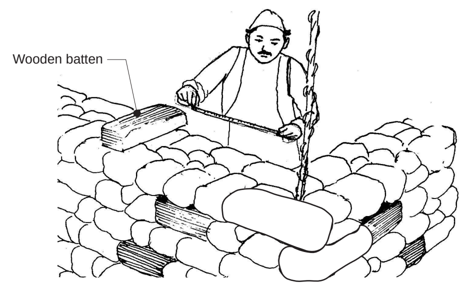


Fig. 46 : Wall junction strengthening

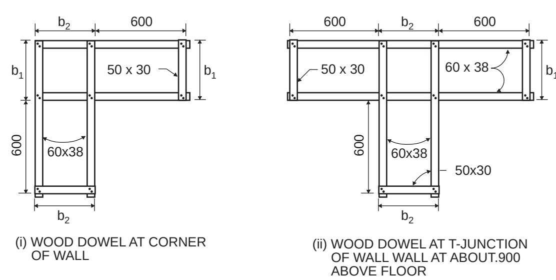


Fig. 47 : Detail of timber stitches

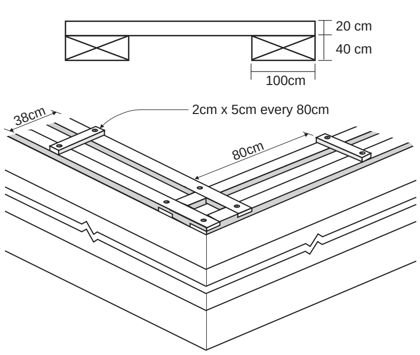


Fig. 48 : Detail of timber band

Block masonry or random-rubble masonry can also be strengthened with timber runners as shown in Fig. 48.

9.5.7 Vertical Reinforcing

Vertical bars should be provided at junctions of walls i.e. at corners and T-Junctions as discussed in section no. 8.3.3.3. For brick masonry in mud mortar, the quantity of vertical steel as specified in Table 8.2 can be used. For stone masonry construction, Table 9.1 shall be followed. Similarly, openings for doors and large opening should also be provided with vertical bars in their jambs as discussed in Section 8.3.3.3.

Table 9.1: Requirements of Vertical steel bars in stone masonry walls

No of storeys	Storey	Diameter of single bar at critical section		
		Category 1	Category II	Category III
One	-	16	12	10
Two	Top	16	12	10
	Bottom	20	16	12
Three	Top	16	12	10
	Middle	20	16	12
	Bottom	20	16	12

The arrangement for providing vertical reinforcing steel in stone wall is shown in Fig. 49. It is important to arrange the bars in various storeys in same vertical line and truly straight. These bars should start from the foundation and must be anchored in roof slab or roof band as shown in Fig. 49. The appropriate location of splicing is just above the lintelbands in various storeys. An overlap length equivalent to 60 diameter of the bar is recommended, bound well by binding wire. These bars should be covered with cement concrete in cavities made around them during masonry construction. The concrete mix should be kept 1:2:4 with fine chips by volume or richer. Method of making the cavity is shown in Fig. 49 by using a pipe sleeve around the bar when masonry is built, then sliding the sleeve up while the mortar is still not set.

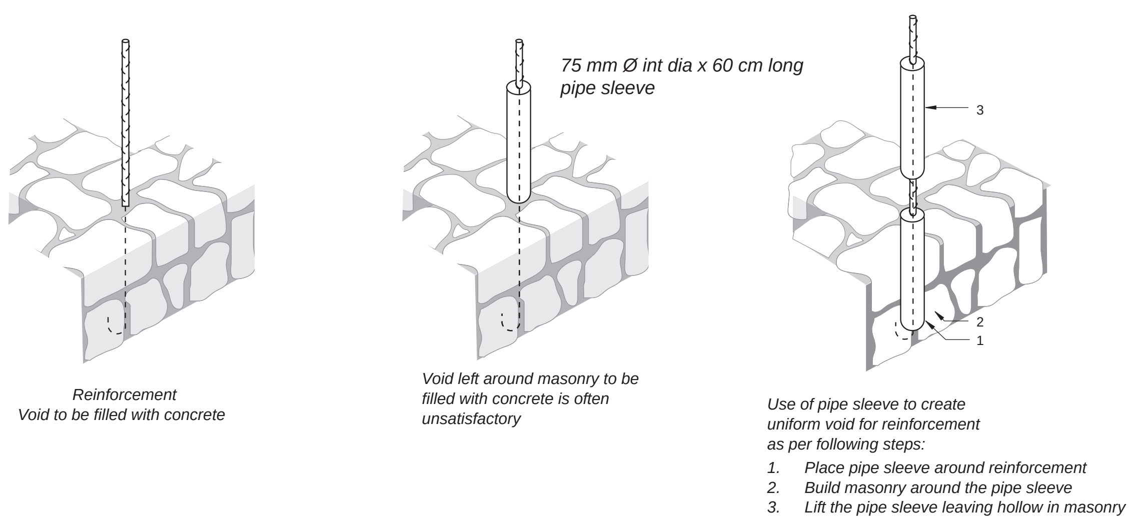


Fig. 49 : Vertical reinforcement in rubble stone wall

10 DETAILING OF RC FRAMES

This section discusses general requirements for construction of RC framed buildings. The reinforcement details prescribed shall be observed in addition to that of reinforcement detail required for normal load.

10.1 Foundation

If isolated footing is used as foundation, it is advised to connect them at foundation level or ground level or just below plinth level as shown in Fig 50.

When a column terminates into a footing or a mat, special confining reinforcement shall extend at least 300 mm into the footing or mat as shown in Fig. 51. The spacing of confining reinforcement shall not be more than 100 mm.

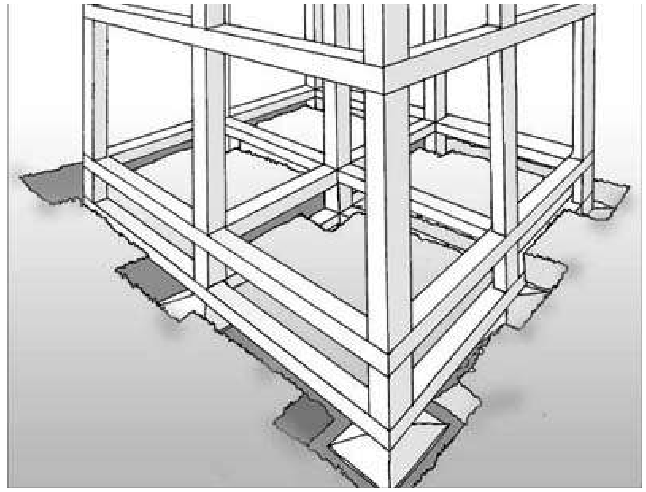


Fig. 50 : Tying up isolating footings

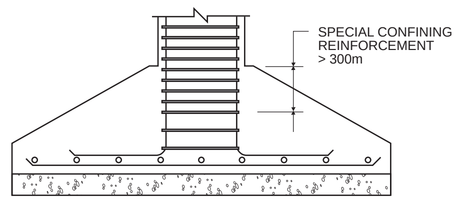


Fig. 51 : Provision of special confining reinforcement into footing

10.2 Beam

10.2.1 Dimensions

- Beams shall preferably have a width to depth ratio of more than 0.3.
- The width of the beam shall not be less than 200 mm.
- The depth of the beam shall preferably be not more than 1/4 of the clear span.

10.2.2 Longitudinal Reinforcement

- Top as well as bottom reinforcement shall consist of at least two bars, of not less than 12 mm, throughout the member length.
- The tension steel in any face, at any section, shall not be less than 0.3% (for concrete grade M15 or mix 1:2:4 and steel yield strength 415 MPa).
- The positive steel at a joint must be at least equal to half the negative steel at that section, subject to minimum of 0.2%.
- The maximum steel percentage on any face at any section shall not exceed 2.5%.
- The steel provided at each of the top and bottom face of the member at any section along its length shall at least equal to 1/4 of the maximum negative moment steel provided at the face of either joint.
- In an external joint, both the top and bottom bars of the beam shall be provided with anchorage length, beyond the inner face of the column, equal to the development length in tension plus 10 times bar diameter minus allowance for 90 degree band (58xdiameter of bar for concrete grade M15 or mix 1:2:4) as shown in Fig 52.

- Splicing of bars by overlapping should be done using full development length (i.e. 56 x diameter of bar for concrete grade M15),
- Spliced length shall be enclosed in stirrups spaced not more than 150 mm apart as shown in Fig. 53.
- Not more than 50% of the bars shall be spliced at any section. If the spacing between centre of splicings is more than 1.3 x lap length, staggered splicing shall be considered.
- Splice position for bottom bars shall be restricted to a region at least 2d (2x depth of beam) away from face of column but excluding the middle quarter length of effective span as shown in Fig. 54.
- Top bars shall be spliced in middle 1/3 of effective span as shown in Fig. 54.
- All longitudinal bars of beam shall pass through longitudinal bars of the column as shown in Fig. 52.

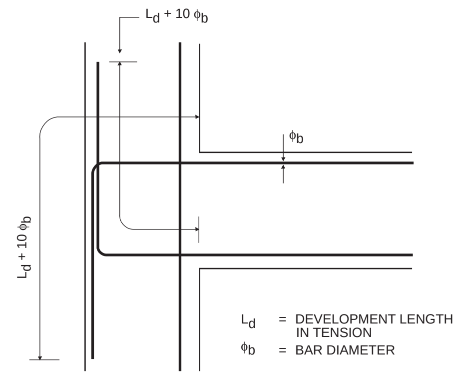


Fig. 52 : Anchorage beam bars in an external joint

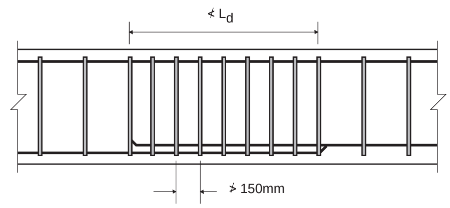


Fig. 53 : Lap splice in beam

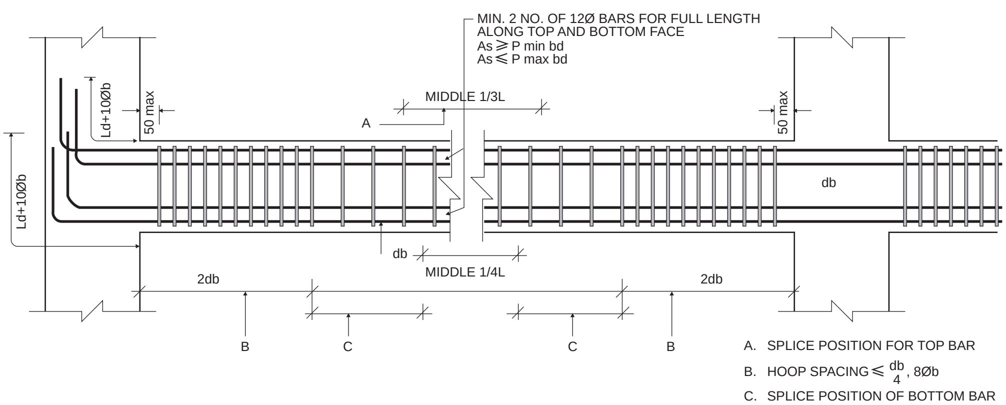


Fig. 54 : Beam reinforcement

10.2.3 Web Reinforcement

- Web reinforcement shall consist of vertical stirrups. The closed stirrup should have a 135^0hook as shown in Fig. 55. The ends of the stirrup should be embedded in confined core as shown in Fig. 55a. In compelling situation, it may also be made up of two pieces of reinforcement; a U-stirrup with a 135^0 hook and a 10 diameter extension at each end, embedded into confined core and a cross tie as shown in Fig. 55b. A cross-tie is a bar having a 135^0 hook with a 10 diameter extension (but not <75 mm) at each ends. The hooks shall engage peripheral longitudinal bars.

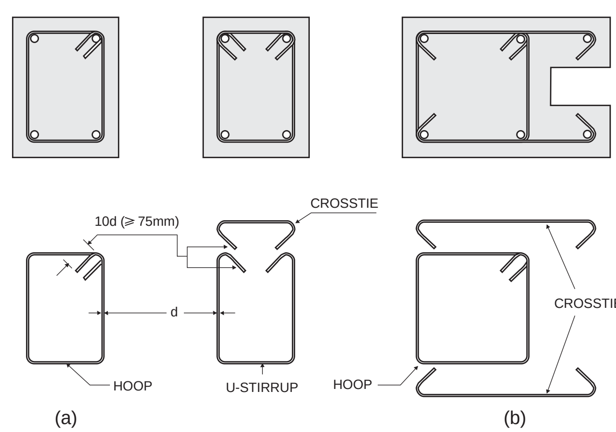


Fig. 55 : Beam web reinforcement

- The minimum diameter of stirrups shall be 6mm. However, in beams with clear span exceeding 5m, the minimum bar diameter shall be 8mm.
- The spacing of stirrups over a length of 2d at either end of a beam shall not exceed (a) d/4, and (b) 8 times diameter of smallest longitudinal bar. However, it need not be less than 100mm as shown in Fig. 54. In rest of the length, stirrups shall be provided at spacing not exceeding d/2.

10.3 Column

10.3.1 Dimensions

- The minimum dimension of the column shall not be less than 200mm. However, in frames which have beams with centre to centre span exceeding 5m or columns of unsupported length exceeding 4m, the shortest dimension of the column shall not be less than 300mm.
- The ratio of shortest cross sectional dimension to perpendicular dimension shall preferably not be less than 0.4.
- Width of column shall preferably be 75mm larger than the supported beam.

10.3.2 Longitudinal Reinforcement

Lap splices shall be provided only in the central half of the unsupported member length as shown in Fig. 56. It should be proportioned as a tension splice. (i.e. lap length shall be 56ϕ for concrete mix 1:2:4 and steel grade fe 415).

- Steel at any section shall not be less than 0.8%.
- Bars less than 12 mm in diameter shall not be used in column as longitudinal reinforcement.
- Closed hoops shall be provided over the entire splice length at spacing not exceeding 150 mm or d/2, preferably 100 mm.
- Not more than 50% of bars be spliced at any one section.

10.3.3 Web Reinforcement

- The stirrups should be closed type having a 135º hook with a 10-diameter extension (but not less than 75mm) at each end (ref. Fig. 57A).
- The parallel legs of rectangular hoops should not be more than 300mm apart. If the length of any side of hoop exceeds 300mm, a cross-tie shall be added (ref. Fig. 57B).
- Alternatively, a pair of overlapping stirrups may be provided within the column (ref. Fig. 57C)

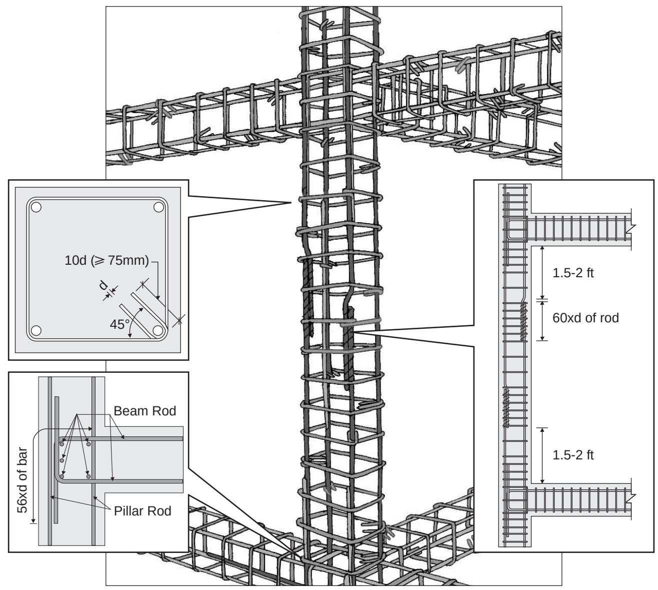


Fig. 56 : Lap splice in beam

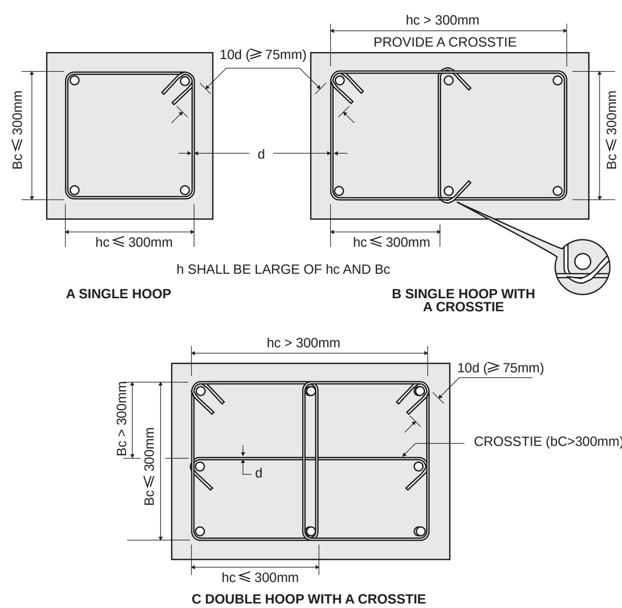


Fig. 57 : Transverse reinforcement in column

- Stirrups shall be provided at the spacing of 100 mm or d/4 (but not less than 75 mm) in the ends of column (a) 1/6 of clear span of column (b) larger lateral dimension of the column; or (c) 450 mm (ref. Fig. 58) whichever is more.

- In the rest of the length, the spacing of stirrups shall not exceed half the shortest lateral dimension of the column.

- Where column is confined by low walls height (as columns abutting walls on opposite sides), stirrups shall be provided at the spacing of 100 mm or d/4 (but not less than 75 mm) throughout the free length of the column.

10.4 Beam Column Joint

10.4.1 Transverse Reinforcement

- In exterior columns stirrups as provided at the ends of column shall also be provided through the beam-column joint (ref Fig 58)

- In interior beam-column joint which has beams framing into all vertical faces of it and where each beam width is at least 3/4 of the column width, stirrups may be provided at the spacing of 200 mm or d/2 whichever is less.

- Stirrups in the joint area may be provided as shown in Fig. 59.

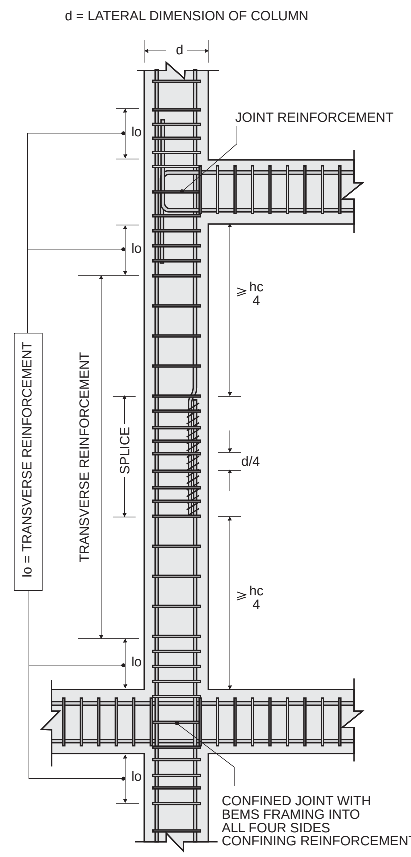


Fig. 58 : Column and joint detailing

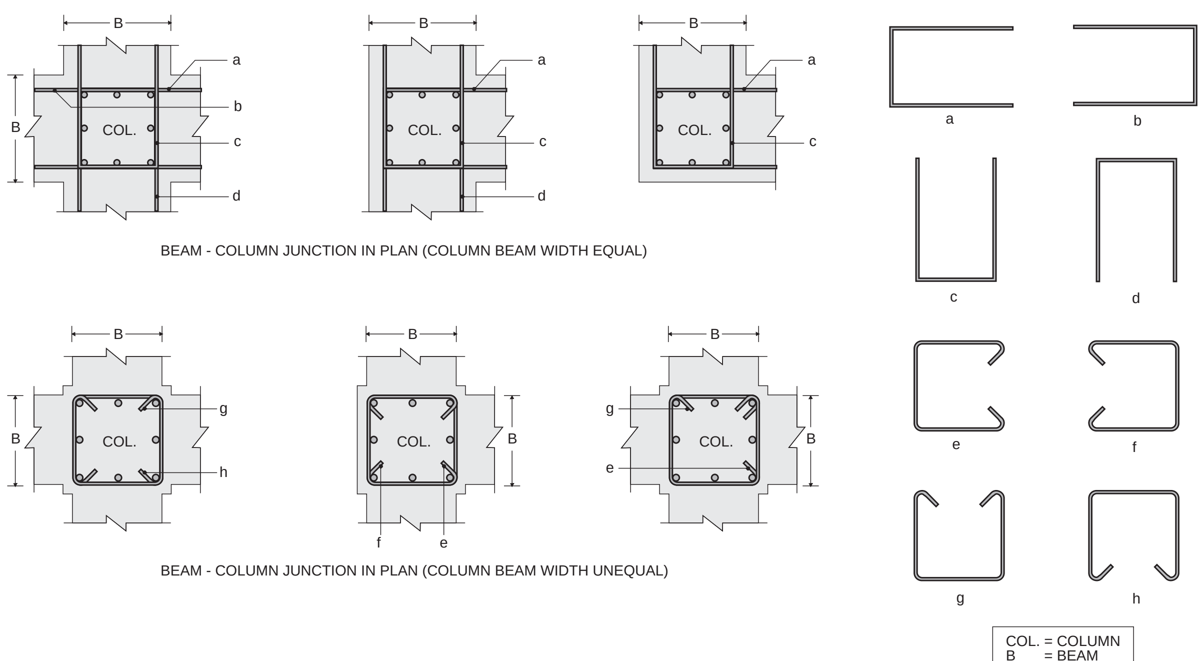


Fig. 59 : Hoop stirrups for joints in frame

11 FLOOR AND ROOF CONSTRUCTION

11.1 General

As a general rule heavy floors and roofs are a seismic hazard. Hence floors as well as roofs should be made as light as structurally and functionally possible. Masonry buildings can have pitched or flat roofs. Both are dealt with below.

The floor and roof should be able to integrate building walls or frame. At the same time it should be able to act as a rigid diaphragm in its own plane. A building with rigid floor (RC floor and roof slab) suffers much less damage compared to a buildng with flexible floor or roof (timber or steel floor and roof structure) unless strengthened for special behavior. Timber floor and roof can also be improved to act as rigid diaphragm. The following consideration should be observed during design and construction of floor and roof in addition to requirements for normal loads:-

- Each floor and flat roof should be situated in a single plane, avoiding sharp dislevelment.
- Cast in situ RC slab construction being superior to other construction systems, should be adopted.
- Light sheeted roof should preferably be used for school building. Wooden roof trusses will be better than using only rafters. Bracing and other details as discussed below should be provided.
- If thatch is used for roof covering, it will be better and safer if made fire resistant by applying mud plaster mixed with bitumen cut back on both surfaces of the thatch.
- The rigid behavior of horizontal diaphragm should not be altered by the presence of discontinuity, such as stairways. Large openings zones in rigid diaphragm should be strengthened with special reinforcement.

11.2 RC Slab

RC slab construction is good from seismic point of view as it helps to improve integrity of building. The following types of floor and roof are recommended:-

- Cast-in-place RC floors or roofs: Two–way floor or roof slab are preferred to one way.
- Floor or roof made of precast elements must be well connected to the tie-beam (seismic band) reinforcement. RC topping screed having minimum thickness of 40mm should be provided. A reinforcing mesh of 4.75mm or 6mm diameter bars at the 200 mm interval in both the orthogonal directions has to be placed at the middepth of topping as shown in Fig. 60. These bars should be well integrated with tie beam.
- Span of cantilever structural elements, such as balconies and overhangs should be limited to 1.2 m as shown in Fig. 61.

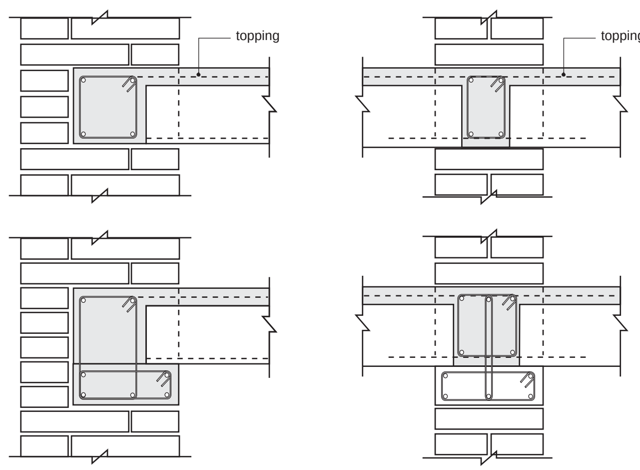


Fig. 60 : Precast slab with reinforced concrete topping

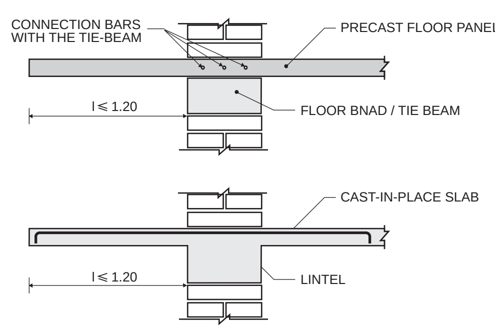


Fig. 61 : Cantilever slab

11.3 Wooden Floor and Flat roof

Timber joist have to be anchored into floor or roof bands by means of well distributed steel anchors as shown in Fig. 62 or using wedges as shown in Fig. 63.

Different members of floor or roof structures should be well tied up with each other using nails and steel straps.

Wooden floors shall be stiffened in their own plane. This can be achieved by one of the following means:-

- Two layers of planks: nailing planks perpendicular to first layer of planks as shown in Fig. 64.
- RC topping: a cast-in-place RC topping, with a minimum thickness of 40 mm shall be provided which is reinforced by 4.75 mm or 6 mm diameter bars placed at an interval of 200 mm in both directions. The reinforcement should be kept at mid height of topping as shown in Fig. 65. In such case, the ends of the reinforcement must be embedded into the RC floor or roof band.

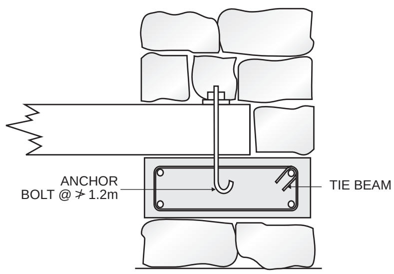


Fig. 62 : Anchorage of timber joists into RC band using anchor bars

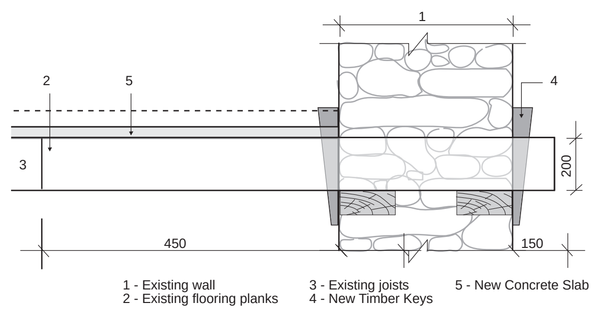


Fig. 63 : Anchorage of timber joists with wall using wedges

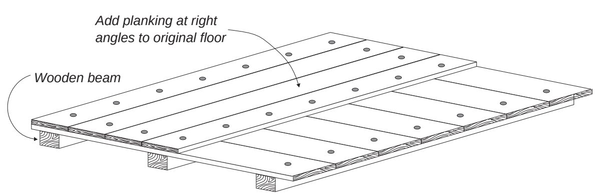


Fig. 64 : Floor stiffening using two layers of planks

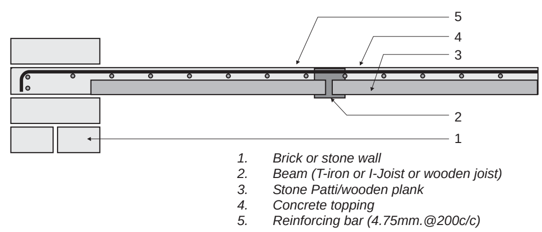


Fig. 65 : Floor stiffening using RC topping

- Bracing: floors or flat roof can be stiffened by nailing diagonal wooden or steel straps or angles from underside of joist or rafter as shown in Fig. 66.

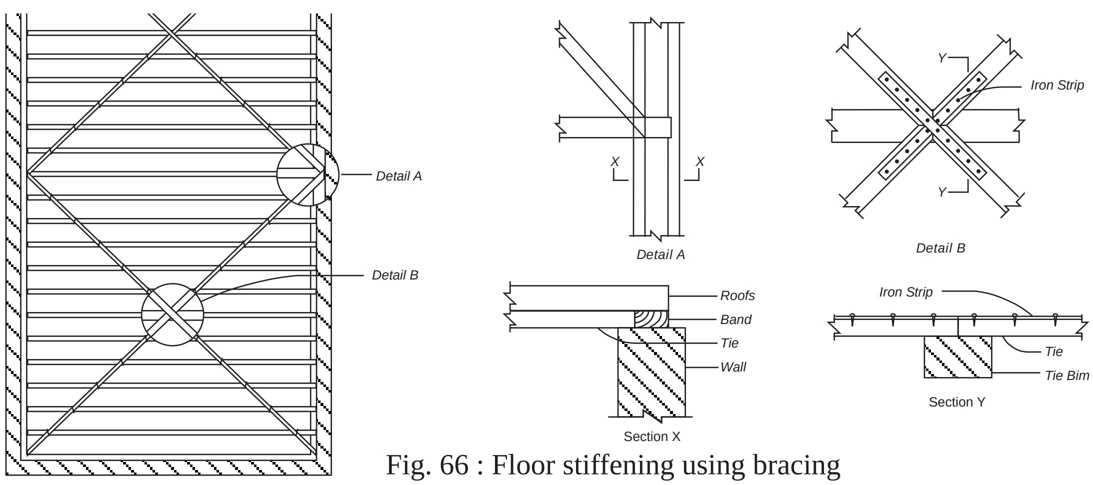


Fig. 66 : Floor stiffening using bracing

11.4 Pitched Roof

- A-type truss are prefered to portal truss (ref. Fig. 67) to eliminate thrust on wall from roof.

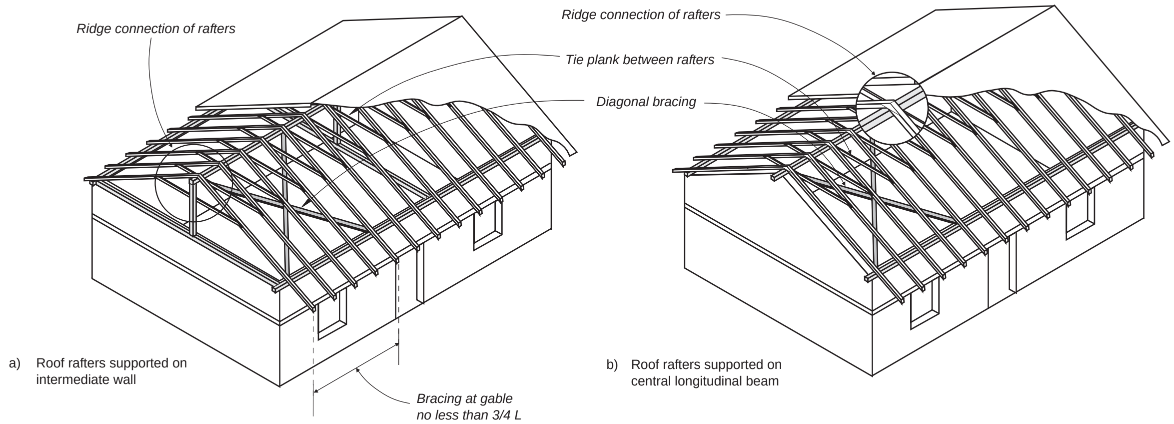


Fig. 67 : Use of A-type trusses to reduce thrust on wall

- Timber rafters or steel truss have to be anchored into roof bands by means of well distributed steel anchors as shown in Fig. 68 or using wedges as shown in Fig. 69.

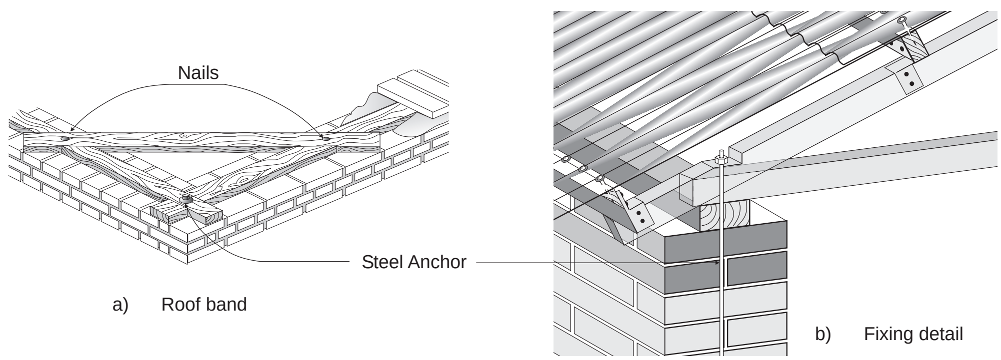


Fig. 68 : Anchorage of timber rafters into RC band using anchor bars

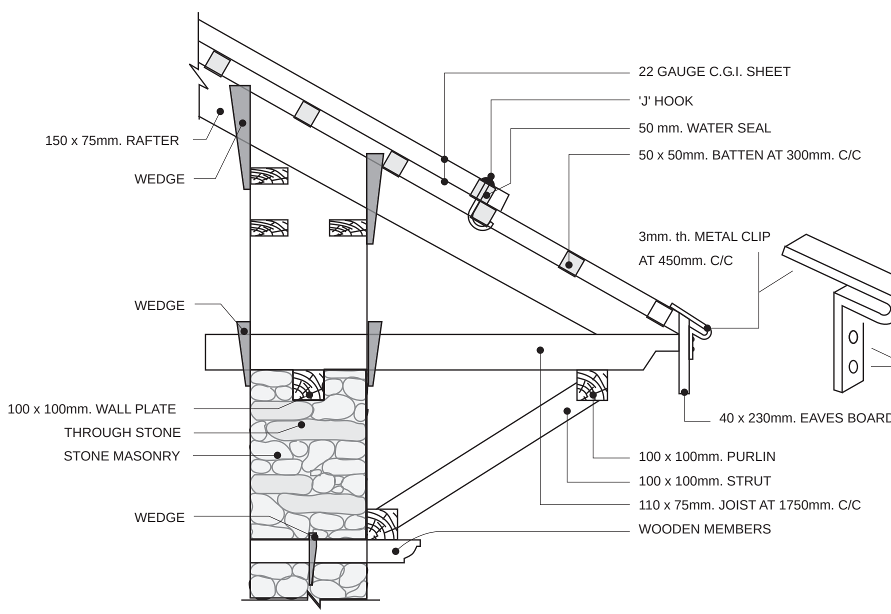


Fig. 69 : Anchorage of timber joists with wall using wedges

- Roof truss and rafter should be braced by nailing or welding wooden members or steel straps/angles in horizontal as well as sloping planes of raftes as shown in Fig. 70.

- Purlins should be well anchored into walls

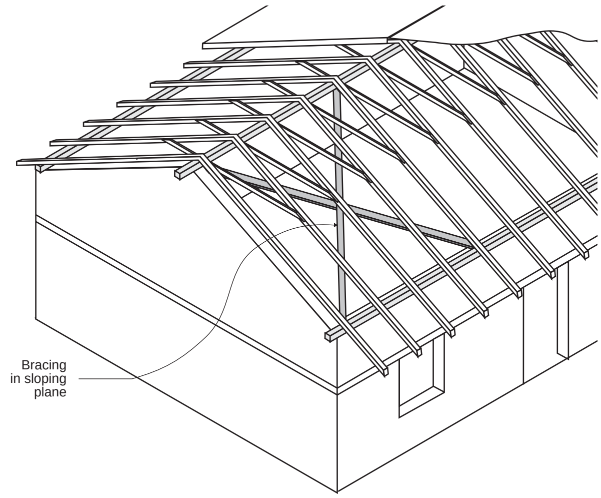


Fig. 70 : Roofing bracing

12 ASSESSMENT OF SAFETY OF MASONRY BUILDINGS

Presently there are no established methods for the assessment of safety of the non-engineered building. However some methods for safety assessment of educational facilities are discussed below. The methods are: *i) visual assessment ii) comparison with Building Code provisions iii) MSK intensity method (based on walling materials and definition of MSK intensity scale) and iv) analytical method.* The first three methods are complementary to each other and are good for preliminary safety assessment whereas the fourth method is a detailed one and requires service of an engineer.

12.1 Visual Assessment

For visually assessing the safety of a building, the following questions should be answered "YES" or "NO" after inspection of the building.

12.1.1 Configuration

- Plan of the building is simple in shape i.e. even if building is elongated its length is less than or equal to three times its width. No complicated plan shape such as “L”, “T”, “C”, “E” has been used.
- Building dimension is same in all the storeys.
- Structural walls or columns are not shifting from storey to storey, they are truly vertical.
- Door and window openings are more or less balanced in walls of opposite face.
- Location of doors and windows in the center of walls and away from corners.
- No walls are longer than 9 m if it is constructed in cement mortar, and 6 m if it is constructed in mud mortar.

12.1.2 Connections

Connections are important from integrity point of view, so must be checked.

- Orthogonal walls are connected together with timber or long stone or stitching.
- Different components of floor are connected with each other with nails and iron straps if constructed of timber.
- Floor joists are well connected with wall structure with help of wedges etc.
- Rafters are well connected with wall structure if roof structure is constructed of timber or steel.
- Floor and roof structure is braced if it is constructed of timber or steel.

12.1.3 Quality of Construction

- All masonry joints are well filled up with mortar.
- Vertical joints are all non-continuous.
- "Through" stone used in stone walls at regular intervals.

12.1.4 Building Condition

- Building cracks due to foundation settlement not observed.
- Deterioration of walling unit due to dampness not observed.
- Rotting of timber, termite attack on timber not observed.

- Excessive sagging of floor joist and rafters not oberved.
- Leakage at roof not observed (especially in mud or mud mortar based buildings as it could be the main source of the problem).
- Separation of orthogonal walls at room corners not observed.
- Tilting, bulging of the walls not observed.
- Rusting of steel bars that could impair the safety of building not observed.

If the answers to these observations are positive, the building can be considered safe provided the building also passes the requirements of safety criteria of Section 12.2. Of course, a building constructed in mud mortar will always be weaker than its counterpart constructed in cement mortar. Construction of educational buildings in mud mortar in general is not recommended.

12.2 Comparison with Safety Provisions in the Building Codes

In this method the component details, method of reinforcing etc, as actually used in the buildings, are compared with those specified in the relevant code of practice. Wherever the actual condition is found deficient, it will indicate damageability. The larger the number and magnitude of deficiencies, the higher will be the vulnerability. For example, the provisions required for two-storeyd brick-masonry building in mud mortar is presented in Table 15.1.

Table 12.1: Code Compliance

S. No.	Items	Safety Criteria	Vulnerability
1	Unit strength (fired brick = 7.5N/mm^2)	Passes	None
2	Mortar (Mud)	Fails	Damageable
3	Wall thickness (not less than 350 mm, 1/14 of wall length)	Passes	None
4	Story height (2.5 to 3.0m)	Passes	None
5	No of story =2	Passes	None
6	Openings (ratio not more than 33% in 1st story)	Passes	None
7	Horizontal band (not provided)	Fails	Damageable
8	Vertical bars (not provided)	Fails	Damageable
9	Dowel bars to stitch corners (not used)	Fails	Damageable
9	Floor (light flexible, no bracing or bandage)	Fails	Damageable
10	Roof bracing (not provided)	Fails	Damageable
11	Overall Assessment		Highly Vulnerable

Similarly, it can be checked for other building structural system and materials.

12.3 MSK Intensity Scale

In this method the maximum damageability of a building is assessed. The damageability of a building is related with the intensity of the earthquake and basic construction material. It thus considers one parameter only, namely the wall type or structural frame, but not the other parameters such as the building configuration, number of storeys, wall density, size of rooms, and quality of construction, etc. Table 15.2 presents damage ratios for buildings of different construction materials and systems.

Table 12.2: Vulnerability Assessment based on MSK intensity Scale

S. No.	Walling Material	VII	VIII	IX
A	**Earthen Walls/ Adobe with Mud Mortar**			
	A.1 2-3 stories	40	60	80
	A.2 1- 1 ½ stories	30	50	70
	A.3 A.1 type with Building Code provision	15	35	55
	A.4 A.2 type with Building Code provision	10	30	50
B	**Field Stone walls in Mud Mortar (2)**			
	B.1 Ordinary, 2 to 3 stories,	50	70	90
	B.2 Ordinary, 1 to 1 ½ stories	45	65	85
	B.3 With 'through stones', 2-3 stories	40	60	80
	B.4 With 'through stones', 1-1 ½ stories	30	50	70
	B.5 B.3 type with Building Code reinforcing	15	35	55
	B.6 B.4 type with Building Code reinforcing	10	30	50
C	**Rectangular Unit Wall in Mud Mortar**			
	C.1 Two or more stories	40	60	80
	C.2 Ordinary 1- 1 ½ stories	30	50	70
	C.3 C.1 type with Building Code reinforcing	15	35	55
	C.4 C.2 type with Building Code rein	10	30	50
D	**Cement Sand Mortar Rectangular Unit**			
	D.1 Three or more stories	20	45	65
	D.2 Ordinary 2 to 2 ½ stories	10	35	55
	D.3 D.1 type with Building Code reinforcing	10	25	45
	D.4 D.2 type with Building Code reinforcing	5	15	35

(1) Loss >70%: destruction to total Collapse, Loss=40-70%: severe damage, Loss <40% minor damage.

(2) Field stone includes boulders, angular and semi-dressed stones. Where round boulders are used, vulnerability will be still higher.

(3) As a general recommendation vulnerability index of 70 or more will require reconstruction, 60–70 may require reconstruction if construction quality and existing condition is poor, otherwise may be repaired & strengthened. However, engineer may take the decision regarding a specific building after inspection.

[Source: Seismic Vulnerability of the Public School buildings of Kathmandu Valley and Methods for reducing it].

12.4 Analytical Method

This method is used for detailed analysis of strength of the building. This method uses the complete load-deflection characteristics of the buildings either employing the intensity-compliant seismic coefficient analysis, or dynamic modal time-history analysis using the peak ground acceleration with response spectra or waveform. This method works well for the engineered buildings and detailed analysis.

13 RETROFITTING OF MASONRY BUILDING

Retrofitting of existing school buildings to improve their seismic resistance seems the most feasible solutions for their protection.

Retrofitting an existing building to improve its seismic resistance involves four main issues. First is the engineering method employed, it includes technical problem of code requirements, design approach, materials and construction techniques. Second is the cost of the project, such as cost of construction, design and testing, and the cost of permits and approvals. Third is the indirect cost of retrofitting such as relocation cost. Fourth is the question of the effectiveness of the retrofitting in reducing the likely damage.

13.1 Philosophy and Approach

The philosophy adopted for retrofitting the school buildings is to i*) achieve fail-safe damage: delayed collapse allowing pupils to escape during an earthquake*, and *ii) achieve reduction in the likely damage allowing post-earthquake repair and re-strengthening at nominal costs*. Retrofitting schemes are generally considered acceptable for those building for which the retrofitting cost does not go beyond 25% of the present value of the building, and which will have, after retrofitting, an economic loss of less than 60% under an earthquake shaking equivalent to MSK intensity IX. Following additional requirements are also considered:-

- Compatibility of the solution with the functional requirements of the structure
- Feasibility of the construction, including availability of materials, construction equipment and personnel
- Sociological consideration
- Aesthetic

13.2 Lessons Learnt from Past Earthquakes

13.2.1 Masonry Buildings

The following appear to be the major problems faced during earthquake shaking in the different types of school buildings and their component elements:-

- Non-integrity of wall, floor and roof and their units
- Out of plane collapse of upper parts of the wall of the flexible roof buildings due to lack of anchoring elements.
- Separation of orthogonal walls at “L” and “T” junctions
- Buildings with rigid floor and roof (RC/RBC floor, roof) suffer diagonal cracking of piers in lower story.
- Delamination of wythes in rubble masonry walls buildings
- Dislocation of stone units from wall (mechanism failure) due to their irregular shape
- Collapse of gable wall as it behaves as free cantilever.

13.3 General Retrofitting Techniques

Commonly, seismic retrofitting should aim at one or more of the following objectives:-

- Eliminating features that are source of weakness or that produce concentrations of stresses in some members, abrupt change of stiffness from floor to floor, concentration of large masses, large opening in walls without proper peripheral reinforcement

- Increasing the lateral strength in one or both directions, by reinforcing or by increasing wall plan areas or the number of walls
- Giving unity to the structure by providing a proper connection between its resisting elements, in such a way that inertia forces generated by the vibration of the building can be transmitted to the members that have ability to resist them. Typical important aspects are the connection between components of floors and roof, between roof or floors and walls, between intersecting walls, walls and foundation.
- Avoiding the possibility of brittle mode of failure by proper reinforcement and connection of resisting members.

13.3.1 Configuration Improvement

13.3.1.1 Modification of Plan

Majority of school buildings have simple design, most of them are rectangular with length to width ratio less than three. The next preferred shapes are elongated rectangle or L-shape. Other shapes also exist. The design of the buildings can be improved by separating wings and/or dividing it in parts as shown in Fig. 19.

To balance the stiffness of the building design, some existing openings may require elimination, reduction in size or even construction of new openings. Similarly, as in new building construction, there should be limitation on openings. Total openings in a building shall not exceed that specified in section 8.3.1 or 9.5.3 as case may be.

13.3.1.2 Elevation Improvement

School building in general is simple in construction though there remains some problem of stiffness distribution in vertical direction. As the construction process has beem incremental, upper storey could have less covered area than lower one making building look like terrace that may lead to rotational effects. The problem can be solved, through not necessary, either by demolition of upper part or construction of the uncovered areas.

13.3.2 Floor or Flat Roof Improvement

Where the roof or floor consists of wooden poles or joists carrying brick, tiles and earth, their integration is necessary. Simultaneously, floor structure should be stiffened in horizontal plane as well. Some of the methods of improvements are listed below:

13.3.2.1 Insertion of a New Slab

Seismic behavior of a masonry building can be improved by replacing an existing timber floor with a rigid slab inserted into existing wall. The slab has to be properly connected to the walls through appropriate keys. Fig 71 shows typical arrangements to be adopted while in Fig 72 details are shown.

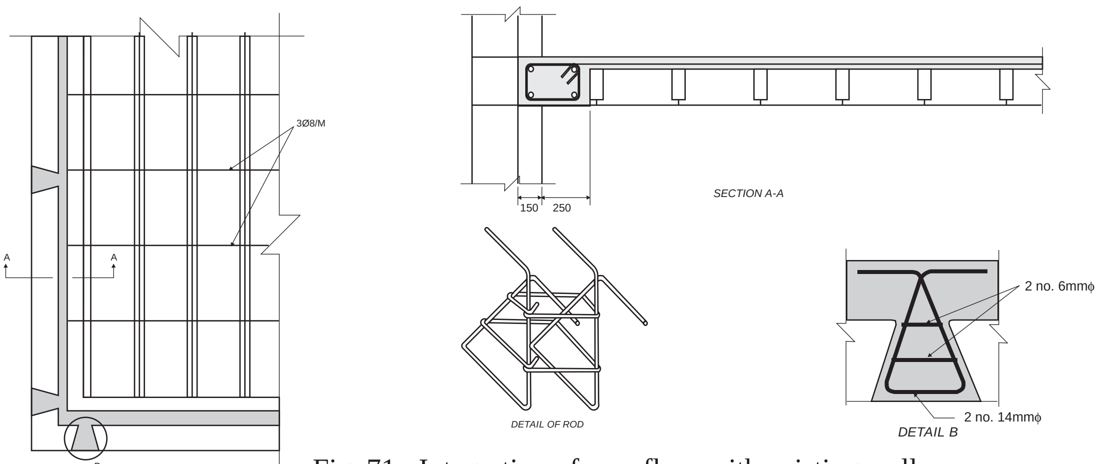


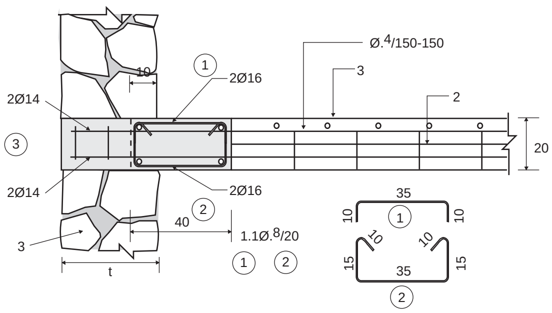
Fig. 71 : Integration of new floor with existing wall

13.3.2.2 *Existing Wooden Floor or Flat Roof*

If the existing wooden floor or flat roof is not replaced by new RC slab, the following actions have to be undertaken to improve behavior of floor structure:

Nailing/ Strapping

The different components of timber floor or flat roof should be well integrated using nails, steel straps to make them one unit.



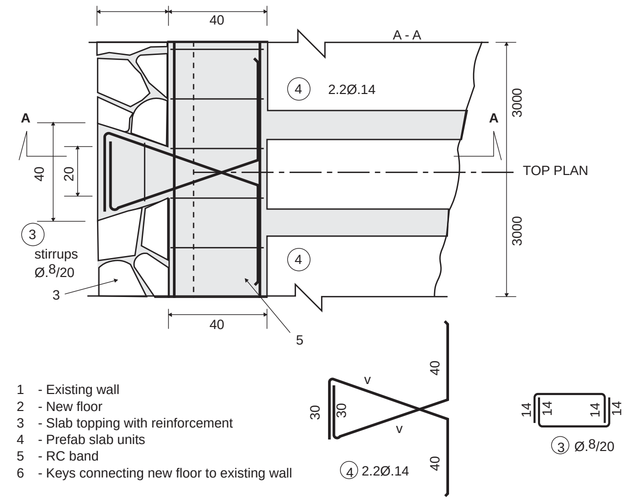


Fig. 72 : Details of inserted slab

Seismic Band

Either insert a timber belt just below the floor or flat roof or construct a RC seismic bandage on the wall faces just below the floor or roof and anchor the floor or roof structure with the belt.

Stiffening the floor structure

This can be achieved either by:

- Nailing a layer of new planks: New layer of plank could be nailed perpendicularly or diagonally to the existing structure (ref. Fig. 73) or

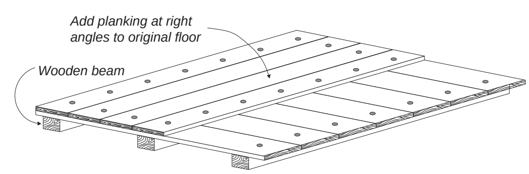


Fig. 73 : Stiffening of wooden floor by wooden planks

- Placing a thin RC slab topping over the existing floor: RC cast-in-place topping, with a minimum thickness of 40 mm must be provided which is reinforced by 4.75mm diameter bars placed at 200 mm intervals in both the directions (ref. Fig. 74) or

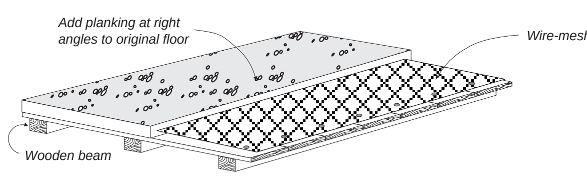


Fig. 74 : Stiffening of wooden floor by RC topping

- Alternatively a steel wire mesh is nailed to existing wooden floor, topped with concrete and connected to the walls by a number of distributed steel anchor. These can be hammered into the wall and a local hand cement grout has to be applied for sealing (ref. Fig. 75)

- Bracing the wooden floor structure: Floor structure can be stiffened by nailing wooden planks or steel straps in the under side of the floor structure and anchoring these new members with wall structure (ref. Fig. 66).

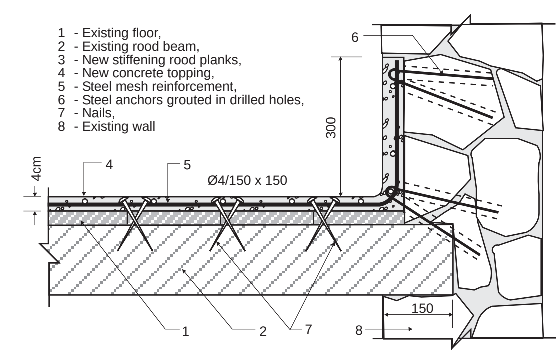


Fig. 75 : Stiffening the existing floor/flat roof by bracing

Connection of the existing floor structure with the walls

If the existing floor structure is not well integrated with wall structure, a proper connection can be achieved by means of devices as shown in Fig. 76a and b.

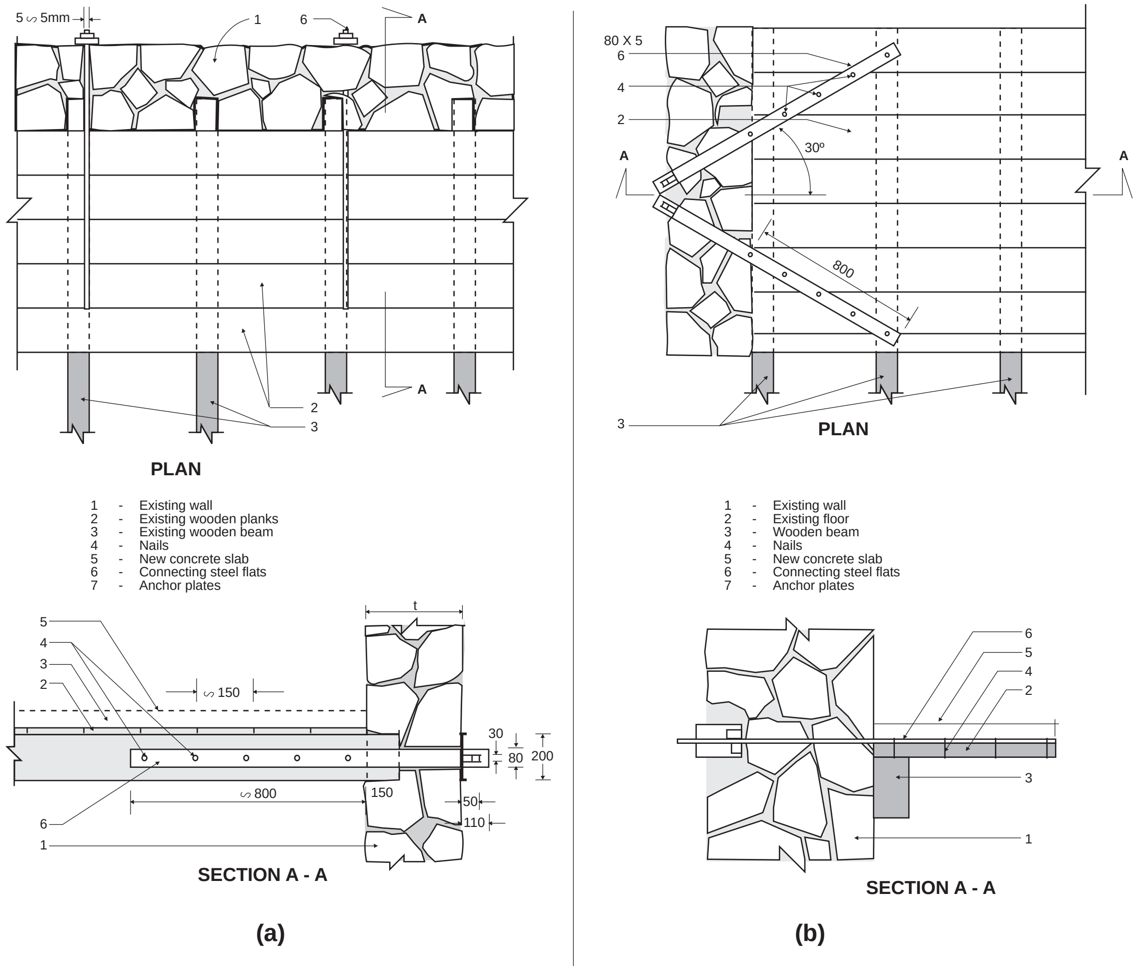


Fig. 76 : Connection of floor with wall (a-b)

It consists of flat steel bars nailed to the wooden supporting beams and to the wooden floor. Holes drilled in the walls to anchore them have to be filled with cement-sand grout. If a steel mesh has been used, the connection can be made as shown in Fig. 72 i.e. inserting a small RC band into the existing walls, the band has to be keyed at least 3m each way.

13.3.2.3 Roof Improvement

Integrity between different elements of timber roof structure, lack of anchorage between roof rafters and wall, and lack of diaphragm action are general problems with timber floor. Following are the identified problems and some remedial measures :-

- Slates and roofing tiles are brittle and easily dislodged. Where possible, they should be replaced with corrugated sheet or asbestos sheet.
- False ceiling of brittle material is dangerous. Non-brittle materials, such as hessian cloth, bamboo matting or light ones of foam substance, could be used.
- Different components of timber roof should be well integrated using nails, steel straps.

- Roof truss frames should be braced by welding or clamping suitable diagonal bracing members in sloping as well as in horizontal plane (ref. Fig. 77).

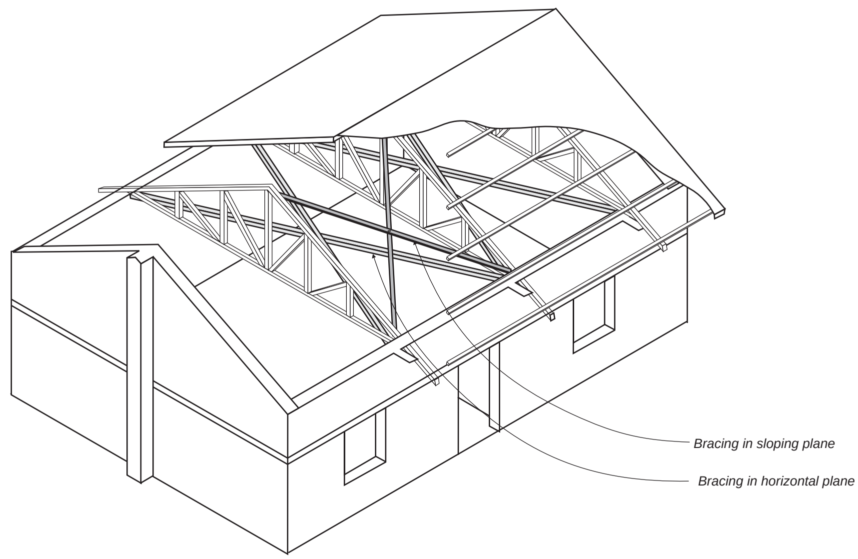


Fig. 77 : Roof bracing

- Anchorage of roof trusses to supporting walls should be improved. A roof level band of RC or timber should be constructed on top of existing wall and the rafters be well anchored into the band with help of rebars, long nails.

- The roof thrust on walls should be eliminated. Fig. 67 illustrates a method in which the rafters are connected with each other at the ridge and horizontal planks are added to take horizontal tension. Where longitudinal wall goes up to the ridge level, the wall top should be dismantled in parts starting from one end, the horizontal plank fixed into position and then rebuilt.

13.3.2.4 Improving Earthquake Resistance of Wall Structure

Earthquake resistance of a masonry building can be improved by increasing the strength and stiffness, reducing the length of existing walls, addition of new walls, reducing the existing opening, changing the location of opening and in some cases even constructing new opening if the openings in opposite face are unbalanced. The measures are discussed below.

Internal cross wall

Long barrack type halls may be subdivided by building cross walls at intermediate points to enhance their stability. The wall should be at least 200 mm thick and should be properly bonded with existing walls by keying masonry units into them and stitching old and new walls. Appropriate foundation must be provided for the new walls. Door and window openings and lintel bands may be introduced into new walls bonded with the external walls by passing bars through and grouting them (ref. Fig. 78).

Buttressing

Where subdivision of the space by internal cross walls is not acceptable due to functional or other reasons (for breaking the longitudinal walls of long barrack type buildings), masonry buttress may be added externally as shown in Fig. 79 or RC column may be introduced into walls as shown in Fig. 80 if wall length is more than as specified in Section 8.

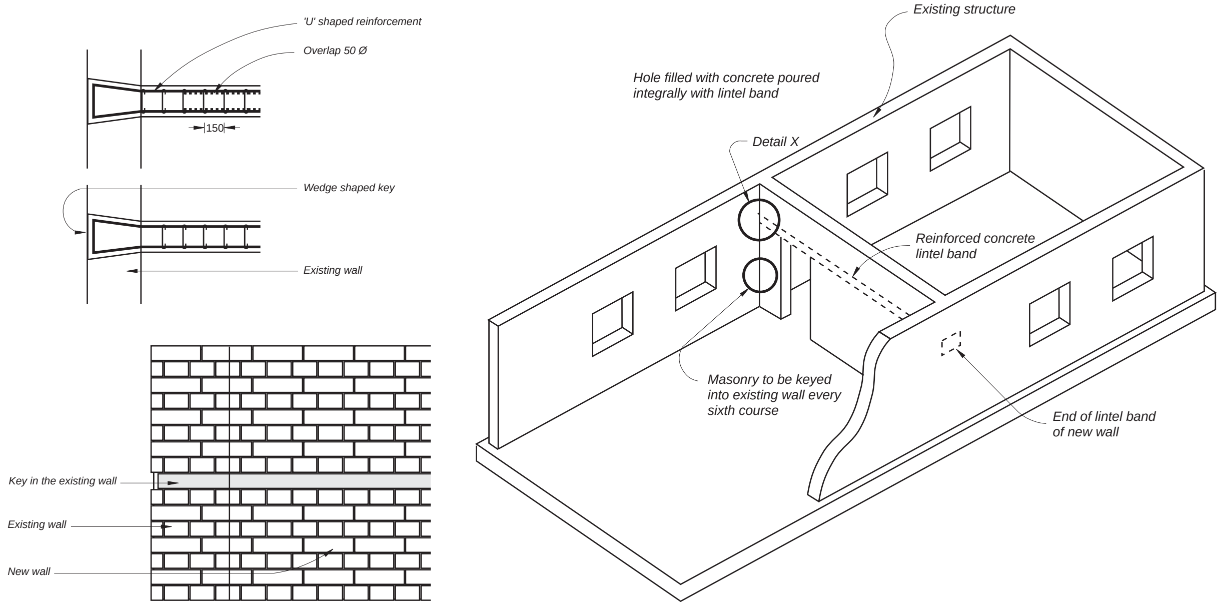


Fig. 78 : Inserting internal cross wall

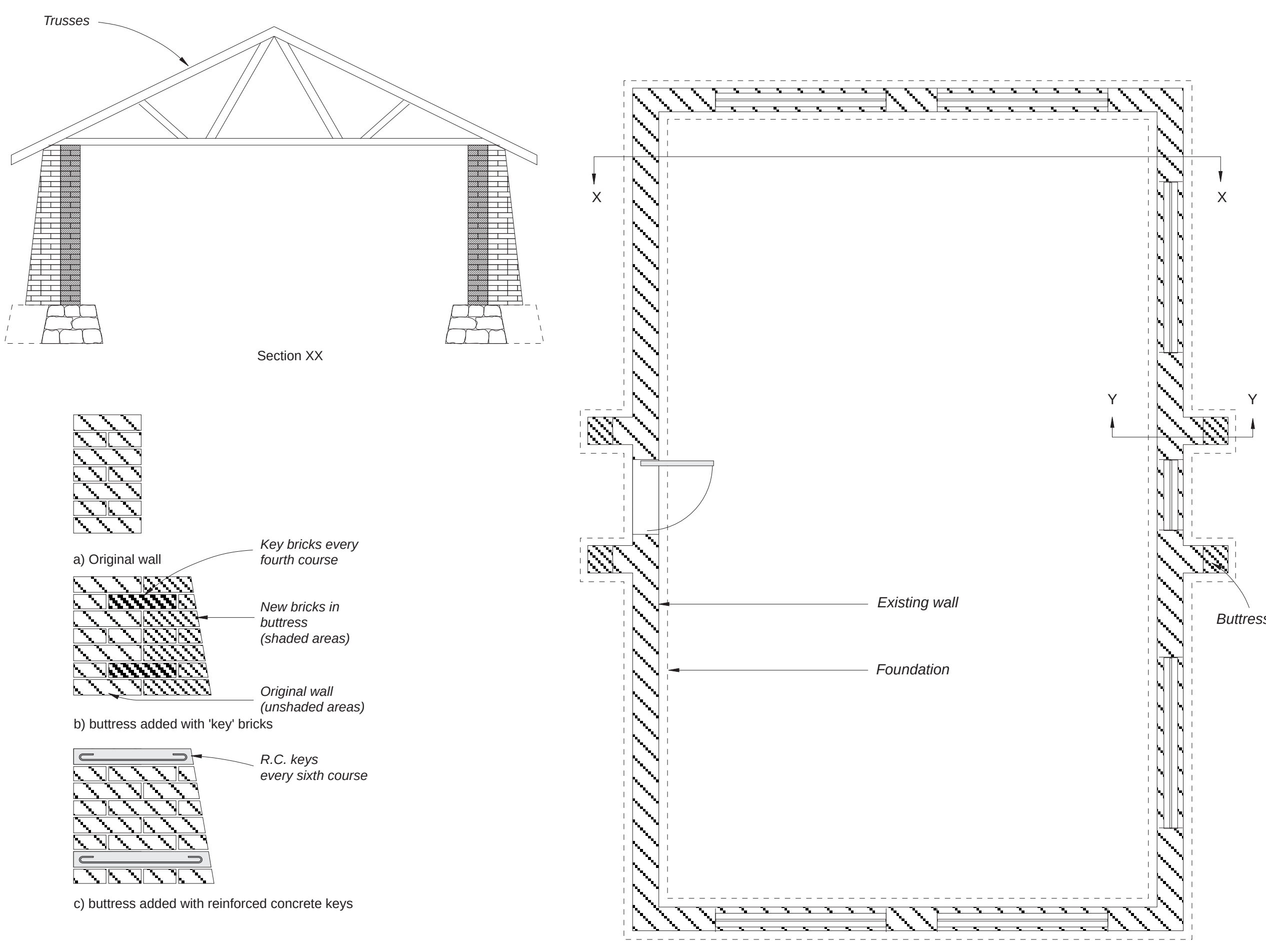


Fig. 79 : Strengthening existing wall with buttressing

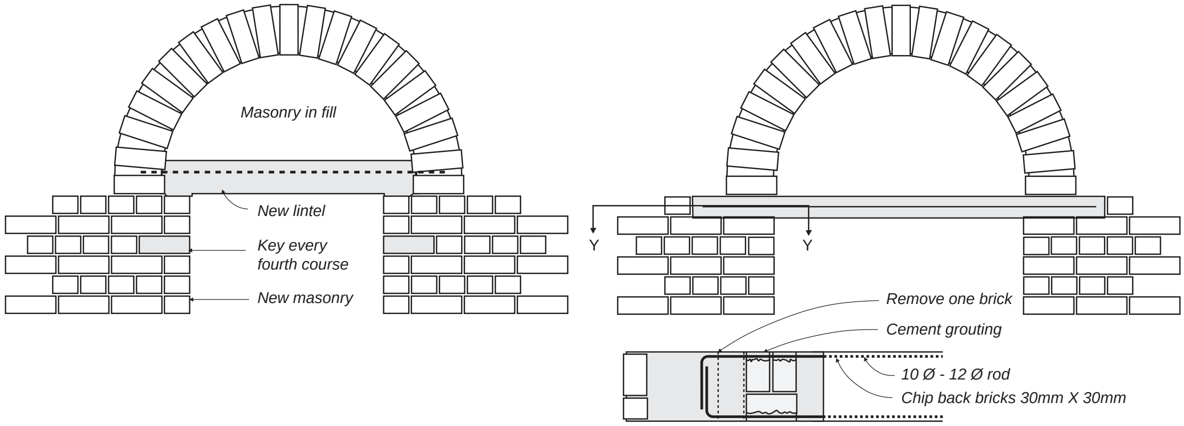


Fig. 80 : Strengthening existing wall with insertion of RC column

Stitching the walls

The weak connection between transverse walls at corners, T-junctions can be improved by stitching these walls with reinforced concrete or inserting timber pieces. It can be done by opening the wall in parts and introducing RC stitch if wall is constructed in mud mortar as shown in Fig. 81. Alternatevely the stitching can be done by drilling walls first, filling the drill hole with cement grout and forcefully inserting steel bar. It should be provided at the spacing of 500-700 mm.

Fig. 81 : Stitching of transverse walls

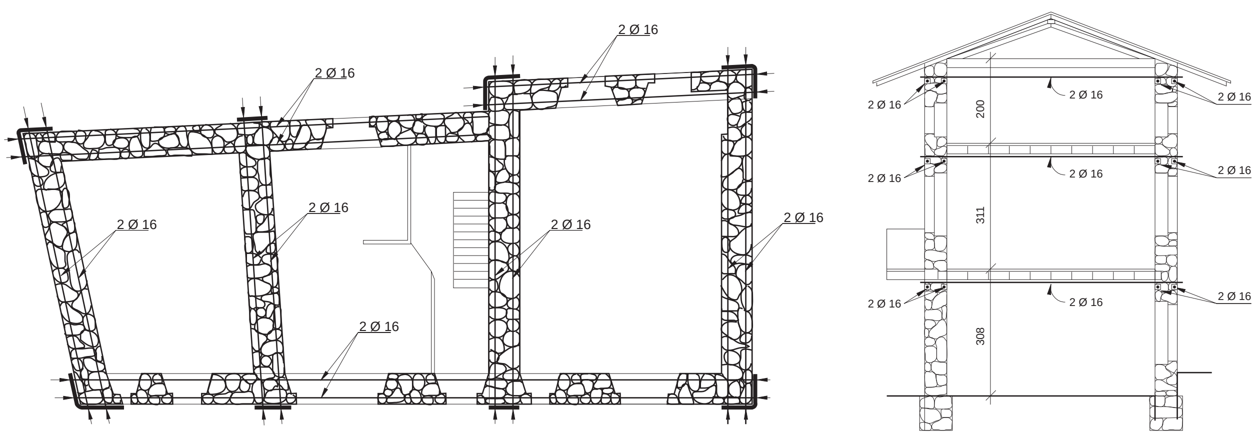


Fig. 82 : Strengthening walls by prestressing

Prestressing

A horizontal compression state induced by horizontal tendons can be used to increase the shear strength of walls. Moreover this will also improve considerably the connection of orthogonal walls (ref. Fig. 82). The easiest way of affecting the precompression is to place two steel rods on the two sides of the wall and tightened. In general two number 16mm diameter bars meet the requirement. Further more, good effects can be obtained by slight horizontal prestressing (about 0.1 MPa) on the vertical section of the wall. Prestressing is also useful to strengthen spandrel beam between two rows of openings in case no rigid slab exists.

Jacketing of walls

Steel mesh (welded wire fabric with mesh size approximately 150 x 150mm) is placed on both the sides of the walls, and interconnected by passing steel (each 500 to 750 mm apart), through the wall or held to the wall by driving spikes (ref. Fig. 83). A 40mm thick cement mortar or micro-concrete layers is then applied on the both faces of the wall thus giving rise to two interconnected vertical plates. These plates basically "basket" the wall, hence improve its shear strength, ductility. This system also improves the connection between transverse walls.

Splint and Bandage

This system is basically extension of "jacketing of wall". In this system the mesh is provided in only critical zones to cut the cost. Splints and bandage are vertical and horizontal belts respectively to tie up walls together as shown in Fig 84. The bandage is provided in the both faces of the wall and interconnected by passing steel (750-900 mm apart). A 40-50mm thick cement mortar or micro-concrete layers is then applied on the steel mesh thus giving rise to a horizontal beam. The main function of bandage is to hold horizontally the various walls together at corners and across the building and thereby prevent out of plane collapse of walls.

Splints are vertical elements, provided at corners, wall junctions, and jambs of openings in external face of the building so as to provide integrity in vertical direction.

Reinforced Concrete Column and Beams technique

In this scheme, RC columns are added at ends of cross and longitudinal walls and horizontal RC beams are added monolithic to the added columns. The beams run all around outside the building just below the ceiling level of roof and floor. Cross ties are used to connect opposite columns. Fig. 85 presents a general view of strengthening by RC column and beam technique.

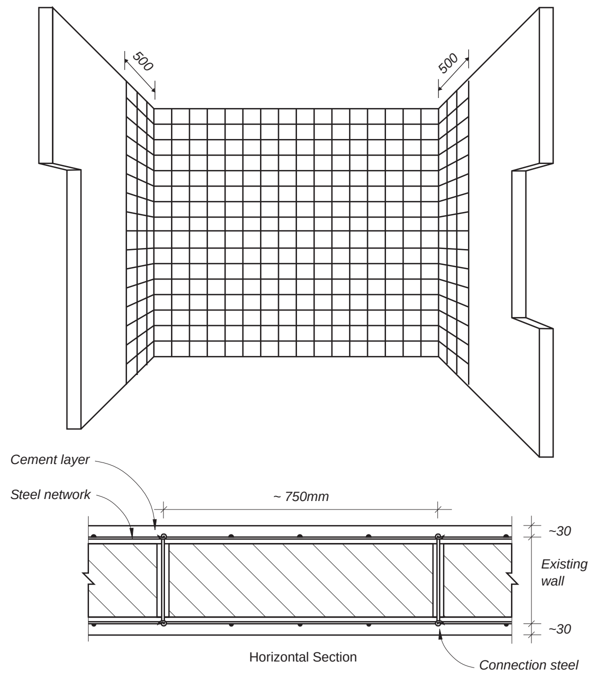


Fig. 83 : Jacketing of walls

Fig. 84 : Splint and bandage strengthening technique

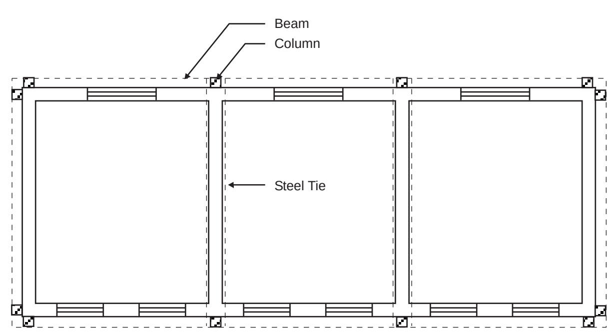


Fig. 85 : Column and beam strengthening technique

Stitching of Wythes

In stone walls constructed without "through" stones, these can be substituted with reinforcement and cement concrete. These can be installed by removing stones from the walls thereby making holes (75mm size) in them. Then an 8mm-diameter bar can be placed in the hole filled with 1:2:4 mix concrete. The steps are shown in Fig 86.

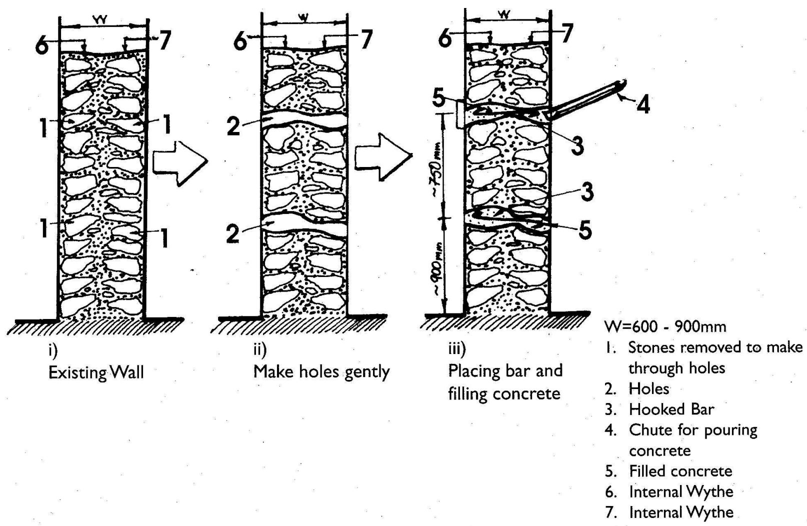


Fig. 86 : Stitching the wyths

Summary of retrofitting work for masonry buildings is presented in table 13.1.

Table 13.1: Selection of Retrofitting Methods for Masonry building

Typical Deficiency	Improvement	Building Type				
Configuration of Problem		Stone building in mud mortar	Brick Building in mud mortar	Stone building in cement mortar	Hollow concrete block in cement mortar	Brick building in cement mortar
Plan shape: L, T, C, E, H, elongated rectangle	Separating different wings and making them rectangular with L<=3b	Y	Y	Y	Y	Y
Vertically irregularity	Making elevation more uniform, symmetrical	Y	Y	Y	Y	Y
Undefined load path (i.e. shifting of walls in upper storey)	Re-plan the working space and rearrange the structural walls without jeopardizing stability of floor/ roof structure	Y	Y	Y	Y	Y
Unsymmetrical opening	Reschedule openings and arrange as required, balance the stiffness distribution	Y	Y	Y	Y	Y
Large and more number of opening	Reduce the size and number of openings, fill the void with new wall anchoring it to existing wall	Y	Y	Y	Y	Y
Weak/ no connection at wall junction	Stitch the junctions	Y	Y	Y	Y	Y
Free Gable wall (wall behaving free cantilever)	Provide gable band and tie the gable wall with roof structure	Y	Y	Y	Y	Y
Long unsupported wall	Repartition the existing space or provide piers at intermediate locations	Y	Y	Y	Y	Y
Delamination	Stitching wythes with through stone, steel bars etc.	Y	-	-	-	-

Typical Deficiency	Improvement	Building Type				
Configuration of Problem		Stone building in mud mortar	Brick Building in mud mortar	Stone building in cement mortar	Hollow concrete block in cement mortar	Brick building in cement mortar
and walls (in timber floor and roof structure)	Tie up different elements of floor/ roof with straps or nails and tie them up with walls with dowel bars/ straps	Y	Y	Y	Y	Y
Lack or tensile vertical reinforcement in wall	Provide splint on outer face or provide columns	Y	Y	Y	Y	Y
Wall susceptible to out-of-plane failure	Provide bandage	Y	Y	Y	Y	Y
Lack of diaphragm effect if flexible/ semi-flexible floor or flat roof	Provide a thin RC topping over the existing flexible floor structure or provide bracing. Anchor the topping or bracing with the walls	Y	Y	Y	Y	Y
Lack of diaphragm effect if flexible roof	Provide bracing at rafter level and anchor the bracing with wall	Y	Y	Y	Y	Y
Heavy flexible floor and roof	Reducing the weight by removing unnecessary materials, changing materials and stiffening floor/ roof	Y	Y	Y	Y	Y
Unanchored parapet wall	Anchoring parapet walls	Y	Y	Y	Y	Y

Y: Required

13.4 Associated Problems

Retrofitting an existing building is a cumbersome task because of associated complications that may pose serious problems during retrofitting. Some of these could be:

- The buildings in the core area are so congested that there remains very little working space for implementing the retrofitting works.
- Courtyard with buildings all around may pose severe configuration problems.
- As the buildings are constructed over long periods of time, a sudden change in the walling, flooring and roofing materials is common in very small space. This fact generally cannot be visualized/verified until the walls are opened. There remains very high possibility of overlooking them.
- Such "surprises" during the implementation of the retrofit works will necessitate changes in the retrofitting design leading to time and cost overruns. This factor should be well considered before the commencement of retrofit works.
- The possibility of future vertical expansion should always be considered especially in core areas, prior to designing the retrofit works.
- Shifting of structural walls in upper stories is common (load path not defined) and it would be difficult to clearly define the load path because of space requirements.
- As the quality control measures are non-existent, there remains no assurance of quality of used material and the detailing. Shifting of columns, beams, cosmetic filling of honeycombing, non-existence of mortar between bricks are the common problems to be considered in the design of retrofit works.
- Frequently a part of timber floor and roof are rotten, insect eaten, sagging excessively needing replacement. It could pose some extra cost.
- In old buildings, use of damp proof course is non existent leading to decay of bricks up to first 1-1.2m from ground level. These bricks may need replacement.

References

1. Arya, A. S.; 1997, *Guidelines for Damage Assessment and Post Earthquake Action* (Part I: Brick House with Clay Tile Roofing, Part II: Brick House with RC Slab or Stone Patti Roofing or CGI Roofing or with RC Roof), Building Materials and Technology Promotion Council (BMTPC), Ministry of Urban Development, Govt. of India, New Delhi, India.

2. Arya, A. S.; *Retrofitting of Stone Houses in Marathwada Area of Maharastra (First Case: Stone Houses with complete wooden frame inside)*, Building Materials and Technology Promotion Council (BMTPC), Ministry of Urban Development, Govt. of India, New Delhi, India.

3. Arya, A. S. et al; 1986, *Guidelines for Earthquake Resistant Non-engineered Construction*, International Association for Earthquake Engineering.

4. Arya, A. S.; 1987; Protection of Educational Buildings against Earthquakes, Educational Building Report #13, UNESCO Principal Regional Office for ASIA and the Pacific, Bangkok, Thailand.

5. Building Construction Under Seismic conditions in Balkan Region, 1983, *Vol. 1: Design and construction of seismic resistant reinforced concrete and shear-wall buildings, Vol. 3: Design and construction of Stone and brick-masonry buildings, Vol. 5: Repair and Strengthening of Reinforced Concrete, Stone, Brick-masonry Buildings*, UNDP/ UNIDO/RER 79/015, Vienna.

6. Chitrakar, G. R., Pandey, Mr. R.; 1986, *Historical Earthquakes of Nepal*, Nepal Geological Society News Bulletin, V. 4, No. 1.

7. Coburn, A., Spencer, R.; *Earthquake Protection*, John Wiley & Sons,

8. IS 1893-1984, *Criteria for Earthquake Resistant Design of Buildings and Structures*, Bureau of Indian Standards, New Delhi, India.

9. IS 4326-1993, *Earthquake resistant Design and Construction of Buildings-Code of Practice*, Bureau of Indian Standards, New Delhi, India.

10. NBC 105-1994, *Seismic Design Of Buildings In Nepal*, His Majesty's Govt. of Nepal, Ministry of Housing and Physical Planning, Department of Buildings, Nepal, 1995.

11. NBC 109-1994, *Unreinforced Masonry*, His Majesty's Govt. of Nepal, Ministry of Housing and Physical Planning, Department of Buildings, Nepal, 1995.

12. NBC 203-1994, *Guidelines for Earthquake Resistant Building Construction: Low Strength Masonry*, His Majesty's Govt. of Nepal, Ministry of Housing and Physical Planning, Department of Buildings, Nepal, 1995.

13. NBC 204-1994, *Guidelines for Earthquake Resistant Building Construction: Earthen Buildings*, His Majesty's Govt. of Nepal, Ministry of Housing and Physical Planning, Department of Buildings, Nepal, 1995.

14. NSET-Nepal, GHI-USA; 1999, *Earthquake Scenario of Kathmandu Valley*, NSET-Nepal, Kathmandu, Nepal.

15. NSET-Nepal, 2000, Seismic Vulnerability of The Public School buildings of Kathmandu Valley and Methods for Reducing it, NSET-Nepal, Kathmandu, Nepal. (An in-house report on the School Earthquake Safety Program, implemented under KVERMP in 1997-2000)

16. NSET-Nepal, University of Roorkee; 2000, *Reconnaissance Report: Chamoli Earthquake of 29th March 1999, India*.

17. ATC; 1996, *Seismic Evaluation and Retrofit of Concrete Buildings*, ATC-40 (Vol. 1and 2), Report No. SSC96-01, Seismic Safety Commission, State of California, USA.

18. Federal Emergency Management Agency, (FEMA 274), NEHRP Guidelines For The Seismic Rehabilitation Of Buildings, Building Seismic Safety Council, Washington D. C., 1988.

19. Federal Emergency Management Agency, (FEMA 274), *NEHRP Commentary On the Guidelines For The Seismic Rehabilitation Of Buildings*, Building Seismic Safety Council, Washington D. C., 1988.

20. Federal Emergency Management Agency, Earthquake Hazard Reduction Series 41 (FEMA 154), Rapid Visual Screening Of Buildings For Potential Seismic Hazard: A Handbook, Building Seismic Safety Council, Washington D. C., 1988.

21. Federal Emergency Management Agency, Earthquake Hazard Reduction Series 42 (FEMA 155), Rapid Visual Screening Buildings For Potential Seismic Hazard: Supporting Document, Building Seismic Safety Council, Washington D. C., 1988.

22. Federal Emergency Management Agency, Earthquake Hazard Reduction Series 47 (FEMA 178), NEHRP Handbook for the Seismic Evaluation Of Existing Buildings, Building Seismic Safety Council, Washington D. C., 1992.

23. IS 13920:1993, Ductile Detailing of Reinforced concrete structures subjected to seismic forces-code of practice, Burean of Indian Standards, N. Delhi, India.

24. NBC 300:1994, Illustrative Design Guidelines for Reinforced concrete Bare Ductile Framed Building, H.S Majesty's Government of Nepal. Ministry of Housing and Plysical Planning, Department of Buildings, Nepal 1998.

25. NBC 106: 1994, Site consideration, His Majesty's Government of Nepal, Ministry of Housing and Physical Planning, Department of Buildings, 1998.

26. Earthquake Resistant Construction and Seismic Strengthening, Government of India, Maharastra Emergency Rehabilitation Program, Revenue and Forest Department, Mumbai, India.