Manual for EQ Safe Building Construction

CSEB Green Buildings in Nepal

July 2012

Government of Nepal
Ministry of Education
Department of Education

actionaid
Actionaid International Nepal

CORD
Center of Resilient Development

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This manual is developed by

Centre of Resilience Development
(CoRD)

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PREFACE

Earthquake is a continuous natural phenomenon of sudden and violent motion of earth caused by volcanic eruption, plate tectonics or man-made explosions that has been changing the earth profile. The magnitude of an earthquake is measured as the amount of energy released at the source, the focal area. An earthquake of magnitude 3 is the smallest normally felt by human beings while the largest recorded under this system are from 8.8 to 8.9 in Magnitude in the Richter scale. The intensity is a measure of how severe the earthquake shaking was at any location, which differs from place to place, and measured most commonly in Modified Mercalli Scale (MMI).

Earthquakes may occur almost everywhere in the world. But certain areas of the world are very susceptible to earthquakes. One of them is Nepal, which ranks 23rd in the world in terms of total natural hazard related deaths which is above 7,000 on the decades from 1988 to 2007 through many devastating earthquake reoccurring every 75-100 years' span.

The primary effect of an earthquake is shaking of a building or infrastructure and this is when the saying "earthquake doesn't kill people, but the buildings do!" comes true. It has different effect on different types of buildings and its parts. i) Structural layout, ii) Quality of materials and construction practices and iii)Lack of earthquake resistance features are the most common reasons for the failure of the building during the shake. The defects usually seen are Lack of structural integrity, roof collapse, out-of-plane wall collapse, in-plane shear cracking, poor quality of construction, foundation problem. This however proves that with appropriate planning, design and technology, the effect can be reduced and lives saved.

Hence various seismic consideration starts from the very first step of soil condition to choice of t he site to the building details like shape, proportion, material, openings, structural elements and many more. Eventually it is possible to build an earthquake resistant building with few alterations and innovative approaches in the conventional building form.

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CHAPTER- I

EARTHQAKE AND STRUCTURE

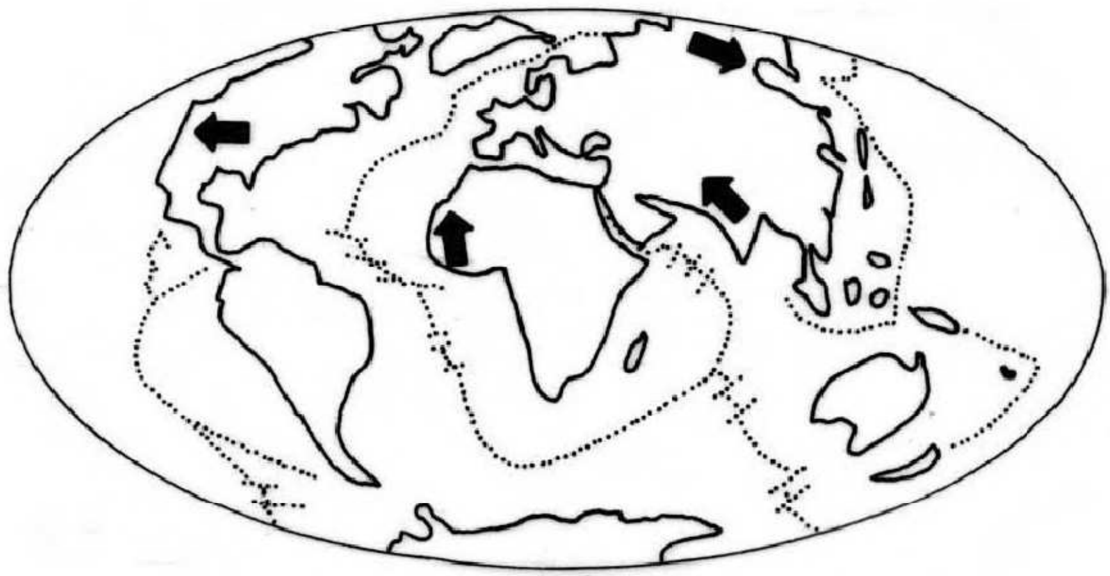


Figure 1 Earthquake structure

1.1 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.

1.2 Origin of Earthquakes

The earth was a single land about two hundred million years ago. This land split progressively over a long period of time and it gave tectonic plates.

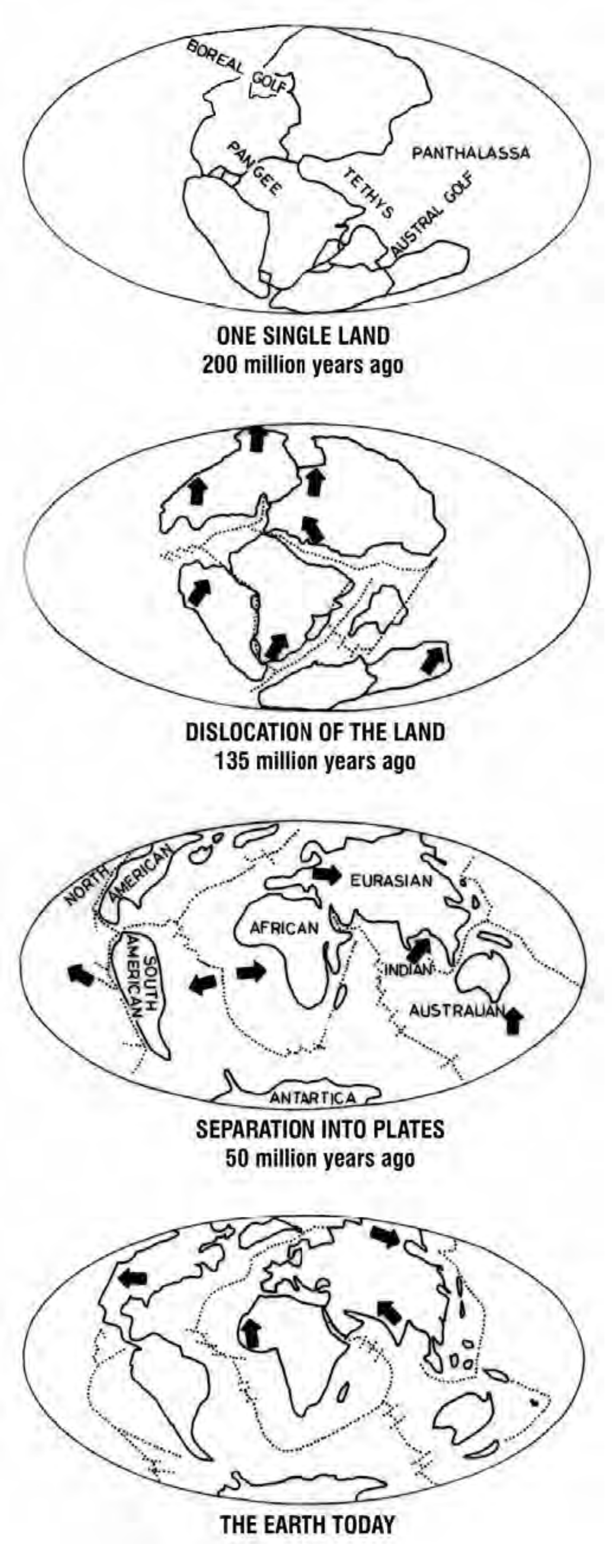


Figure 2 Tectonic plate

Theses tectonic plates are still moving and earthquakes are the result of these movements. Therefore, the continents of the earth are like several pieces of a crust – the tectonic plates, which are floating on a viscous mass – the magma. The latter is like a thick liquid composed of rocks in fusion.

Under various circumstances, these tectonic plates are still moving, very slowly, towards each other or away from each other.

These movements generate a lot of friction, which generate tensions and compressions in the earth crust. This friction is like energy, which gets stored in the deepest strata of the ground.

Earthquakes happen when the ground cannot accumulate anymore this energy, which is then released with violence on the surface of the globe.

The original focus of the earthquake is called the hypocenter. It lies deep into the ground. The geographical point on the surface, which is vertical to the focus, is called the epicenter.

1.3 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 manmade 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 Figure. 2). The theory of plate tectonics hold the plate ride upon the more mobile mantle, and are driven by some yet unconfined mechanism, perhaps thermal convection currents. When the plates (push) 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 fault. 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.

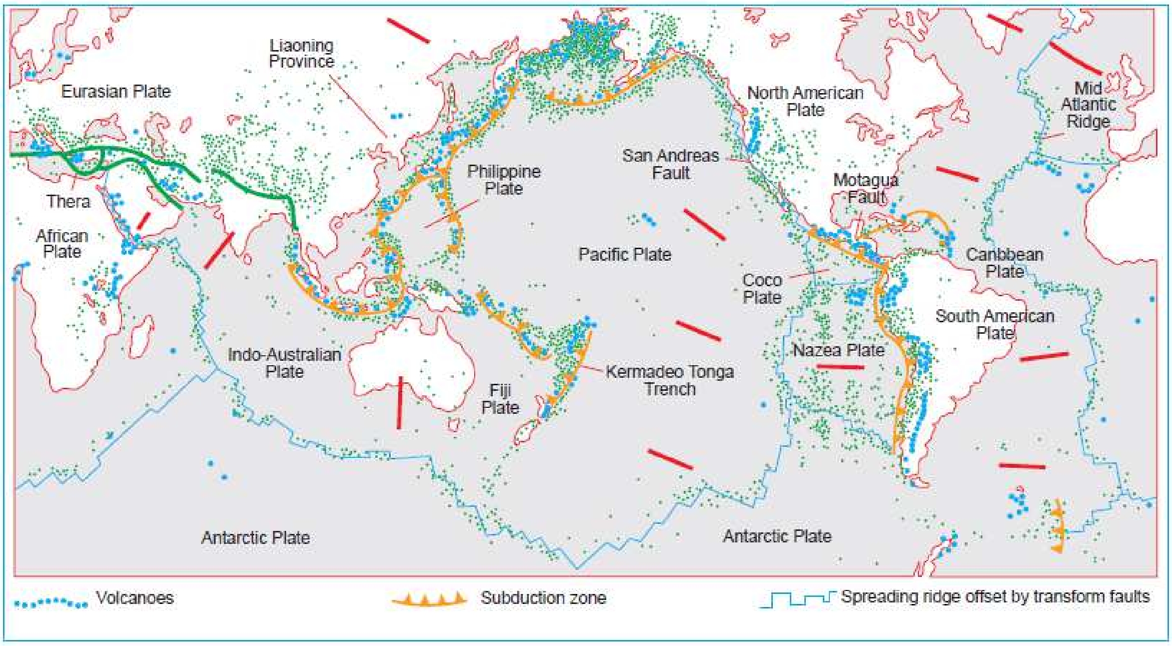


Figure 3 Different plates of Earth

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. Figure 4. The fault rupture generates vibrations called seismic waves which radiate from the focus in all directions.

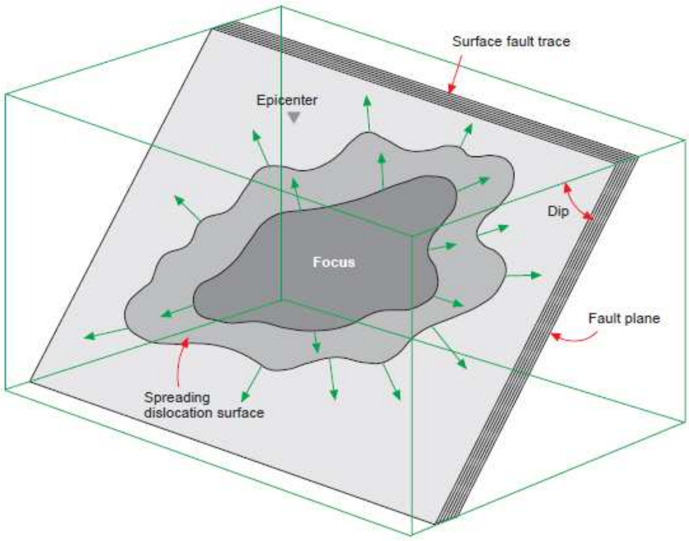


Figure 4 Epicenter and focus

1.4 Earthquake Locations

Earthquakes may occur almost everywhere in the world. But certain areas of the world are very susceptible to earthquakes (ref. Figure 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.

1.5 Types of Earthquake

Earthquakes can be of various natures. The most frequent ones are due to the movement of tectonic plates. Earthquakes can have other natures: volcanic or caving in.

- Tectonic earthquakes are the most devastating ones. The energy stored, due to the slow friction during a very long period of time, is tremendous. The earth crust is plastic enough to store this energy for a long time and without elastic failure. When the earth crust cannot store anymore this energy, it is released in the form of a tectonic earthquake.
- Volcanic earthquakes are due to the movement of magma under the earth crust. Its causes can be a local push of magma, which breaks the earth crust. A caving in of an underground cavity, which was created by a magma movement, can also be its origin. The other origin of volcanic earthquakes is volcanic explosions and eruptions. Volcanic earthquakes are not much devastating.
- Caving in earthquakes are quite exceptional. The caving in of the ceiling of underground cavities creates them. They can happen everywhere on the globe and they are not very powerful and devastating.

1.6 Seismic Waves

The seism focus generates spherical pulses, which propagate like concentric waves. They are called body waves. These initial waves have a longitudinal action and they are called primary or P waves. These waves induce second body waves, S waves. When P & S waves reach the surface they create 2 other waves: Love & Rayleigh waves.

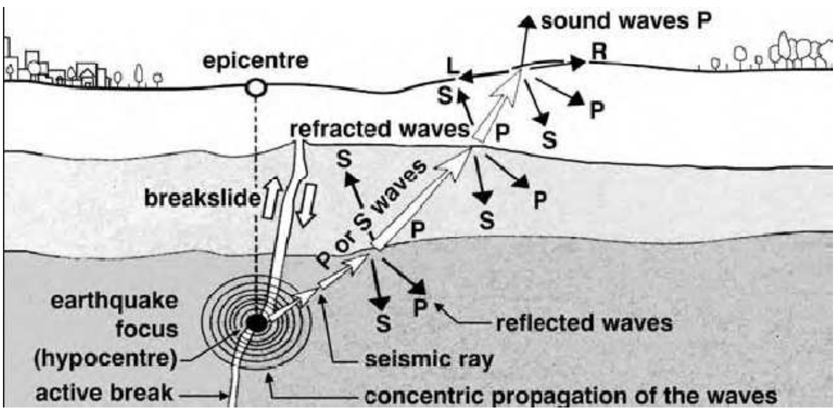


Figure 5 Seismic waves

P Waves

Their manifestation creates a change in volume and generates compression and dilatation of the ground. Their velocity is high: 5 to 8 Km/s.

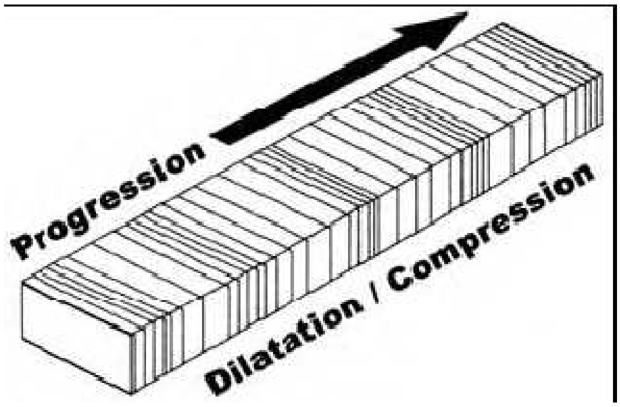


Figure 6 P waves

S waves

They also called shear transverse waves and they are very destructive. The soil oscillates vertically and perpendicularly to their direction. Their velocity is lower than P waves: 3 to 5 Km/s.

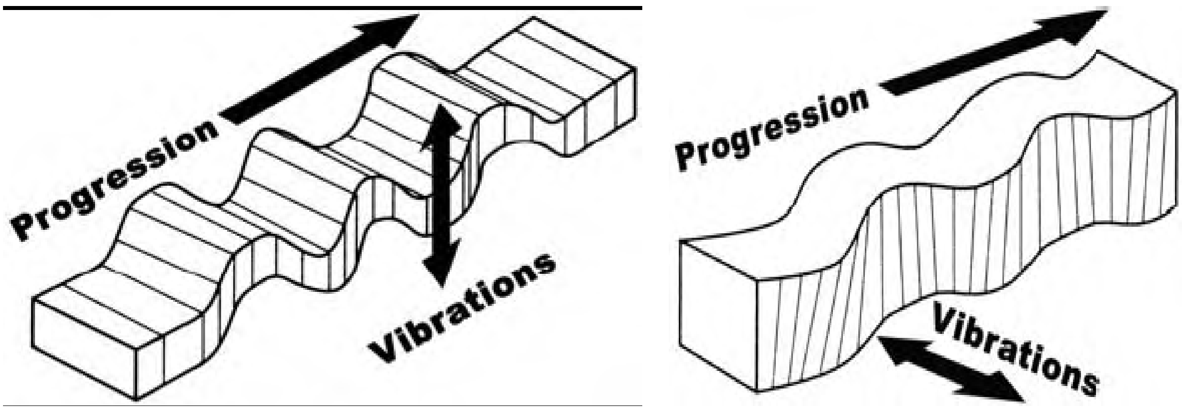


Figure 7 S waves

L waves

(Love waves)
They are also transversal ones, like S waves. The soil oscillates horizontally and perpendicularly to their direction. Their velocity is like S waves.

R waves

(Rayleigh waves)

The soil oscillates in an elliptical movement, counter clockwise to their direction. Their velocity is a little lower than that of S waves.

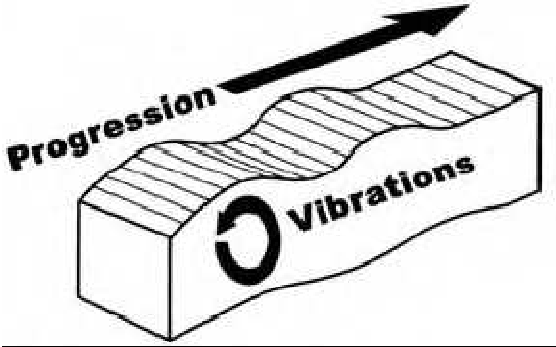


Figure 8 R waves

1.7 Measurement of Earthquakes

Two scales are used for the measurement of earthquakes: the Richter scale and the Mercalli scale.

Earthquake Magnitude

The magnitude of an earthquake is a measure of the amount of energy released 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 human beings. Largest earthquake that have been recorded under this system are from 8.8 to 8.9 in Magnitude.

Earth quake 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. 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 degrees 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 1.1.

Table 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 masonry buildings
IX	Poorly built masonry structures collapse
X	Most Masonry and frame structure destroyed
XI	Catastrophic damage 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 1.2. Seismic zones of Intensity VII, VIII and IX are amenable for incorporation of earthquake protection measures at reasonable cost.

Table 2 Approximate relationships between Magnitude and MSK Intensity scale

Earthquake magnitude Richter. M	Expected annual number	Maximum expected intensity	Radius of felt area (km)	Felt area (sq km)
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	1	XI-XII	800	2.000.000

Source: Earthquakes by Don de Nevi, Celestial Arts. Calif., May 1977, p.l02.

1.8 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 sub-ducting 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 damaging earthquake in 1833 and the earlier earthquake recorded event in the most comprehensive catalogue to date occurred in 1223. Huge damage and casualties occurred due to these events (ref. Table 1.3). There are frequent small to medium size earthquakes in different pails of the country with localized effects. Nepal continues to face a high level of earthquake hazard and risk.

Table 3 Major earthquakes of Nepal

Year	Date	Earthquakes epicenter	Human		Building, Temples	
			Death	Injuries	Collapsed	Damaged
1993		Jajarkot	NA	NA	40% of the buildings wet estimated to be affected	
1988	2l 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	
1347						
1260	NA	NA	NA	NA	NA	NA
1255	07 Jun	NA	One third of the total Population including King Abhaya Malla, killed		Many buildings and temples collapsed	
1223						

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 stands on. 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. Figure 9 shows the secondary active fault associated with the above mentioned Himalayan fault system.

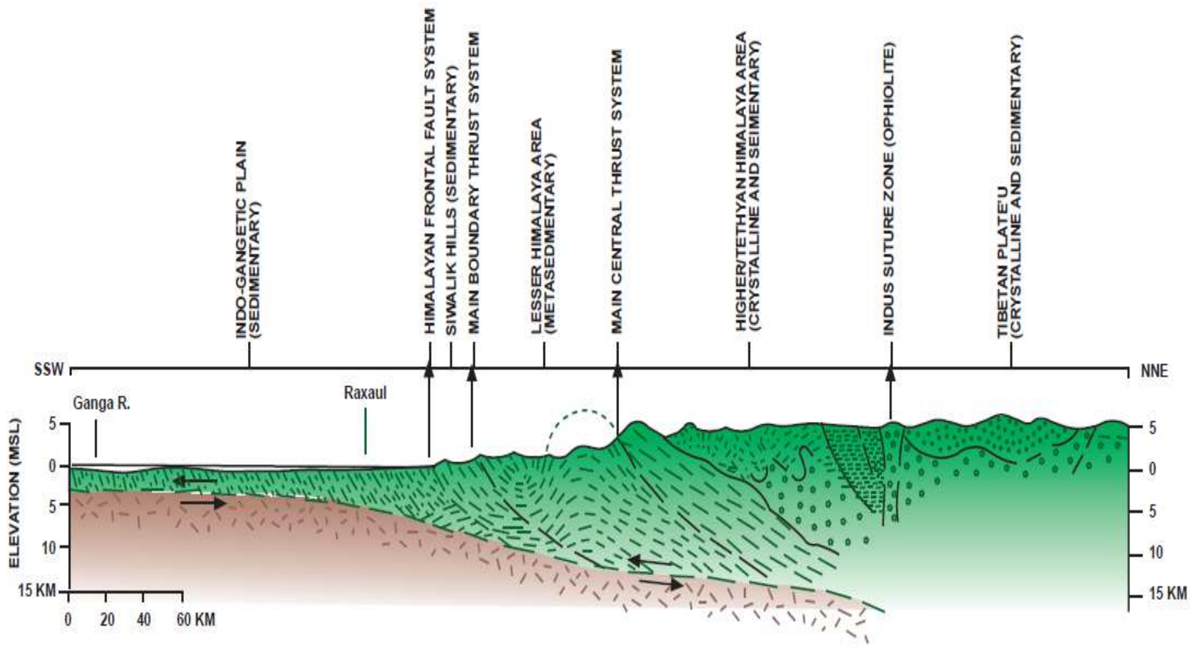


Figure 9 Schematic tectonic cross section through central Nepal

1.9 Seismic Hazard of Nepal

Figure 10 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.

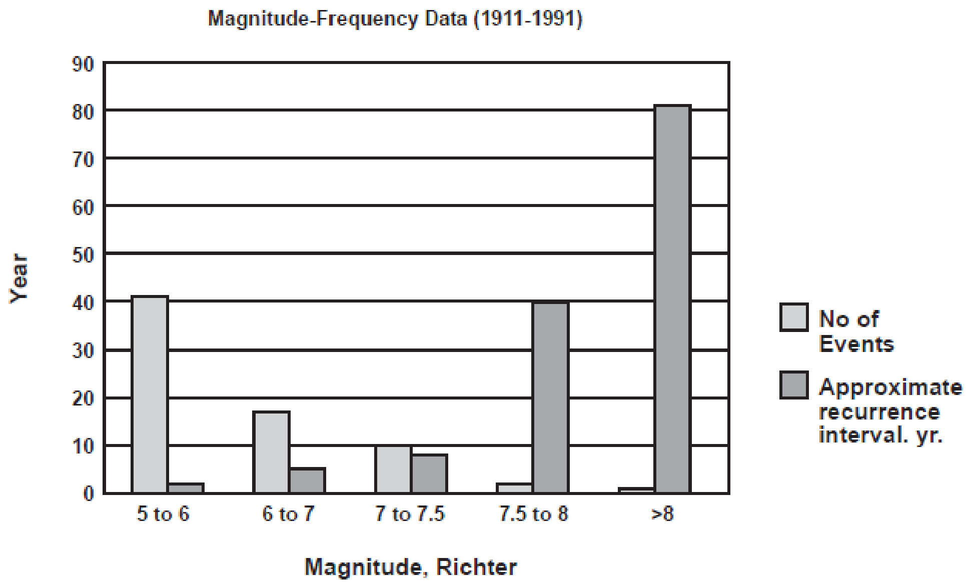


Figure 10 Seismic hazard of Nepal

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 Nepal is shown in Figure 24 in Section 3.

1.10 Ground Motion during an Earthquake

As we have seen in the previous page, the hypocenter of an earthquake generates various types of waves. When they reach the surface, the ground shakes everywhere horizontally and vertically especially near the epicenter. The motions are always reversible and this implies that buildings vibrate in all directions and in a very irregular manner due to the inertia of their masses.

1.11 Seism Prediction

It is not possible to predict earthquakes. Parameters involved and the absence of sufficient data makes it impossible to foresee, where, when and with which magnitude would strike an earthquake.

1.12 Earthquake Prevention

If it is not possible to predict earthquakes, it is possible to prevent major damages and most of life's losses. India is divided in five zones and there are several Indian standards, which defines building codes for earthquake resistance. The design of every engineered or non-engineered building must follow it.

Further, the construction must be sound that means by people who should follow the state of the art in construction, or at least the basics of masonry, and who are conscious of their responsibility in the execution of a building, which must resist an earthquake.

The prevention of earthquakes is based on the possibility of buildings to resist earthquakes without sudden collapse.

CHAPTER II
EARTHQUAKE EFFECT

Earthquakes don't directly kill people. Ground shaking destroys infrastructure and buildings and hence, it is of a material nature.(?) Death of people occurs by the collapse of buildings in which they live. Therefore, the real cause of life's loss is wrongly built or inappropriate constructions, which instantly collapse without warning.

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

2.1 Ground Effect

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

2.1.1 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 Figure 11).

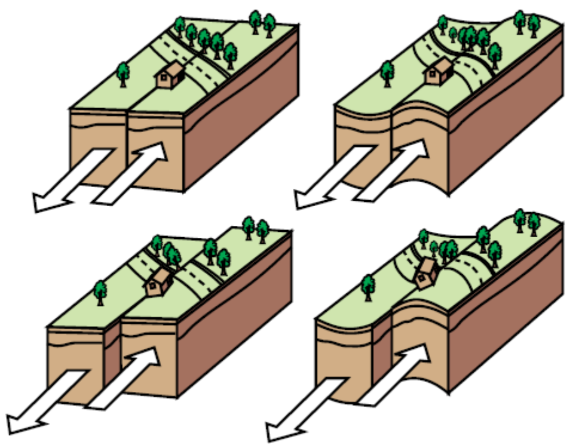


Figure 11 Development of surface faulting

2.1.2 Liquefaction Settlements

Seismic shaking may cause sinking or tilting or cracking or collapse of buildings when soil is compacted or consolidated. Certain types of soil, 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 liquefied (ref. Figure 12). It is more prominent if the foundation soil consists of uniform loose sands within a depth of about 8m below the around surface and is either fully saturated by or submerged under water. The buildings resting on such ground may tilt or sink and may collapse.

Figure 12 Liquefaction

2.1.3 Land slides

Earthquakes cause landslides where the hill slopes are unstable due to badly fractured rocks or consist of loose material (ref. Figure 13). The effect is more pronounced in rainy season when the soil is wet than in dry season.

Figure 13 Earthquake induced landslide

2.1.4 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 infra structures (ref. Figure 14).

Figure 14 Building damage due to rock fall

2.2 Effect 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 Figure 15). The shaking loosens the joints of different components of building that leads to subsequent damage or collapse.

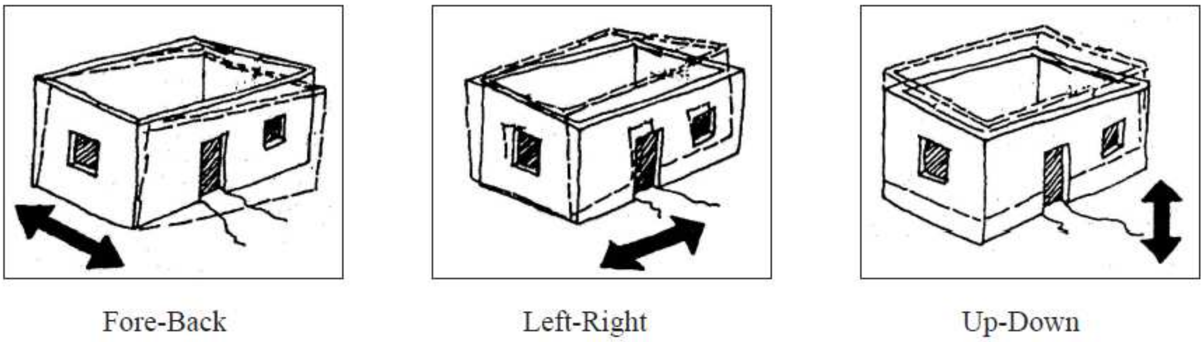


Figure 15 Ground shaking

2.2.1 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 tinder 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, heavier the building 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 iii (ref. Figure 16).

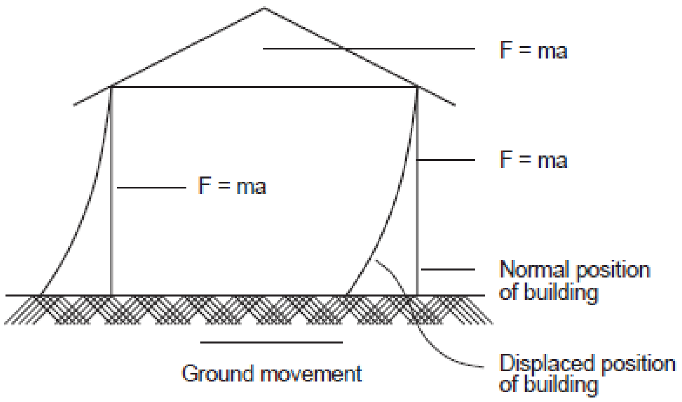


Figure 16 Ground motion and inertia force

2.2.1.1 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 portrayed in Figures 15, 19 and 20 (a, b).

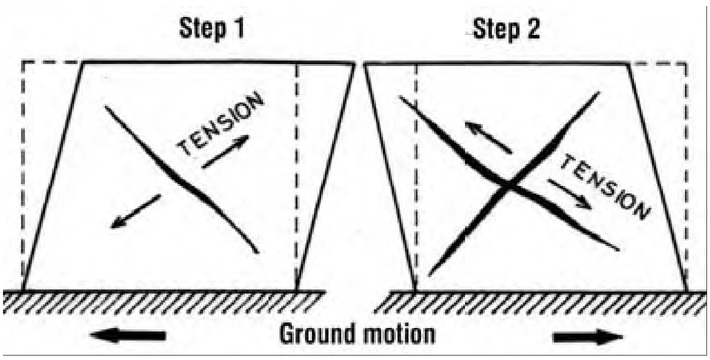


Figure 17 Ground motion in wall plane

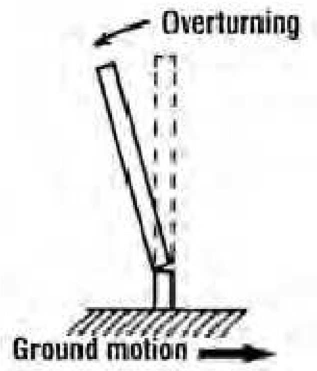
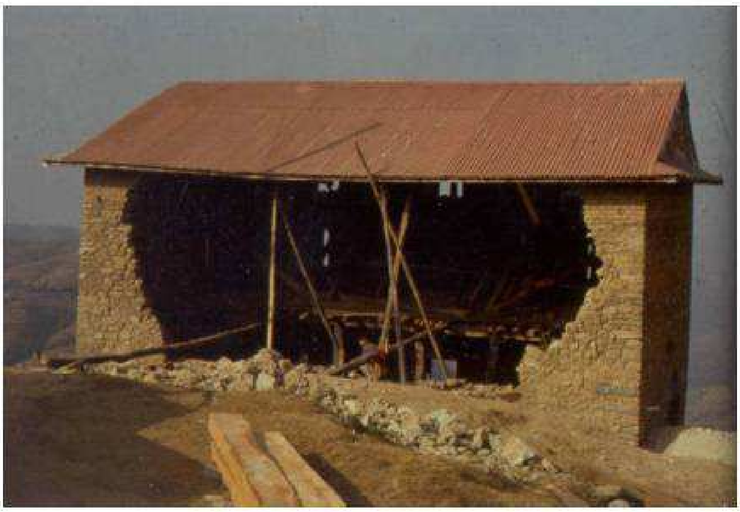
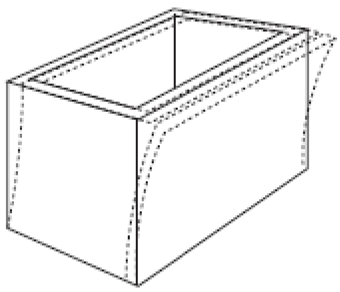


Figure 18 Ground motion perpendicular to the wall

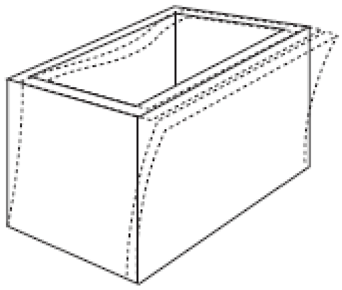


(1988 Udaypur earthquake)

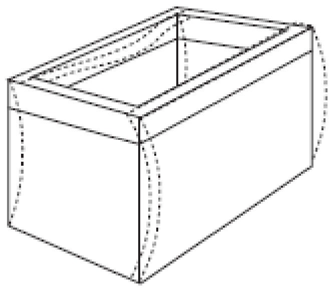
Figure 19 Wall collapse



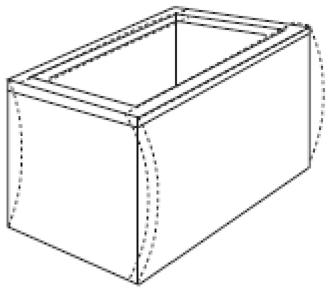
a) Structural walls are not tied together at junctions and roof level



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

Figure 20 Vibration of masonry building during earthquake ground motion

Figure 21 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. 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, 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.

<u>2.2.1.2 Failure Mechanism of RC Framed Building</u>

RC framed buildings fail during large earthquakes mainly due 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

2.2.2 Building Damage

<u>2.2.2.1 Masonry Buildings</u>

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

<u>Roofs</u>

- 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 Figure 11)
- 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 nibble 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

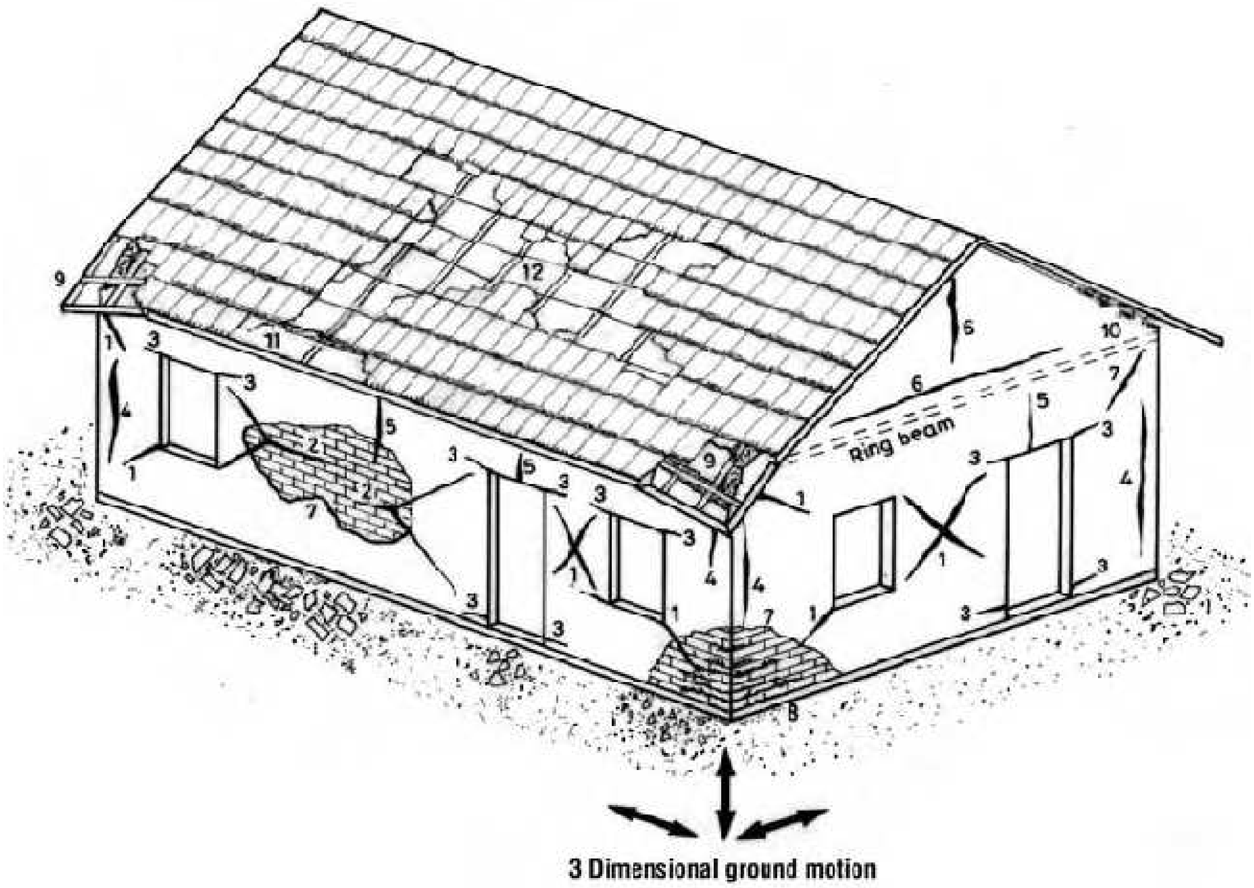


Figure 22 Ground motion

1: Diagonal shear crack of piers
2: Horizontal shear crack of long pier
3: Bending cracks at feet and lintels
4: Bending crack of wall (bad corner bond)
5: Bending crack of spandrel
6: Bending crack of gable
7: Plaster peeling off
8: Crushing of weak masonry under vertical ground motion
9: Damage of corner eaves under vertical ground motion
10: Badly anchored roof, pulled out by vertical ground motion
11: Falling of tiles from the roof eave
12: Damage of tiles roof with shear (roof not braced)

2.2.2.2 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

2.3 General Damages

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

2.4 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.

2.4.1 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 (i.e., 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 suffer torsional motions as shown in Figure 13.

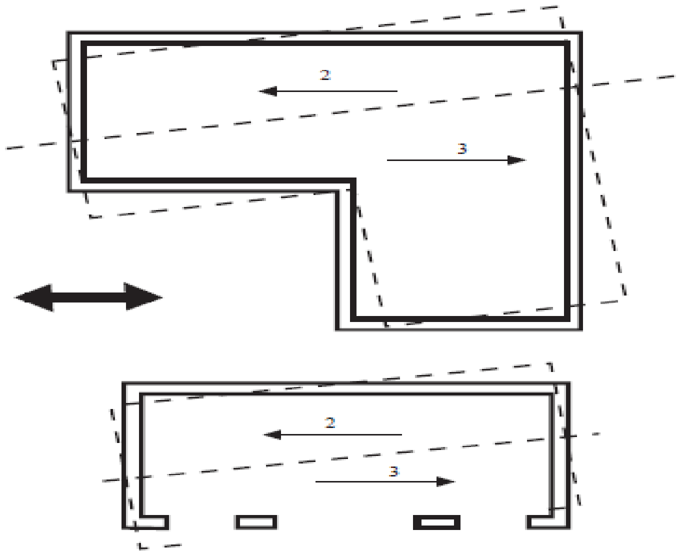


Figure 23 Torsion in unsymmetrical plan building

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 i.e. 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 i.e., omission of walls in a particular storey (for e.g. 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.

2.4.2 Quality of Material and Construction Practices

Construction material 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 especially evident in the case of stone masonry and adobe buildings. Irregular shape of stones, further destabilize the wall by their relative movements (mechanism failure).

Buildings with good construction materials but built by inferior techniques cannot 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 sonic 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.

2.4.3 Lack of Earthquake Resistance Features

- Lack of structural integrity
- Roof collapse
- Out-of-plane wall collapse
- In-plane shear cracking
- Poor quality of construction
- Foundation problems

CHAPTER III

SEISMIC CONSIDERATIONS OF BUILDING DESIGN

3.1 Seismic Zones

It is important to know in which zone the facility is located. A Simplified seismic hazard map of Nepal is shown in figure 24. In the map, the area west of Kathmandu and confined between the Himalayas and southern terai has the highest level of seismic hazard.

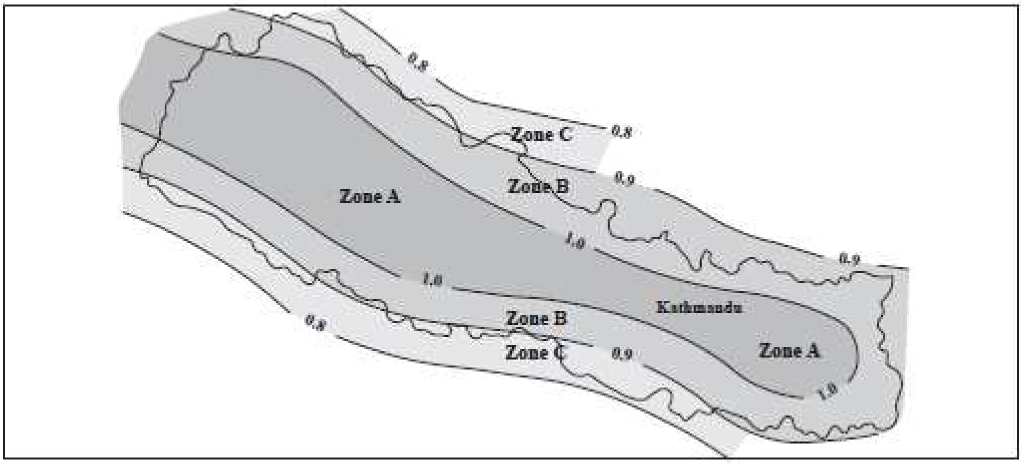


Figure 24 Seismic zoning map of Nepal

3.2 Soil Condition

Soil can be classified into four types (ref. Table 3.1).

Table 3.1: Soil Classification

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 coal-se 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 i.e. 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.

3.3 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 priority against earthquake damages and which will be given lower priority. School 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.

CHAPTER IV

SITE COSIDERATIONS

4.1 Choice of Site

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

4.1.1 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.

DO NOT BUILD: On steep/ unstable slopes or loose ground

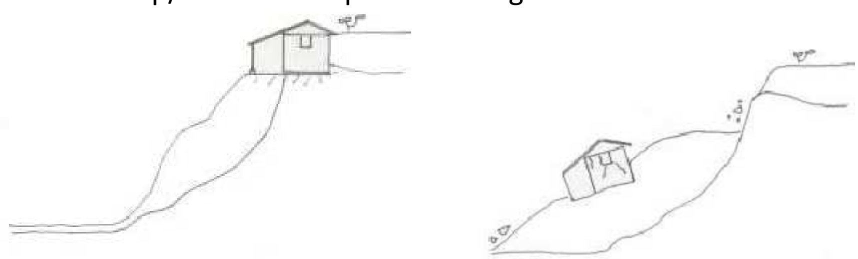


Figure 25 Building on unstable slope

DO NOT BUILD: On areas susceptible to landslides and rock fall

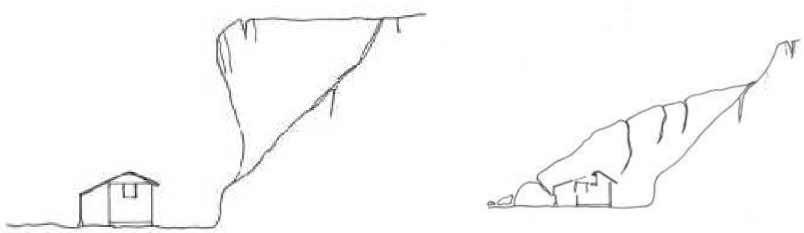


Figure 26 Building on landslide area

If building near a slope position house a minimum of 4ft from the slope and provide a retaining wall if necessary.

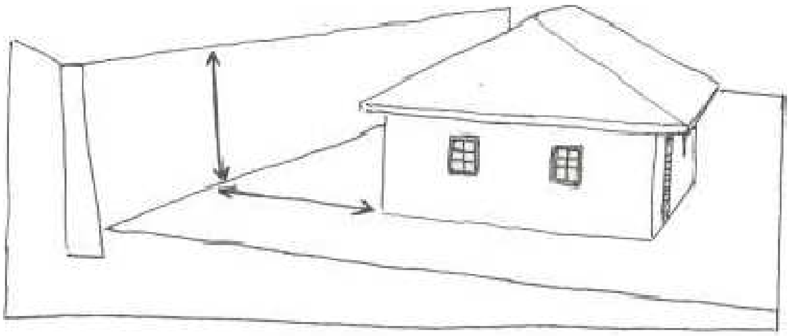


Figure 27 Building near a steep slope

If building on a sloping site terrace and level the land prior to beginning house construction.

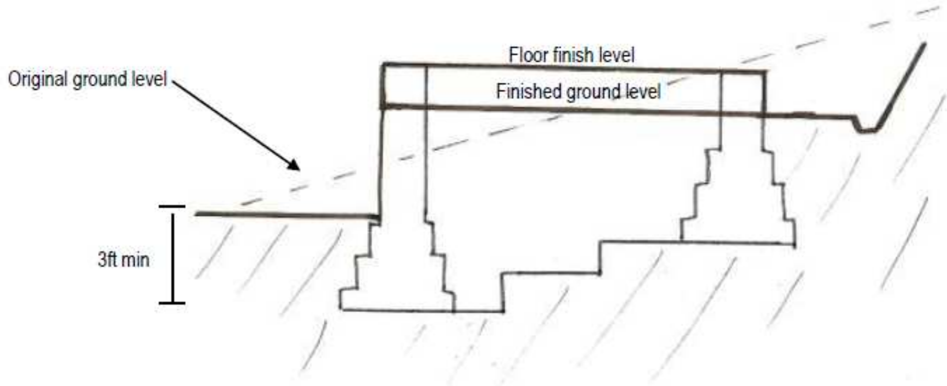


Figure 28 Building on different level

DO: Place buildings a good distance between each other (at least equal to height of tree or house).

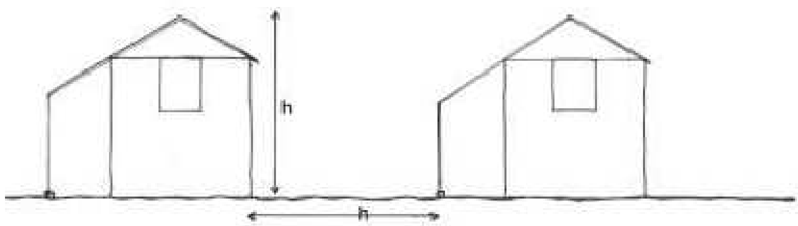


Figure 29 Buildings at adequate distance

4.1.2 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.

4.1.3 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 pound 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 tile principal active faults identified so far within Nepal and can be referred to this purpose.

4.1.4 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.

DONT BUILD: Near rivers as water saturated soils can lose bearing capacity during ground shaking (this is termed liquefaction) and flooding can be a risk.

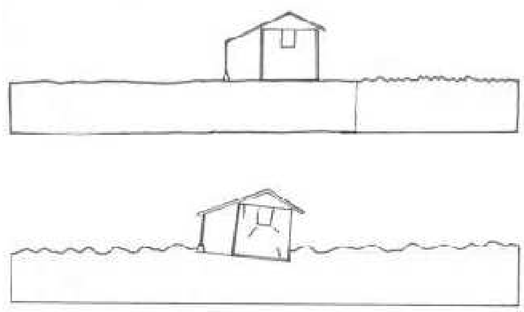


Figure 30 Building near river

4.1.5 Ground Topology

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.

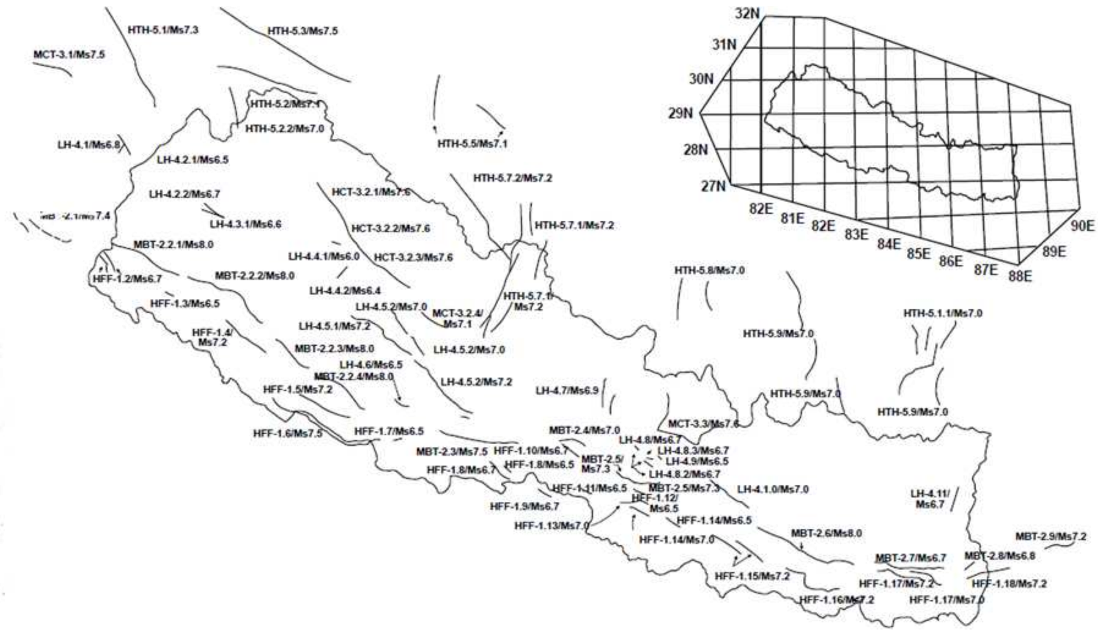
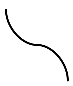


Figure 31 Active faults of Nepal and surrounding region

(Source: Site Consideration. NBCDP)

LEGEND:



= Earthquake Sources (Active Faults)

MBT -2.2.3IMs7.2 = INTERPRETED LOCATIONS OF EARTHQUAKE SOURCES

Based on locations of active faults from geologic, remote sensing and micro seismicity data.

Fault number and assigned maximum magnitude are indicated.

EXAMPLE:

MBT - 2.2.3 / Ms7.2

MAXIMUM MAGNITUDE

FAULT NUMBER

HFF- HIMALAYAN FRONTAL FAULT SYSTEM

MBT- MAIN BOUNDRY THRUST SYSTEM

MCT- MAIN CENTRAL THRUST SYSTEM

LH- LESSER HIMALAYAAREA
HTH- HIGHER TETHYAMHIMALAYA AREA
IGP- INDO-GANGETIC PLAIN AREA

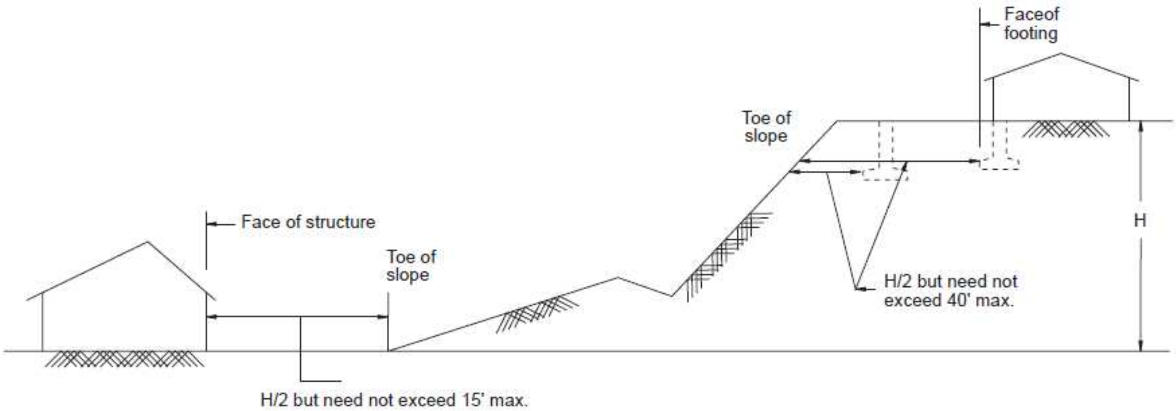


Figure 32 Preparing a building site in a sloping terrain

4.2 **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.

CHAPTER V

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.

5.1 Building Configuration

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

• The building as a whole or its various pails should be kept symmetrical along both the axes. Lack of symmetry leads to torsional effects and hence adds 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 around 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. Figure 34).

• Separation of a large building into separate parts is a good practice for allowing the pails 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 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 Figure 33 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.

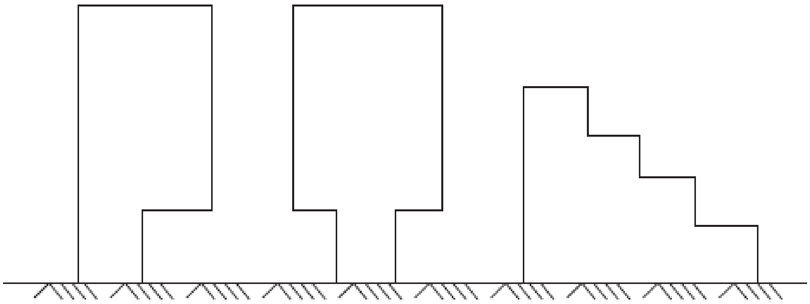
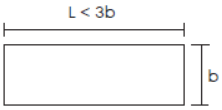
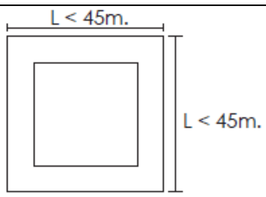
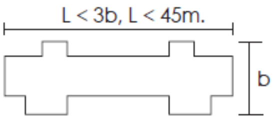
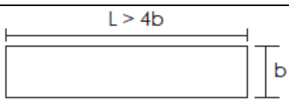
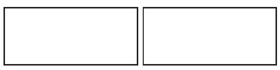


Figure 33 Building with changing elevation

• 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
 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

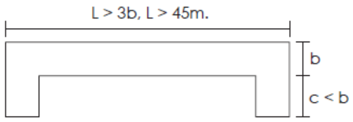
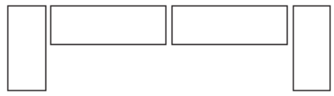
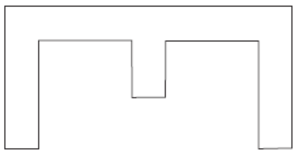
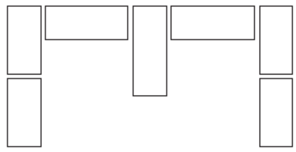
 E. Too long and narrow with some projections	 E. Divide building in suitable parts
 F. Too long. projections too large	 F. Divide building in suitable parts

Figure 34 Plan shapes and improvement

The best shapes for earthquake resistant buildings are regular shapes and preferably with two symmetry axes. In this case the centers of gravity and rigidity will be the same or close to each other and therefore there will not be any torsion in the building.

When it is not possible to have regular shapes, it is possible to improve the earthquake resistance by dividing the building in several parts.

5.2 Distribution of Load Bearing Element

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. Walls must be firmly connected together to the floors roofs which must be able to act as rigid diaphragms.

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.

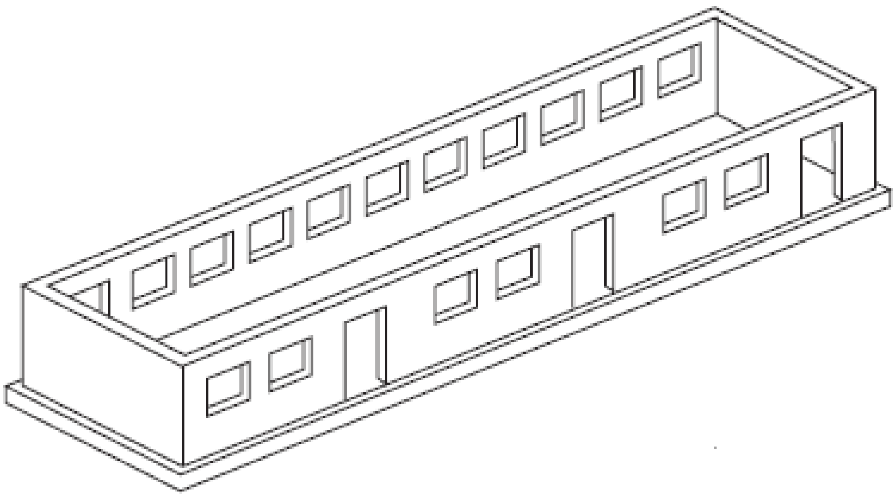
Considering the significance of the structural walls, these walls should have a minimum thickness of 0.38 m for stone masonry buildings, 0.35 m for brick in mud mortar and of 0.23 m for brick or block masonry in cement mortar.

In order to obtain satisfactory performances for different masonry systems, the distances between the structural walls should be limited as given in Table 5.1.

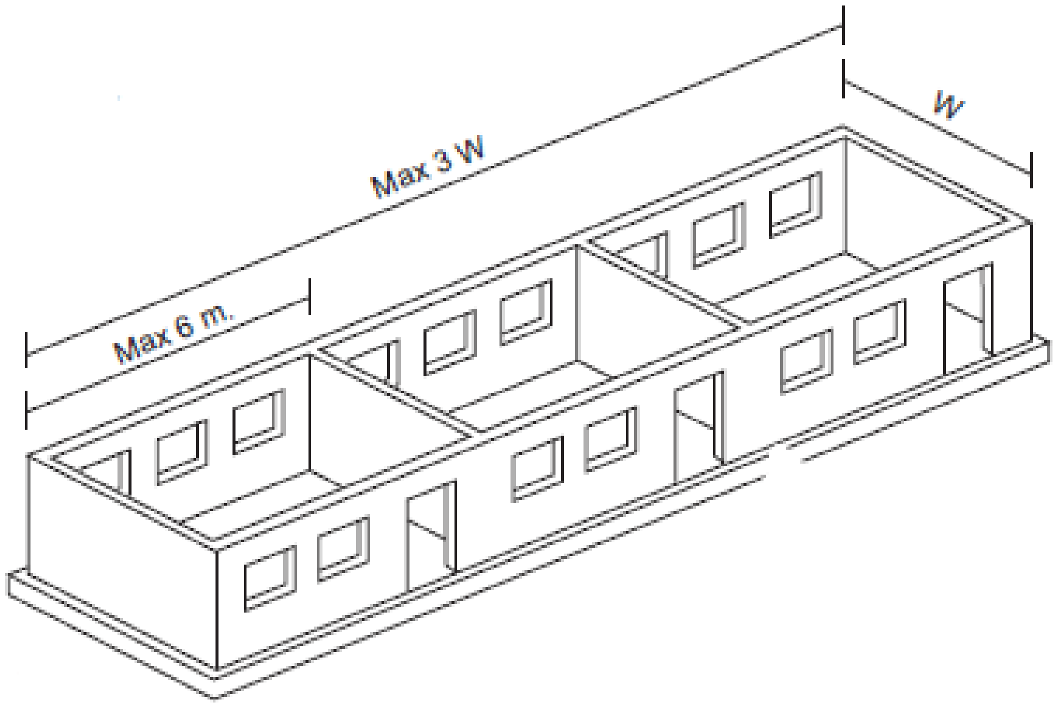
Table 4 Limiting distance between structural walls in different construction systems

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

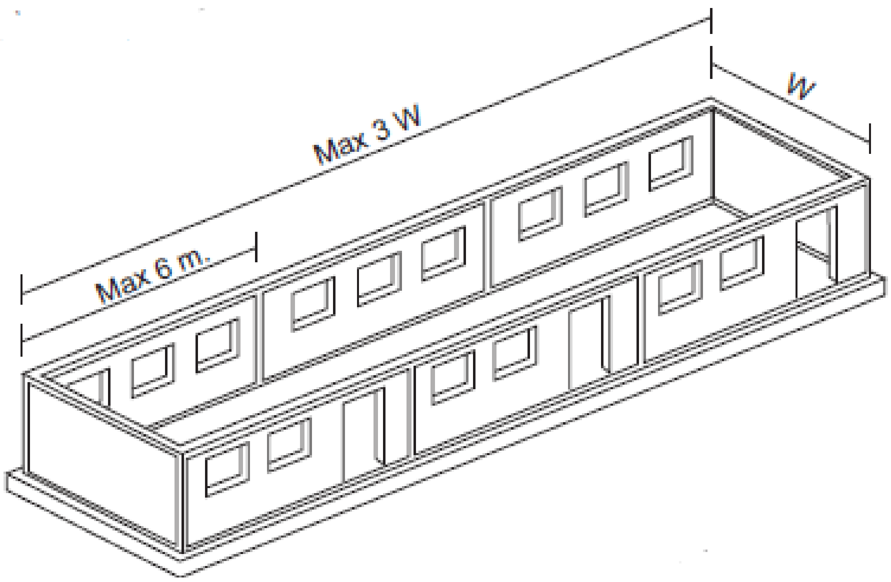
Using the above recommended values, the resulting structural layout, however, should be verified by calculations. Limiting factors may be the vertical load-bearing capacity and the out-of-plane bending capacity of these walls. If wall distance is more than the recommended distance the walls should be laterally supported as shown in Figure 35. 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 4.0 m in adobe or stone-in-mud. 5.0 m in case of brick in mud and 6.0 m in case of brick in cement mortar.



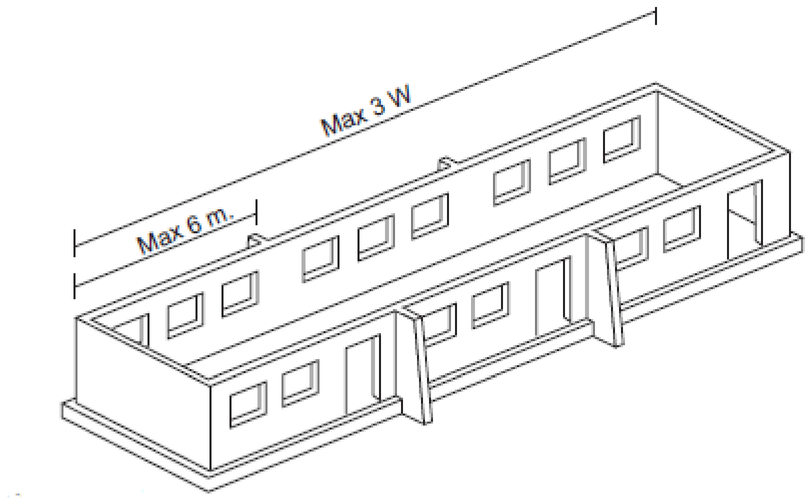
a) Unsatisfactory; long unsupported walls



b) Satisfactory; box-like enclosures



c) Satisfactory; long walls supported by RC. Columns



d) Satisfactory; long walls supported by buttresses

Figure :35 Lateral support to long walls

5.3 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 asymmetry 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 possible

• 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.

Doors and windows reduce the lateral resistance of walls to shear. Hence, they should preferably be small and rather centrally located. When a specific design cannot follow this basic specification, the specifications mentioned below (IS 4326: 1993) must be followed.

Table 5.2: Opening Specification

	1 STOREY	2 STOREY	3 STOREY
$B_1 + B_2 + B_3$	≤ 0.5 L_1	≤ 0.42 L_1	≤ 0.33 L_1
$B_6 + B_7$	≤ 0.5 L_2	≤ 0.42 L_2	≤ 0.33 L_2
B_4	≥0.5 H_2 (But not less than 60 cm)		
B_5	≥0.25 H_1 (But not less than 60 cm)		
H_3	≥0.5 B_8 (But not less than 60 cm)		
H_4	≥0.5 B_7 (But not less than 60 cm)		
Notes: - H_3 is calculated from B_8, which is wider than B_2 - H_4 is calculated from B_7, which is wider than B_9			

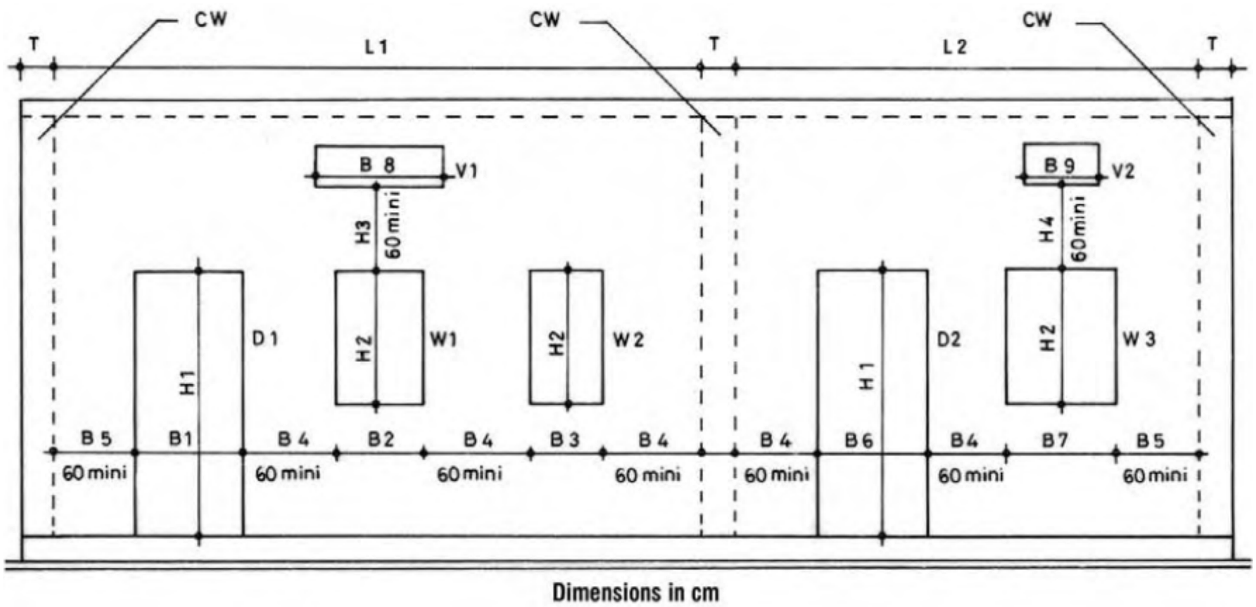


Figure 36 Opening specification

D_1, D_2 = Doors
W_1, W_2, W_3 = Windows
V_1, V_2 = Ventilators
CW = Cross walls
T = Thickness of cross walls
B_8 is wider than B_2 - B_7 is wider than B_9

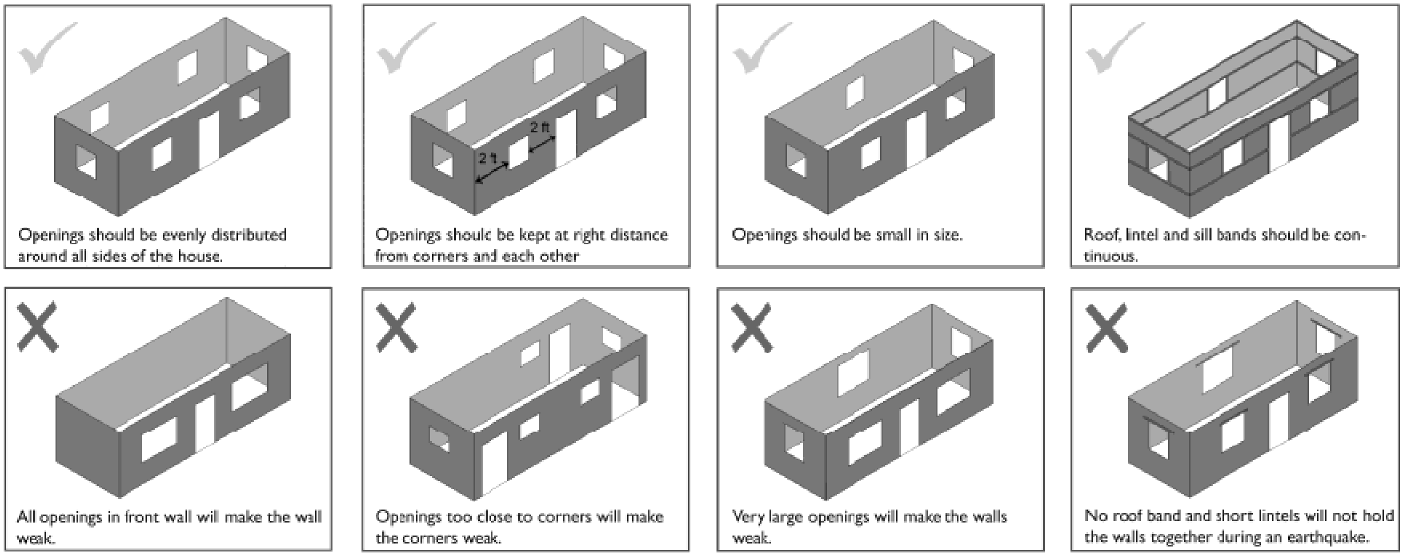


Figure 37 Locations of openings

CHAPTER VI

BASIC DESIGN GUIDELINES FOR EARTHQUAKE RESISTANCE

An earthquake resistant building is able to accumulate a lot of energy without major failure. It will swing and sway and it might be damaged. But it would not collapse before giving very visible signs. Therefore, people would be able to leave the building before it would collapse. An earthquake resistant building, which has been damaged, could most of the time be repaired.

"Specialist studies show that the ability to construct buildings that have both flexibility and cohesion is one of the most important considerations when designing earthquake resistant structures. A main objective is to provide an effective linking of different parts of a building so as to enable them to work together and avoid the dislocation which causes collapse."

McDonald, Roxanna, Introduction to Man-made disasters and their effects on buildings, (Oxford: Architectural Press, 2003) 36.

6.1 Separation Gap

Buildings with irregular and asymmetrical shapes are more fragile than simple ones. Hence they should be split into simpler shapes like shown above.

These various parts will vibrate at a different frequency and amplitude under the reversible ground shakings. Therefore they will hit each other and will be mutually damaged. A gap should be kept between them to avoid collision.

This gap can be filled with a crumbly material, which will be crushed under the shocks, or it can be left empty. In both cases, care should be taken for the waterproofing of the joint with a system that does not link again both parts.

The separation gap must be minimum 25 mm for ground floor buildings and for higher ones the gap should be increased by 10 mm per storey more. (Ref. IS 4326: 1993)

6.2 Ductility

Masonry components are most of the time brittle ones. Some reinforcements can be added to make a structure more ductile with these brittle materials. Wood and bamboo can be advantageously used. Reinforced cement concrete members are always more efficient, when they are well done and well distributed.

Ring beams at various levels, which are linked together with vertical ties, will reinforce the structure very well and make it ductile.

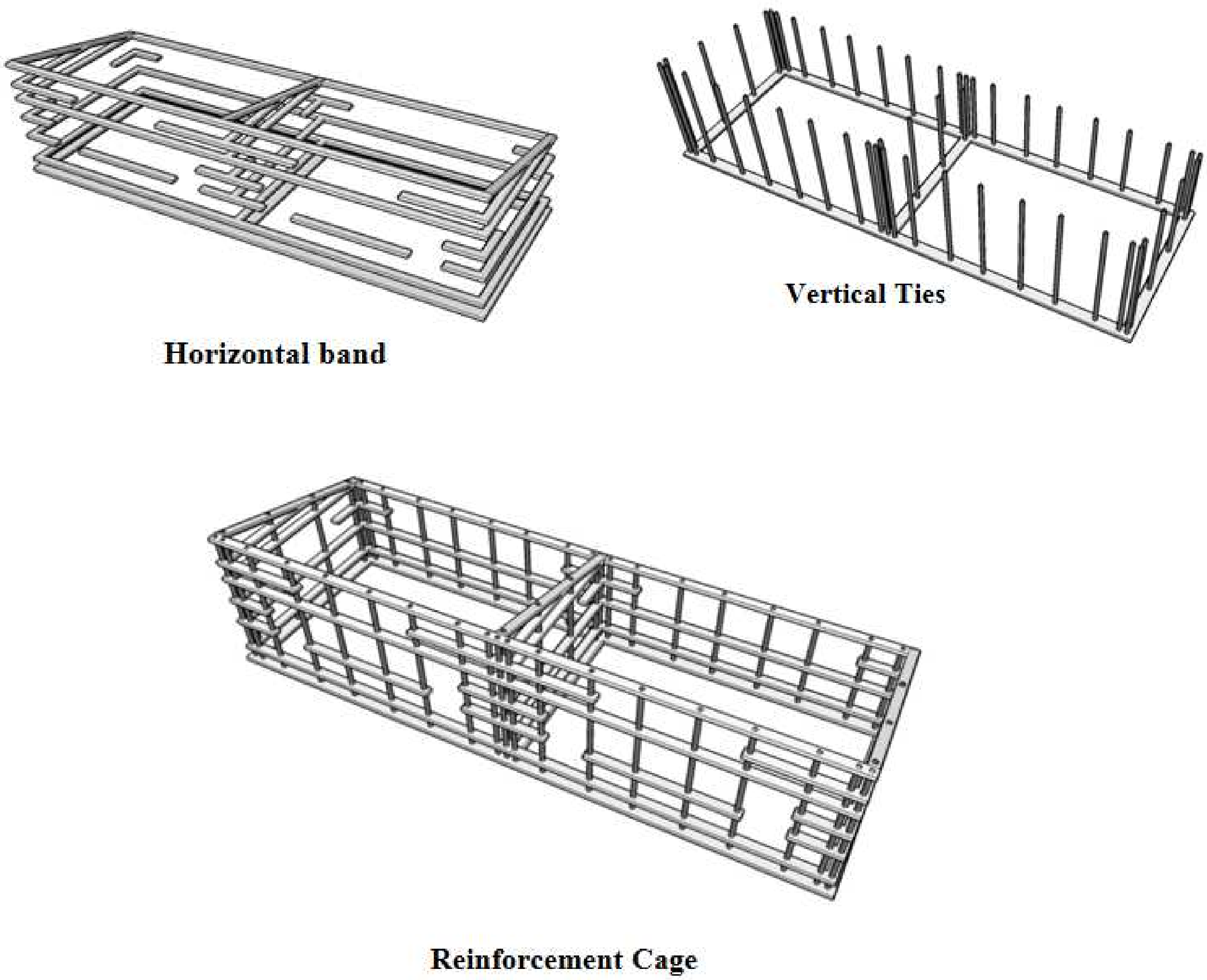


Figure 38Reinforcement in masonry structure

6.2.1 Seismic Bands (Ring Beams)

A seismic band is the most critical earthquake-resistant provision in a stone masonry building. The band acts like a ring or belt, as shown in Figure 39. Seismic bands hold the walls together and ensure integral box action of an entire building. Also, a lintel band reduces the effective wall height. As a result, bending stresses in the walls due to out-of-plane earthquake effects are reduced and the chances of wall delaminating are reduced.

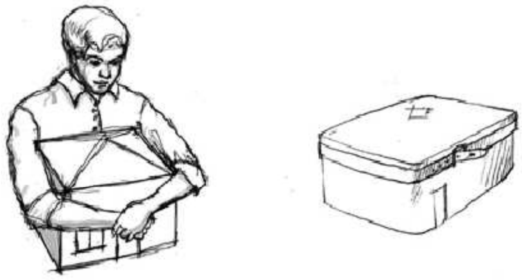


Figure 39 A seismic band acts like a belt (adopted from: GOM 1994)

During earthquake shaking, a band undergoes bending and pulling actions, as shown in Figure 40. A portion of the band perpendicular to the direction of earthquake shaking is subjected to bending, while the remaining portion is in tension.

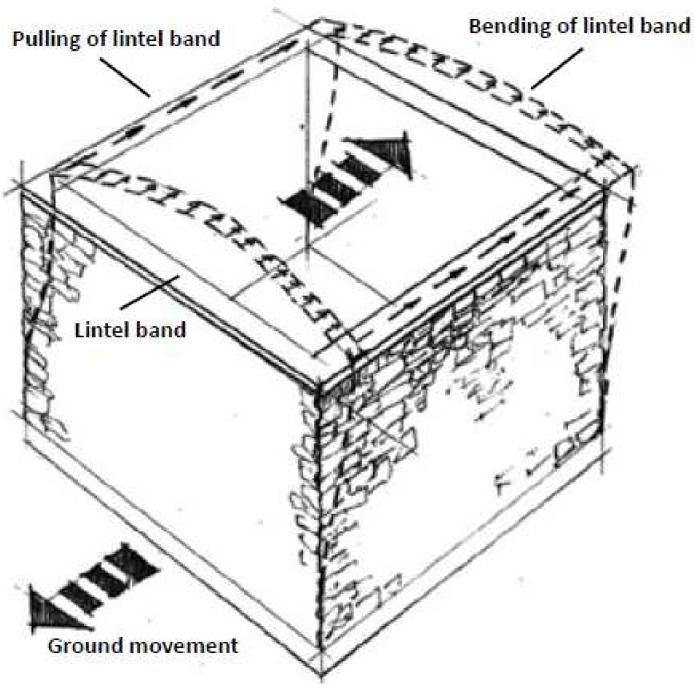


Figure 40 Pulling and bending of lintel band in a stone masonry building

6.2.2 Vertical Reinforcement

Even if horizontal bands are provided, masonry buildings are weakened by the openings in their walls. During earthquake shaking, the masonry walls get grouped into three sub-units and these three discrete sub-units are:

- Spandrel masonry (Between lintel band and roof band)
- Wall pier masonry (Between sill and lintel band)

- Sill masonry (Between plinth band and sill band)

When the ground shakes, the inertia force causes the small-sized masonry wall piers to disconnect from the masonry above and below. These masonry sub-units rock back and forth, developing contact only at the opposite diagonals (ref. Figure 42). The rocking of a masonry pier can crush the masonry at the corners. Rocking is possible when masonry piers are slender, and when weight of the structure above is small. Otherwise, the piers are more likely to develop diagonal (X-type) shear cracking (ref. Figure 43); this is the most common failure type in masonry buildings.

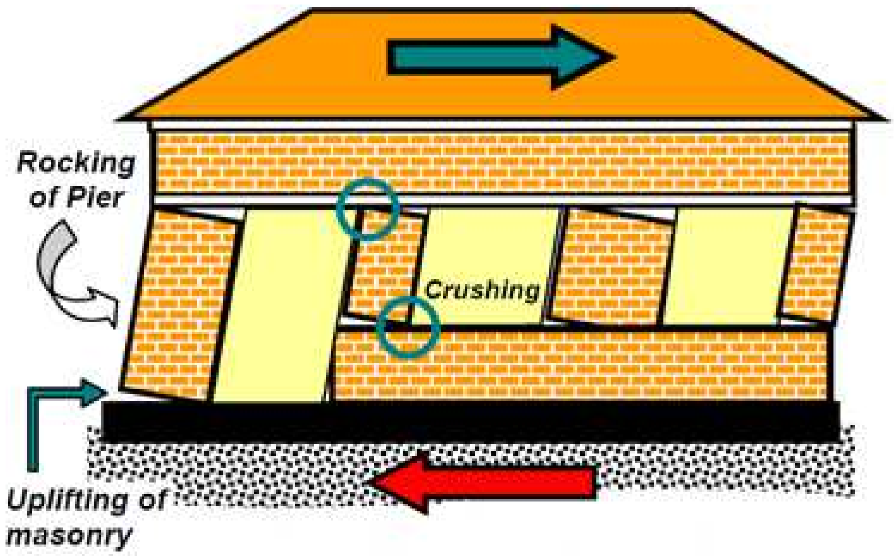


Figure 41 Rocking masonry piers

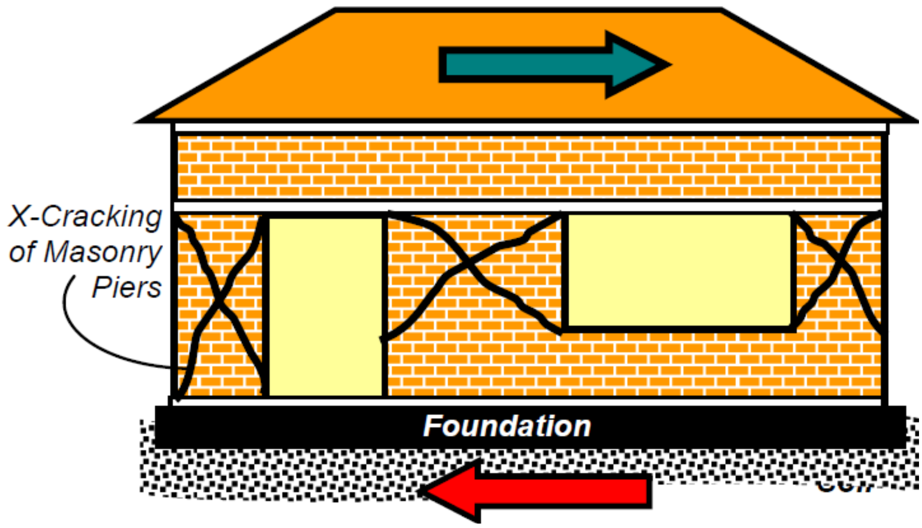


Figure 42 X-cracking masonry piers

During strong earthquake shaking, the building may slide just under the roof, below the lintel band or at the sill level. Sometimes, the building may also slide at the plinth level. The exact location of sliding depends on numerous factors including building weight, the earthquake-induced inertia force, the area of openings, and type of doorframes used.

Embedding vertical reinforcement bars in the edges of the wall piers and anchoring them in the foundation at the bottom and in the roof band at the top (ref. Figure 44), forces the slender masonry piers to undergo bending instead of rocking. In wider wall piers, the vertical bars enhance their capability to resist horizontal earthquake forces and delay the X-cracking. Adequate cross-sectional area of these vertical bars prevents the bar from yielding in tension. Further, the vertical bars also help protect the wall from sliding as well as from collapsing in the weak direction.

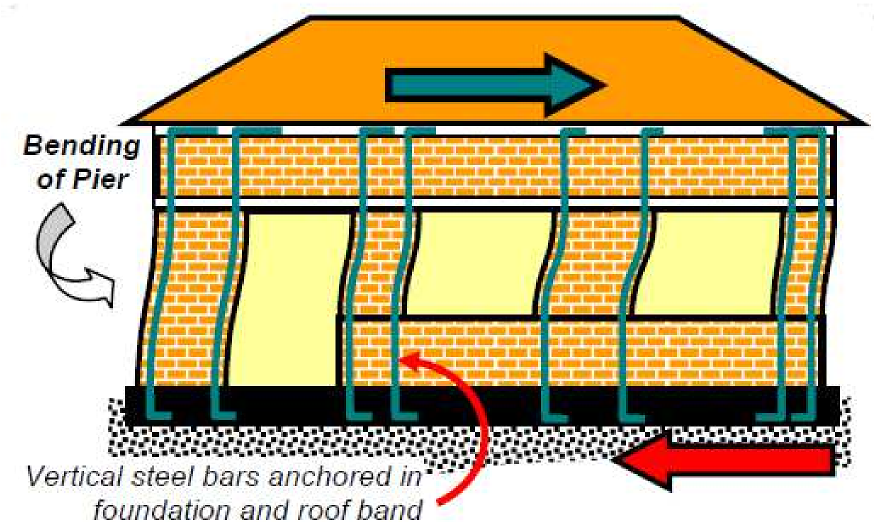


Figure 43 Vertical reinforcement in masonry walls

Sliding failure mentioned above is rare, even in unconfined masonry buildings. However, the most common damage, observed after an earthquake, is diagonal X-cracking of wall piers, and also inclined cracks at the corners of door and window openings. When a wall with an opening deforms during earthquake shaking, the shape of the opening distorts and becomes more like a rhombus - two opposite corners move away and the other two come closer. Under this type of deformation, the corners that come closer develop cracks (ref. Figure 45). The cracks are bigger when the opening sizes are larger. Steel bars provided in the wall masonry all around the openings restrict these cracks at the corners (ref. Figure 46). In summary, lintel and sill bands above and below openings, and vertical reinforcement adjacent to vertical edges, provide protection against this type of damage.

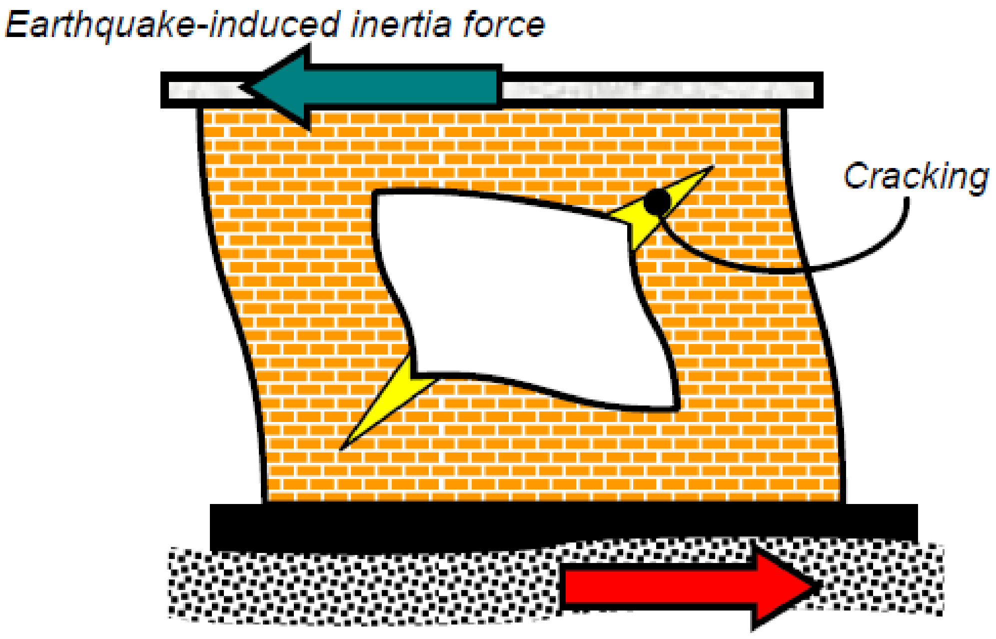


Figure 44 Cracking in building with no corner reinforcement

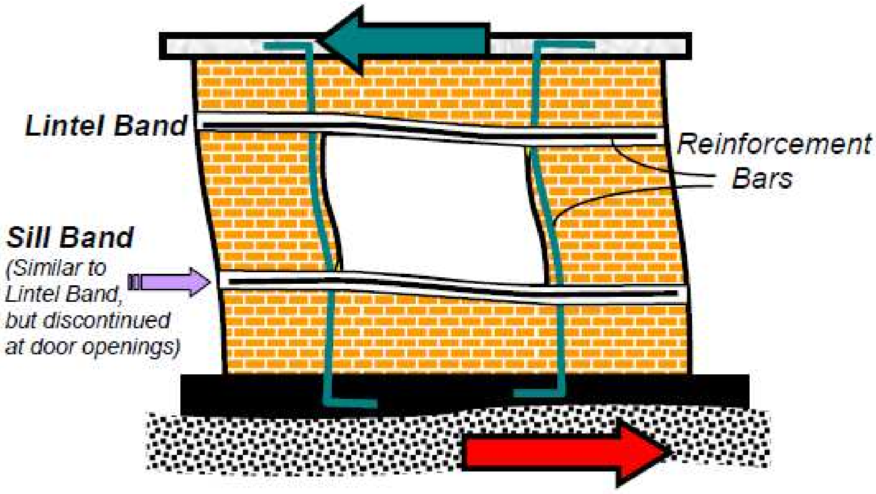


Figure 45 No cracks in building with vertical reinforcement

6.3 Rigidity Distribution

The center of gravity of the plan should also preferably be the center of rigidity of the vertical masses. This would avoid torsion of the building.

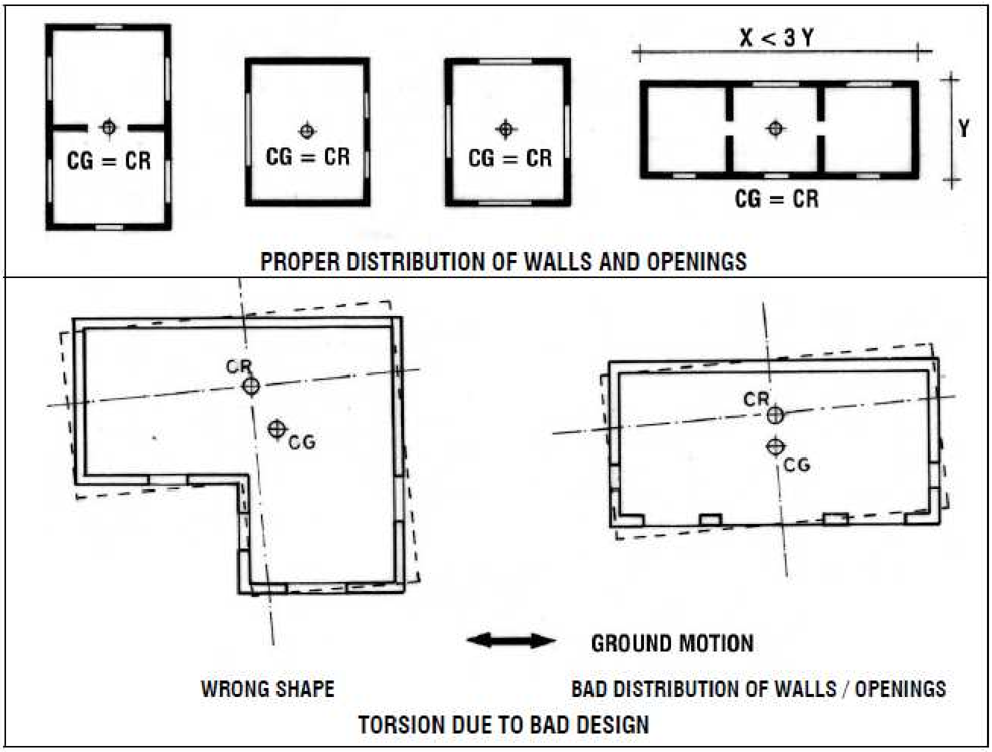


Figure 46 Distribution of walls and openings

The vertical rigidity of the building should also be well distributed.

Change in the structural system from one floor to another or different building height would increase the damage potential.

Vertical ties should link the various floors and ring beams.

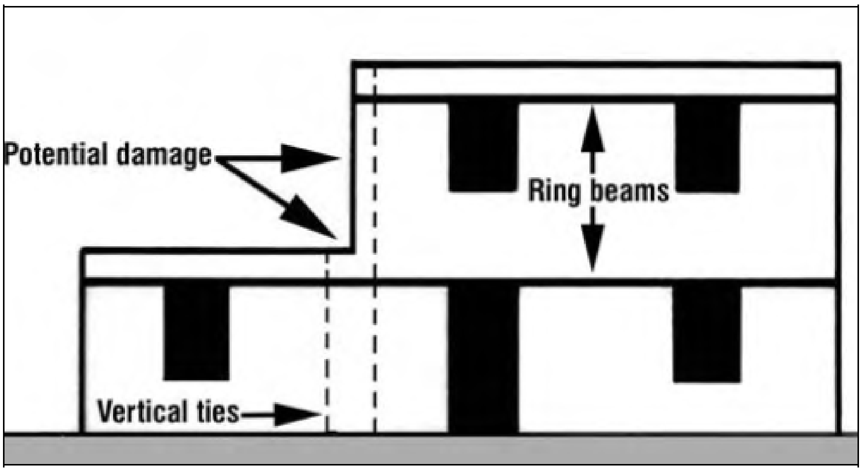


Figure 47 Vertical ties in various floors and ring beams

6.4 Simplicity

Simplicity in the ornamentation is the best approach. Large cornices, vertical or horizontal cantilevered projections, cladding materials, etc. are dangerous during earthquakes. They should be avoided.

6.5 Foundations

Certain types of foundations are more susceptible to damage than others. Isolated footing of columns can easily be subjected to differential settlement, particularly when they rest on soft soils. Mixed foundations in the same building are also not suitable. What works best in most of cases is trench foundation.

1. The minimum depth and width of foundation should be 3ft (ref. Figure 49) in case of soft soil. If the soil is hard then the depth of foundation may be limited to 1.5ft.
2. After the excavation and leveling of the earth surface, a 6 inch thick concrete pad (1:3:6) should be provided (ref. Figure 49).
3. In case of loose soil, 3 bars of half inch diameter should be provided lengthwise and half inch diameter bars should be provided widthwise at a spacing of 12 inches (ref. Figure 50).

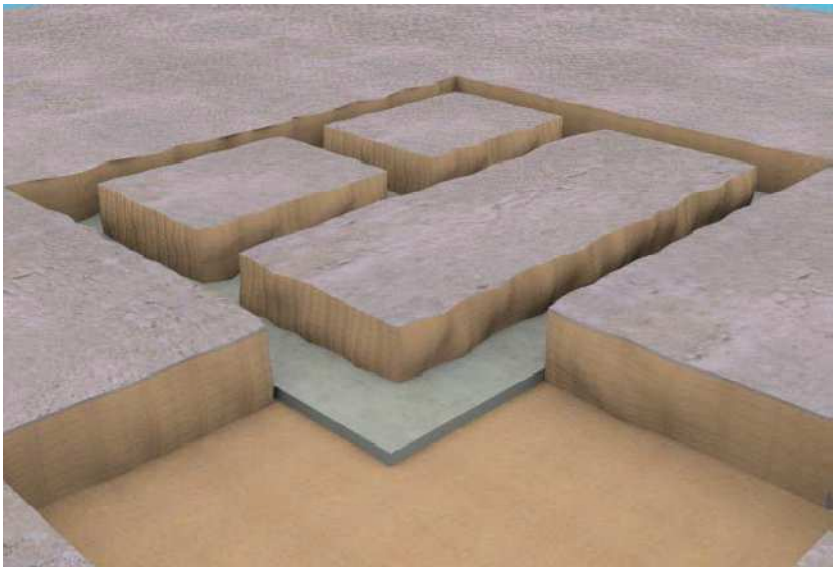


Figure 48 Strip foundation under the walls of the building

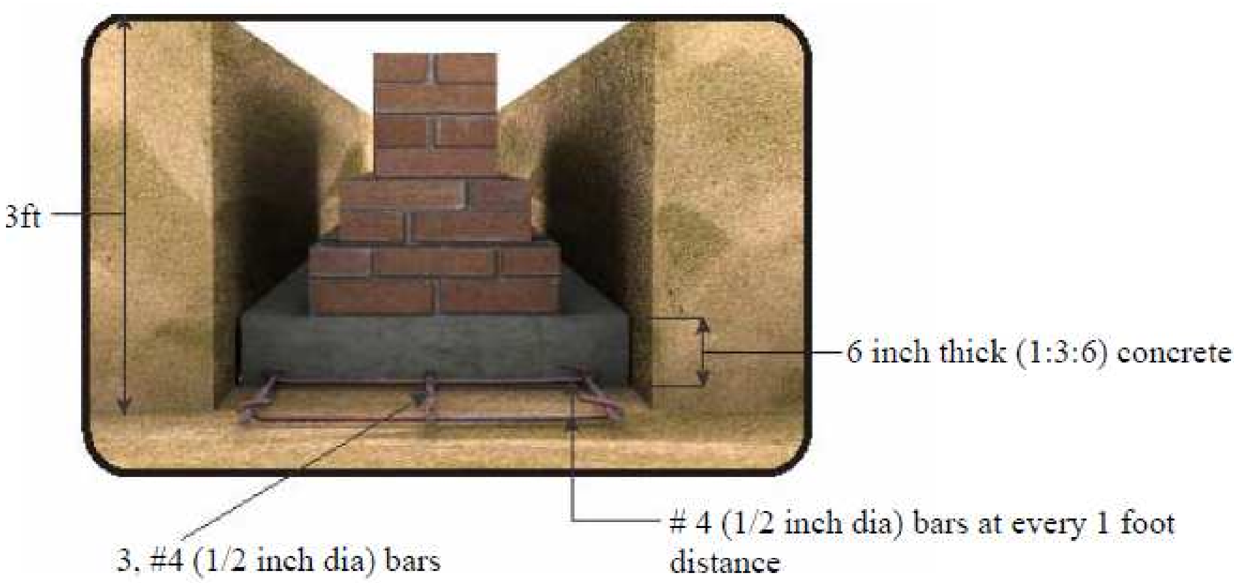


Figure 49 Foundation detail

4. Foundation of the whole building should be constructed on the same level. The foundation constructed on different levels may lead to settlement of the building (ref. Figure 51)

Figure 50 Building constructed on unleveled foundation leading to its settlement

6.6 Wall Construction:

1. The thickness of brick walls should not be less than 9 inches, while walls constructed of solid concrete blocks can be of 8 inches minimum thickness.(ref. Figure 52)
2. None of the room walls should be longer than 8m. (ref. Figure. 53)
3. The height of each storey in the building should be limited to 10 feet.
4. The mortar used in the construction of masonry walls should have 1:6 ratio, which means the use of one bag of cement with three wheelbarrows of sand (ref. Figure 52)

5. Some people prepare a large quantity of mortar and use it in several hours, which is a wrong practice. The right practice is to prepare such quantity of mortar which could be used within an hour.
6. Don't raise wall more than 1m height in a day.
7. Thickness of the mortar joint between two brick courses should not be more than 3/8 inches in any case. The use of thick mortar would result in weak walls.

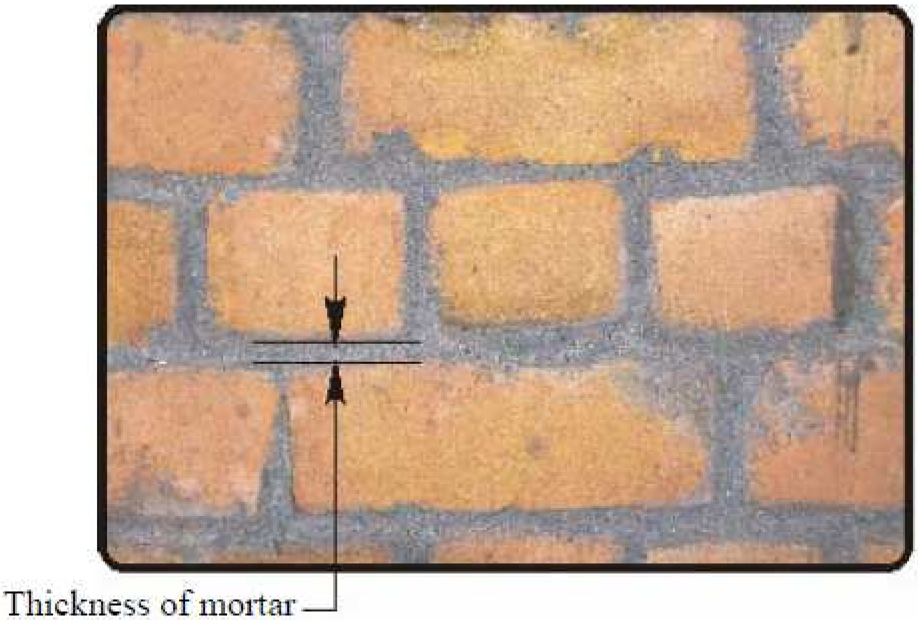


Figure 51 Brick masonry

8. Blocks should be kept soaked in water for one to two hours(?) prior to their use. In this way, bricks do not absorb the moisture from the mortar and a strong bond between the mortar and brick is ensured. Whereas concrete blocks need only to be wetted before their use.
9. Minimum 7 days curing is required for masonry work. Use clean, potable water for curing. Remember improper curing may reduce the strength of walls drastically.

6.7 Long Walls

They should be designed as shear walls to resist the ground motion in the plane of the wall. To resist the bending moment occurred by the ground motion perpendicular to the wall, they should be braced either by a buttress or by a cross wall. Any opening in a wall should follow the specifications mentioned in the next paragraph.

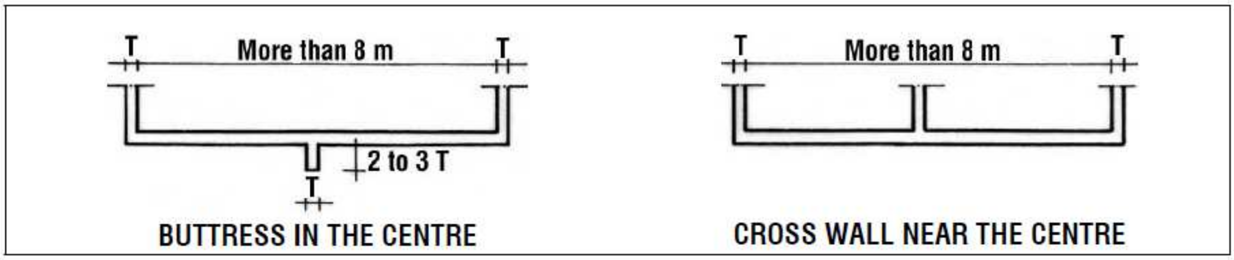


Figure 52 Long walls

6.8 Structural Integrity (Box Action)

Past earthquakes have shown that damage to masonry buildings is significantly reduced when building components are well connected and the building vibrates like a monolithic box. There is a need to provide additional elements to tie the walls together and ensure acceptable seismic performance. Structural integrity of a building can be achieved by developing a box action by ensuring good connections between all building components-foundations, walls, floors, and roof. Key requirements for the structural integrity in a masonry building are:

- Stiff foundation
- Good connection between wall and foundation
- Good connection at wall corners
- Ring beam
- Vertical ties
- Small openings
- Good connection between wall and roof

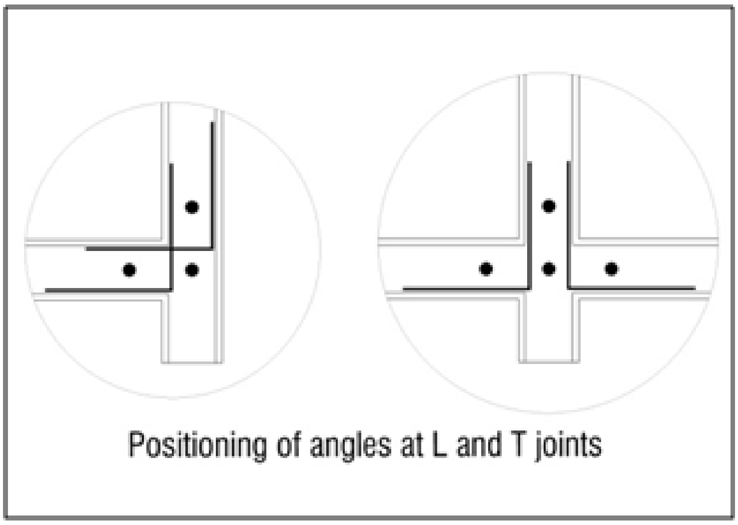


Figure 53 Connection between walls

CHAPTER VII

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 of generally 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 fiat or sloping timber roofs and little or no foundation. The classroom sizes 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 Quality of Construction Materials

7.2.1 Concrete

The concrete to be used in footings may be 1 5MPa, but in columns, beams and slabs, etc, should have a minimum crushing strength of 20 N/mm2 (20MPa) at 28 days for a 150 mm cube.

7.2.1.1 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.

7.2.1.2 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.

7.2.1.3. Sand

Sand shall consist of siliceous materials having hard strong, durable and 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 2OMPa is expected to meet strength requirements.

7.2.2 Brickwork

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

7.2.2.1 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 5.0 N/mm^2 for two and 7 N/mm^2 for three storeyed building.

7.2.2.2 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 1/4 to 1/2 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.

7.2.2.3 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.

7.2.3 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.

7.3 Quality of Construction

Performance of non-engineered buildings during past earthquakes has 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 I-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.

CHAPTER VII

MASONRY BUILDING

8.1 Building Units In Cement Mortar

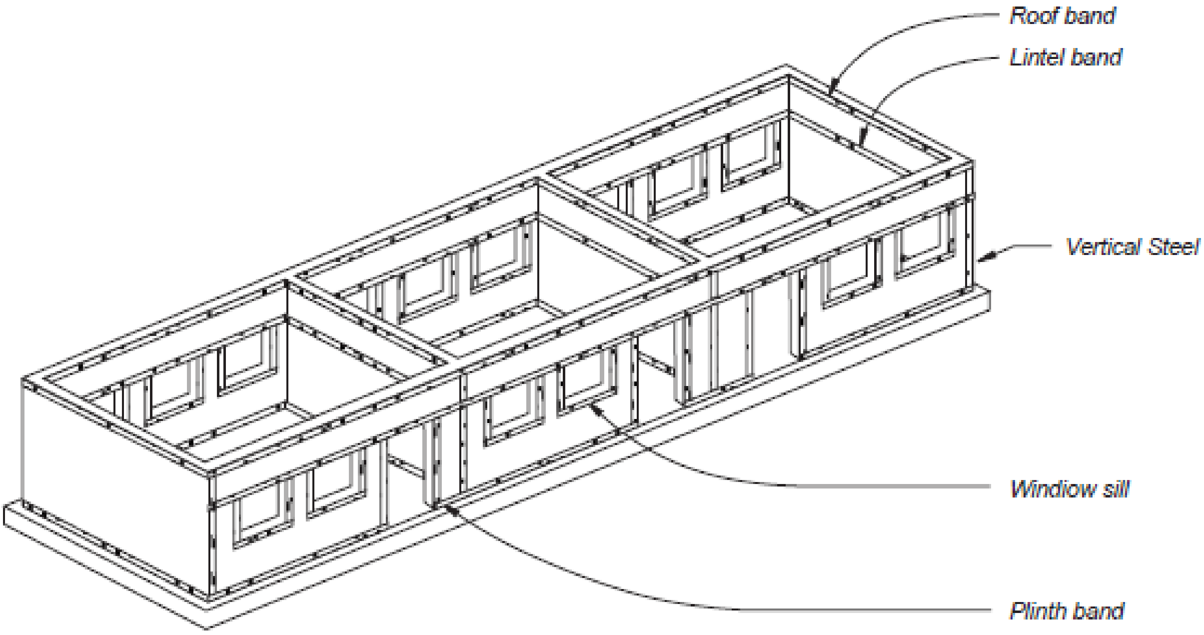
8.1.1 Improving Buildings for Seismic Safely

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:

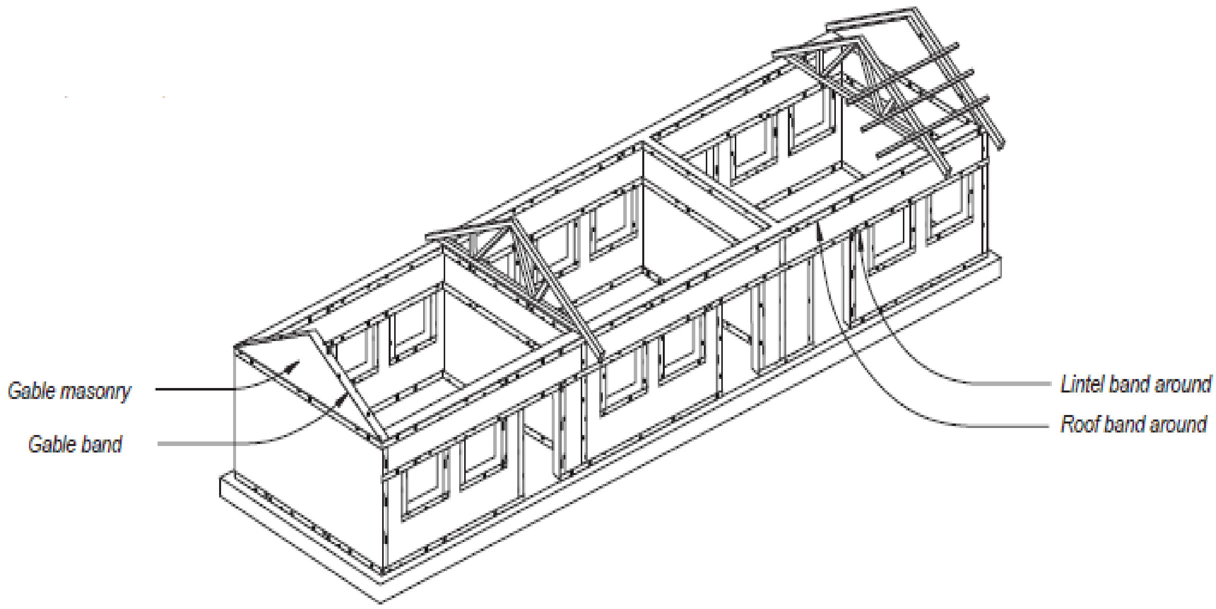
- Stitching of walls: To strengthen wall junctions by stitching as these are potentially weak point
- Bands: To avoid out of plane collapse of walls, these should be reinforced with RC bands at different levels
- Gable ends: Reinforcement around gables with gable band and connection to purlins
- Floor 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.

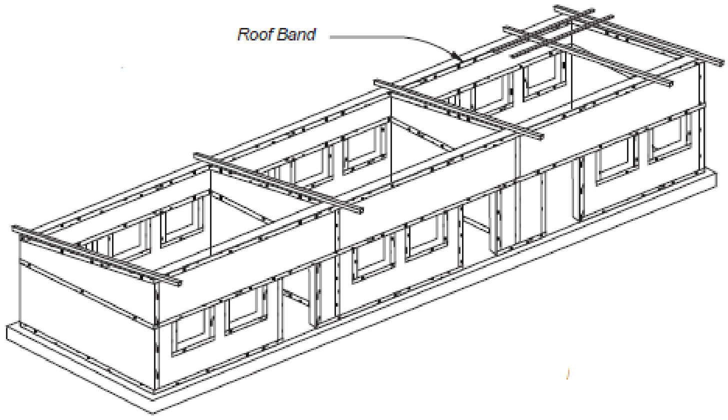
Figure 55 shows the critical locations for providing horizontal and vertical reinforcement in walls. The amount and actual provision of reinforcement depends upon and varies with the combination of design seismic conditions as categorized in Table 4.2 and as detailed in the following sections wherein 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.



a) Flat roof building



b) Building with pitched roof



c) Building with lean-to roof

Figure 54 Locations for reinforcing

8.1.2 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 750 mm 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.

8.1.3 Walls

8.1.3.1 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 supports 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 null.

d. The vertical distance between two openings should not be less than 600mm nor less than half the width of the smaller opening width. Figure 56 illustrates the above points.

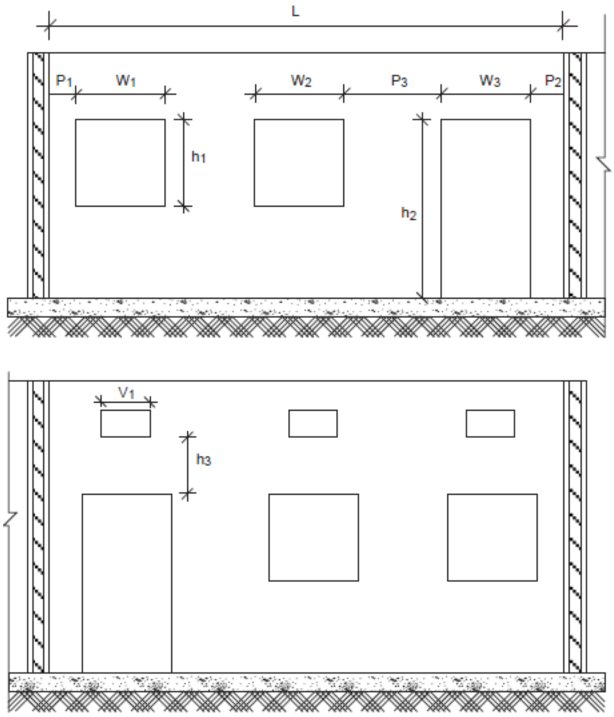


Figure 55 Opening

Rule 1: P1 > 0.25 h1 and P2> 025 h2

Rule 2: W1+W2+W3 <05L for one storey building
<0.42L for two storey building
<0.33L for three storey building

Rule 3:P3> 0.5h2

Rule 4: h3> 600mm or> 0.5 V1 (whichever is more)

8.1.3.2 Reinforcement of Opening

Where openings do not comply with the above geometrical requirements they should be strengthened as shown in Figure 57 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.

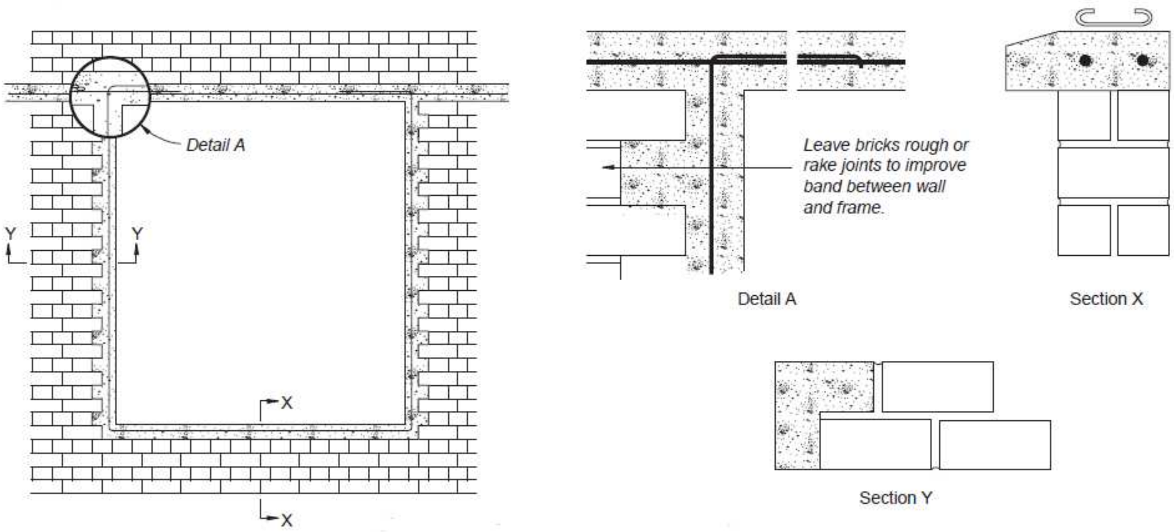


Figure 56 Reinforcing of openings

8.1.3.3 Wall Reinforcement

- 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 Figure 58 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 Figure 59.

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. Figure 60, a,b) are placed in every 500-700 mm interval and taken into the walls to sufficient length so as to provide fill bond strength. These bars can be embedded into one brick course thick cement concrete as shown in Figure 60c. Alternatively, these bars can be replaced with 3. 25mm galvanized wires or chicken mesh (ref. Figure 62) embedded into mortar layer. These dowels or chicken mesh do not serve to reinforce the walls in horizontal bending except near the junctions.

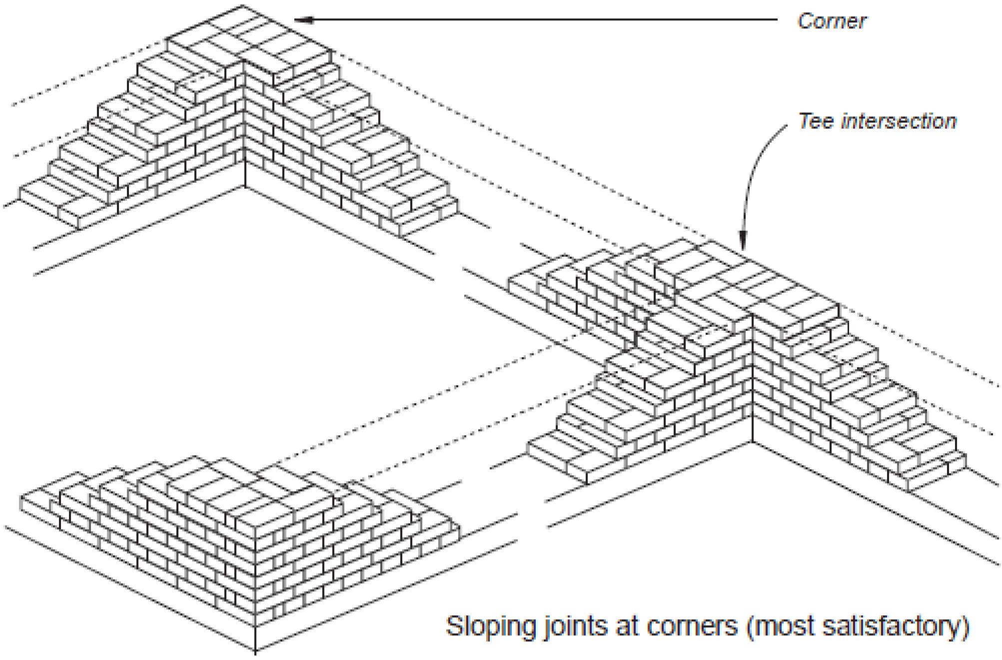


Figure 57 Staggered toothed wall joint

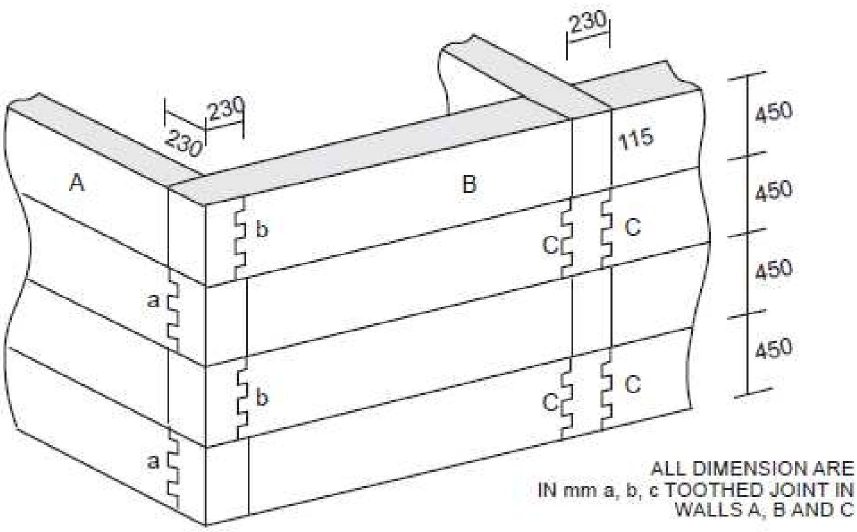


Figure 58 Stepped wall joint stitching

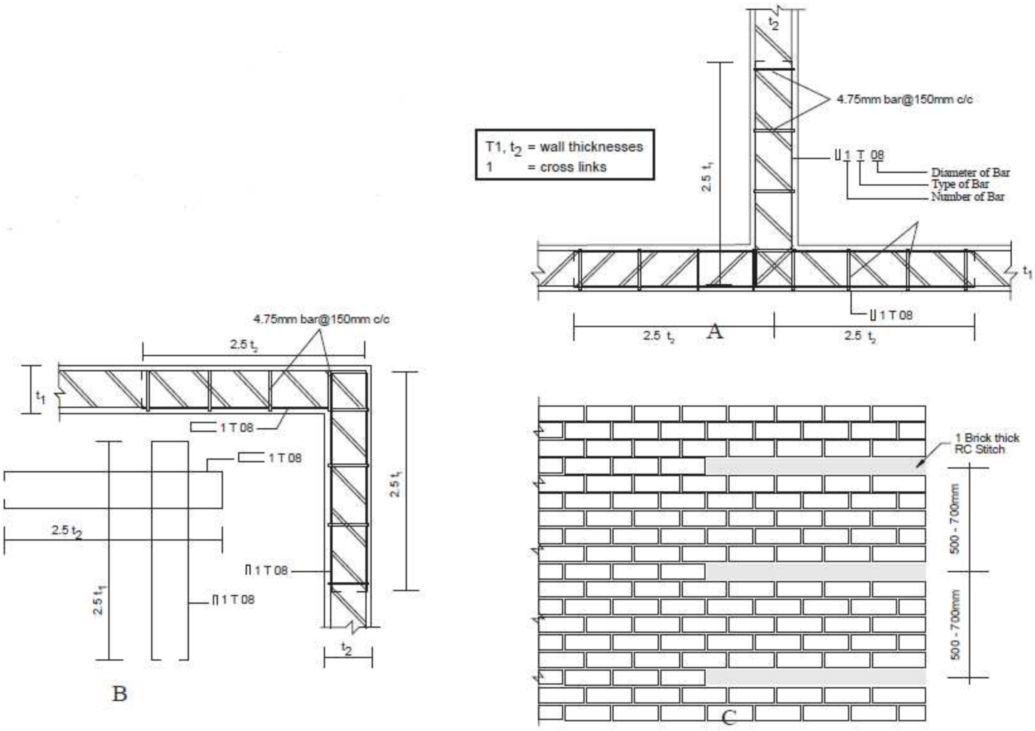


Figure 59 Joint strengthening by dowel reinforcement placed in one joint

- Bands

A continuous band, also called 'ring beam' or 'collar beams 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 Figure 63.

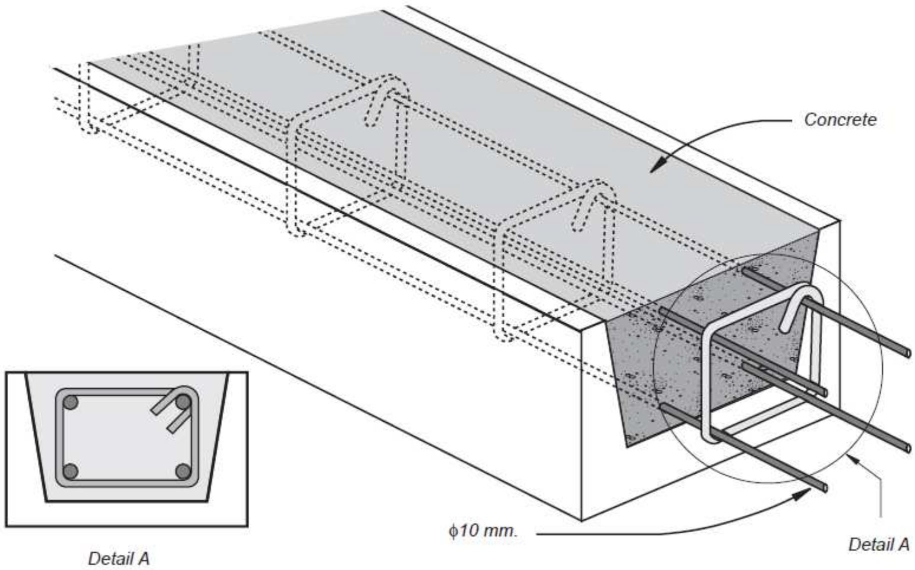


Figure 60 Section of Horizontal band

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 amid 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 continuous with the cave 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 75 mm 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 Figure 64.

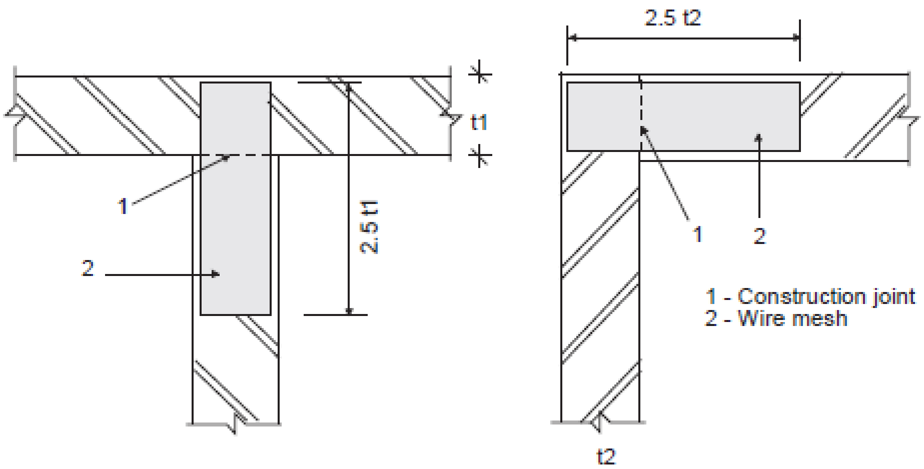


Figure 61 Joint strengthening by wire fabric

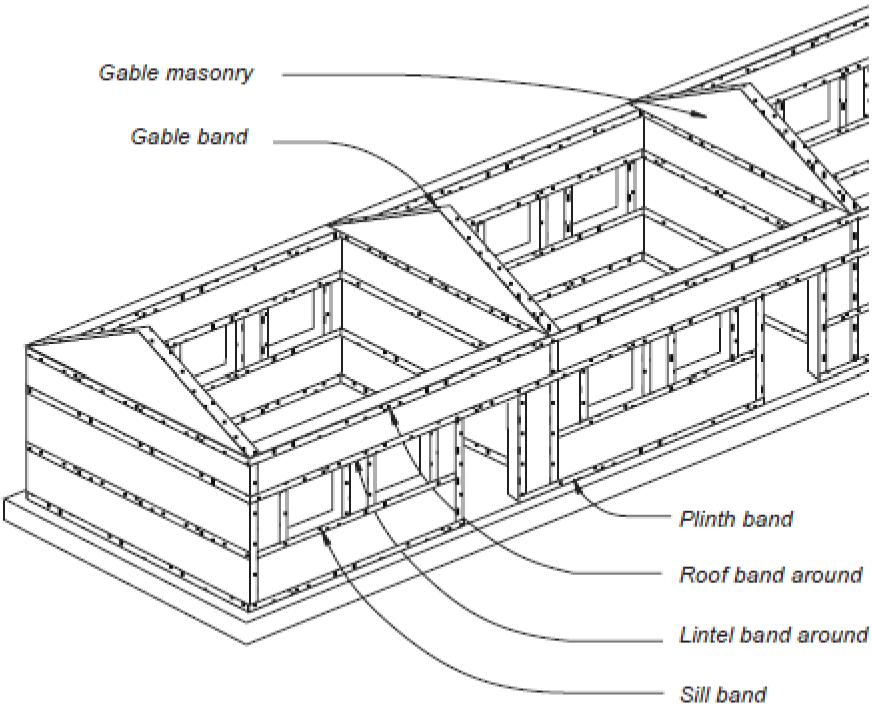


Figure 62 Bands at different levels

Figure 63 Reinforced concrete band

8.1.3.1.1 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	NO. of bars	Diameter	No. of bars	Diameter	No. of bar	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. 75nuu 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 embedded in band itself.

- Vertical Reinforcement

Vertical bars should be provided at junctions of walls, i.e., 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 Figure 65 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 Figure 65.

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.

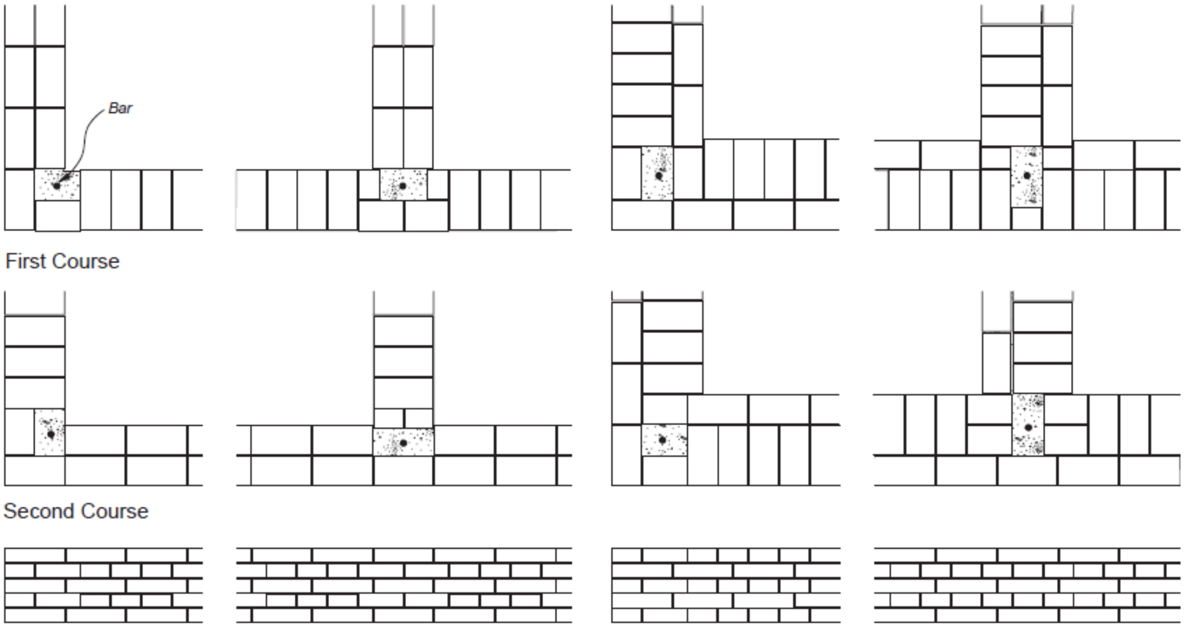


Figure 64 Vertical reinforcement in brick wall

Details of vertical steel placement in door/window jambs is shown in Figure 57.

8.2 Low Strength Masonry

8.2.1 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.

8.2.2 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 categories III. Dressed stones can be treated as rectangular blocks.

• Random nibble 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.

8.2.3 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

8.2.4 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/cm2)
• 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

8.2.5 Walls

<u>8.2.5.1 Thickness</u>

Brick wall: The minimum thickness of rectangular block wall shall be made 1.5 units, that is, 300 mm for 200 nun 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 Figure 66.

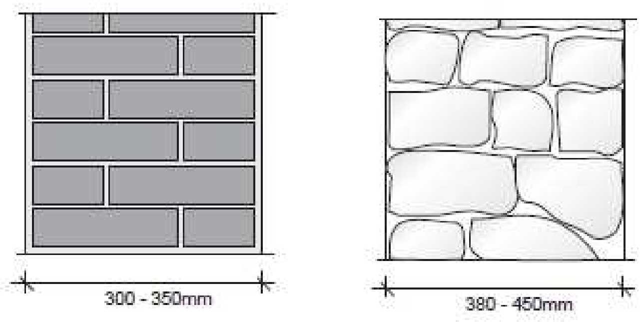


Figure 65 Cross section of stone wall

8.2.5.2 Buttresses

Buttress should be constructed by projecting walls beyond the corner and T-junctions and wherever wall length is more than 6 in. It helps to retain the integral action of walls. The buttress at junctions also facilitates the connection of collar beams with each other (ref. Figure 67). 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.

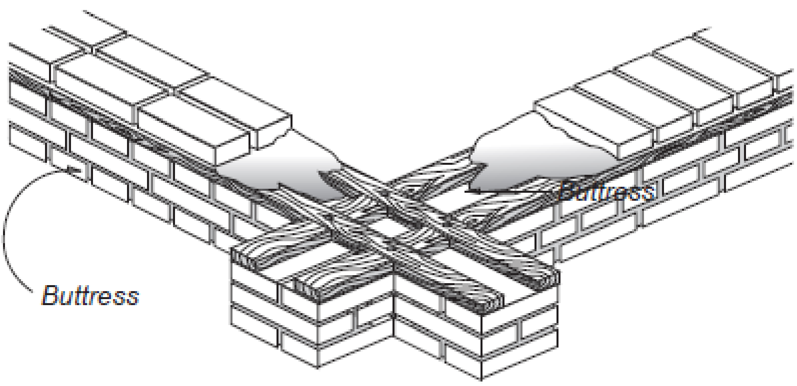


Figure 66 Use of buttress

8.2.5.3 Door and Window Openings

- 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. Figure 68).

- 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 in. The sum of the widths of openings in a wall should not exceed 1/3 of the total wall length (ref. Figure 69).

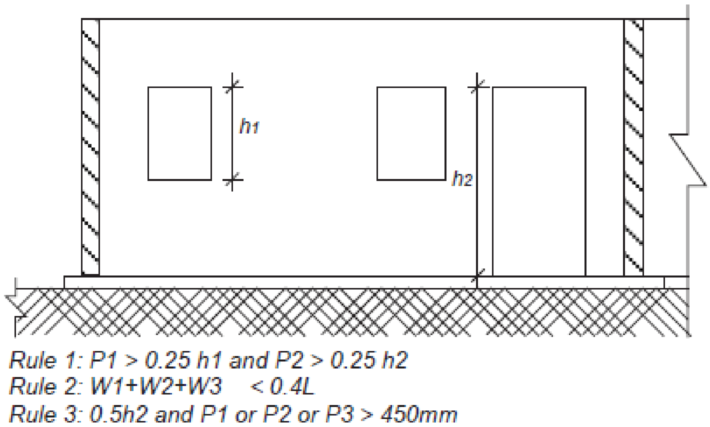


Figure 67 Opening sizes in bearing walls constructed of rectangular blocks

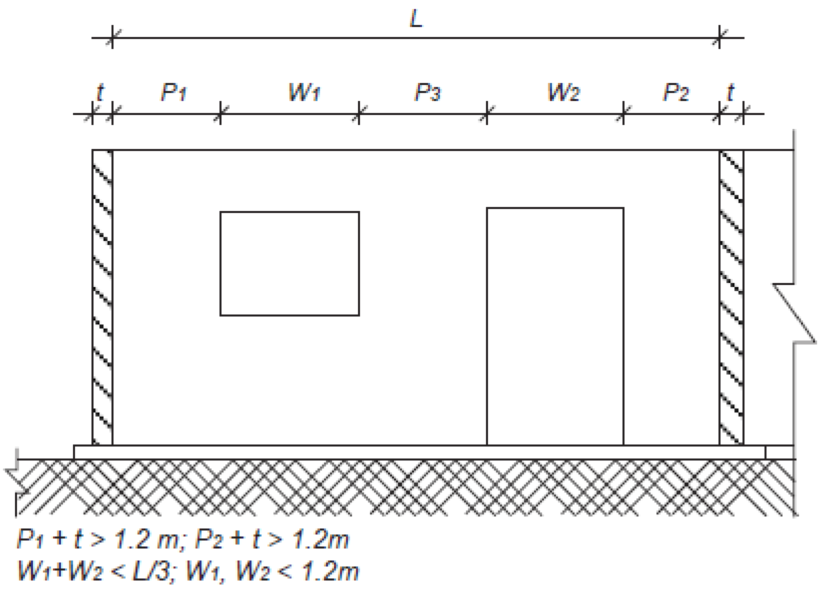


Figure 68 Opening sizes in bearing walls constructed of random nibble

8.2.5.4 Construction

- Block masonry

Problems associated with block masonry in mud mortar are very similar to that in cement mortar. For brick or masonry dressed stone construction in mud mortar, details discussed in Section 8.1.3.3 can be adopted.

- 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 Figure 70.

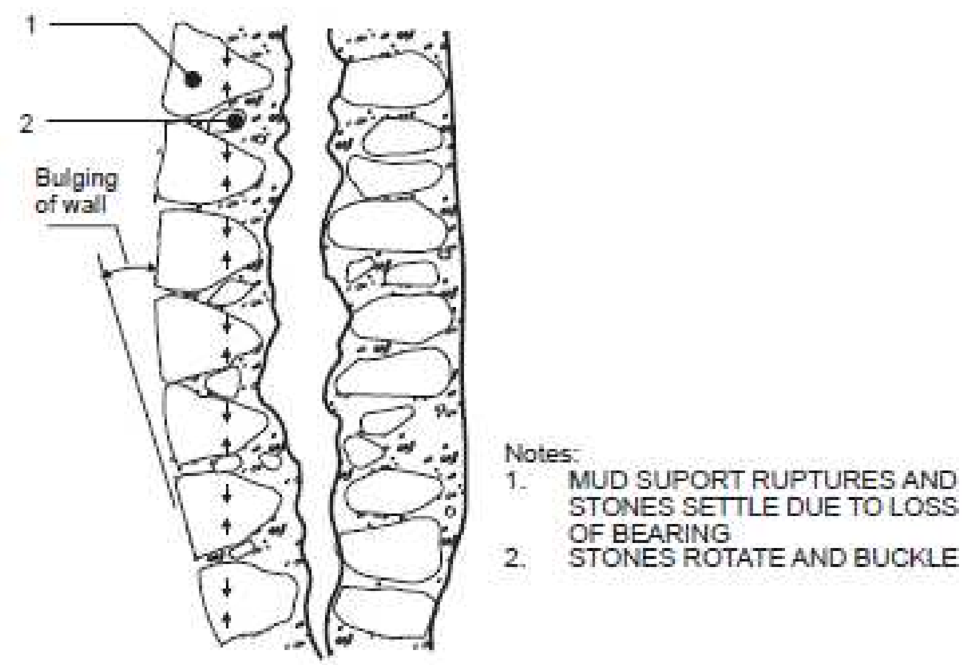


Figure 69 Stone wall delamination with buckled wythes

8.3 CSEB Building

8.3.1 Definition

Compressed Stabilized Earth Block (CSEB) is the improved form of one of the oldest, easy locally available and socially accepted earth materials used in building construction. It satisfies most or all of the above mentioned requirements very well, especially in developing countries like Nepal. It offers numerous benefits, including energy efficiency, the use of natural non-toxic construction materials that are resistant to earthquakes, fire and pests. This construction is comparatively low cost and easy construction comparing with modern conventional building methods.

8.3.2 Design & Construction

1. Structural safety of buildings
    - Design and construction as per National Building Code
    - Safe against Earthquake and strong storms
    - Construction supervision by qualified Engineers/Sub-Engineers.
2. Child-friendly design & construction.
3. Environment-friendly design & construction
    - Enforcement of National Environmental Guidelines for School Improvement and facility Management in Nepal
4. Inclusive design & construction for disables
    - Ramp construction for wheel chair movement
5. Community contribution in facility development
    - Creates ownership feeling
    - Ensures sustainability of the created facilities
    - Ensures regular repair & maintenance

8.3.3 8.3.3 Earthquake Safety Measures

•Vertical and Horizontal Reinforcement at Corners and Junctions
•RCC band at DPC, Lintel and Gable levels
•Wind Bracing for roof protection
•Tubular steel frame structure
•Gable height reduced by providing CGI sheet panel
•Buttress walls

8.3.4 Basic Design Guidelines for CSEB

8.3.2.1General principles for a good design
- “Good boots and a good hat”.

That means built a good basement:
(Minimum 25-cm high)

And good overhangs:
(Minimum 25 cm wide or better 50 cm)

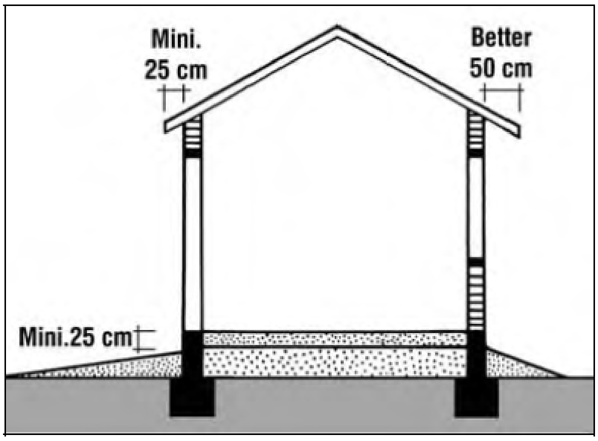


Figure 70 Roof and foundation

8.3.2.2 Compressive strength for earthquake resistant CSEB

- Design the walls (thickness + stability) according to the load bearing capacity of **wet CSEB.**
- The minimum admissible crushing load of HI CSEB should be 25 Kg/cm^2 under wet conditions. (After 3 days immersion)
- Keep at least a safety factor of 10 from the wet crushing strength (σ_c) for HI CSEB.

Example: A HI CSEB has a σ_c wet of $25/kg/cm^2$: the maximum load bearing for the basement will be: $25/10 = 2.5kg/cm^2$

8.3.2.3 Shear strength

- Avoid any major difference of load bearing in CSEB walls: especially with a different floor height.

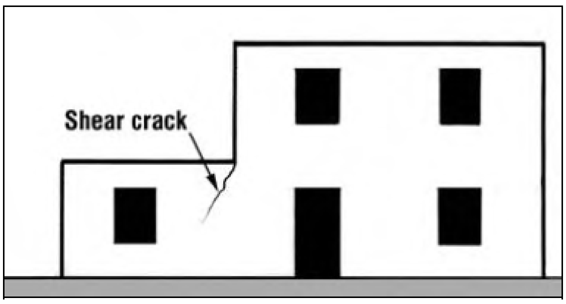


Figure 71 Stress concentration

8.3.2.4 Water absorption and erosion.

- Avoid any concentration or accumulation of water in any part or surrounding of the building.
- Avoid any run off of water on any part of the building (i.e. leakage)

8.3.2.5 Module of blocks
- Design the building according to the module of blocks.
The module of the block is its nominal size + the mortar thickness.

8.3.2.6 How to dimension a building
A strong and clean block-work must follow the block module. The dimension of the building should fit with the block module theory:

A = Outside to Outside = (X . M) - J = (X . module) – 0.5 cm
B = Inside to Inside = (X . M) + J = (X . module) + 0.5 cm
C = Outside to Inside = (X . M) = (X . module)

M= module of the block = the block dimensions + the mortar joint thickness.
J = joint thickness

The module for the Auram block 240 is 24 cm and the joint thickness is 5 mm, which is the optimum joint thickness for interlocking blocks.

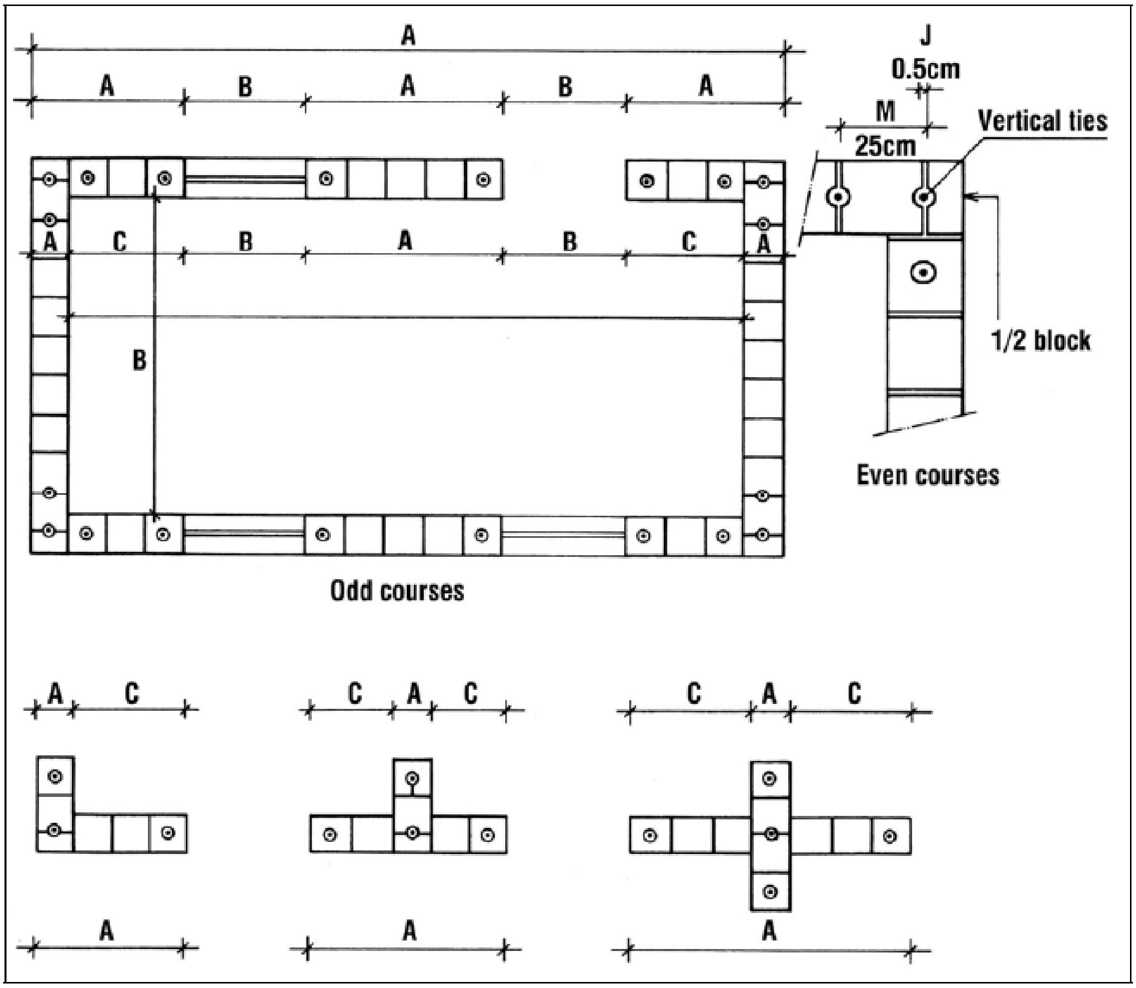


Figure 72 Dimensioning a building

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