EARTHQUAKE SAFETY CONSTRUCTION: FROM GUIDELINES TO PRACTICE

Experiences from School Earthquake Safety Initiative Project

Chapter 1. Introduction

Earthquake damages residential buildings and infrastructures alike. The damages witnessed in the past tell a compelling story that among the damages caused to infrastructures, damages to school facilities are disproportionately high. Many schools in the earthquake prone regions are vulnerable to earthquakes and are susceptible to severe damages often killing the students and teachers during an earthquake. In addition to the already existing vulnerable schools, many schools are being constructed without proper compliance to earthquake safety standards. The Millennium Development Goals (MDGs) envisage education for all by 2015. In order to achieve this target, there is a large pressure to build thousands of classrooms in many of the developing countries and non-compliance to the safety standards means vulnerable schools are increasing. As witnessed in the past, the school buildings, which are supposed to provide education to children, are also the cause of death in many disasters.

Recently in May 2008, Wenchuan Earthquake in Sichuan, China killed about 7,000 students trapped in damaged school buildings. When an earthquake hit Spitak area of Northern Armenia during school hours in 1988, many children lost their lives due to collapse of school buildings. For example, 285 children out of 302 in total died at one school. This resulted in almost 2/3 of total deaths of 25,000 were children and adolescents.

In the 1999 Chi-Chi Earthquake, Taiwan 43 schools in Nantou and Taichung area were completely destroyed and a total of 700 schools nationwide were damaged to different extent. The 2001 Gujarat Earthquake in India caused damages to over 11,600 schools (World Bank 2001). Another case is 2005 Kashmir earthquake. The earthquake occurred as the school day was beginning and led to death of 18,000 children trapped in damaged schools. The Kashmir earthquake resulted in collapse of 6,700 schools in North-West Frontier Province and 1,300 in Pakistan-administered Kashmir. Recognizing that school age children spend majority of their waking hours at school, there is always a high possibility that an earthquake struck while they are at school.

Therefore, school buildings need to be protected from disasters as they save life of children and they can also help to work as shelter in post disaster scenario. Moreover, resilient schools are effective medium for disseminating disaster risk reduction awareness in the communities, can act as center of learning, can be instrumental in transfer of technology to the communities and have significant role to build disaster resilient communities. The activities like retrofitting of school and new construction with safety measures can spread message to the community of the importance of resilient buildings to reduce disaster impact.

The objective of this publication is, therefore, to provide the necessary concept and know-how to the communities, local construction workers and junior engineers for earthquake resistant construction and the experiences from school earthquake retrofitting during the SESI project. It is also targeting government officials, partner organizations and trainers and may be used as technical reference. It will be the basis of training and capacity building.

The publication starts with the basic information of earthquake and how the buildings behave during an earthquake. The manuals for earthquake safety constructions, which is developed by SESI project counterparts in India, Fiji, and Indonesia will be presented in the second section. The last section is the experiences of seismic school retrofitting in four countries: India, Indonesia, Fiji and Uzbekistan.

Chapter 2. Earthquake and Behavior of Buildings during Earthquake

2.1 Basic information of earthquake

2.1.1 The earth and its interior

Long time ago, a large collection of material masses coalesced to form the Earth. Large amount of heat was generated by this fusion, and slowly as the Earth cooled down, the heavier and denser materials sank to the center and the lighter ones rose to the top. The differentiated Earth consists of the Inner Core (radius ~1290km), the Outer Core (thickness ~2200km), the Mantle (thickness ~2900km) and the Crust (thickness ~5 to 40km). Figure 1 shows these layers. The Inner Core is solid and consists of heavy metals (e.g., nickel and iron), while the Crust consists of light materials (e.g., basalts and granites). The Outer Core is liquid in form and the Mantle has the ability to flow.

At the Core, the temperature is estimated to be ~2500°C, the pressure ~4 million atmospheres and density ~13.5 gm/cc; this is in contrast to ~25°C, 1 atmosphere and 1.5 gm/cc on the surface of the Earth.

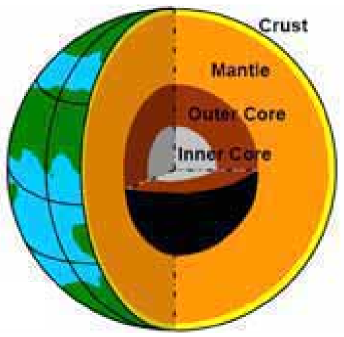


Figure 1: Inside the Earth

2.1.2 The circulations

Convection currents develop in the viscous Mantle, because of prevailing high temperature and pressure gradients between the Crust and the Core, like the convective flow of water when heated in a beaker (Figure 2). The energy for the above circulations is derived from the heat produced from the incessant decay of radioactive elements in the rocks throughout the Earth's interior. These convection currents result in a circulation of the earth's mass; hot molten lava comes out and the cold rock mass goes into the Earth. The mass absorbed eventually melts under high temperature and pressure and becomes a part of the Mantle, only to come out again from another location, someday. Many such local circulations are taking place at different regions underneath the Earth's surface, leading to different portions of the Earth undergoing different directions of movements along the surface.

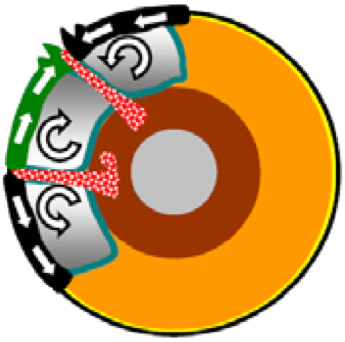


Figure 2: Local Convective Currents in the Mantle

2.1.3 Plate tectonics

The convective flows of Mantle material cause the Crust and some portion of the Mantle, to slide on the hot molten outer core. This sliding of Earth's mass takes place in pieces called Tectonic Plates. The surface of the Earth consists of seven major tectonic plates and many smaller ones (Figure 3). These plates move in different directions and at different speeds from those of the neighboring ones. Sometimes, the plate in the front is slower; then, the plate behind it comes and collides (and mountains are formed). On the other hand, sometimes two plates move away from one another (and rifts are created). In another case, two plates move side-by-side, along the same direction or in opposite directions. These three types of inter-plate interactions are the convergent, divergent and transform boundaries (Figure 4), respectively. The convergent boundary has a peculiarity (like at the Himalayas) that sometimes neither of the colliding plates wants to sink. The relative movement of these plate boundaries varies across the Earth; on an average, it is of the order of a couple to tens of centimeters per year.

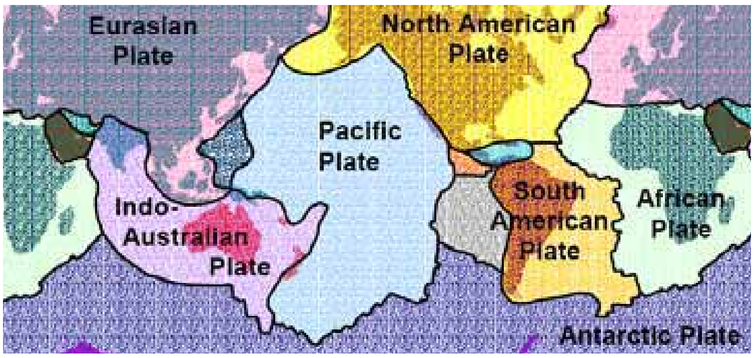


Figure 3: Major Tectonic Plates on the Earth's surface

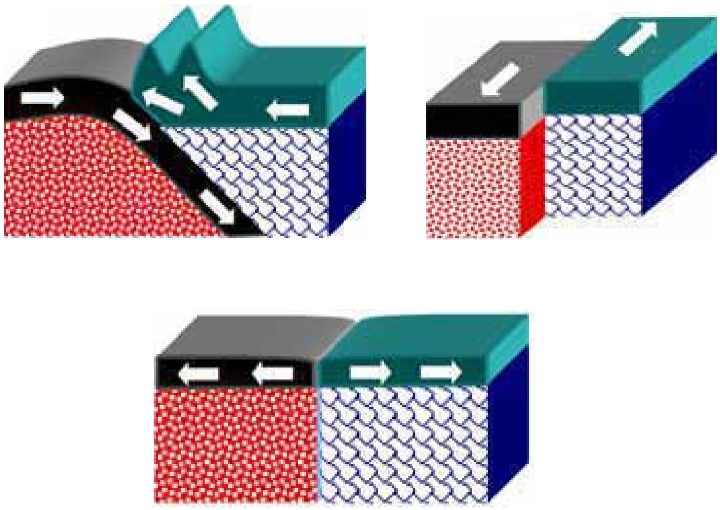


Figure 4: Types of Inter-Plate Boundaries

2.1.4 The earthquake

Rocks are made of elastic material, and so elastic strain energy is stored in them during the deformations that occur due to the gigantic tectonic plate actions that occur in the Earth. But, the material contained in rocks is also very brittle. Thus, when the rocks along a weak region in the Earth's Crust reach their strength, a sudden movement takes place there (Figure 5); opposite sides of the fault (a crack in the rocks where movement has taken place) suddenly slip and release the large elastic strain energy stored in the interface rocks.

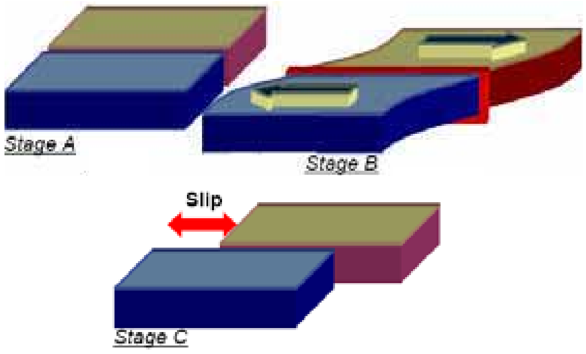


Figure 5: Elastic Strain Build-Up and Brittle Rupture

The sudden slip at the fault causes the earthquake, a violent shaking of the Earth when large elastic strain energy released spreads out through seismic waves that travel through the body and along the surface of the Earth. And, after the earthquake is over, the process of strain build-up at this modified interface between the rocks starts all over again (Figure 6). Earth scientists know this as the Elastic Rebound Theory. The material points at the fault over which slip occurs usually constitute an oblong three-dimensional volume, with its long dimension often running into tens of kilometers.

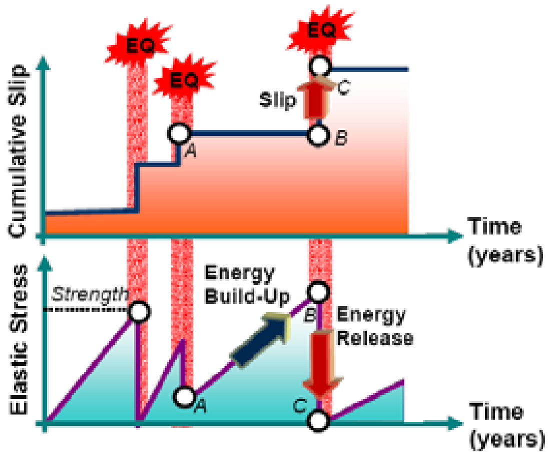


Figure 6: Elastic Rebound Theory

2.1.5 Types of earthquakes and faults

Most earthquakes in the world occur along the boundaries of the tectonic plates and are called Interplate Earthquakes (e.g., 1897 Assam (India) earthquake). A number of earthquakes also occur within the plate itself away from the plate boundaries (e.g., 1993 Latur (India) earthquake); these are called Intra-plate Earthquakes. In both types of earthquakes, the slip generated at the fault during earthquakes is along both vertical and horizontal directions (called Dip Slip) and lateral directions (called Strike Slip) (Figure 7), with one of them dominating sometimes.

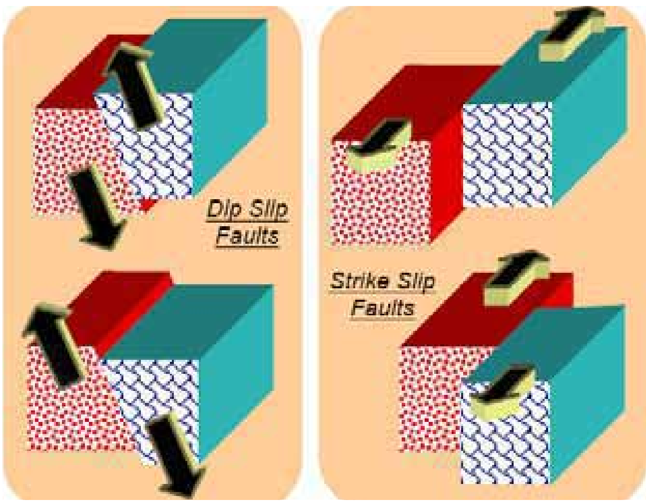


Figure 7: Type of Faults

2.1.6 Seismic waves

The Earthquake releases elastic energy, which travels in the rock medium in the form of waves. One could classify such waves into two types, namely body waves and surface waves. While the body waves travel through the body of the medium (i.e. rock), the surface waves travel along the surface of a boundary or along a discontinuity in the medium. The Body waves are two types P-waves (Primary waves) S-waves (Secondary waves). The surface waves are also two types: Rayleigh waves and love waves. Body waves have spherical wave front.

Surface waves have cylindrical wave front. Hence, body waves dissipate faster than the surface waves. Thus at far off places no body waves will be recorded. In general Vp>Vs>Vl>Vr. When body waves (P- and S-waves) hit the ground (i.e. free boundary) these are reflected back such that at the ground the motion is amplified almost twice. Hence shaking in mines is much less than that on the ground surface. S-waves and love waves cause transverse motion of foundations. Hence these are more effective in damaging the structures.

Earthquake waves are affected by both soil conditions and topography. For instance, in alluvium or water filed soils. The seismic wave amplitude may be either increased or decreased as they pass to the surface from the more rigid basement rock. At the top or bottom of a ridge, shaking may intensify depending on the direction from which the waves are coming and whether the wavelengths are long or short.

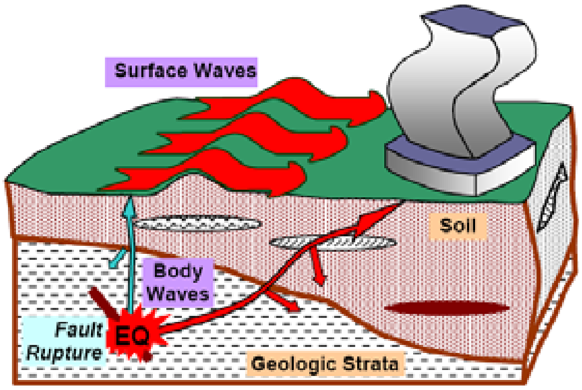


Figure 8: Arrival of Seismic Waves at a Site

2.1.7 Terminology

a. Epicenter

The point on the fault where slip starts is the Focus or Hypocenter, and the point vertically above this on the surface of the Earth is the Epicenter (Figure 1). The depth of focus from the epicenter, called as Focal Depth, is an important parameter in determining the damaging potential of an earthquake. Most of the damaging earthquakes have shallow focus with focal depths less than about 70km. Distance from epicenter to any point of interest is called epicentral distance.

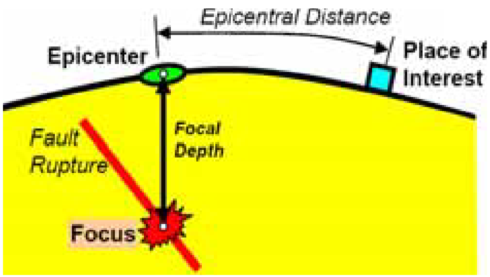


Figure 9: Basic terminologies

A number of smaller size earthquakes take place before and after a big earthquake (i.e., the Main Shock). Those occurring before the big one are called Foreshocks, and the ones after are called Aftershocks.

b. Magnitude

Magnitude is a quantitative measure of the actual size of the earthquake. Professor Charles Richter noticed that (a) at the same distance, seismograms (records of earthquake ground vibration) of larger earthquakes have bigger wave amplitude than those of smaller earthquakes; and (b) for a given earthquake, seismograms at farther distances have smaller wave amplitude than those at close distances. These prompted him to propose the now commonly used magnitude scale, the Richter Scale. It is obtained from the seismograms and accounts for the dependence of waveform amplitude on epicentral distance. This scale is also called Local Magnitude scale. There are other magnitude scales, like the Body Wave Magnitude, Surface Wave Magnitude and Wave Energy Magnitude. These numerical magnitude scales have no upper and lower limits; the magnitude of a very small earthquake can be zero or even negative.

Earthquakes are often classified into different groups based on their size (Table 1). Annual average number of earthquakes across the Earth in each of these groups is also shown in the table; it indicates that on an average one Great Earthquake occurs each year.

Table 1: Table 1: Global occurrence of earthquakes

Group	Magnitude	Annual Average Number
Great	8 and higher	1
Major	7 – 7.9	18
Strong	6 – 6.9	120
Moderate	5 – 5.9	800
Light	4 – 4.9	6,200 (estimated)
Minor	3 – 3.9	49,000 (estimated)
Very Minor	< 3.0	M2-3: ~1,000/day; M1-2: ~8,000/day

c. Intensity

Intensity is a qualitative measure of the actual shaking at a location during an earthquake, and is assigned as Roman Capital Numerals. There are many intensity scales. Two commonly used ones are the Modified Mercalli Intensity (MMI) Scale and the MSK Scale. Both scales are quite similar and range from I (least perceptive) to XII (most severe). The intensity scales are based on three features of shaking – perception by people and animals, performance of buildings, and changes to natural surroundings.

d. Magnitude versus Intensity

Magnitude of an earthquake is a measure of its size. For instance, one can measure the size of an earthquake by the amount of strain energy released by the fault rupture. This means that the magnitude of the earthquake is a single value for a given earthquake. On the other hand, intensity is an indicator of the severity of shaking generated at a given location. Clearly, the severity of shaking is much higher near the epicenter than farther away. Thus, during the same earthquake of a certain magnitude, different locations experience different levels of intensity.

2.2 Behavior of Buildings during Earthquake

2.2.1 Inertia forces in structures

Earthquake causes shaking of the ground. So a building resting on it will experience motion at its base. From Newton's First Law of Motion, even though the base of the building moves with the ground, the roof has a tendency to stay in its original position. But since the walls and columns are connected to it, they drag the roof along with them (Figure 10).

This is much like the situation that you are faced with when the bus you are standing in suddenly starts; your feet move with the bus, but your upper body tends to stay back making you fall backwards.

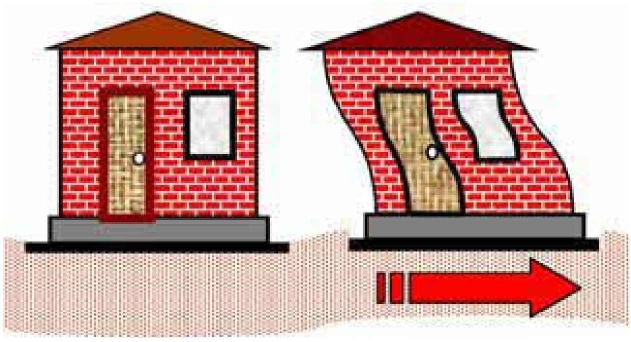


Figure 10: Effect of Inertia in a building when shaken at its base

This tendency to continue to remain in the previous position is known as inertia. In the building, since the walls or columns are flexible, the motion of the roof is different from that of the ground. Structures designed for gravity loads, in general, may not be able to safely sustain the effects of horizontal earthquake shaking.

Hence, it is necessary to ensure adequacy of the structures against horizontal earthquake effects. These lateral inertia forces are transferred by the floor slab to the walls or columns, to the foundations, and finally to the soil system underneath. So, each of these structural elements (floor slabs, walls, columns, and foundations) and the connections between them must be designed to safely transfer these inertia forces through them. Walls or columns are the most critical elements in transferring the inertia forces.

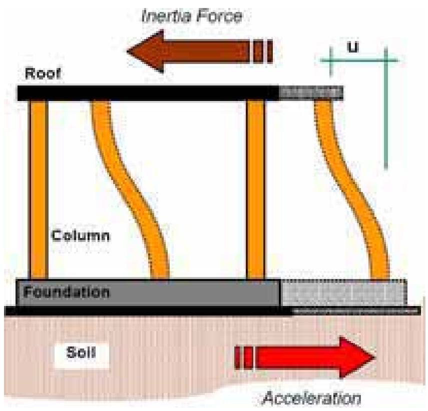


Figure 11: Inertia force and relative motion within a building

2.2.2 Torsion

Twist in buildings, called torsion by engineers, makes different portions at the same floor level to move horizontally by different amounts. This induces more damage in the columns and walls on the side that moves more. Many buildings have been severely affected by this excessive torsional behavior during past earthquakes. It is best to minimize (if not completely avoid) this twist by ensuring that buildings have symmetry in plan (i.e., uniformly distributed mass and uniformly placed vertical members). If this twist cannot be avoided, special calculations need to be done to account for this additional shear forces in the design of buildings. But, for sure, buildings with twist will perform poorly during strong earthquake shaking.

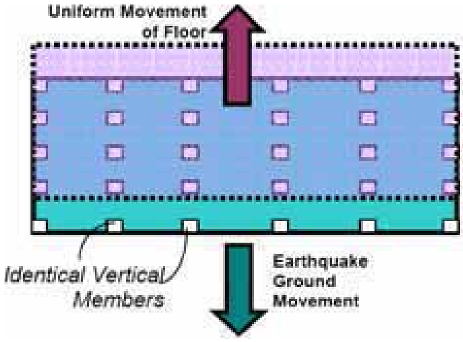


Figure 12: Identical vertical members placed uniformly in plan of building cause all points on the floor to move by same amount

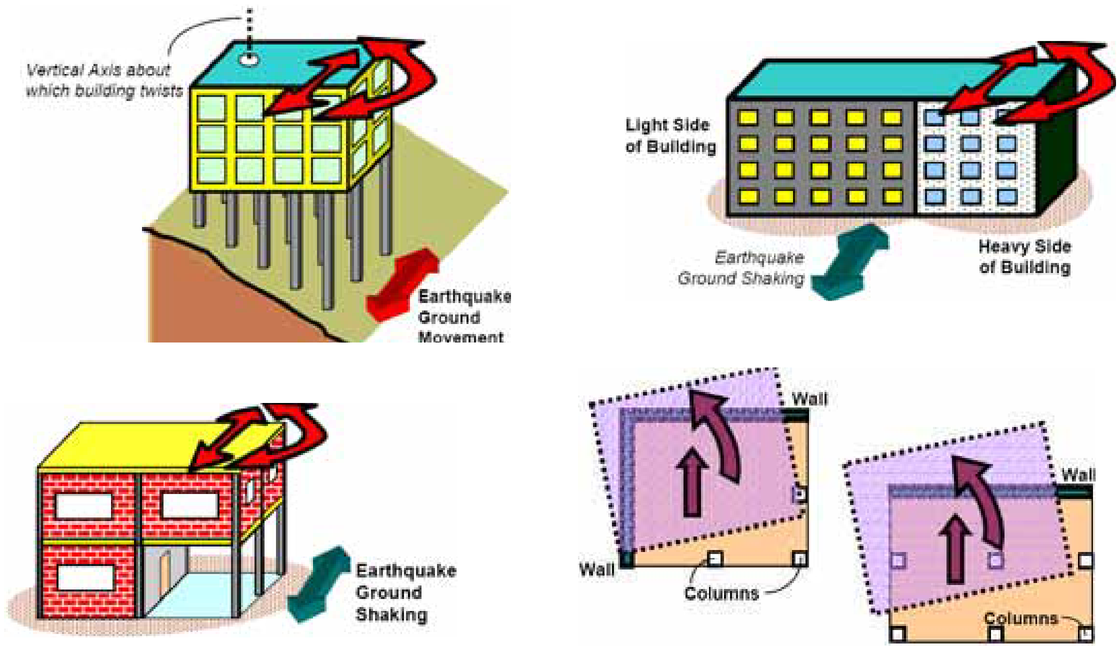


Figure 13: Types of Building Twists during Earthquake

2.2.3 Ductility

Formally, ductility refers to the ratio of the displacement just prior to ultimate displacement or collapse to the displacement at first damage or yield. Some materials are inherently ductile, such as steel, wrought iron and wood. Other materials are not ductile (this is termed brittle), such as cast iron, plain masonry, adobe or concrete, that is, they break suddenly, without warning. Brittle materials can be made ductile, usually by the addition of modest amounts of ductile materials, Such as wood elements in adobe construction, or steel reinforcing in masonry and concrete constructions. For these ductile materials to achieve a ductile effect in the overall behavior of the component, they must be proportioned and placed so that they come in tension and are subjected to yielding. Thus, a necessary requirement for good earthquake-resistant design is to have sufficient ductile materials at points of tensile stresses.

Masonry can carry loads that cause compression (i.e., pressing together), but can hardly take load that causes tension (i.e., pulling apart). Concrete is another material that has been popularly used in building. Concrete is much stronger than masonry under compressive loads, but again its behavior in tension is poor. The properties of concrete critically depend on the amount of water used in making concrete; too much and too little water, both can cause havoc. In general, both masonry and concrete are brittle, and fail suddenly. Steel is used in masonry and concrete buildings as reinforcement bars of diameter ranging from 6mm to 40mm. Reinforcing steel can carry both tensile and compressive loads. Moreover, steel is a ductile material. This important property of ductility enables steel bars to undergo large elongation before breaking.

Concrete is used in buildings along with steel reinforcement bars. This composite material is called reinforced cement concrete or simply reinforced concrete (RC). The amount and location of steel in a member should be such that the failure of the member is by steel reaching its strength in tension before concrete reaches its strength in compression. This type of failure is ductile failure, and hence is preferred over a failure where concrete fails first in compression. Therefore, contrary to common thinking, providing too much steel in RC buildings can be harmful even. It consists of horizontal and vertical members, namely beams and columns. The seismic inertia forces generated at its floor levels are transferred through the various beams and columns to the ground. The correct building components need to be made ductile. The failure of a column can affect the stability of the whole building, but the failure of a beam causes localized effect. Therefore, it is better to make beams to be the ductile weak links than columns. This method of designing RC buildings is called the strong column weak-beam design method.

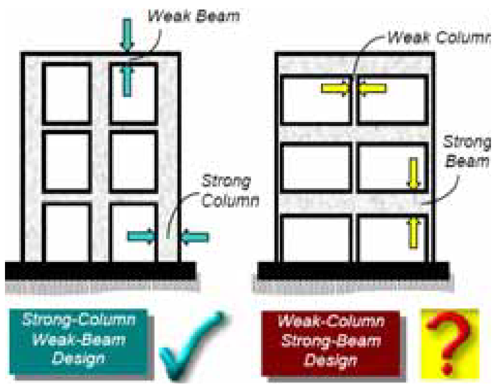


Figure 14: Reinforced Concrete Building Design

Chapter 3. Training Manual from India

3.1 Introduction

India is developing country having population more than 100 carores where major population stays in the villages and the masons construct their houses. The use of seismic code is not in practice. Constructions are done with the traditional methods by masons and contractor. Some of the region such as Himalayan-Nagalushai region, Indo-Genetic Plain, Western India, Kutch and Kathiawar regions are geologically unstable parts of the country, and some devastating earthquakes of the world have occurred there. Strong earthquakes have also visited a major part of the peninsular India, but these were relatively few in number occurring at much larger time intervals at any site, and had considerably lesser intensity.

The earthquake resistant design of structures taking into account seismic data from studies of these Indian earthquakes has become very essential, particularly in view of the intense construction activity all over the country.

Most of the public buildings are vulnerable to the earthquake in higher seismic zone. Generally public buildings are designed for the higher loads but in case of the schools, design is adopted locally, some of the buildings designed by government department have not followed the seismic design due to lake of information related to earthquake technology.

This manual is prepared for the government junior engineers or technicians who are working at local levels and they can provide technical helps to the school authorities through this manual.

3.2 Indian Seismology And Himalayan Region

3.2.1 Seism Zoning Of India

The seismic zone maps are revised from time to time as more understanding is gained on the geology, the tectonics and the seismic activity in the country. The Indian Standards provided the first seismic zone map in 1962, which was later revised in 1967 and again in 1970. The map has been revised again in 2002 shown in figure2.1., and it now has only four seismic zones – II, III, IV and V. The areas falling in seismic zone I in the 1970 version of the map are merged with those of seismic zone II. Also, the seismic zone map in the peninsular region has been modified. Madras now comes in seismic zone III as against in zone II in the 1970 version of the map. This 2002 seismic zone map is not the final word on the seismic hazard of the country, and hence there can be no sense of complacency in this regard. The national Seismic Zone Map presents a large-scale view of the seismic zones in the country.

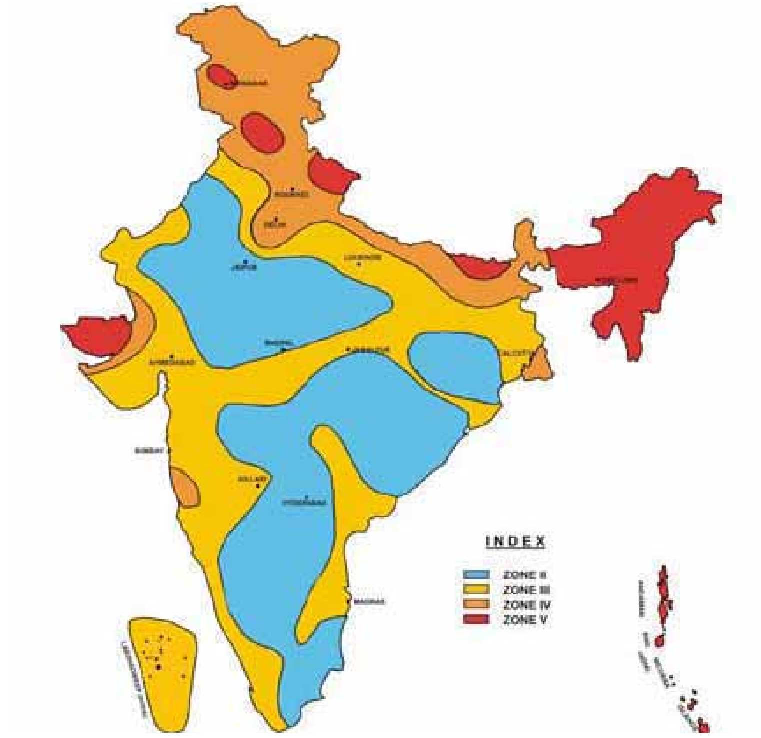


Figure 15: Seismic Zone Map Of India

Local variations in soil type and geology cannot be represented at that scale. Therefore, for important projects, such as a major dam or a nuclear power plant, the seismic hazard is evaluated specifically for that site. Also, for the purposes of urban planning, metropolitan areas are microzoned. Seismic microzonation accounts for local variations in geology, local soil profile, etc.

3.2.2 Tectonic Features Of India

India lies at the northwestern end of the Indo-Australian Plate, which encompasses India, Australia, a major portion of the Indian Ocean and other smaller countries. This plate is colliding against the huge Eurasian Plate (see figure 2.2.) and going under the Eurasian Plate; this process of one tectonic plate getting under another is called subduction. A sea, Tethys, separated these plates before they collided. Part of the lithosphere, the Earth's Crust is covered by oceans and the rest by the continents. The former can undergo subduction at great depths when it converges against another plate, but the latter is buoyant and so tends to remain close to the surface. When continents converge, large amounts of shortening and thickening takes place, like at the Himalayas and the Tibet.

Three chief tectonic sub-regions of India are the mighty Himalayas along the north, the plains of the Ganges and other rivers, and the peninsula. The Himalayas consist primarily of sediments accumulated over long geological time in the Tethys. The Indo- Genetic basin with deep alluvium is a great depression caused by the load of the Himalayas on the continent. The peninsular part of the country consists of ancient rocks deformed in the past Himalayan-like collisions. Erosion has exposed the roots of the old mountains and removed most of the topography. The rocks are very hard, but are softened by weathering near the surface. Before the Himalayan collision, several tens of millions of years ago, lava flowed across the central part of peninsular India leaving layers of basalt rock. Coastal areas like Kachchh show marine deposits testifying to submergence under the sea millions of years ago.

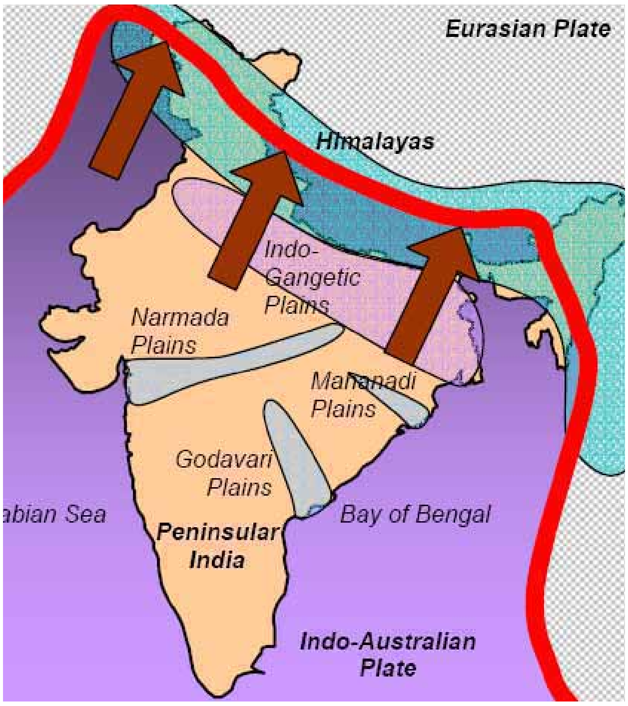


Figure 16: Geological Layout And Tectonic Plate Boundaries At India

3.3 Seismic Construction of RC Buildings

3.3.1 Foundation

The structure shall not be founded on such loose soils, which will subside or liquefy during an earthquake, resulting in large differential settlements. The sub-grade below the entire area of the building shall preferably be of the same type of the soil. Wherever this is not possible, a suitably located separation or crumple section shall be provided.

Loose fine sand, soft silt and expansive clays should be avoided. If unavoidable, the building shall rest either on a rigid raft foundation or on piles taken to a firm stratum. However, for light constructions the following measures may be taken to improve the soil on which the foundation of the building may rest:

- Sand piling, and
- Soil stabilization.

3.3.2 Beam-Column and joints

a. Beams

Beam is a part of building frame and it carries earthquake-induced forces. Beam sustains two basic failures, namely flexure and shear (Figure 17). Flexure or bending failure: This failure takes place due to more steel present on tension face, concrete crushes in the compression and this is brittle failure and therefore undesirable. If relatively less steel present on tension face, the steel yields first and redistribution occurs in the beam until eventually the concrete crushes in compression; this is a ductile failure and hence is desirable. Thus, more steel on tension face is not necessarily desirable. The ductile failure is characterized with many vertical cracks starting from the stretched beam face, and going towards its mid-depth cracking on the side of the beam that stretches.

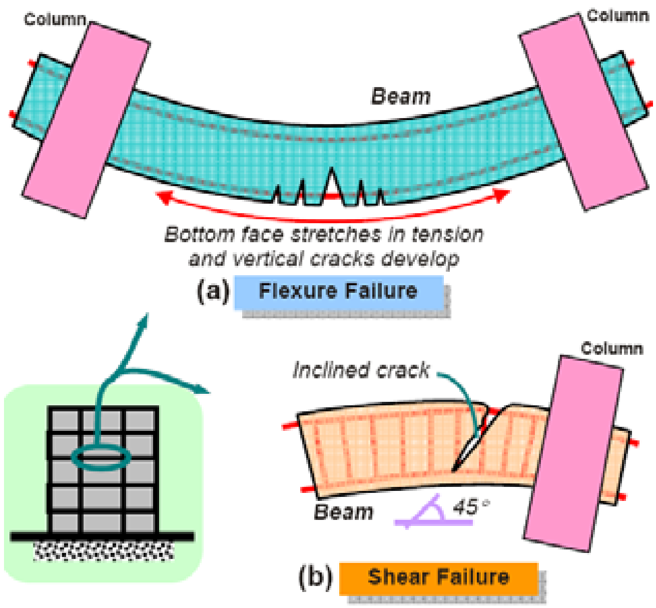


Figure 17: Two types of damages in beams

Shear failure: A beam may also fail due to shearing action. A shear crack is inclined at 45° to the horizontal; it develops at mid-depth near the support and grows towards the top and bottom faces. Closed loop stirrups are provided to avoid such shearing action. Shear damage occurs when the area of these stirrups is insufficient. Shear failure is brittle, and therefore, shear failure must be avoided in the design of RC beams. The Indian Ductile Detailing Code IS13920-1993 prescribes Beam reinforcement details that are mentioned below:

- At least two bars go through the full length of the beam at the top as well as the bottom of the beam.
- At the ends of beams, the amount of steel provided at the bottom is at least half that at top.

Requirements related to stirrups in reinforced concrete beams:

1. The diameter of stirrup must be at least 6mm; in beams more than 5m long, it must be at least 8mm.
2. Both ends of the vertical stirrups should be bent into a 135° hook, and extended sufficiently beyond this hook to ensure that the stirrup does not open out in an earthquake.
3. The spacing of vertical stirrups in any portion of the beam should be determined from calculations
4. The maximum spacing of stirrups is less than half the depth of the beam (Figure 18).
5. For a length of twice the depth of the beam from the face of the column, an even more stringent spacing of stirrups is specified, namely half the spacing mentioned in 3. (Figure 18)

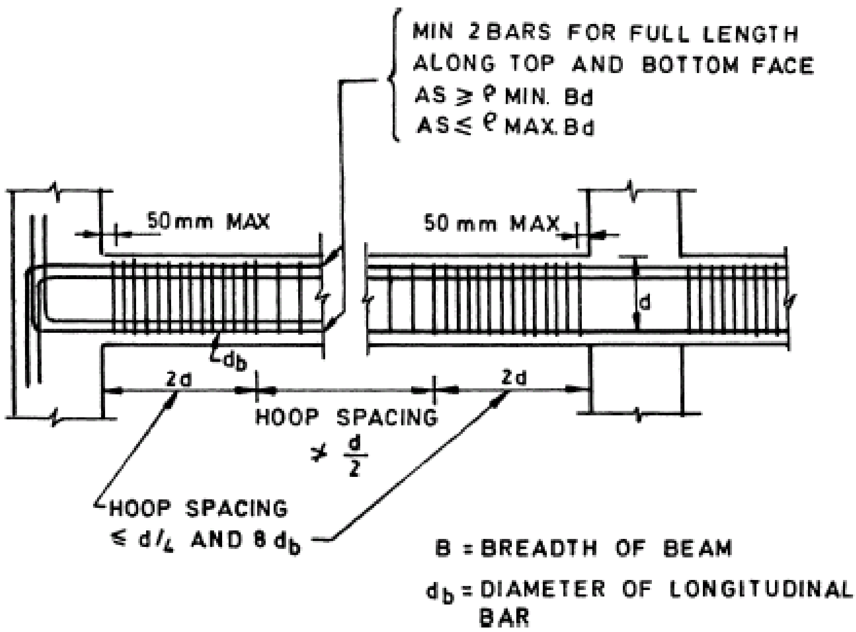


Figure 18: Beam reinforcement

Lapping of bars: Lapping of bars should be away from the face the column, and not at locations where they are likely to stretch by large amounts and yield (e.g., bottom bars at mid-length of the beam). Moreover, at the locations of laps, vertical stirrups should be provided at a closer spacing.

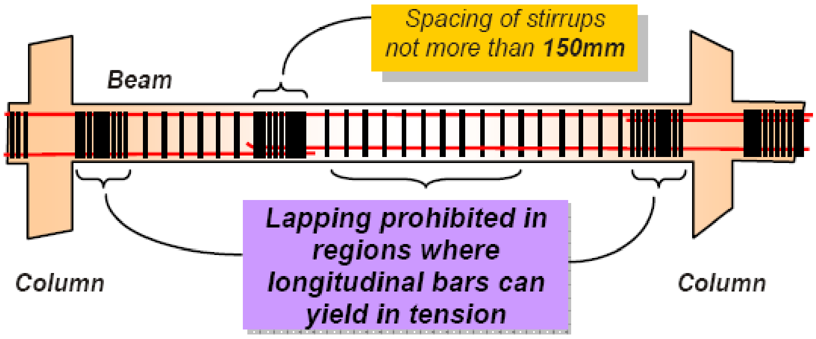


Figure 19: Details of lapping steel reinforcement in seismic beams

b. *Column*

Column the vertical member in R.C building can sustain two types of damage, namely axial flexural (or combined compression bending) failure and shear failure. Shear failure is brittle and must be avoided in columns by providing transverse ties at close spacing.

The Indian Ductile Detailing Code IS:13920-1993 requires columns to be at least 300mm wide. A column width of up to 200mm is allowed if unsupported length is less than 4m and beam length is less than 5m. Columns that are required to resist earthquake forces must be designed to prevent shear failure by a skillful selection of reinforcement. The Indian Standard IS13920-1993 prescribes following details for earthquake-resistant columns (Figure 20):

1. Closely spaced ties must be provided at the two ends of the column over a length not less than larger dimension of the column, one-sixth the column height or 450mm.
2. Over the distance specified in item (1) above and below a beam-column junction, the vertical spacing of ties in columns should not exceed D/4 for where D is the smallest dimension of the column (e.g., in a rectangular column, D is the length of the small side). This spacing need not be less than 75mm not more than 100mm. At other locations, ties are spaced as per calculations but not more than D/2.
3. The length of tie beyond the 135° bends must be at least 10 times diameter of steel bar used to make the closed tie; this extension beyond the bend should not be less than 75mm.

In columns where the spacing between the corner bars exceeds 300mm, the Indian Standard prescribes additional links with 180° hook ends for ties to be effective in holding the concrete in its place and to prevent the buckling of vertical bars. These links need to go around both vertical bars and horizontal closed ties (Figure 20b); special care is required to implement this properly at site.

Lapping of bars IS:13920-1993 prescribes that the lap length be provided only in the middle half of column and not near its top or bottom ends. Also, only half the vertical bars in the column are to be lapped at a time in any storey. Further, when laps are provided, ties must be provided along the length of the lap at spacing not more than 150mm.

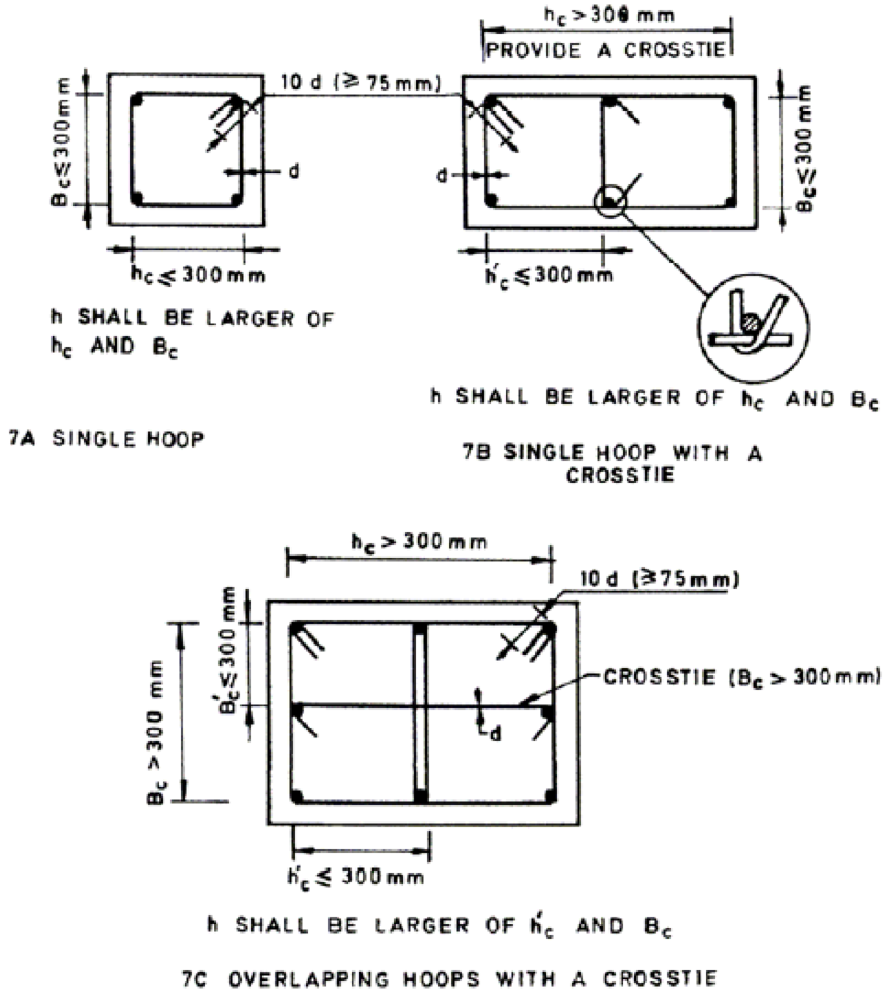


Figure 20: Transverse Reinforcement in Column

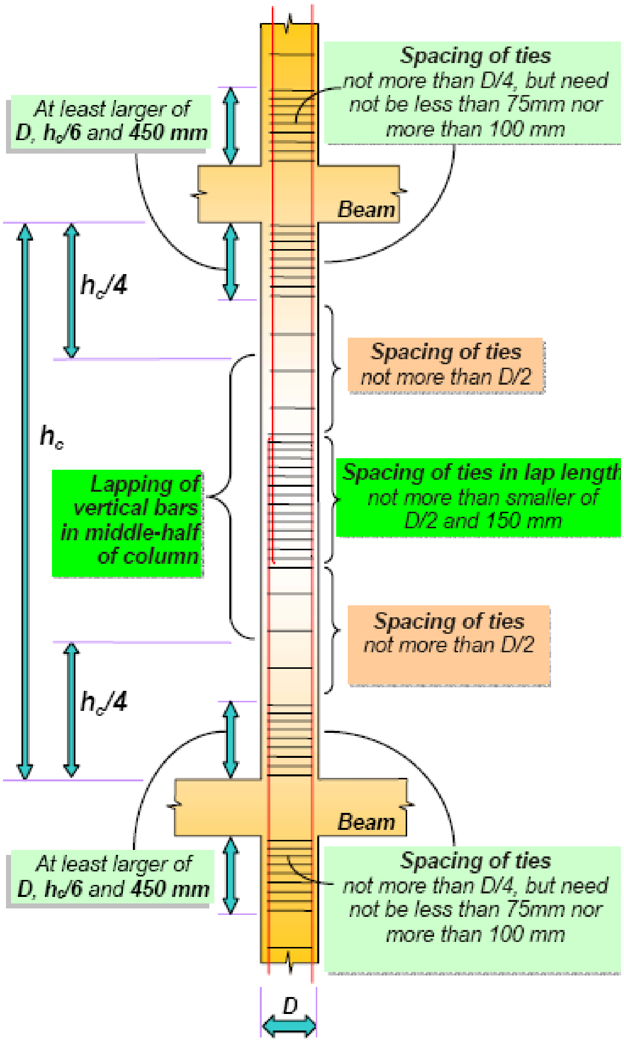


Figure 21: Column And Joint Detailing

c. Beam-column joints

Beam –column joints is extremely critical portion of RC frame building. Special care is required for implementing the details of beam column joints on site. Failure of beam column joints may lead to the failure of the entire structure. Providing large column size and closely spaced closed-loops steel ties around column bars in joint region is essential to resist the earthquake force.

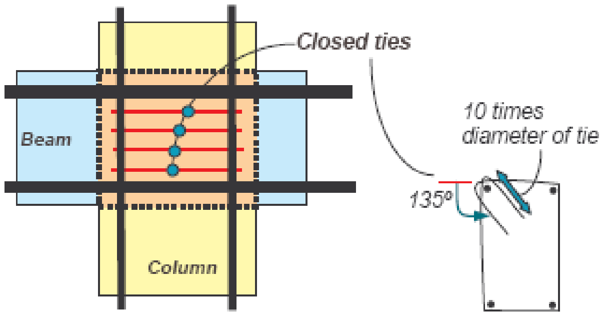


Figure 22: Closed loop steel ties in beam-column joints

3.3.3 Avoiding Short Column

In new buildings, short column effect should be avoided to the extent possible during architectural design stage itself. When it is not possible to avoid short columns, this effect must be addressed in structural design. The Indian Standard IS: 13920-1993 for ductile detailing of RC structures requires special confining reinforcement to be provided over the full height of columns that are likely to sustain short column effect.

In existing buildings with short columns, different retrofit solutions can be employed to avoid damage in future earthquakes. Where walls of partial height are present, the simplest solution is to close the openings by building a wall of full height – this will eliminate the short column effect.

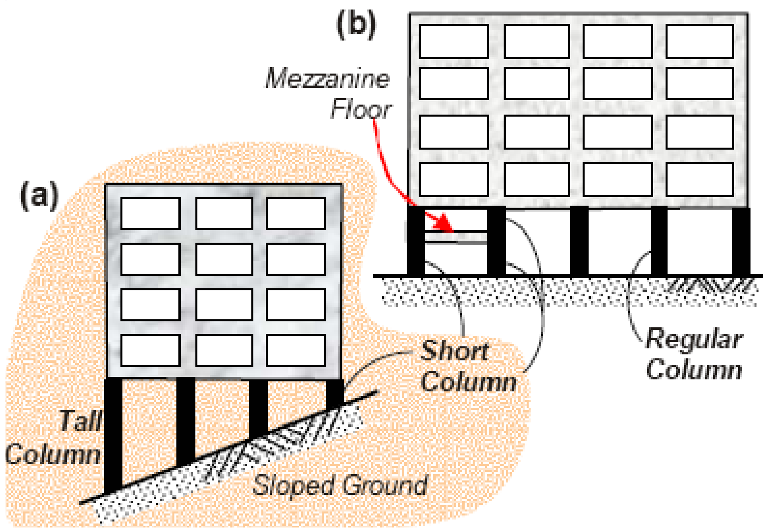


Figure 23: Buildings with short column

3.3.4 Open storey or Soft Storey Problem

Code IS:1893 (Part 1) -2002 has included special design provisions related to soft storey buildings. Firstly, it specifies when a building should be considered as a soft and a weak storey building. Secondly, it specifies higher design forces for the soft storey as compared to the rest of the structure. The Code suggests that the forces in the columns, beams and shear walls (if any) under the action of seismic loads specified in the code, may be obtained by considering the bare frame building (without any infills). However, beams and columns in the open ground storey are required to be designed for 2.5 times the forces obtained from this bare frame analysis.

For all new RC frame buildings, the best option is to avoid such sudden and large decrease in stiffness and/or strength in any storey; it would be ideal to build walls (either masonry or RC walls) in the round (Figure 24).

Designers can avoid dangerous effects of flexible and weak ground storeys by ensuring that too many walls are not discontinued in the ground storey, i.e., the drop in stiffness and strength in the ground storey level is not abrupt due to the absence of infill walls.

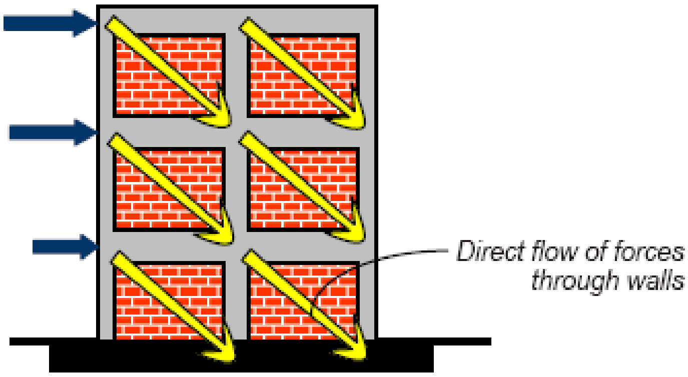


Figure 24: Avoiding open ground problem

3.3.5 Building With Shear Wall

Reinforced concrete (RC) buildings often have vertical plate-like RC walls called Shear Walls (Figure 25) in addition to slabs, beams and columns. These walls generally start at foundation level and are continuous throughout the building height. Their thickness can be as low as 150mm, or as high as 400mm in high rise buildings. Shear walls are usually provided along both length and width of buildings (Figure 5.11.). Shear walls are like vertically oriented wide beams that carry earthquake loads downwards to the foundation. Properly designed and detailed buildings with shear walls have shown very good performance in past earthquakes.

Shear wall buildings are a popular choice in many earthquake prone countries, like Chile, New Zealand and USA. Shear walls are easy to construct, because reinforcement detailing of walls is relatively straightforward and therefore easily implemented at site. Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing earthquake damage in structural and nonstructural elements (like glass windows and building contents).

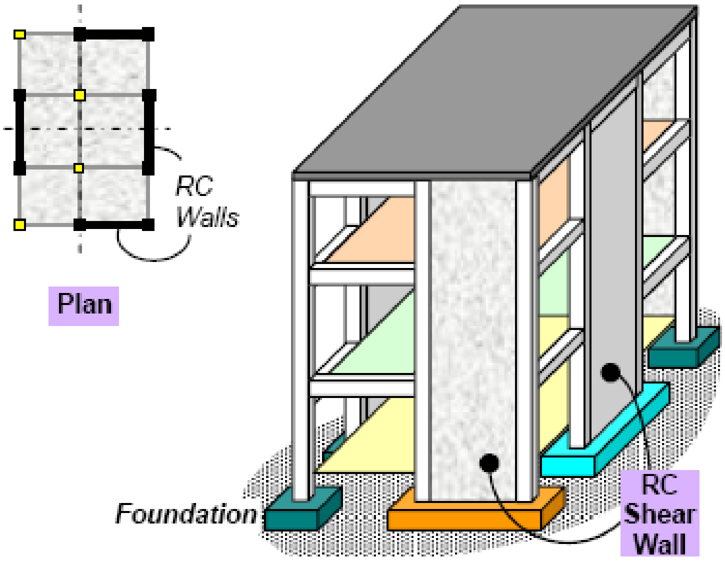


Figure 25: RC shear walls in buildings

3.3.6 Reinforcement Bars In RC Walls

Steel reinforcing bars are to be provided in walls in regularly spaced vertical and horizontal grids (Figure 26a). The vertical and horizontal reinforcement in the wall can be placed in one or two parallel layers called curtains. Horizontal reinforcement needs to be anchored at the ends of walls. The minimum area of reinforcing steel to be provided is 0.0025 times the cross-sectional area, along each of the horizontal and vertical directions. The vertical reinforcement should be distributed uniformly across the wall cross-section.

Boundary Elements: Under the large overturning effects caused by horizontal earthquake forces, edges of shear walls experience high compressive and tensile stresses. To ensure that shear walls behave in a ductile way, concrete in the wall end regions must be reinforced in a special manner to sustain these load reversals without loosing strength (Figure 26b). End regions of a wall with increased confinement are called boundary elements. This special confining transverse reinforcement in boundary elements is similar to that provided in columns of RC frames.

Sometimes, the thickness of the shear wall in these boundary elements is also increased. RC walls with boundary elements have substantially higher bending strength and horizontal shear force carrying capacity, and are therefore less susceptible to earthquake damage than walls without boundary elements.

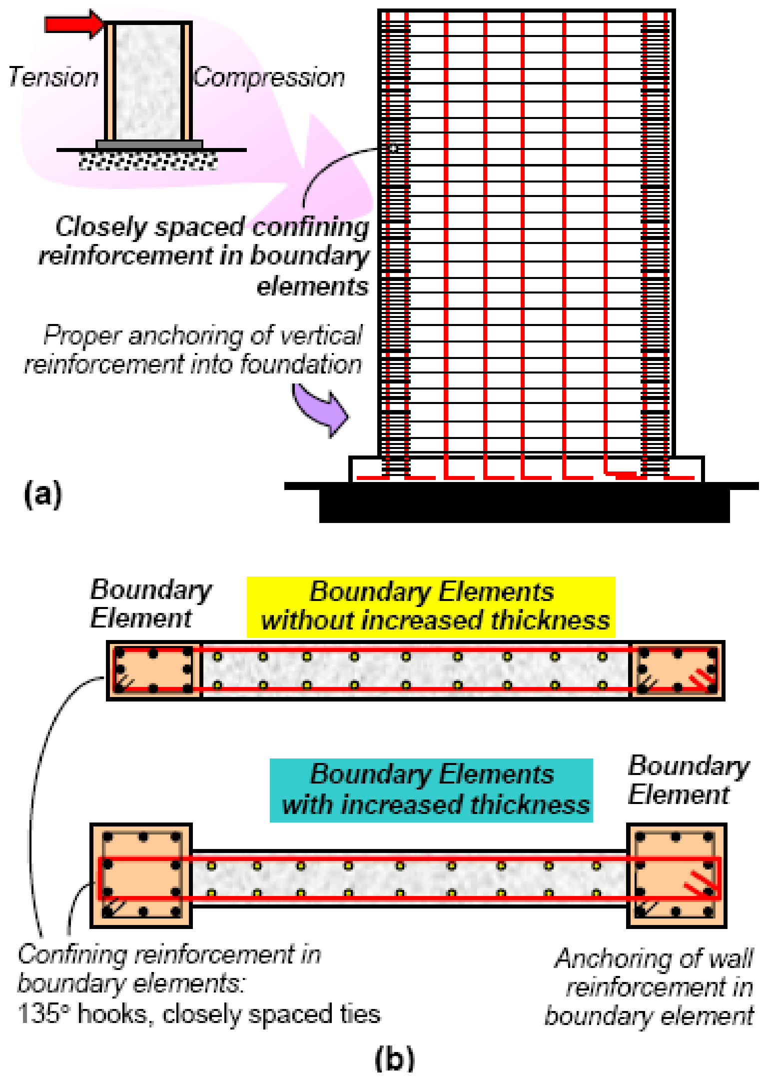


Figure 26: Layout of main reinforcement in shear wall

3.4 Seismic construction of Masonry Buildings

3.4.1 Box Type Construction

Masonry buildings have large mass and hence attract large horizontal forces during earthquake shaking. They develop numerous cracks under both compressive and tensile forces caused by earthquake shaking. The focus of earthquake resistant masonry building construction is to ensure that these effects are sustained without major damage or collapse. Appropriate choice of structural configuration can help achieve this.

The structural configuration of masonry buildings includes aspects like (a) overall shape and size of the building, and (b) distribution of mass and (horizontal) lateral load resisting elements across the building. Large, tall, long and unsymmetrical buildings perform poorly during earthquakes. A strategy used in making them earthquake resistant is developing good box action between all the elements of the building, i.e., between roof, walls and foundation (Figure 27). Loosely connected roof or unduly slender walls are threats to good seismic behavior. For example, a horizontal band introduced at the lintel level ties the walls together and helps to make them behave as a single unit.

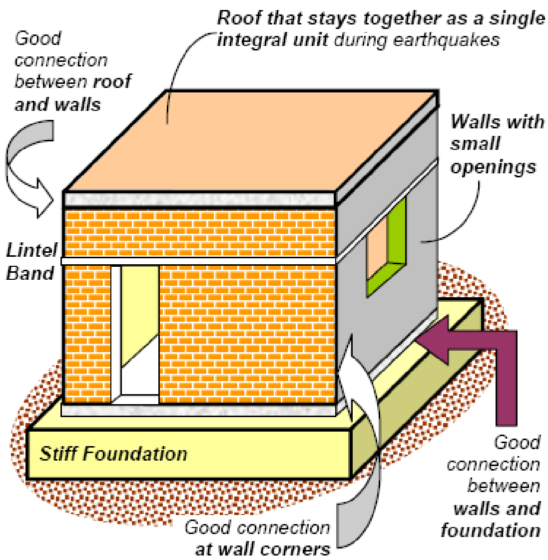


Figure 27: Essential Requirements To Ensure Box Action In A Masonry Building

3.4.2 Foundation

The sub-grade below the entire area of the building should preferably be of the same type of the soil. Wherever this is not possible, the buildings should preferably be separated into units and then the units should be located separately.

Loose fine sand soft silt and expansive clays should be avoided. If unavoidable the following measures may be taken to improve the soil on which the foundation of the building may rest

- Sand piling/under reamed piling/stone columns, etc.
- Soil stabilization.

3.4.3 Walls

a. Walls In Stone Masonry

The wall thickness should not exceed 450mm. The wall should have a thickness of at least one-sixth its height. Round stone boulders should not be used in the construction! Instead, the stones should be shaped using chisels and hammers. Use of mud mortar should be avoided in higher seismic zones.

Instead, cement-sand mortar should be 1:6 (or richer) and lime-sand mortar 1:3 (or richer) should be used. The masonry walls should be built in construction lifts not exceeding 600mm. Through-stones (each extending over full thickness of wall) or a pair of overlapping bond-stones (each extending over at least ¾ths thickness of wall) must be used at every 600mm along the height and at a maximum spacing of 1.2m along the length. In place of 'through' stones, 'bonding elements' of steel bars 8 to 10 mm dia bent to S-shape or as hooked links may be used with a cover of 25 mm from each face of the wall (see figure.4.2), wood bars of 38 mm × 38 mm cross section or concrete bars of 50 mm × 50 mm section with an 8 mm dia rod placed centrally may be used in place of 'through' stones. The wood should be well treated with preservative so that it is durable against weathering and insect action. The unsupported length of walls between cross-walls should be limited to 5m; for longer walls, cross supports raised from the ground level called buttresses should be provided at spacing not more than 4m.

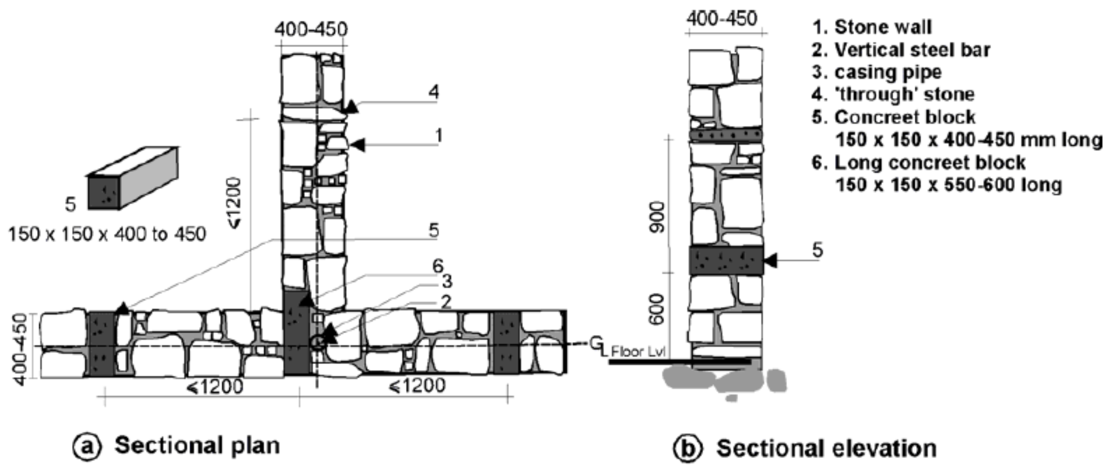


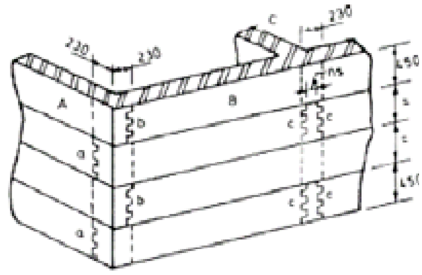
Figure 28: `Through' stone or bond elements in stone wall built in mud mortar

b. Wall In Brick Masonry

The fired bricks should have a compressive strength not less than 3.5 MPa. Strength of bricks and wall thickness should be selected for the total building height. The mortar should be lime-sand (1: 3) or clay mud of good quality. Where horizontal steel is used between courses, cement-sand mortar (1: 3) should be used with thickness so as to cover the steel with 6 mm mortar above and below it. Where vertical steel is used, the surrounding brickwork of 1 × 1 or 1½ × 1½ brick size depending on wall thickness should preferably be built using 1: 6 cement-sand mortar.

The minimum wall thickness shall be one brick in one storey construction and one brick in top storey and 1½ brick in bottom storeys of up to three-storey construction. It should also not be less than 1/16 of the length of wall between two consecutive perpendicular walls.

For achieving full strength of masonry, the usual bonds specified for masonry should be followed so that the vertical joints are broken properly from course to course. To obtain full bond between perpendicular walls, it is necessary to make a sloping (stepped) joint by making the corners first to a height of 600 mm and then building the wall in between them. Otherwise the toothed joint should be made in both the walls, alternately in lifts of about 450 mm the details are shown in the figure 4.3.



a, b, c — Toothed joints in wall A, B, and C
All dimensions in millimetres.

Figure 29: Alternated Toothed Joints In Walls At Corner and T-Junction

c. *Openings In Wall*

Door and window openings in walls reduce their lateral load resistance and hence should preferably be small and more centrally located. The size and position of openings shall be as given in Table 4.1. and Figure 4.4. Openings in any storey shall preferably have their top at the same level so that a continuous band could be provided over them including the lintels throughout the building.

Table 2: Size and opening of bearing wall

Description	Building category	
	A, B, and C	D
Distance b_5 from inside corner of outside wall. Min	230mm	600mm
Total length of openings ratio. Max $(b_1+b_2+b_3)/l_1$ or $(b_6+b_7)/l_2$ One storied building Two and three storied building	 0.46 0.37	 0.42 0.33
Pier width between consecutive openings b_4	450mm	560mm
Vertical distance between two openings one above other h_3. Min	600mm	600mm
Width of opening of ventilator b_8. Max	750mm	750mm

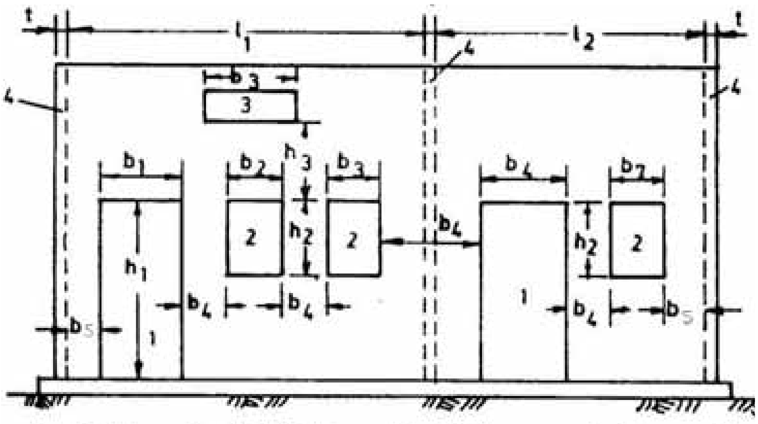


Figure 30: Dimension Of Opening

Where openings do not comply with the guidelines of (Table 2), providing reinforced concrete lining as shown in Figure 31 should strengthen them, with 2 high strength deformed (H S D) bars of 8 mm dia. The use of arches to span over the openings is a source of weakness and shall be avoided, otherwise, steel ties should be provided.

Figure 31:

Note: to identify the building category in table 4.1 please follow the calculation given in IS 4326 1993.

3.4.4 Importance Of Bands

Horizontal bands are the most important. The bands are provided to hold a masonry building as a single unit by tying all the walls together, and are similar to a closed belt provided around cardboard boxes. There are four types of bands in a typical masonry building, namely gable band, roof band, lintel band and plinth band (Figure 4.6.), named after their location in the building. The lintel band is the most important of all, and needs to be provided in almost all buildings. The gable band is employed only in buildings with pitched or sloped roofs. In buildings with flat reinforced concrete or reinforced brick roofs, the roof band is not required, because the roof slab also plays the role of a band. However, in buildings with flat timber or CGI sheet roof, roof band needs to be provided. In buildings with pitched or sloped roof, the roof band is very important. Plinth bands are primarily used when there is concern about uneven settlement of foundation soil.

The lintel band ties the walls together and creates a support for walls loaded along weak direction from walls loaded in strong direction. This band also reduces the unsupported height of the walls and thereby improves their stability in the weak direction. Reinforcement and bending details of band at corner are given in the figure.

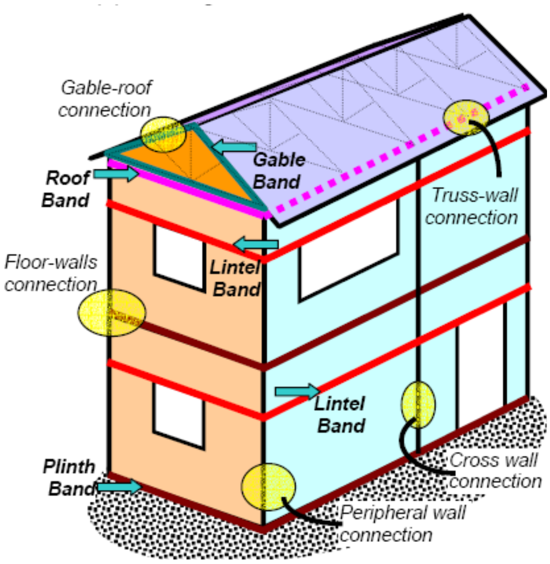


Figure 32: Horizontal bands in masonry building

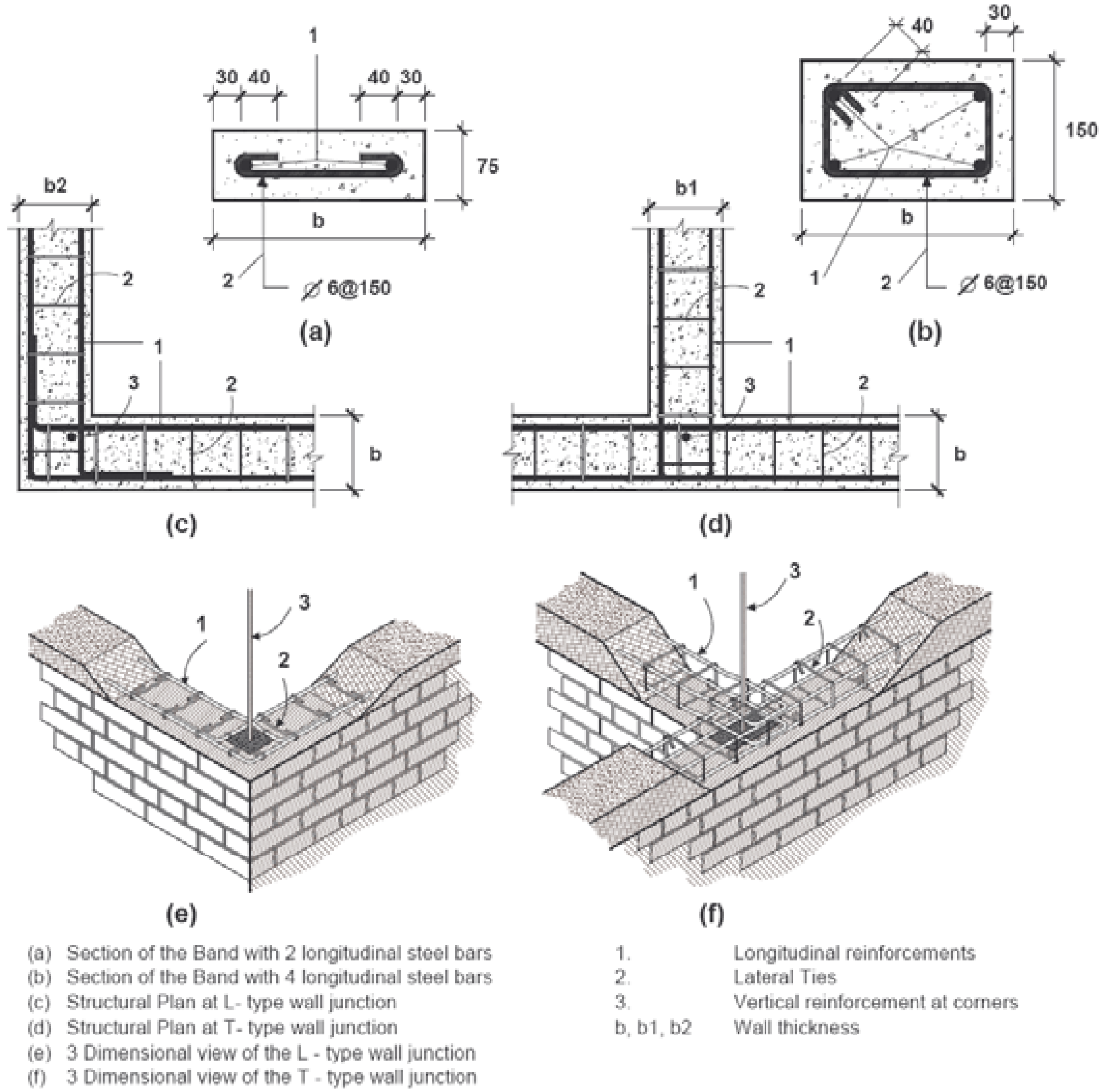


Figure 33: Reinforcement And Bending Details Of Seismic Band

3.4.5 Floor

The height of each storey should not exceed 3.0m. In general, stone masonry buildings should not be taller than 2 storeys when built in cement mortar, and 1 storey when built in lime or mud mortar. Flat roof or floor should not preferably be made of tiles or ordinary bricks supported on steel, timber or reinforced concrete joists, nor they shall be of a type which in the event of an earthquake is likely to be loosened and parts or all of which may fall. If this type of construction cannot be avoided, the joists should be blocked at ends and bridged at intervals such that their spacing is not altered during an earthquake.

3.4.6 Roofs

For pitched roofs, corrugated iron or asbestos sheets should be used in preference to country, Allahabad or Mangalore tiles or other loose roofing units. All roofing materials shall be properly tied to the supporting members. Heavy roofing materials should generally be avoided.

Pent Roofs: All roof trusses should be supported on and fixed to timber band reinforced concrete band or reinforced brick band. The holding down bolts should have adequate length as required for earthquake and wind forces. Where a trussed roof adjoins a masonry gable, the ends of the purlins should be carried on and secured to a plate or bearer which should be adequately bolted to timber reinforced concrete or reinforced brick band at the top of gable end masonry.

At tie level, all the trusses and the gable end should be provided with diagonal braces in plan so as to transmit the lateral shear due to earthquake force to the gable walls acting as shear walls.

3.4.7 Vertical Reinforcement

Vertical steel at corners and junctions of walls, which are up to 350 mm thick, should be provided as specified in the Table 4.3. For walls thicker than 350 mm, the area of the bars should be proportionately increased.

The vertical reinforcement should be properly embedded in the plinth masonry of foundations and roof slab or roof band so as to develop its tensile strength in bond. It should pass through the lintel bands and floor slabs or floor level bands in all storeys. Bars in different storeys may be welded or suitably lapped. Typical details of providing vertical steel in brickwork at corners and T-junctions are shown in figure 4.9. For providing vertical bar in stone masonry, use of a casing pipe is recommended around which masonry be built to height of 600 mm (see Figure 4.8). The pipe is kept loose by rotating it during masonry construction. It is then raised and the cavity below is filled with concrete mix and rodded to compact it.

3.5 Seismic retrofitting

3.5.1 Assessment

Assessment is carried out to determine the condition of existing building. Generally two type of assessments are carried out one is visual assessment and another is detailed assessment.

a. Assessment methods

Self-assessment: This is an assessment format, which can be used by any common public to assess their own building.

Rapid visual screening: The purpose of this assessment is to prioritize buildings for seismic safety enhancement and to help to develop long-term national program to reduce vulnerabilities.

Detailed assessment: The purpose of this assessment is to identify the deficiency in existing building and suggest the appropriate retrofitting measures. In this survey detailed investigation is carried out of the each structure elements from foundation to roof. Computer based analysis is also used to analyze the building condition.

Damage assessment: This assessment is used after any disaster to know the total damage and to plan the rehabilitation program. Through this survey building are categorize (Less damage to totally damage building) based on the damage condition, appropriate funds are given for the repair, retrofit or replace the building

3.5.2 Seismic Retrofitting of buildings

Many existing buildings do not meet the seismic strength requirements of present earthquake codes due to original structural inadequacies and material degradation due to time or alterations carried out during use over the years. Their earthquake resistance can be upgraded to the level of the present day codes by appropriate seismic retrofitting techniques, such as mentioned below

- Increasing the lateral strength in one or both directions by increasing column and wall areas or the number of walls and columns.
- Giving unity to the structure, by providing a proper connection between its resisting elements, in such a way that inertia forces generated by the vibration of the building can be transmitted to the members that have the ability to resist them. Typical important aspects are the connections between roofs or floors and walls, between intersecting walls and between walls and foundations.
- Eliminating features that are sources of weakness or that produce concentration of stresses in some members. Asymmetrical plan distribution of resisting members, abrupt changes of stiffness from one floor to the other, concentration of large masses and large openings in walls without a proper peripheral reinforcement are examples of defects of this kind.
- Avoiding the possibility of brittle modes of failure by proper reinforcement and connection of resisting members.

3.5.3 Retrofitting of Masonry buildings

a. Modification of Roofs or Floors

Slates and roofing tiles are brittle and easily dislodged. Where possible, they should be replaced with corrugated iron or asbestos sheeting. False ceilings of brittle material are dangerous. Non-brittle material, like hessian cloth, bamboo matting or light ones of foam substances, may be substituted. Roof truss frames should be braced by welding or clamping suitable diagonal bracing members in the vertical as well as horizontal planes. Anchors of roof trusses to supporting walls should be improved and the roof thrust on walls should be eliminated. Figure 34 and Figure 35 illustrate one of the methods for pitched roofs without trusses.

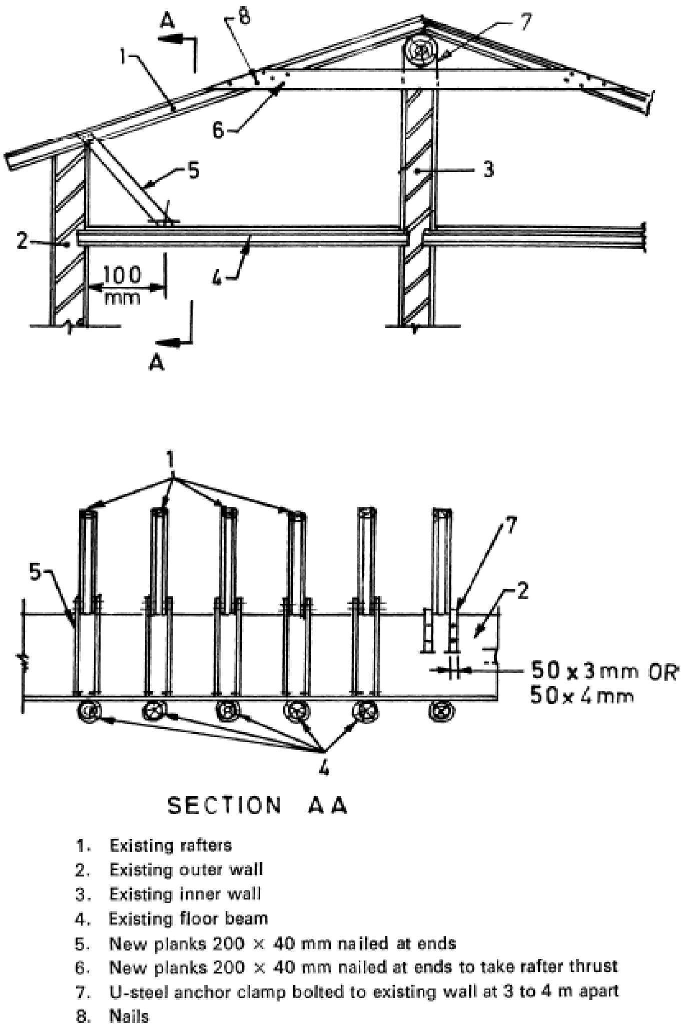


Figure 34: Roof Modification To Reduce Thrust Of Walls

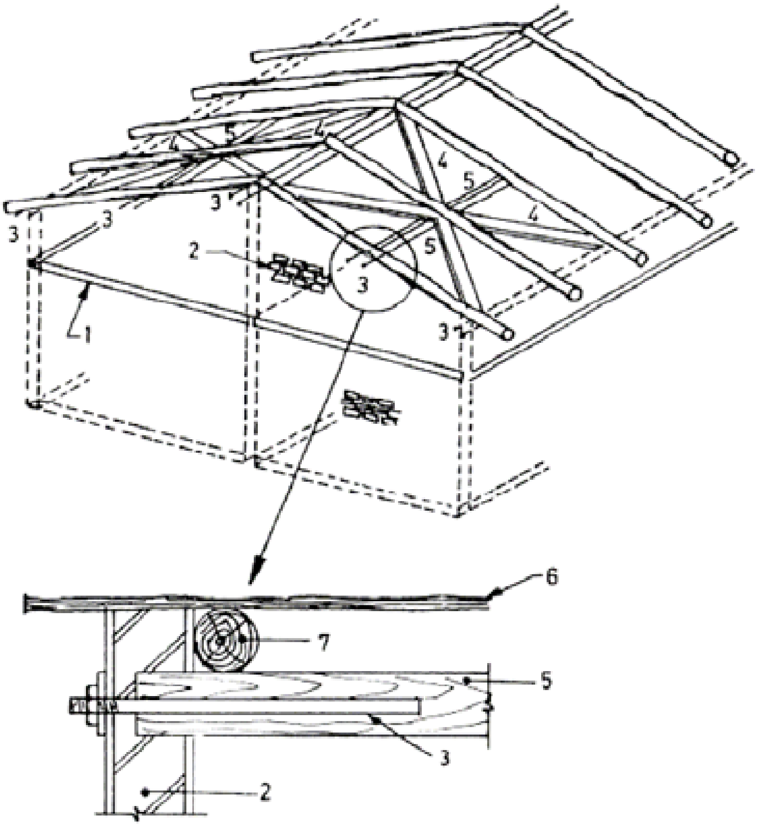


Figure 35: Details Of New Roof Bracing

Where the roof or floor consists of prefabricated units like RC rectangular T or channel units or wooden poles and joists carrying brick tiles, integration of such units is necessary. Timber elements could be connected to diagonal planks nailed to them and spiked to an all round wooden frame at the ends.

Reinforced concrete elements may either have 40 mm cast-in-situ-concrete topping with 6 mm dia bars 150 mm c/c both ways or bounded by a horizontal cast-in-situ-reinforced concrete ring beam all round into which the ends of reinforced concrete elements are embedded. Figure 36 shows one such detail.

Roofs or floors consisting of steel joists flat or segmental arches must have horizontal ties holding the joists horizontally in each arch span so as to prevent the spreading of joists. If such ties do not exist, these should be installed by welding or clamping.

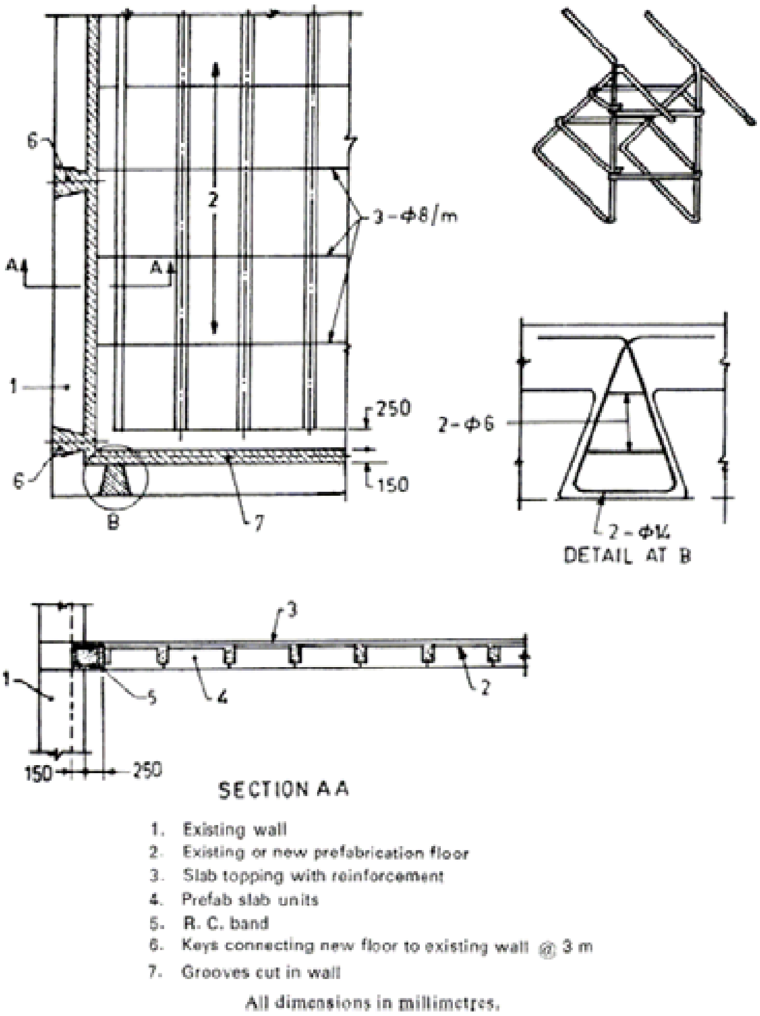
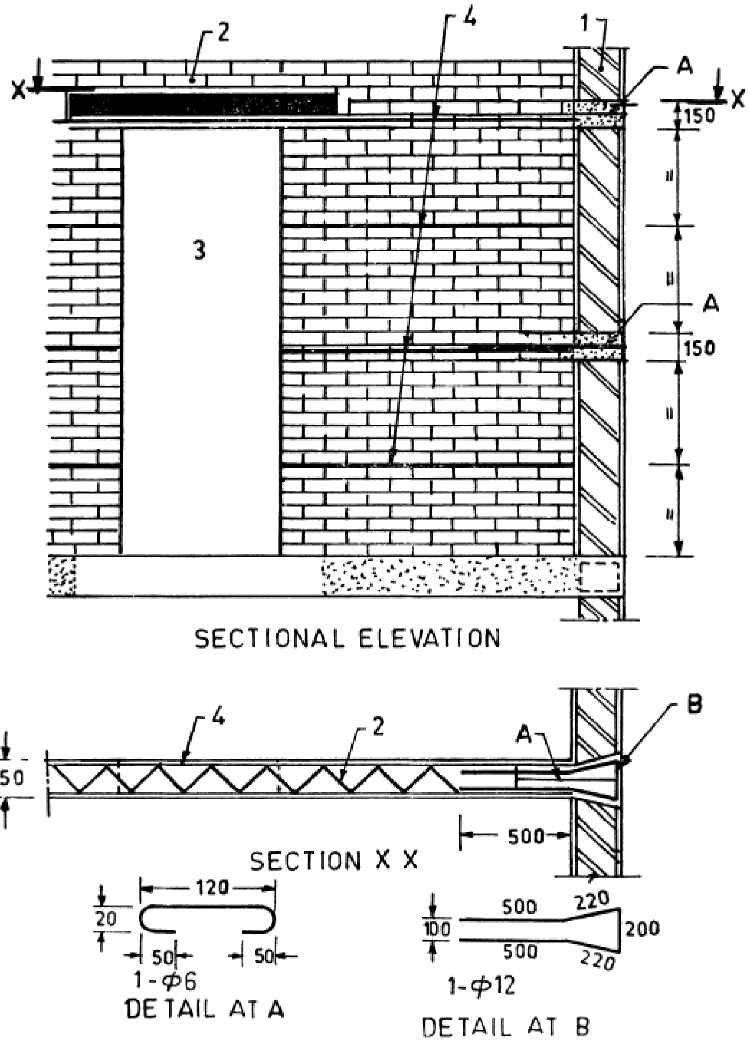


Figure 36: Integration And Stiffening Of An Existing Floor

3.5.4 Strengthening of walls

a. Inserting new wall

Unsymmetrical buildings may produce dangerous torsional effects during earthquakes. Insertion of cross wall will be necessary for providing transverse supports to longitudinal walls of long barrack-type buildings used for various purposes such as schools and dormitories. The main problem in such modifications is the connection of new walls with old walls. Figure 37, Figure 38 and Figure 39 show three examples of connection of new walls to existing ones. The first two cases refer to a T- junction whereas the third to a corner junction. In all cases the link to the old walls is performed by means of a number of keys made in the old walls. Steel is inserted in them and local concrete infilling is made. In the second case, however, connection can be achieved by a number of steel bars inserted in small length drilled holes filled with fresh cement-grout, which substitute keys.



1. Existing wall
2. New wall
3. Door opening
4. Horizontal reinforcement (examples of truss system shown)

All dimensions in millimetres.

Figure 37: Connection Of New And Old Brick Walls (T-Junction)

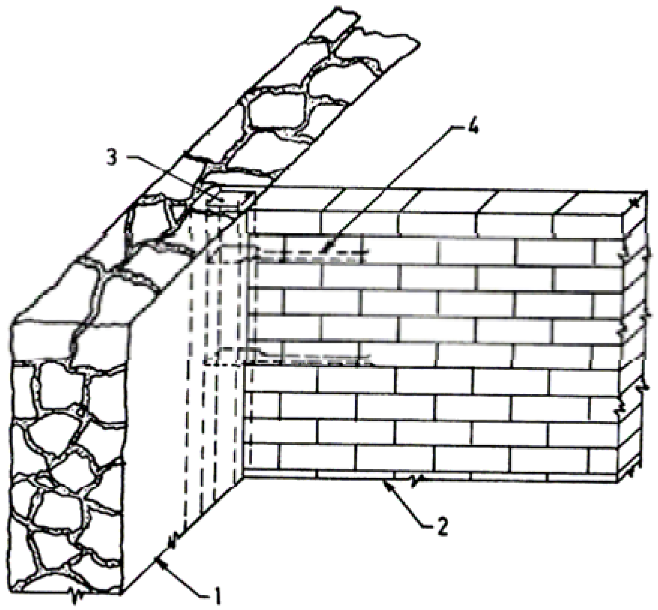


Figure 38: Connection Of New Brick Wall With Existing Stone Wall

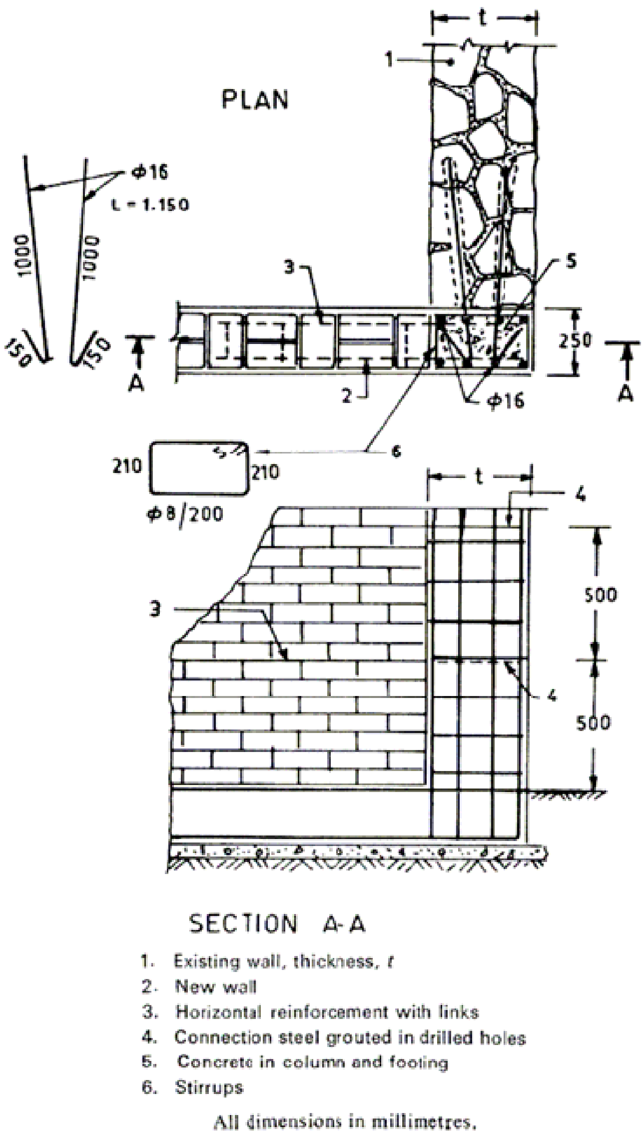


Figure 39: Connection OF New And Walls (Corner Junction)

b. Grouting

A number of holes are drilled in the wall (2 to 4 in each square metre) (see Figure 40). First water is injected in order to wash the wall inside, and to improve the cohesion between the grouting mixture and the wall elements. Secondly, a cement water mixture (1: 1) is grouted at low pressure (0.1 to 0.25 MPa) in the holes starting from the lower holes and going up. Alternatively, polymeric mortars may be used for grouting. The increase of shear strength, which can be achieved in this way, is considerable. However, grouting cannot be relied on as far as the improving or making a new connection between orthogonal walls is concerned.

NOTE — The pressure need for grouting can be obtained by gravity flow from super elevated containers.

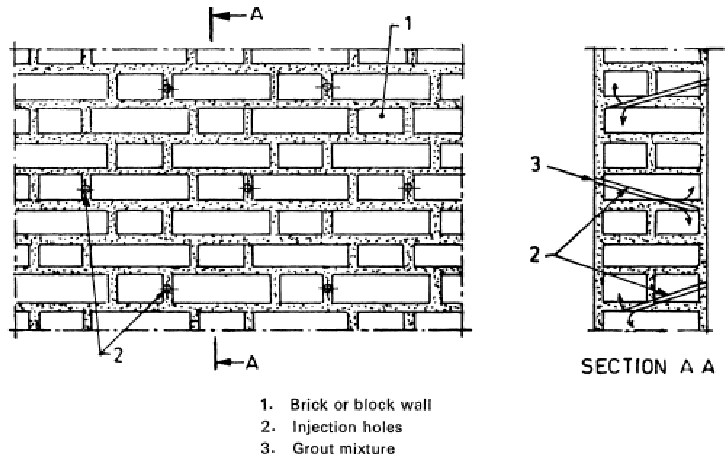


Figure 40: Grout or Epoxy Injection In Existing Weak Walls

3.5.5 Achieving Integral Box Action

The overall lateral strength and stability of bearing wall buildings is very much improved, if the integral box like action of room enclosures is ensured. This can be achieved by (a) use of pre-stressing (b) providing horizontal bands. Strength of shear walls is achieved by providing vertical steel at selected locations as described below

a. Pre-stressing

A horizontal compression state induced by horizontal tendons can be used to increase the shear strength of walls. Moreover, this will also improve, considerably, the connections of orthogonal walls (see Figure 41). The easiest way of affecting the pre-compression is to place two steel rods on the two sides of the wall and stretching them by turnbuckles. Note that, good effects can be obtained by slight horizontal pre-stressing (about 0.1MPa) on the vertical section of the wall. Pre-stressing is also useful to strengthen spandrel beam between two rows of openings in the case no rigid slab exists. Opposite parallel walls can be held to internal cross walls by pre-stressing bars as illustrated above the anchoring being done against horizontal steel channels instead of small steel plates. The steel channels running from one cross wall to the other will hold the walls together and improve the integral box like action of the walls.

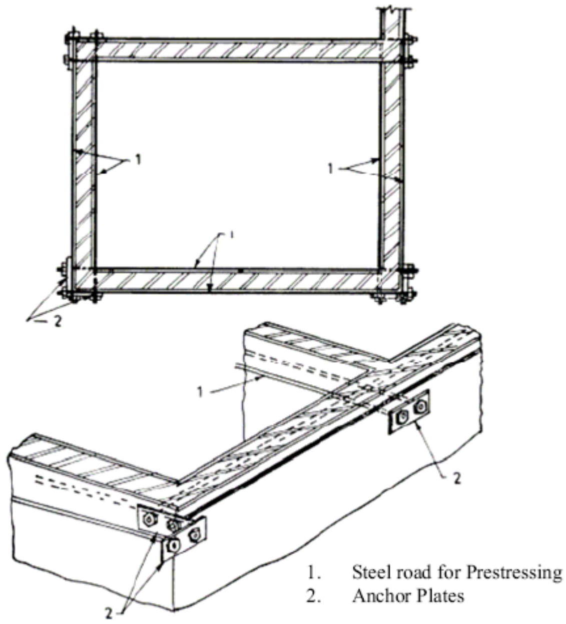


Figure 41: Strengthening Of Wall By Pre-stressing

b. External Binding

The technique of covering the wall with steel mesh and mortar or micro concrete may be used only on the outside surface of external walls but maintaining continuity of steel at the corners. This would strengthen the walls as well as bind them together. As a variation and for economy in the use of materials, the covering may be in the form of vertical splints located between the openings and horizontal 'bandages' formed over spandrel walls at suitable number of points only (see Figure 42).

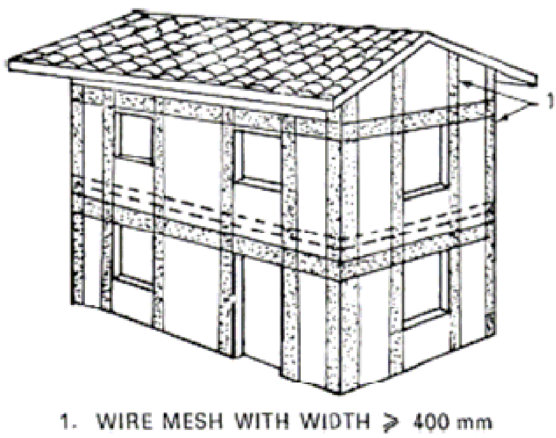


Figure 42: Split And Bandage Strengthening Technique

3.5.6 Ferro-cement strengthening

The plaster on both sides of the wall is removed the mortar joints are raked out up to 15-20mm depth, surface is cleaned and wet with water and a coat of cement slurry or polymer enhanced cement slurry is applied. A 10 mm thick coat of cement sand plaster (1:3 cement: coarse sand) or 1:1.5:3 micro concrete is applied. The surface of the plaster is roughened to have good bond with the second coat.

Welded wire mesh is fixed on the surface of plaster/micro concrete using 150 mm long nails. The wire mesh and nails are galvanized to protect them from corrosion. Alternatively the wire mesh on the two sides of the wall can be anchored together using 3 mm galvanized wire or J bolts passing through holes drilled in the wall. The anchors are used at every 450 mm. After clamping the wire mesh on the two sides of wall, the wires/bolts are grouted in the holes. After fixing the wire mesh, second coat of plaster or micro-concrete (16-20 mm thick) is applied.

3.5.7 Strengthening of random rubble masonry

Random rubble masonry walls are most vulnerable to delaminate and complete collapse and must be strengthened by internal impregnation by rich cement mortar grout in the ratio of 1: 1 as explained in Grouting or covered with steel mesh and mortar.

Damaged portions of the wall, if any should be reconstructed using richer mortar. In thick walls, 'through' stones or bonding elements shall be installed, if not present originally, at each one-third point along the length and height of wall

For providing RC through elements in existing wall, a hole in the wall is to be made at selected location by gently removing the stones from the two sides of the wall. Care has to be taken in removing the stones, is filed with concrete and a steel rod bent at two ends is provided as shown in figure.

3.5.8 Masonry Arches

If the walls have large arched openings in them, it will be necessary to install tie rods across them at springing levels or slightly above it by drilling holes on both sides and grouting steel rods in them (see Figure 43a). Alternatively, a lintel consisting of steel channels or I-shapes could be inserted just above the arch to take the load and relieve the arch as shown at Figure 43b. In jack-arch roofs, flat iron bars or rods shall be provided to connect the bottom flanges of I-beams connected by bolting or welding (see Figure 43c).

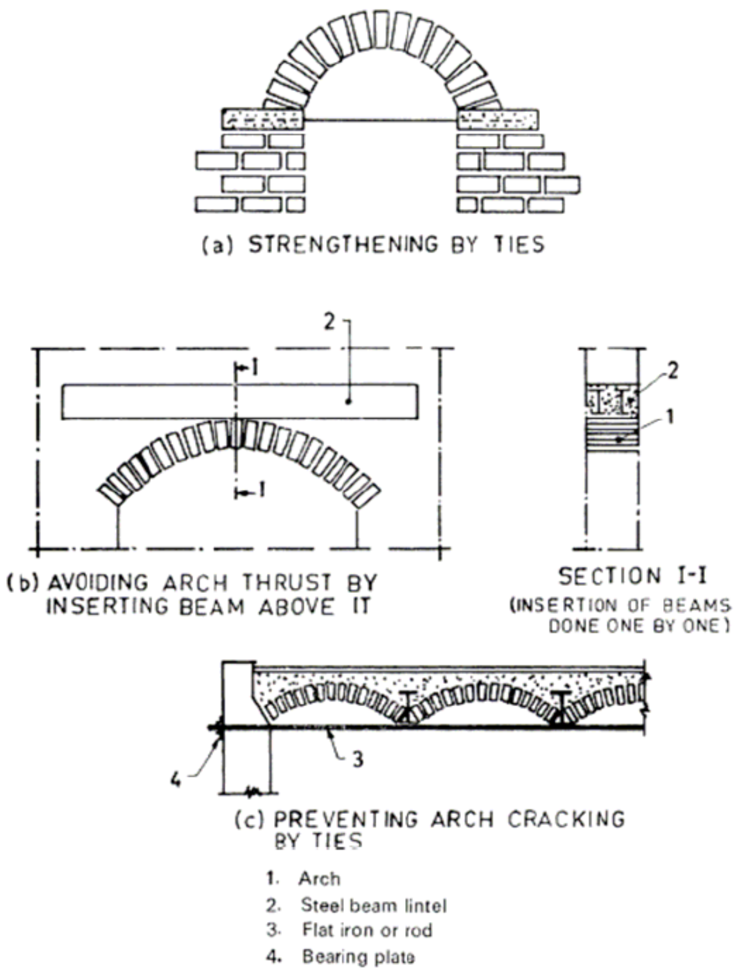


Figure 43: Strengthening An Arched Opening In Masonry Wall

3.5.9 Strengthening Long Walls

Masonry walls are weak in out of plane action. Large unsupported lengths and heights need to be supported laterally. These supports can be provided either by cross walls or by buttresses. The cross walls and buttresses need to be properly connected with the existing wall. Figure shows the details of connecting a buttress with an existing wall and Fig shows the details of connecting a new masonry wall with existing rubble tone masonry.

3.5.10 Strengthening Reinforced Concrete Members

a. Columns

Reinforced concrete columns can best be strengthened by casing, that is, by providing additional cage of longitudinal and lateral tie reinforcement around the columns and casting a concrete ring (see Figure 44). The desired strength and ductility can thus be built-up.

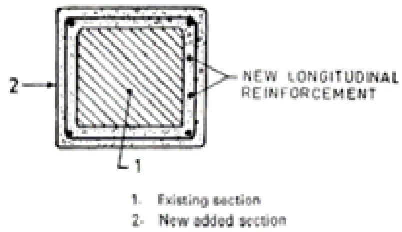


Figure 44: Casing A Concrete Column

b. Beams

A reinforced concrete beam can be encased as shown in Figure 45a. For holding the stirr-up in this case, holes will have to be drilled through the slab. Alternatively it can be jacketed as shown in Figure 45b, and Figure 45c wherein holes will need to drilled through web of existing beam for the new stirrups. Desired quantity of longitudinal and transverse steel may be added in each case. Reinforced concrete beams can also be strengthened by applying pre-stress to it so that opposite moments are caused to those applied. The wires will run on both sides of the web outside and anchored against the end of the beam through a steel plate. Loss of pre-stress due to creep relation and temperature fall shall be duly considered.

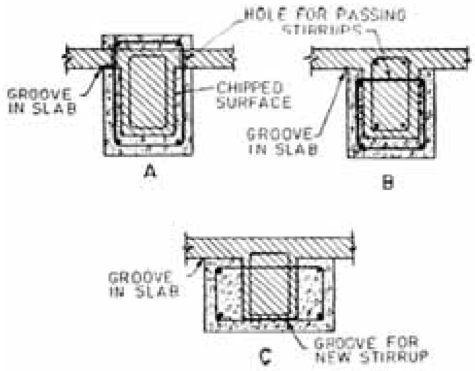


Figure 45: Increasing The Section And Reinforcement Of Existing

c. Strengthening of Foundations

Strengthening of foundations before or after the earthquake is the most involved task since it may require careful under pinning operations. Some alternatives are given below for preliminary consideration of the strengthening scheme:

- Introducing new load bearing members including foundations to relieve the already loaded members. Jacking operations may be needed in this process.
- Improving the drainage of the area to prevent saturation of foundation soil to obviate any problems of liquefaction, which may occur because of poor drainage.
- Providing apron around the building to prevent soaking of foundation directly and draining off the water.
- Adding strong elements in the form of reinforced concrete strips attached to the existing foundation part of the building. These will also bind the various wall footings and may be provided on both sides of the wall (see Figure 46) or only one side of it. In any case,

the reinforced concrete strips and the wall have to be linked by a number of keys inserted into the existing footing.

NOTE — To avoid disturbance to the integrity of the existing wall during the foundation strengthening process proper investigation and design is called for.

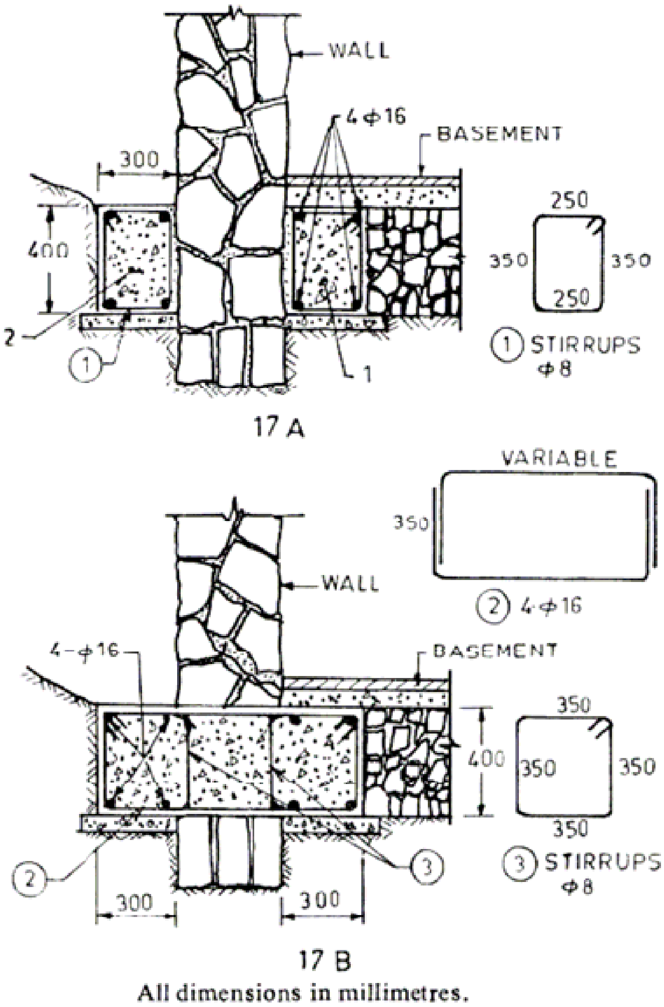


Figure 46: Strengthening Existing Foundation (R.C. Strip on Both Sides)

Chapter 4. Training Manual from Fiji

4.1 Introduction

Natural Hazards such as Earthquake, Cyclone, Flood and Tsunami are normal occurrences in our region and Fiji in particular. The government has to meet bulk of the cost of damages caused by such hazards. The high cost of rehabilitation work required after the occurrence of a hazard can be reduced if some proactive works are undertaken to ensure that new structures are properly built and maintained so as to ensure that they serve their purpose and existing structures are upgraded to a minimum standard.

Building retrofitting is the process of strengthening a building structure so that it can better withstand natural hazards such as Earthquake, Cyclone, Flood and Tsunami, etc. The introduction of this manual is expected to assist technicians, masons and carpenters to improve existing buildings and contribute to the construction and maintenance of safe and sound houses, especially schools for our children.

The manual has been prepared under the UNCRD Program on "Reducing Vulnerability of School Children to Earthquakes." Although the Manual focuses on Retrofitting of School Buildings, the same concept can also be applied to any other public or private building.

The Manual is aimed at assisting Technicians, Masons and Carpenters to gain better understanding of retrofitting work required using the concept and procedures outlined in the Manual. It is also aligned to the "Home Building Manual: which was prepared by the Fiji Building Standard Committee that produced the Fiji National Building Code in 1990. The Home Building Manual is a guide which Home Owners can use within it's limitations to design and construct their own homes. Construction details in this Training Manual should be used as minimum standards of construction for retrofitting existing school buildings (one or two storey construction) as the construction of new ones.

Although the Manual targets Technicians, Masons and Carpenters, it is hoped that policy makers, administrators, school managers and principals will also realize the great risks involved in the use of unsafe school public buildings and take appropriate steps to allocate more resources for the improvement of those buildings.

4.2 Earthquake Prone Areas in Fiji

Fiji sits on the top of the conjunction between three major Tectonic Plates. Earthquake prone areas can be identified from maps showing past occurrences of earthquakes. In Fiji, one such map was produced from information provided in a paper that was prepared by Trevor Jones and is reproduced here as Figure 47. It will be noted from the Earthquake map that a lot of earthquakes of different magnitudes have occurred in Fiji in past years. Concentration of such earthquakes can be found along the Yasawa Group, Northern side of Taveuni and North of Kadavu. It can therefore be said that these are the areas that will be more subjected to earthquakes than those with less concentration of activity. Proper care must therefore be taken when designing and building in those areas.

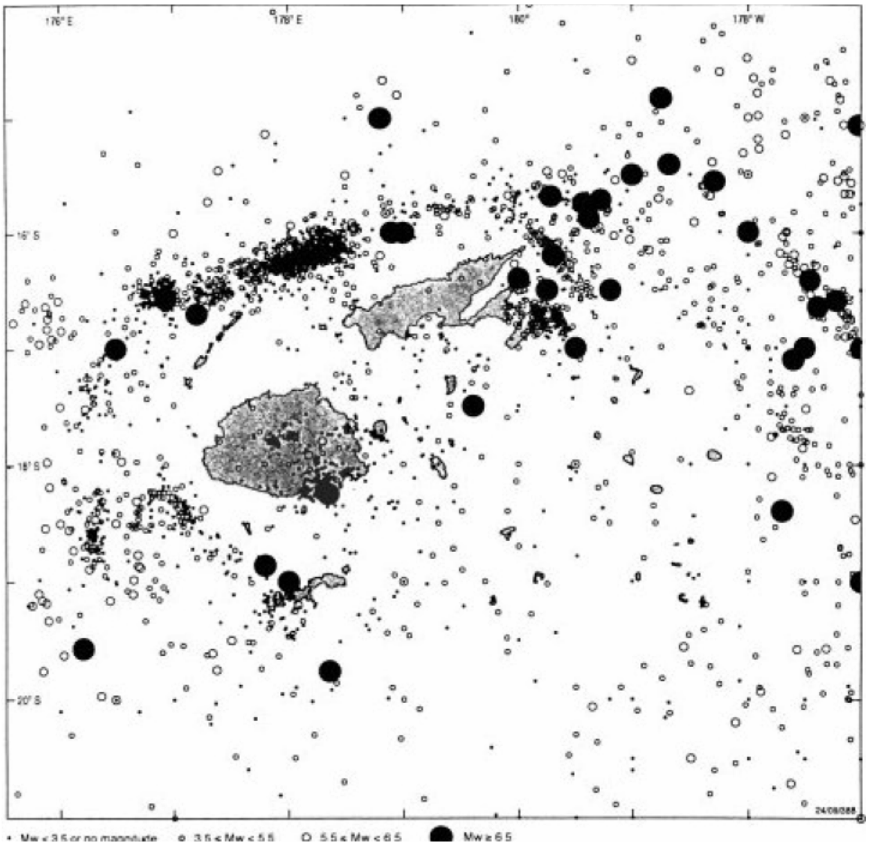


Figure 47: The occurrences of earthquakes in Fiji

Preliminary Earthquake Risk Zoning Map The Risk Zoning Map for Fiji (Figure 48) identifies three high risk zones : Yasawa Group, Northern Taveuni and Northern Kadavu.

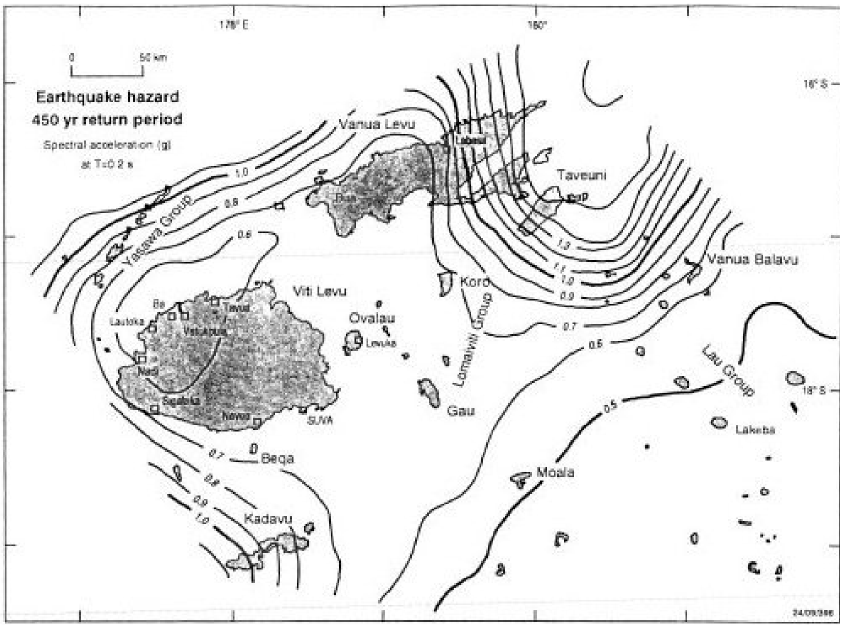


Figure 48: Probabilistic earthquake hazard assessment for Fiji

The earthquake zone factor is used by Design Engineers to ensure that the designed structure will be able to withstand or minimize the effect of earthquake in a particular area.

4.3 Damages Caused By Earthquakes

The vibration energy transmitted through the earth causes strong shaking of the ground. The shaking of the ground can cause the following damages:

- Collapse of structures that in turn may kill or injure occupants
- Landslide or landslip is the movement of earth or surface down a slope due to heavy gravity. It can vary in size from a single boulder or a massive amount of materials in a debris avalanche.
- Vibration caused by earthquake may overturn equipment and furniture in a building causing damages and may also result in fire

4.4 Structures At Risk

- Low strength masonry buildings
- Structures with heavy roof and little lateral support
- Reinforced concrete structures that are wrongly designed or poorly constructed
- Timber framed buildings better withstand earthquake if they are well built and the elements or members are well connected
- Buildings built on loose soils or sited on weak slopes are also at risk in an earthquake

4.5 Best Protection Against Earthquake

- Good and strong construction
- Proper sitting of the building. Avoid sitting the building on unstable sites

4.6 Earthquake Retrofitting for School Buildings

Earthquake retrofitting is the modification of existing school buildings to make them more resistant to earthquake or seismic activity, ground motion or soil failure. Most school buildings in Fiji are of single or two storey construction and are made of timber, masonry or reinforced concrete. Retrofitting work discussed will focus on those types of buildings. The retrofitting work or method of construction used to counter the effect of earthquake and cyclone on school buildings of one or two stories are similar. If they are properly carried out, the building should be able to better withstand the effect of both earthquake and cyclone.

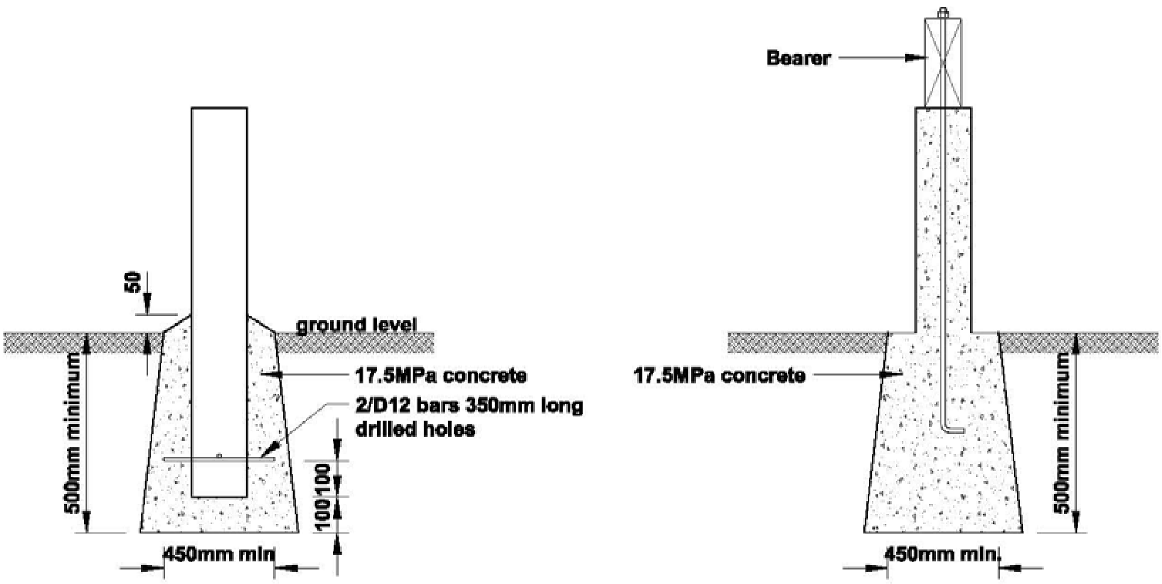


Figure 49: Anchor piles

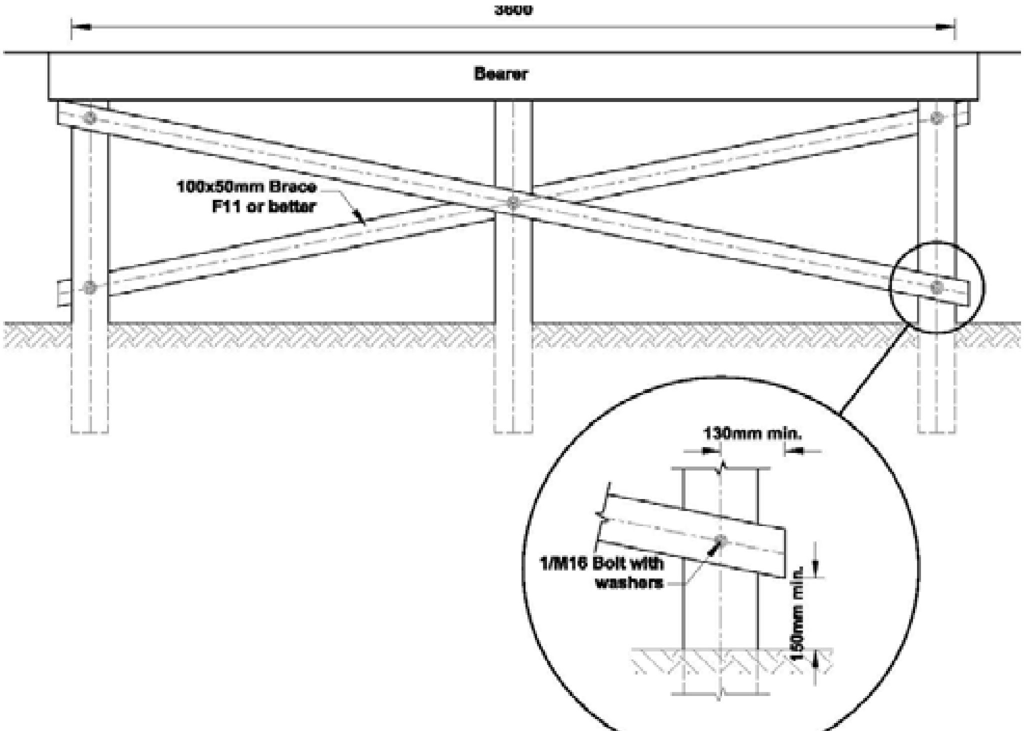


Figure 50: Sub-floor bracing types

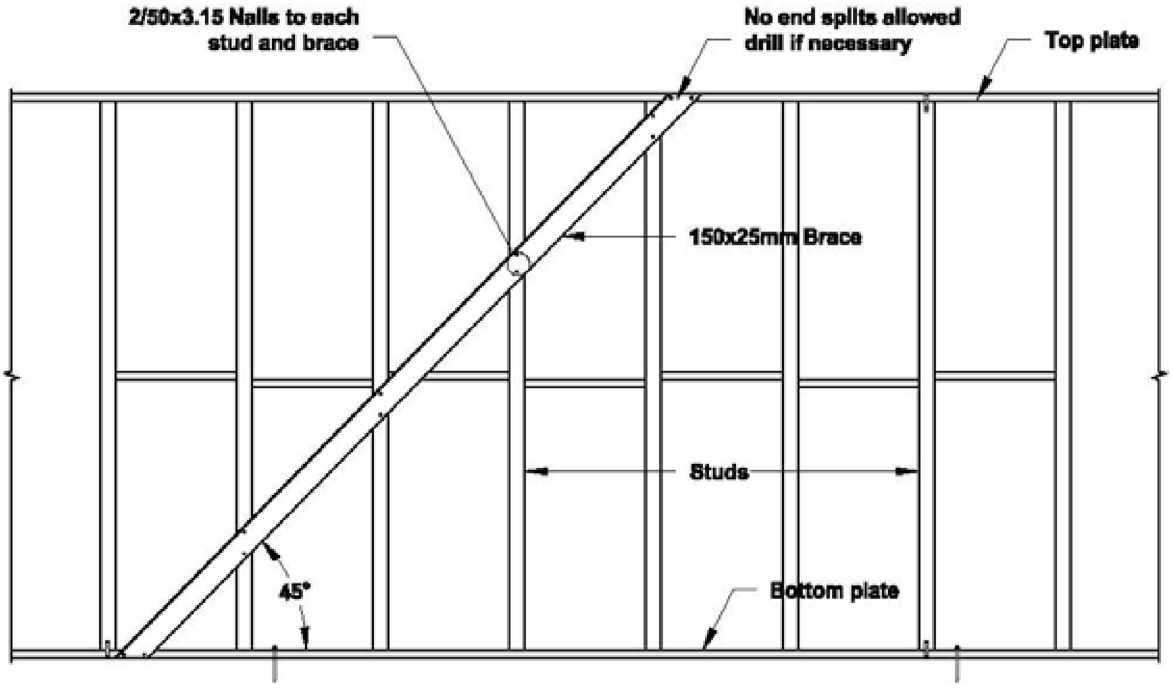


Figure 51: Timber brace

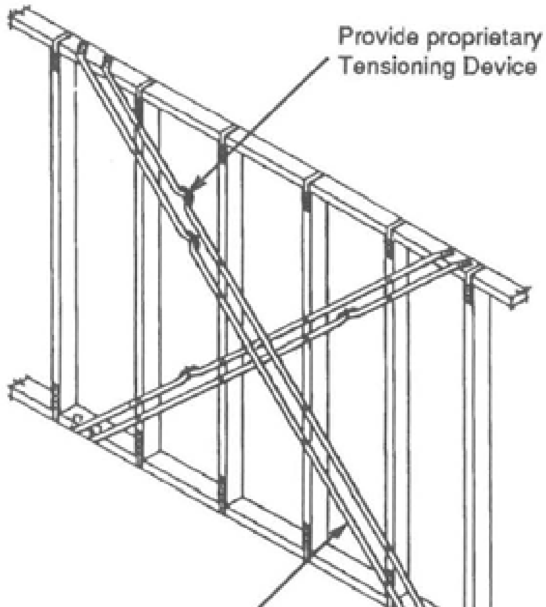


Figure 52: Metal braces

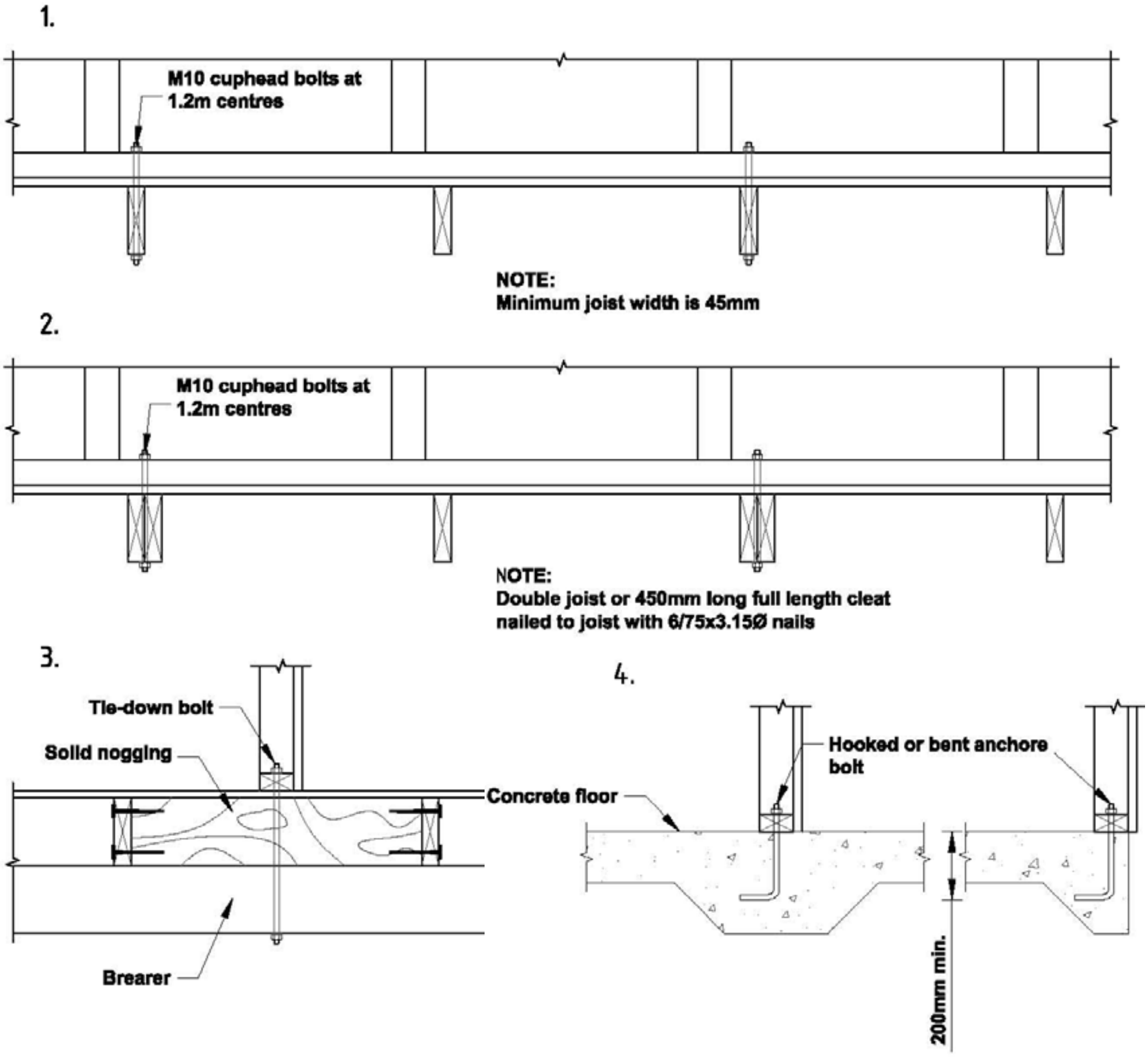


Figure 53: Tie down: Bottom of bracing walls

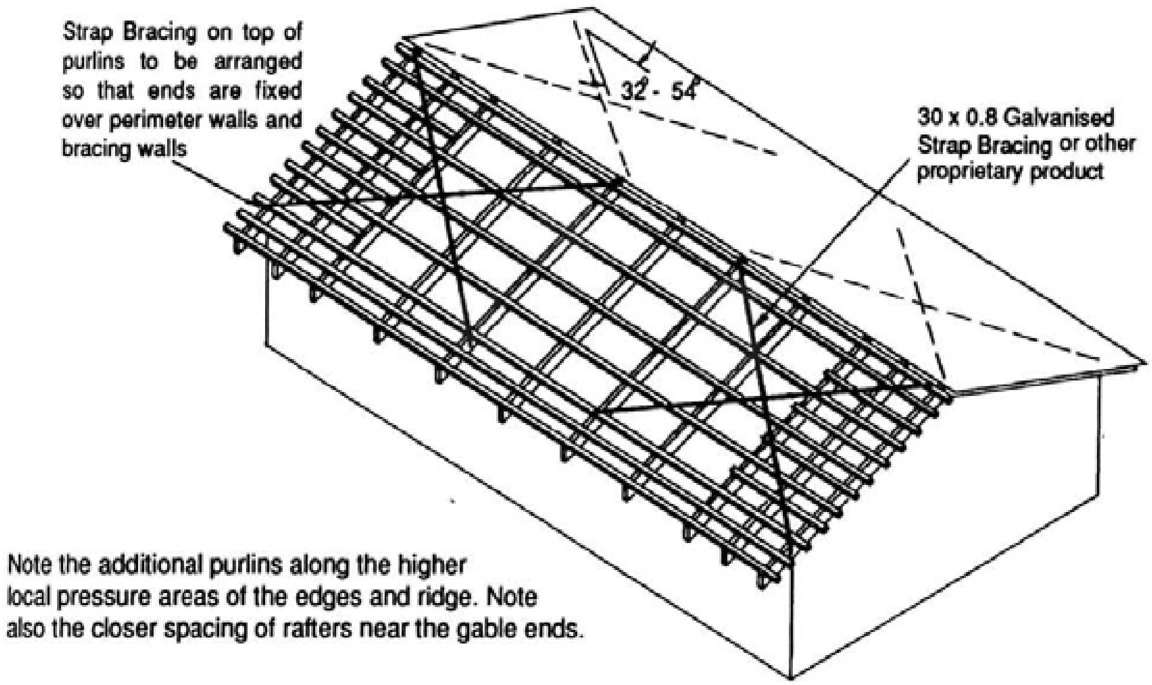
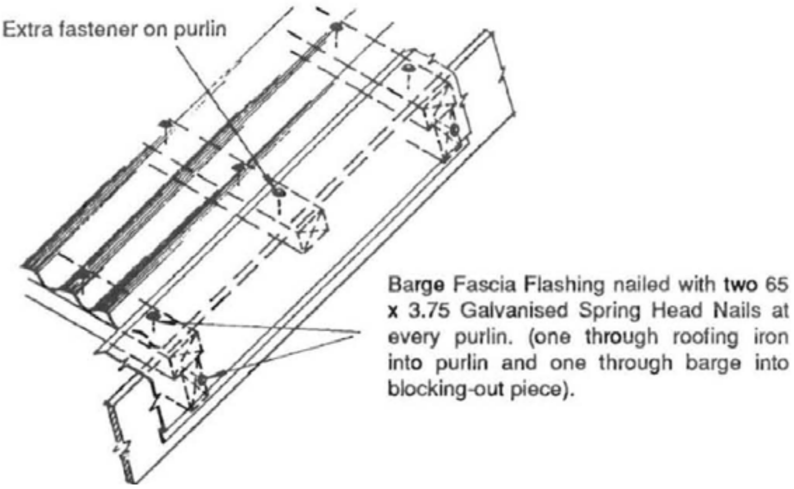
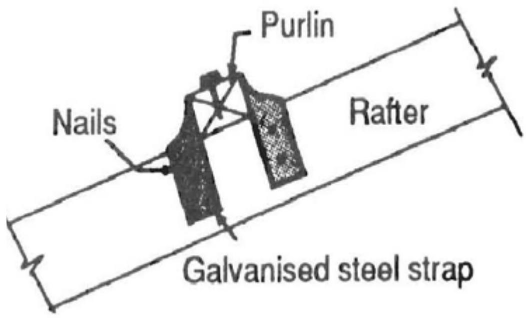


Figure 54: Rafter roof framing details

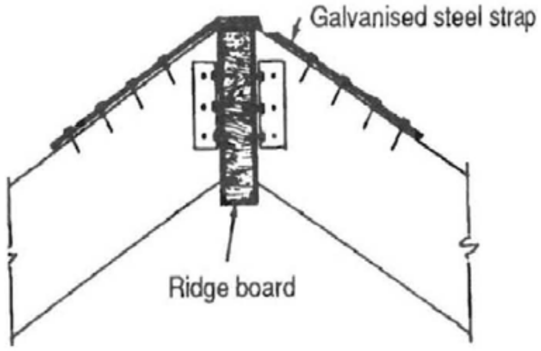
FIXING OF BARGE FLASHING AT GABLE END



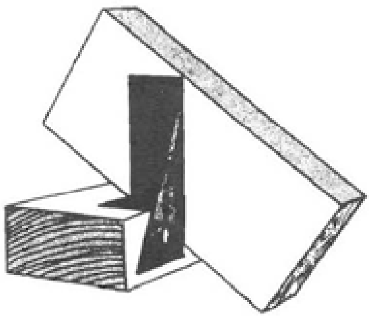
CONNECTION OF PURLINS



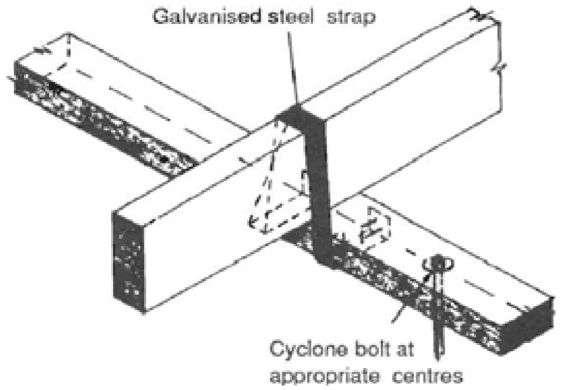
CONNECTION AT THE RIDGE JOINT



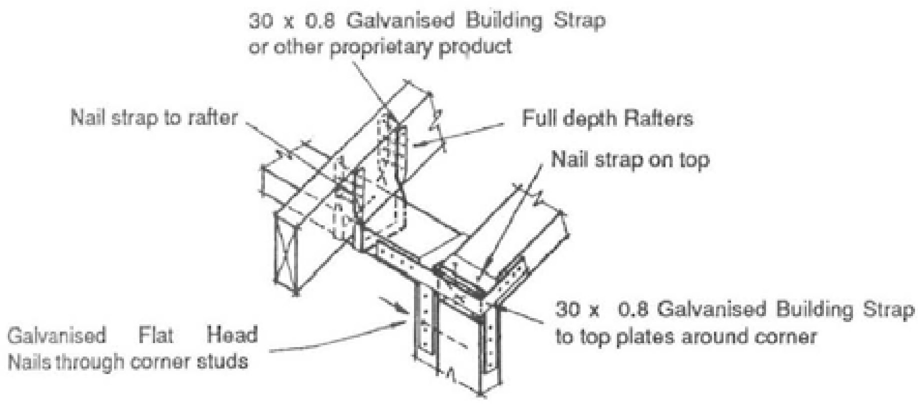
CONNECTION USED TO SECURE RAFTERS TO TOP PLATES



FIXING OF RAFTER TO TOP PLATE



FIXING OF GABLE END WALLS TO SIDE WALLS AT TOP PLATE LEVEL



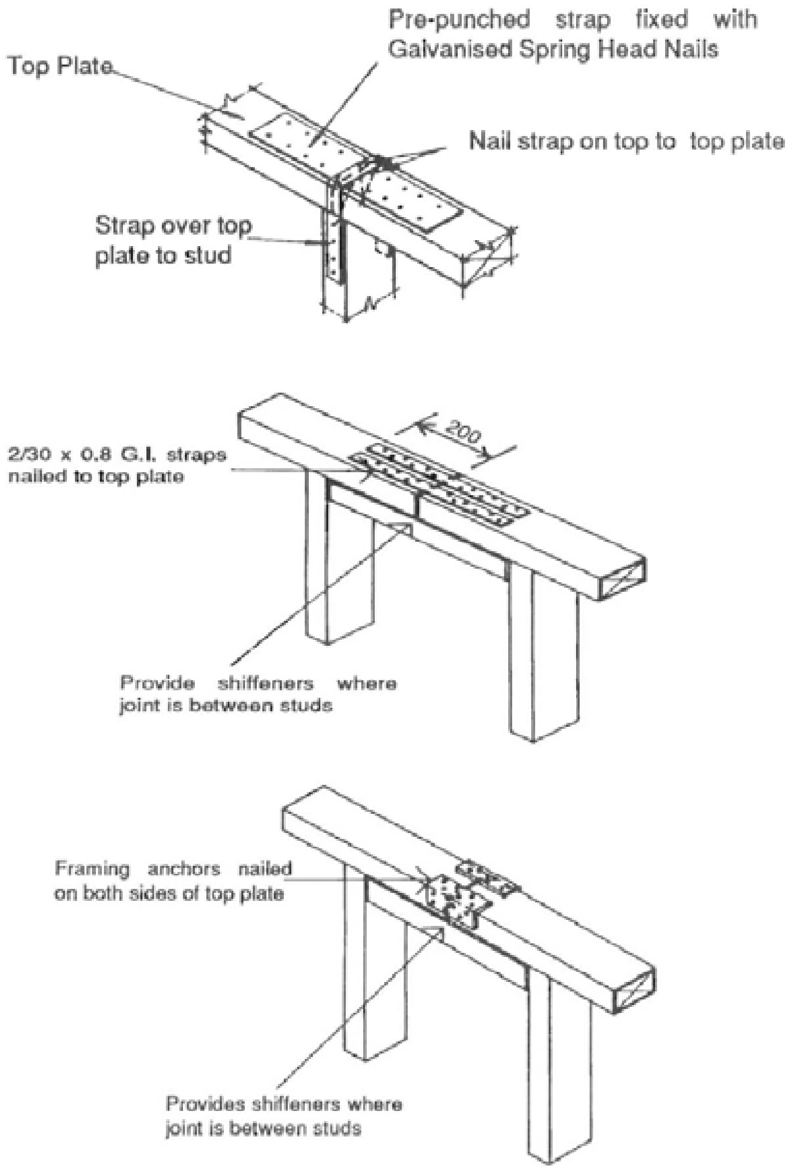
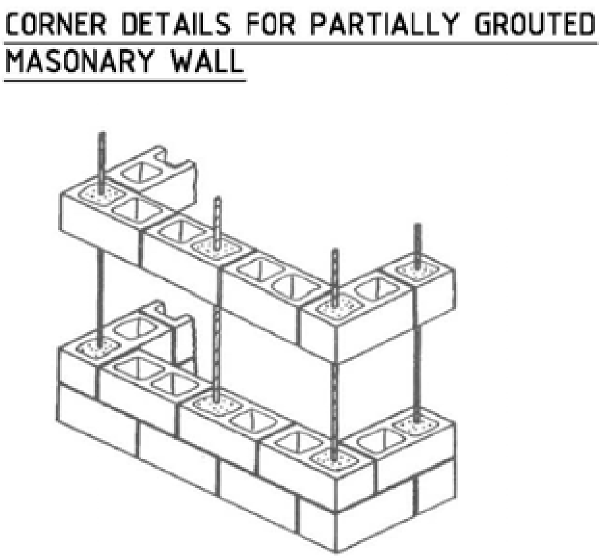
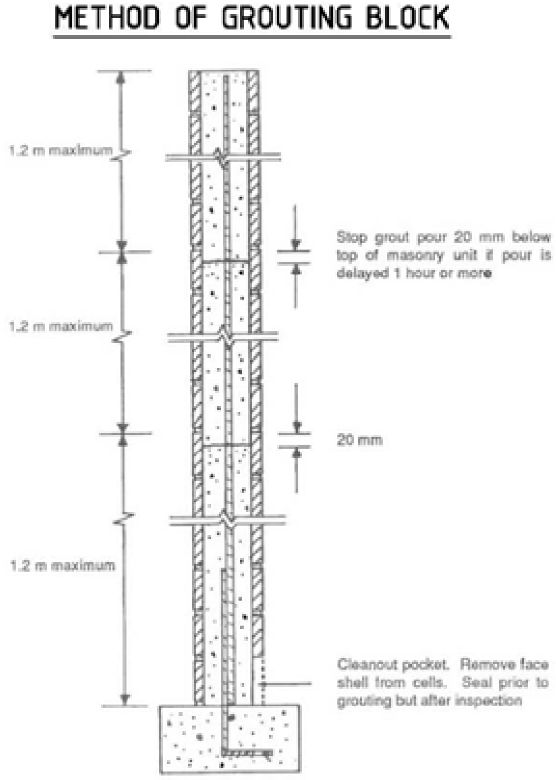


Figure 55: Joints in top plates





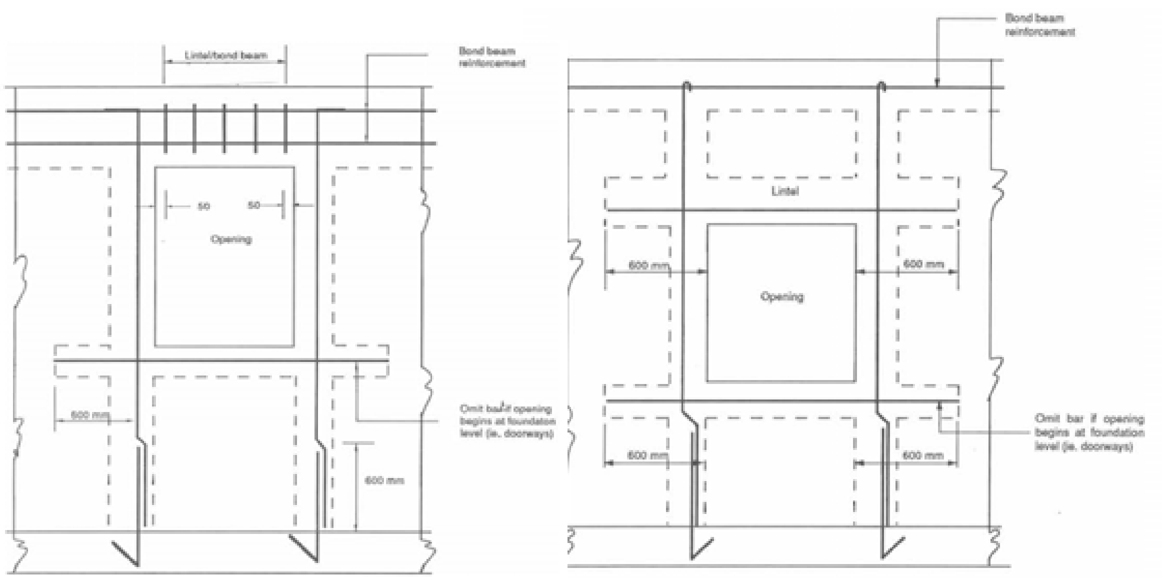


Figure 56: Reinforcement details around openings in walls

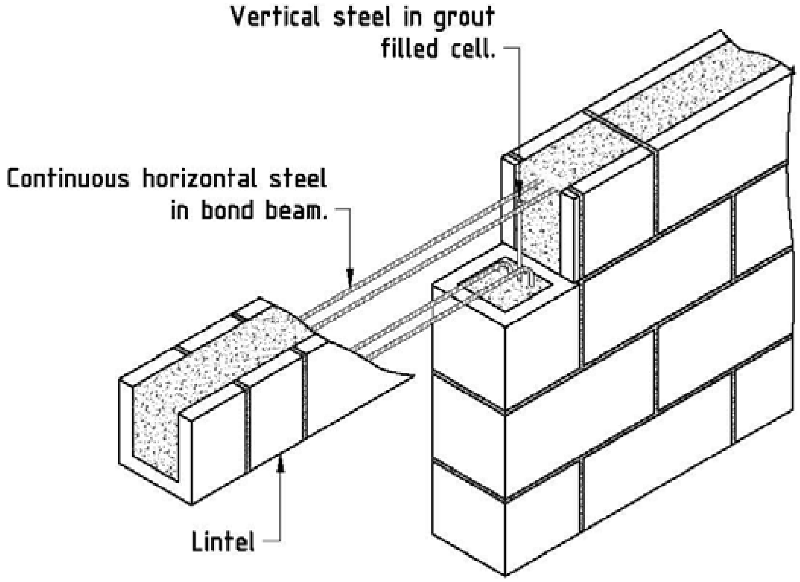


Figure 57: Lintel and bond beam details

Chapter 5. Training manual from Indonesia

5.1.1 Proper site selection

The site conditions play a vital role in seismic safety of a building. Hazardous sites should be avoided for building construction to minimize risks against natural disasters. Site investigations will assist in identifying potential danger of sliding, erosion, land subsidence or liquefaction during an earthquake. The local practice of managing any such hazard should be given due considerations. A safer site is the one having (see Figure 58):

- No danger of landslides
- Sufficient plantation on slope
- Trees not too close to the house
- Mild slope
- Far from river banks

Building should not be constructed near steep and unstable slopes. Cliffs made of soft or crumbly, clay loam, deposited materials, etc. should be avoided. Landslides or rock fall areas should be avoided while selecting a site for building construction. Apparently some slopes may look stable, but failure could be triggered by an earthquake. Landslides and rock falls can damage buildings partially or completely. Simple indication of sustained stability of a slope is the presence of upright standing trees on it. Abnormally inclined trees on a slope indicate instability of the hill slope.

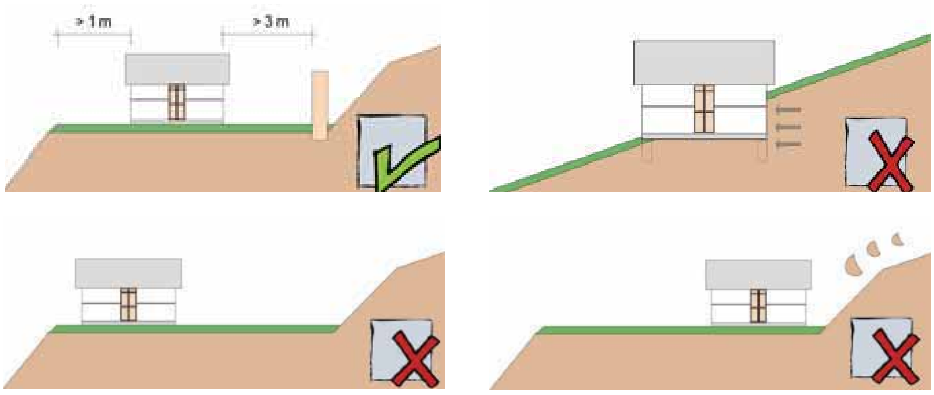


Figure 58: Site selection

5.1.2 Firm base and solid foundation

Seismic-resistant building needs a solid foundation that is well connected to the walls. Reinforced monolithic concrete foundations are best. If fired brick or rubble stone foundations are used, add a reinforced concrete beam on the top of the foundation (see Figure 59).

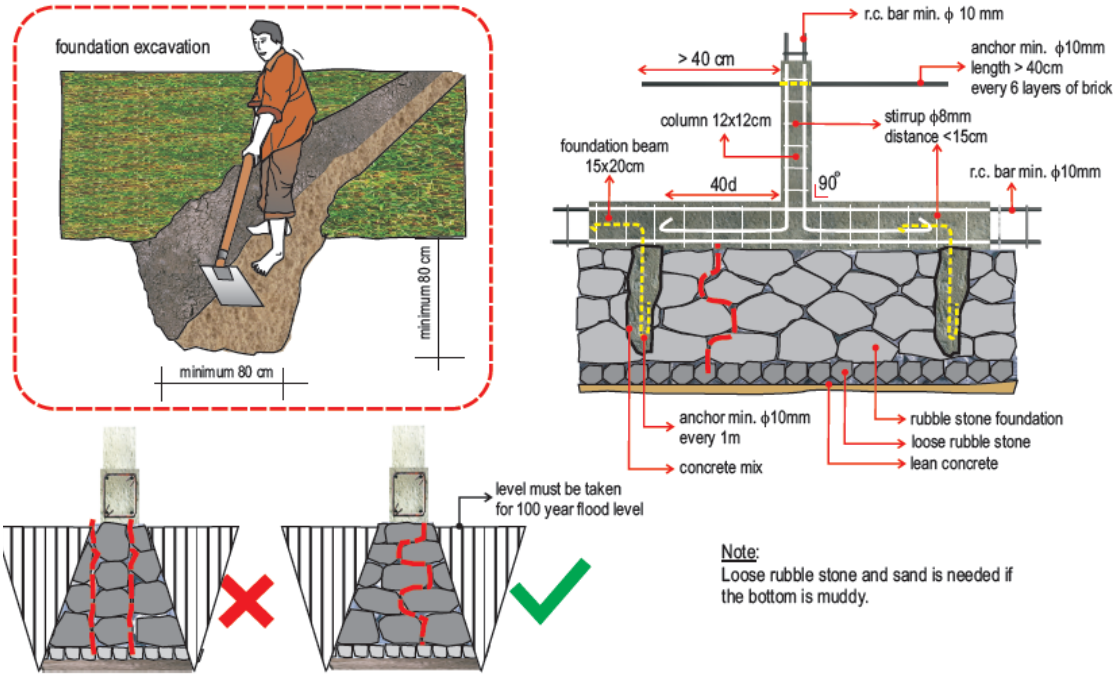


Figure 59: Stone foundation

5.1.3 Regular, low and symmetrical layout

The behavior of a building during an earthquake depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground. In tall buildings with large height-to-base size ratio the horizontal movement of the floors during ground shaking is large (Figure 60a). In short but very long buildings the damaging effects during earthquake shaking are many (Figure 60b). In buildings with large plan area like warehouses, the horizontal seismic forces can be excessive to be carried by columns and walls (Figure 60c).

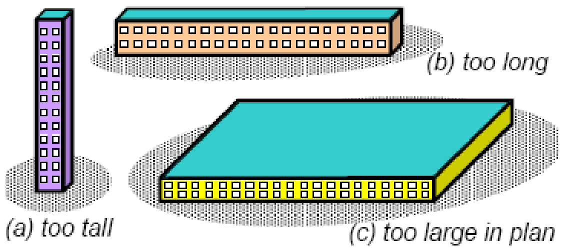


Figure 60: Buildings shapes and sizes

In general, buildings with simple geometry in plan have performed well during strong earthquakes (Figure 61a). Buildings with re-entrant corners, like those U, V, H and + shaped in plan have sustained significant damage (Figure 61b). Many times, the bad effects of these interior corners in the plan of buildings are avoided by making the buildings in two parts. For example, an L-shaped plan can be broken up into two rectangular plan shapes using a separation joint at the junction (Figure 61c).

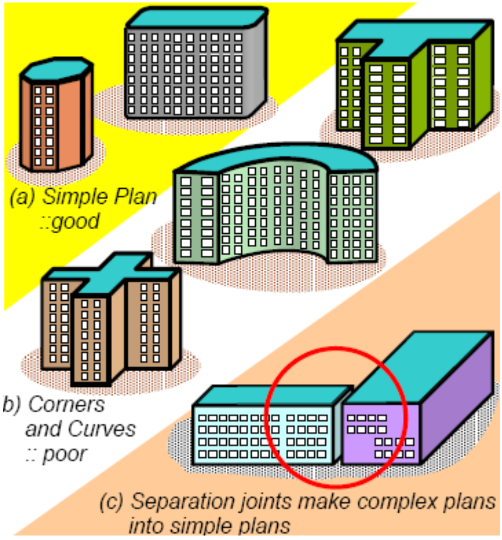


Figure 61: Simple plan shape buildings do well during earthquakes.

Often, the plan is simple, but the columns/walls are not equally distributed in plan. Buildings with such features tend to twist during earthquake shaking. The earthquake forces developed at different floor levels in a building need to be brought down along the height to the ground by the shortest path; any deviation or discontinuity in this load transfer path results in poor performance of the building. Buildings with vertical setbacks (like the hotel buildings with a few stories wider than the rest) cause a sudden jump in earthquake forces at the level of discontinuity (Figure 62a).

Buildings that have fewer columns or walls in a particular storey or with unusually tall storey tend to damage or collapse, which is initiated in that storey (Figure 62b). Many buildings with an open ground story intended for parking collapsed or were severely damaged during earthquake. Buildings on sloppy ground have unequal height columns along the slope, which causes ill effects like twisting and damage in shorter columns (Figure 62c). Buildings with columns that hang or float on beams at an intermediate storey and do not go all the way to the foundation have discontinuities in the load transfer path (Figure 62d). Some buildings have reinforced concrete walls to carry the earthquake loads to the foundation. Buildings, in which these walls do not go all the way to the ground but stop at an upper level, are liable to get severely damaged during earthquakes (Figure 62e).

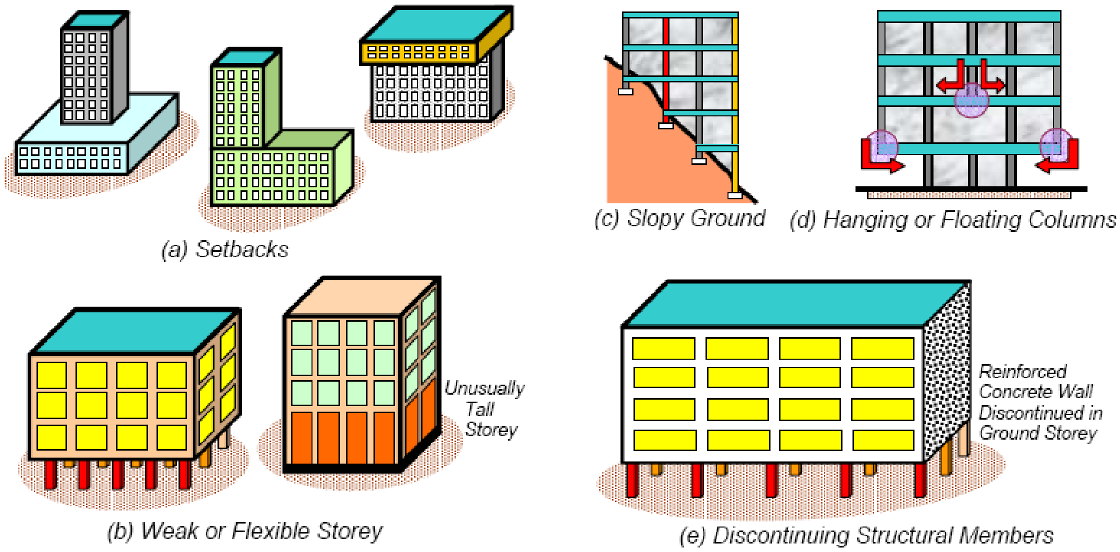


Figure 62: Sudden deviations in load transfer path along the height lead to poor performance of buildings.

5.1.4 Properly connected walls

A simple way of making walls behave well during earthquake shaking is by making them act together as a box along with the roof at the top and with the foundation at the bottom. A number of construction aspects are required to ensure this box action. Firstly, connections between the walls should be good. This can be achieved by (a) ensuring good interlocking of the courses at the junctions, and (b) employing horizontal bands at various levels, particularly at the lintel level. Secondly, the sizes of door and window openings need to be kept small. The smaller the opening, the larger is the resistance offered by the wall. Thirdly, the tendency of a wall to topple when pushed in the weak direction can be reduced by limiting its length-to-thickness and height to thickness ratios (Figure 63). A wall that is too tall or too long in comparison to its thickness is particularly vulnerable to shaking in its weak direction (Figure 64).

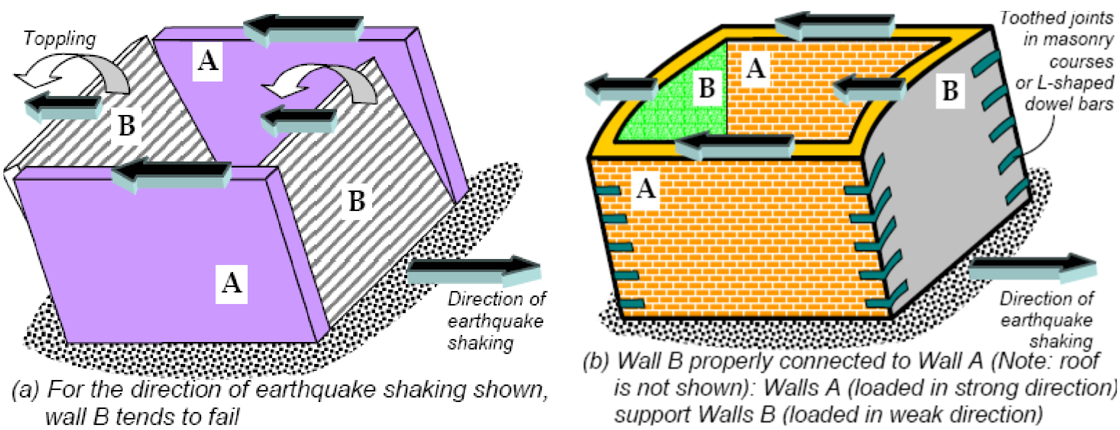


Figure 63: Wall behavior with/out connection

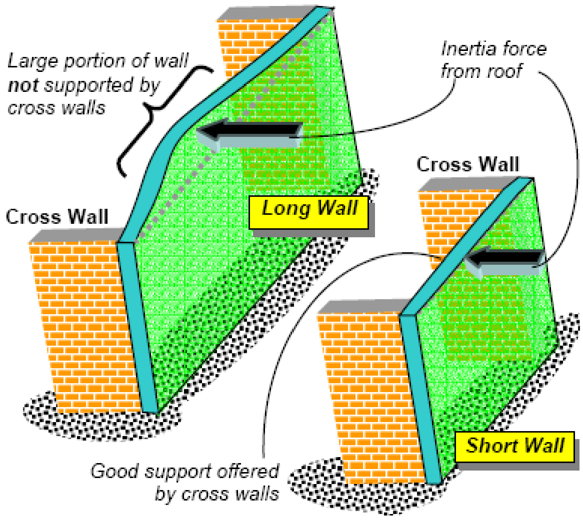


Figure 64: Long wall and short wall

5.1.5 Appropriate openings

Openings in the wall are necessary for providing doors and windows. But larger and number of openings make the wall weak. Therefore the number and size of openings should be limited. The width of an opening should preferably not be more than 1.2m. Distance between an exterior corner of the building and the opening should not be less than 60cm. Gap between two openings or the wall length between any two openings (doors and/or windows) should not be less than 60cm. The sum of the width of openings in a wall should not exceed 50% of the total wall length.

5.1.6 Well connected foundations, walls and roofs

Horizontal bands are the most important. The bands are provided to hold a building as a single unit by tying all the walls together, and are similar to a closed belt provided around cardboard boxes. There are four types of bands in a typical building, namely gable band, roof band, lintel band and plinth band (see Figure 65), named after their location in the building. The lintel band is the most important of all, and needs to be provided in almost all buildings. The gable band is employed only in buildings with pitched or sloped roofs. In buildings with flat reinforced concrete or reinforced brick roofs, the roof band is not required, because the roof slab also plays the role of a band. However, in buildings with flat timber or CGI sheet roof, roof band needs to be provided. In buildings with pitched or sloped roof, the roof band is very important. Plinth bands are primarily used when there is concern about uneven settlement of foundation soil.

The lintel band ties the walls together and creates a support for walls loaded along weak direction from walls loaded in strong direction. This band also reduces the unsupported height of the walls and thereby improves their stability in the weak direction. Reinforcement and bending details of band at corner are given in Figure 66, Figure 67, and Figure 68.

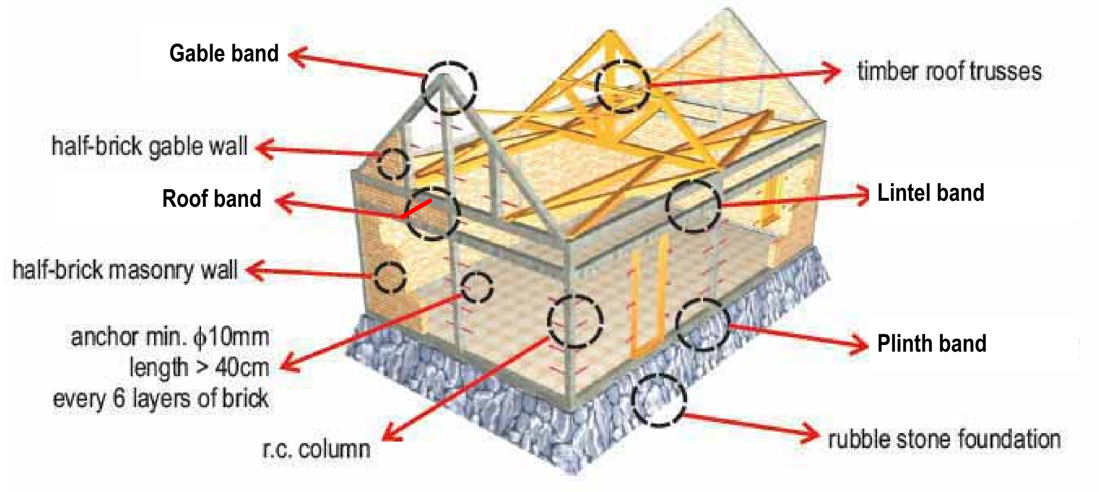


Figure 65: Location of horizontal bands

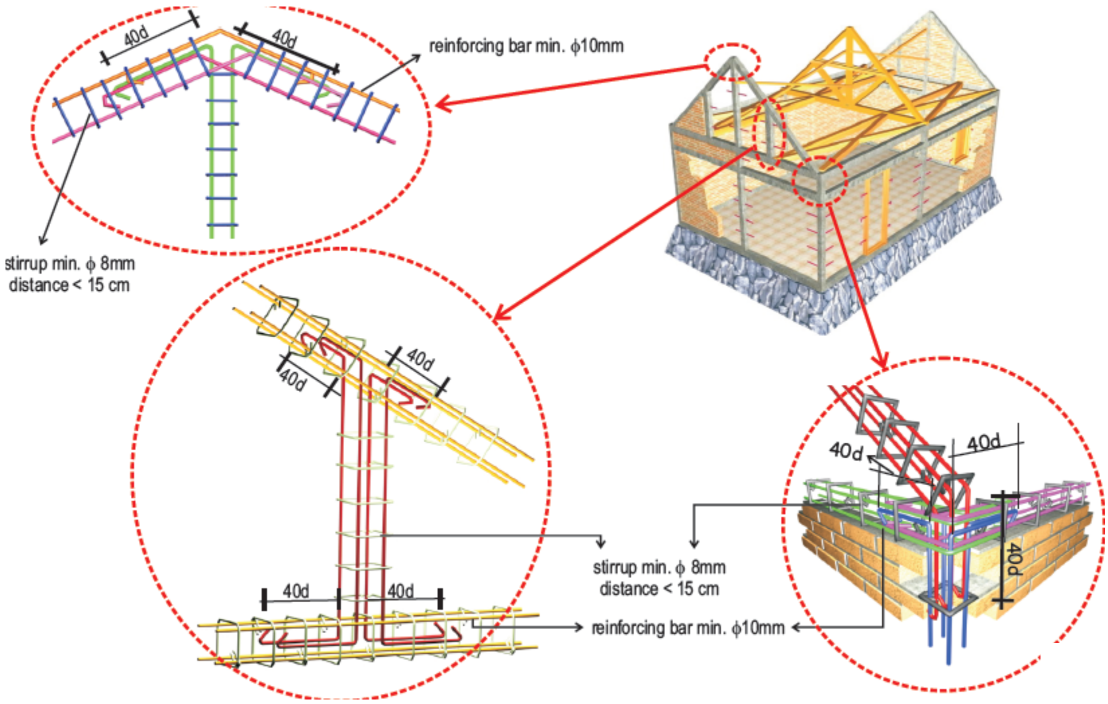


Figure 66: Reinforcement and bending details of band

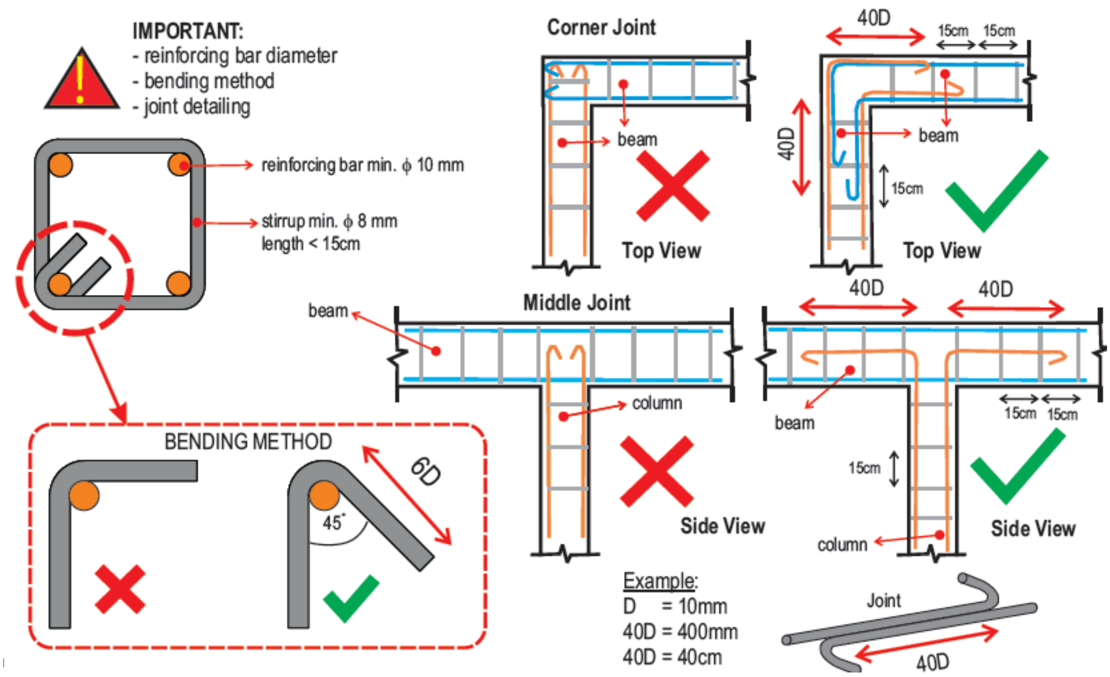


Figure 67: Seismic resistant detailing of joints

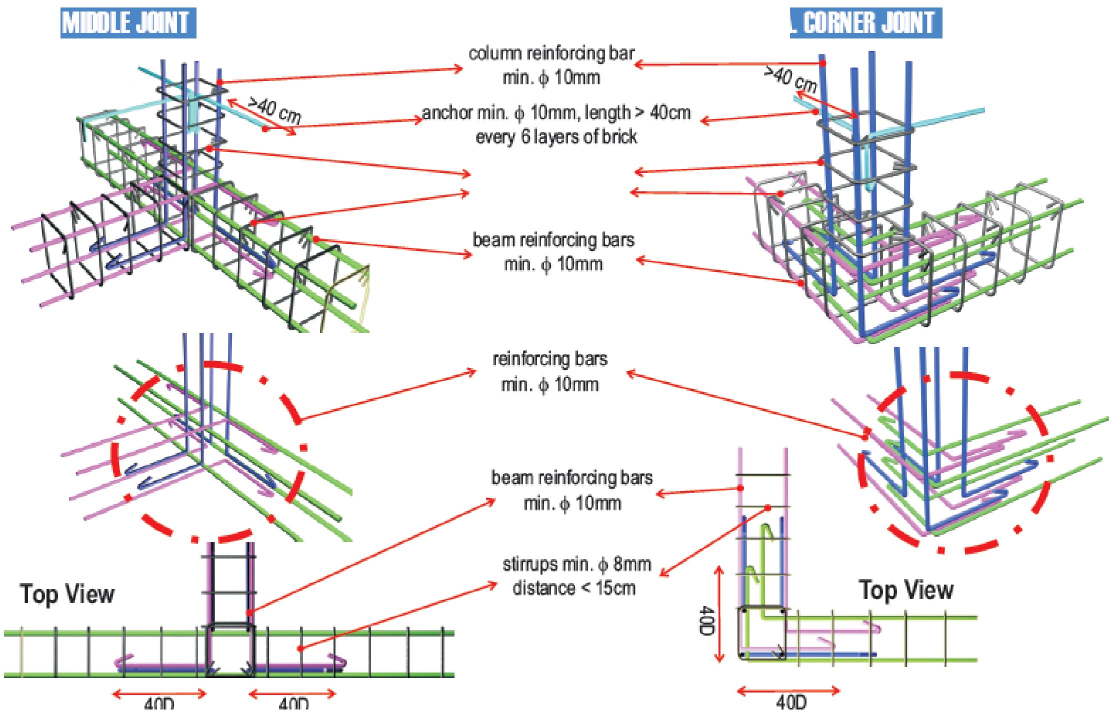


Figure 68: Plinth band reinforcing details

5.1.7 Well connected all elements of roof

All roofing materials shall be properly tied to the supporting members (see Figure 69). Heavy roofing materials should generally be avoided. All roof trusses should be supported on and fixed to timber band reinforced concrete band or reinforced brick band. The holding down bolts should have adequate length as required for earthquake and wind forces. Where a trussed roof adjoins a masonry gable, the ends of the purlins should be carried on and secured to a plate or bearer which should be adequately bolted to timber reinforced concrete or reinforced brick band at the top of gable end masonry.

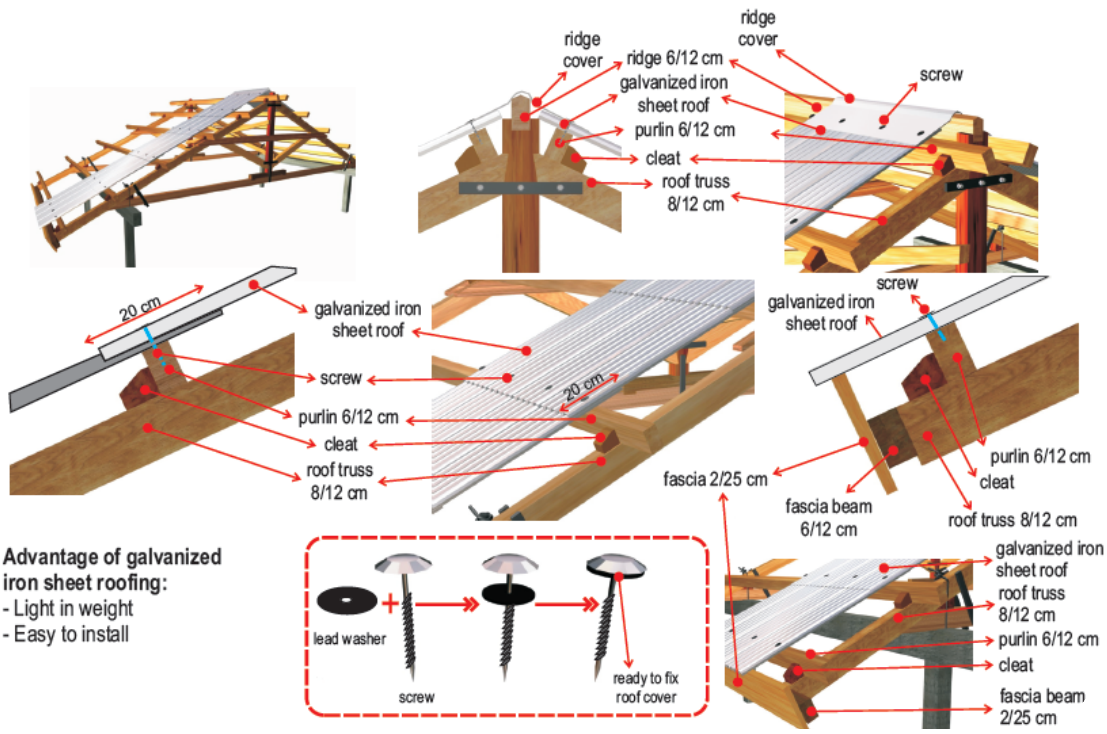


Figure 69: Roof covering

At tie level, all the trusses and the gable end should be provided with diagonal braces in plan so as to transmit the lateral shear due to earthquake force to the gable walls acting as shear walls (see Figure 65 and Figure 70)

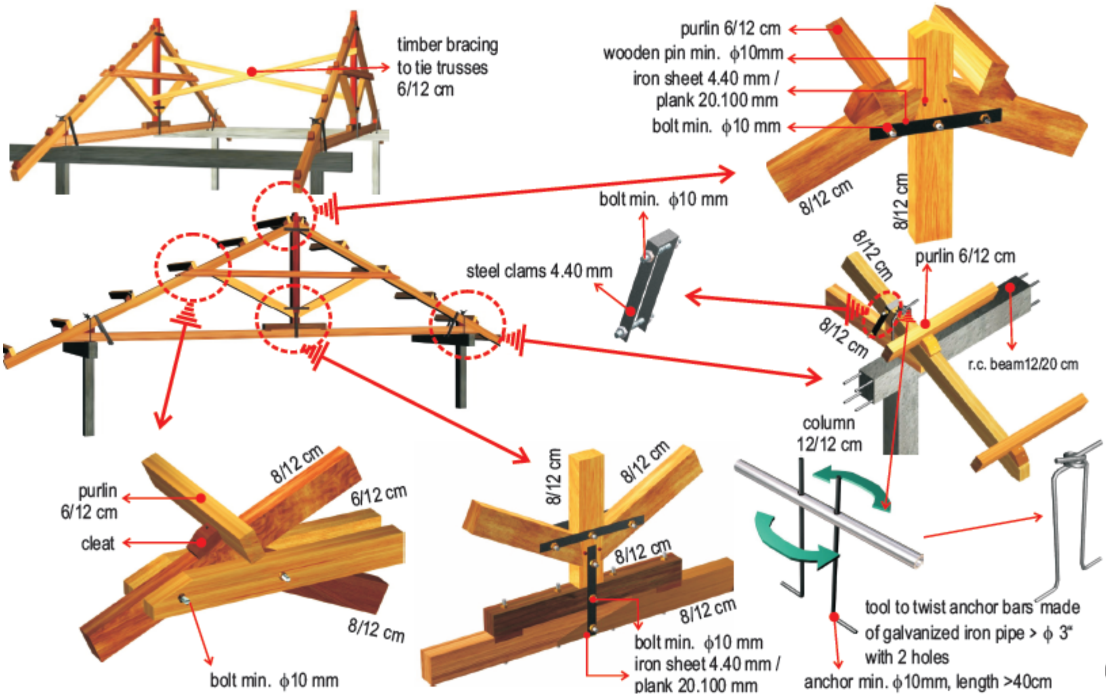


Figure 70: Timber roof trusses

5.2 Care in Concrete Construction

In reinforced concrete work, the most important requirement for good behavior is good quality of concrete, which is not usually achieved in non-engineered construction. Here simple guidelines are given for making concrete of adequate strength.

5.2.1 Good construction materials

Choice of materials affects the strength of the building.

- Coral sand should never be used in any construction.
- Coarse sand should be sieved to remove stones, fine particles and dust.
- If the sand comes from a dirty or seawater source, it must be washed.

Sand needs to be the same coarse texture and does not have stones in it or a lot of dust. Sand can be tested by lifting up a handful and letting it fall back to the ground. If a significant portion of it blows away instead of falling straight down, it has too much dust and needs to be sieved.

Debris should not be allowed to be mixed with any of the ingredients for making concrete. Such debris seriously weakens the strength of concrete. This sand will need to be cleaned before it is used for mixing into concrete. All plastic, leaves, grass, and other debris must be removed before using sand or gravel for making concrete. Harmful debris particularly enters the concrete when it is mixed by hand on the ground.

Figure 71: Construction materials

5.2.2 Mixing materials

Where mixing is done manually without using a power driven mixer, it should be done on an impervious platform, say, using iron sheets or cemented floor. For making a mix of 1:2:3, three pails of gravel should first be measured and flattened on the platform, then two pails of sand should be spread on the gravel and finally one pail of cement opened on top. The material should first be mixed thoroughly in dry state so as to obtain uniform color and then water added. The quantity of water should be enough to make a soft ball of the mixed concrete in hand. A little wetter mix is better for hand compaction and drier mix where vibrator is used for compaction.

- Good clean ingredients with little water makes strong concrete
- Ensure adequate cement is added
- Mix ingredients well
- Limit water, and use only clean water. Concrete should stand up when mixed, not flow away due to excessive water
- Do not use any water that is salty. This destroys concrete strength
- Use only properly selected, clean ingredients

Figure 72: Preparing concrete mix

5.2.3 Formwork

The quality of not only the concrete surface but also the strength of concrete depends on the surface of the formwork and its imperviousness to the leakage or oozing out of the water and cement through the joints. Wooden formwork with well-formed surface and joints between planks should be used. Use of water resistant plywood for the skin of the formwork will give very good surface of the concrete.

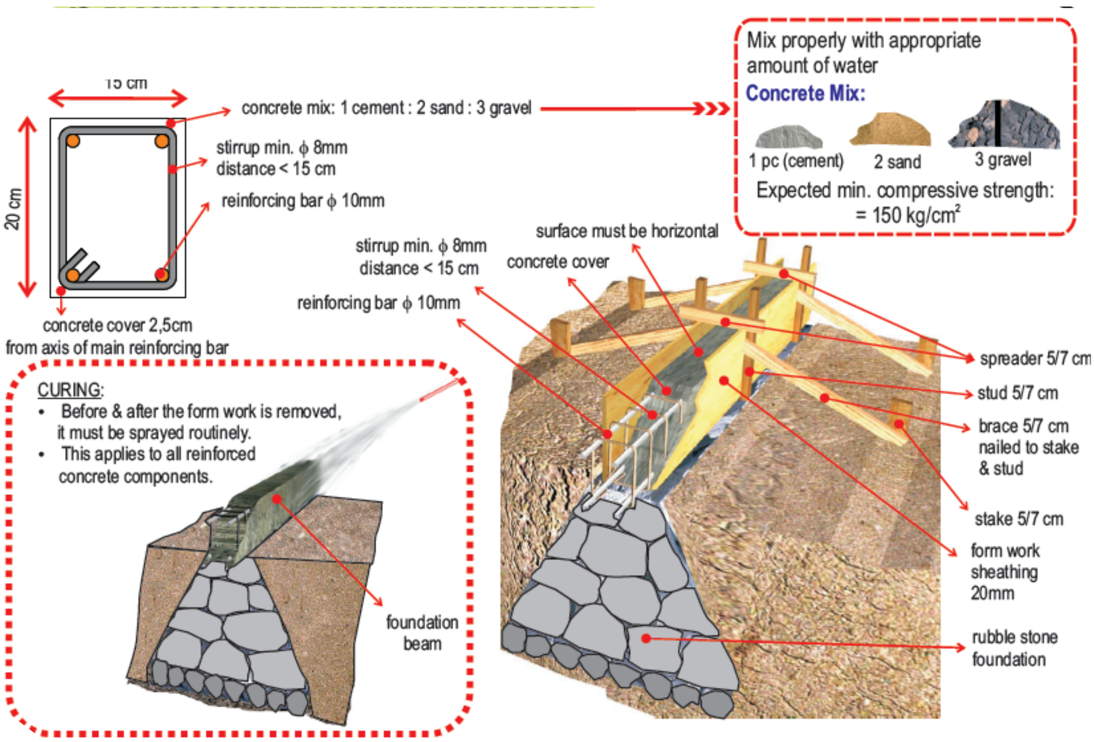


Figure 73: Placing concrete in foundation beam

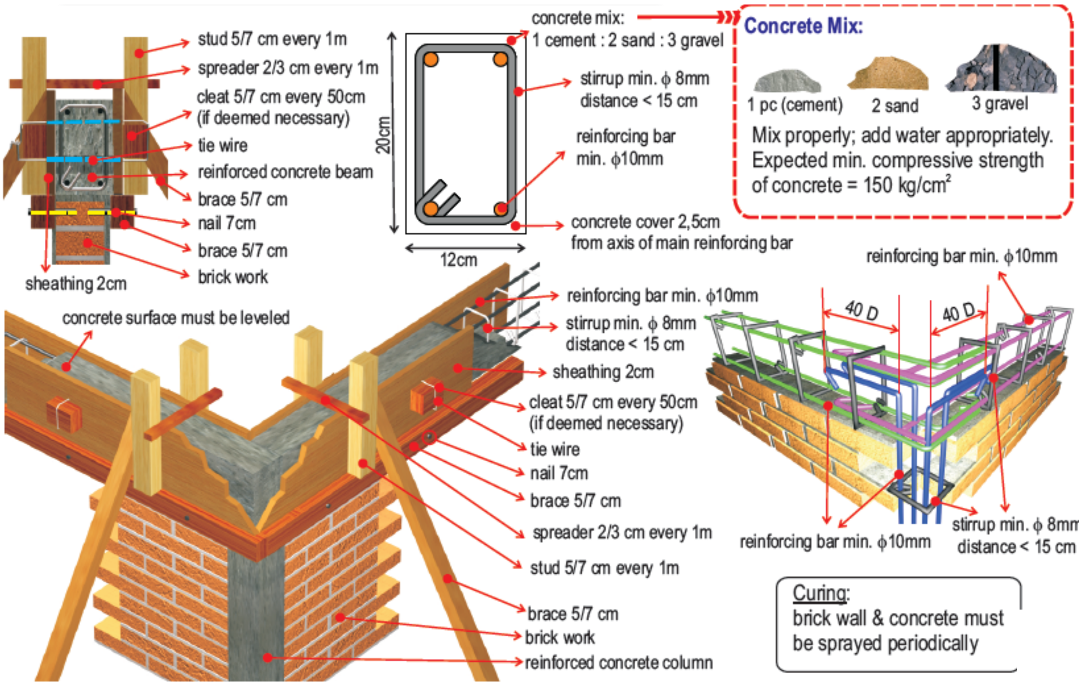


Figure 74: Joint details and placing concrete in beams

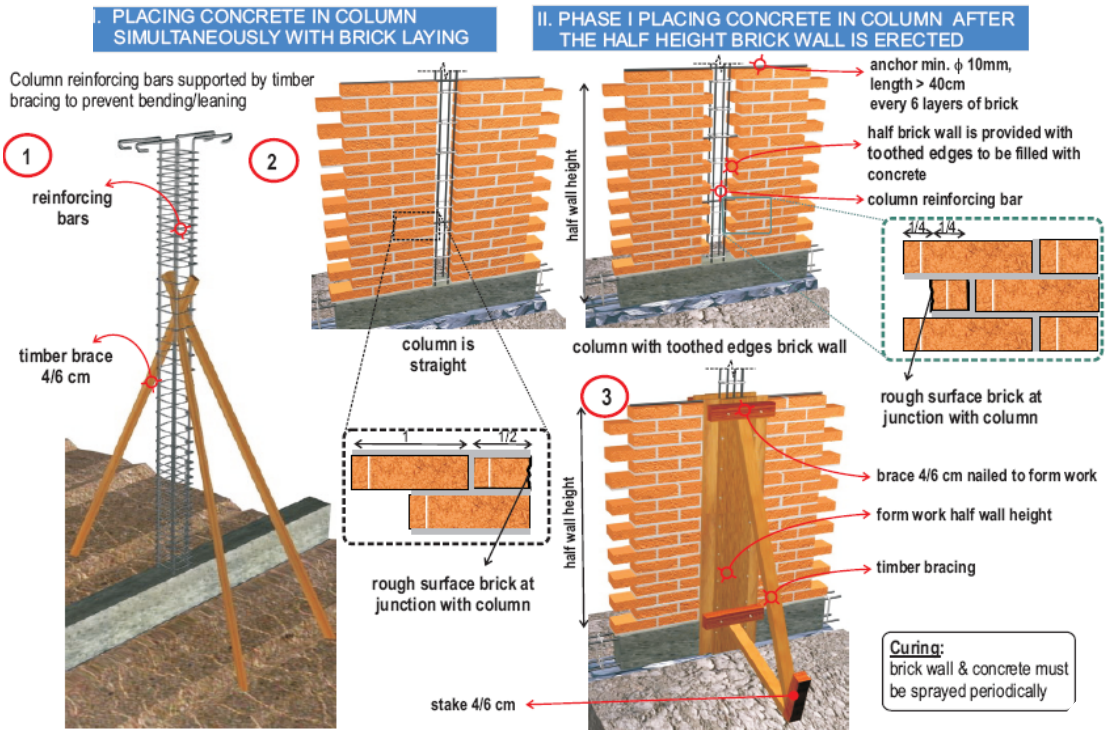


Figure 75: Placing concrete in column simultaneously with laying brick

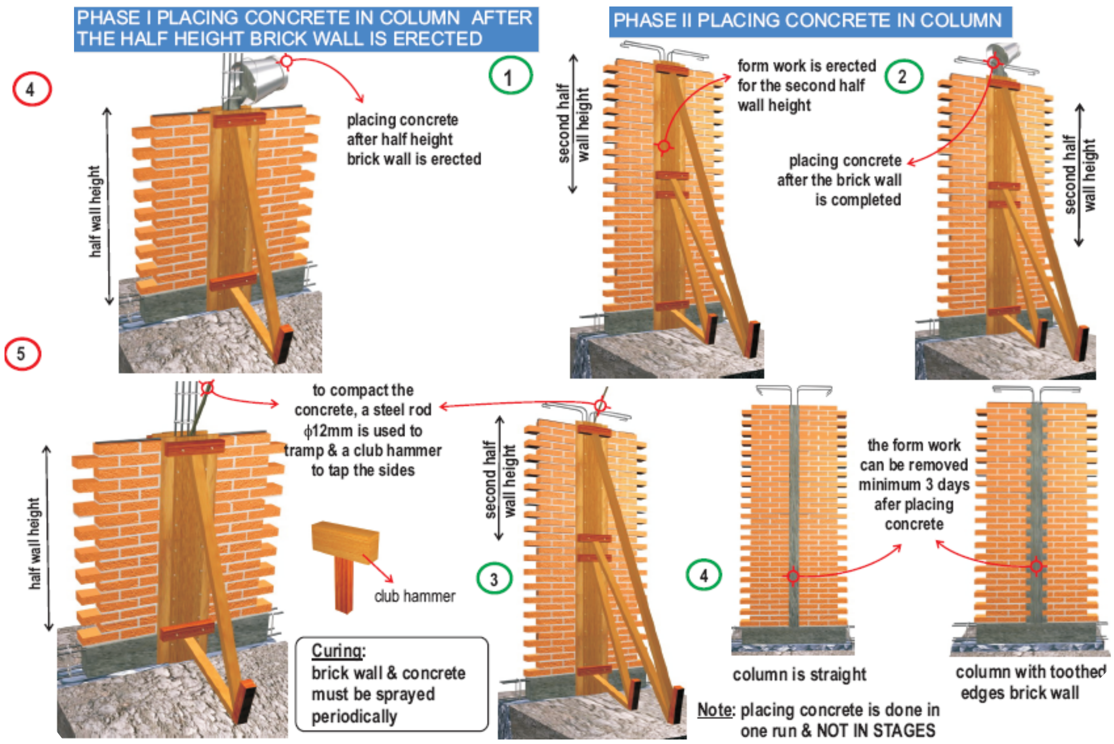


Figure 76: Placing concrete in column after erecting haft height brick wall

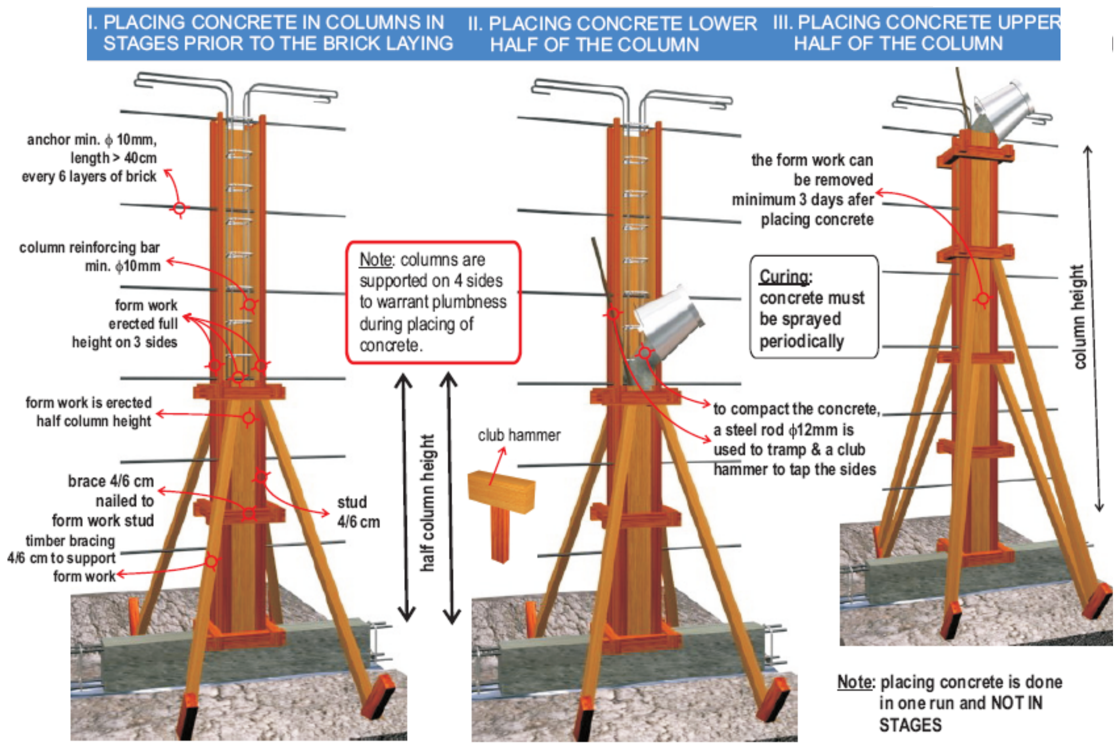


Figure 77: Placing concrete in column before laying brick wall

5.2.4 Placing of reinforcement

While placing reinforcing bars, the following points must be taken care of otherwise the structure will get into undefined weaknesses:

- Minimum clear cover to the reinforcement: l5 mm to the bars in slabs, 25 mm to bars in beams and columns. In large columns, say 450 mm in thickness, the cover should be 40 mm. For achieving proper cover, a simple and effective method is to make cement mortar brickets of required size and install them between the bars and formwork. Tying with bars with thin binding wire will ensure the proper cover.
- Tying of longitudinal bars with transverse bars and stirrups and links at each crossing with binding wire.
- Minimum overlap in bars: 45 times the diameter of the bar for plain mild steel and 60 times the diameter for high strength deformed bar. The overlapping portion should preferably be wound with binding wire.
- Shape of links and stirrups: The ends of bars should be hooked by bending through 180º in mild-steel bars and 135º in deformed bars, see Figure 6.3.

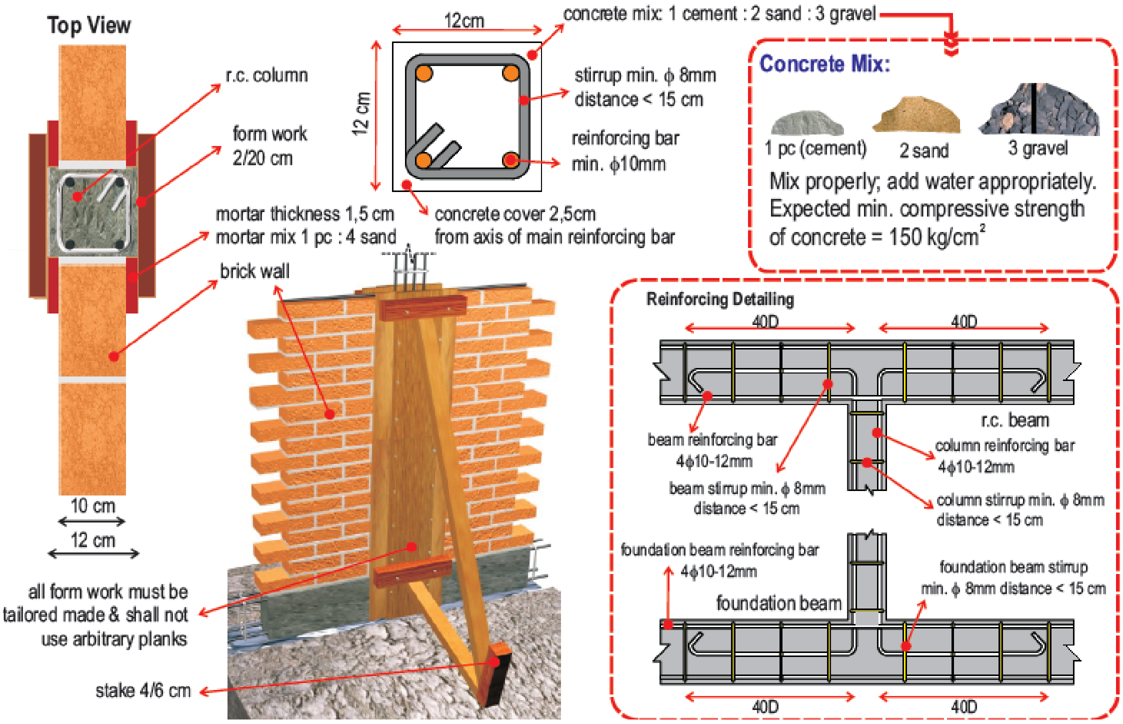


Figure 78: Reinforcing bar detailing and placing concrete in column

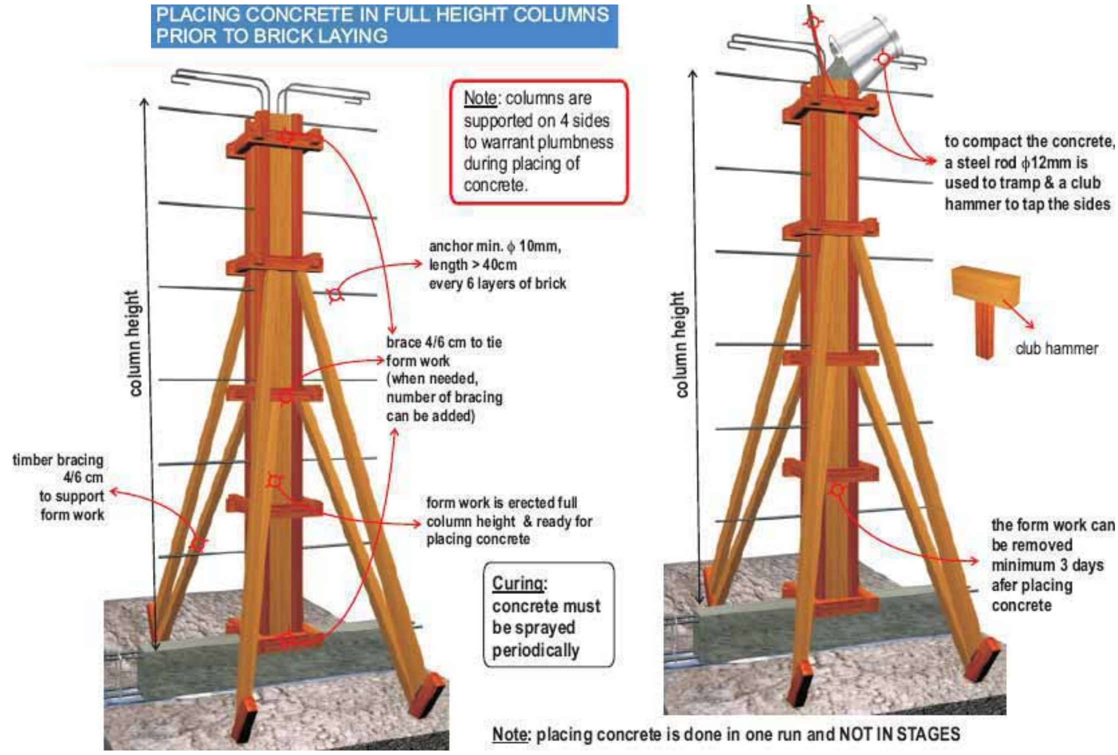


Figure 79: Placing concrete in full height column before laying brick

5.2.5 Casting and compacting concrete

The concrete should normally be cast in Figure 6.2 Use of cement brickets for cover Figure 6.3 Hooks at ends of bars one continuous operation so as to avoid discontinuity of more than one hour. Mixed concrete should not be allowed to stay on the platform by more than 45 minutes and must be placed in the forms and compacted continually. Hand compaction must be done by rodding through the freshly placed concrete. Simply leveling the surface with trowels will leave voids in the mass. It may be mentioned that lack of compaction results in large reduction in concrete strength, hence utmost attention should be given to this factor. For rodding, good results will be obtained by using 16 mm diameter rods about 50 cm long.

5.2.6 Curing of concrete

Concrete work requires water curing for a minimum of 14 days so as to gain its strength, otherwise the gain of strength is low and concrete becomes brittle. Concrete slabs may be kept under water by onding of water over it by making barriers all around the edges. Columns should be kept covered with wet empty gunny bags. Keeping the side forms intact on the beam webs will prevent the evaporation of water from the concrete and help in curing. Covering any concrete surface with polyethylene sheets after wetting the surface will help retain the moisture.

Chapter 6. Experiences from India

India is one of the project countries for "Reducing vulnerability of school children to earthquakes". The unique geo-geographic setting at the northern-western fringe of the youngest mountain chain (The Himalayas) placed Himachal Pradesh in the most active seismic zone (Zone V). Hence, in India the project activities are to be carried out in Shimla district of Himachal Pradesh. The project envisages the development of the training manual for technicians on designing of earthquake resistant buildings and two training programs for the technician on the usage of the training manual. For training of technician an awareness of the community living near the school building SEEDS will select school buildings for carrying out retrofitting. For selection of the school buildings SEEDS technical team surveyed different school buildings in Shimla district.

6.1 Methodology

Rapid Visual Screening (RVs)

- For mass scale evaluation of buildings in city
- Only visual inspection and limited addition information
- Based on behavior of buildings in past earthquake
- Rapid, based on checklists
- Inspecting a building from out side "side walk survey" to come to a conclusion weather the building is probably adequate for earthquake forces likely to occur at site or there are reasonable doubts that the building may not perform satisfactorily
- Should the building be subjected to more detailed evaluation?

For conducting rapid visual survey of the school buildings questionnaire was used as given in appendix 1 along with this report. Questionnaire consists of information about different sections related to schools broadly it's been divided into two parts i.e. Part A and Part B. Part A is about general information of schools like Geographical information, school information, community information, disaster history, availability of resources, and site information. Part B consists of detailed information about the building to be retrofitted like history, plan of the building, site condition, building block details, defects in building and retrofitting details. Main objective of selection of schools in one block is to spread the message in entire block so awareness can be generated among the community living in the area. Out of these buildings we have selected three schools for carrying out retrofitting in the schools. Details of all the school buildings are as given below.

6.2 Seismic Vulnerability Assessment Results

6.2.1 Geographical Information

This school building is situated in Junga subdivision. It is developed division in terms of resources as it is a centre for different administration activities. This place is situated about 40kms from the Shimla city. Altitude of this place is not as high as other places and its kind if valley with lots of flat land.

6.2.2 School information

This is Government Primary school with is having classes from nursery to 5th standard. There are about 120 students in this school. This school building is one of the oldest buildings as this was constructed during the British time by the King of that time. There are 5 teachers in this school who are running the classes. This school is also a part of education department of Himachal Pradesh. The campus where this school is situated is also having middle and higher secondary school in the same campus.

6.2.3 Community Information

Because of the subdivision and location of the area there are lots of families residing in this area. There are about 400 families living in this area. Road from Shimla to this place is very good in condition and it's is easily visible place because of the huge campus of the school.

6.2.4 Disaster History

This place is also falling under very high seismic zone. There were some incidents of past minor earthquakes in the area but with very less damages. This area is also prone to landslide during the time of monsoon. As such there are no major disasters in this area in the past and awareness among the community about disaster management is also very low.

6.2.5 School Property

This school building is situated in very large campus. There are five other buildings situated in this place with the huge play ground in front of it. The block for Primary school was constructed in 1931 A.D. main construction materials used for the construction of the school building is stone and wood with mud mortar.

Thickness of the wall is 18" and partitions are made out of the plywood. This school building is having G+1 type structure. There is one storey below the building shown in the figure. Plan of the building is simple rectangle. There is a veranda in front of cladding as shown in the figure. Roofing is made out of CGI sheets. There is also a falls ceiling at the roof level for better thermal comfort. There is a huge play ground in front of the school building with the dimensions about (100MX200M). This school campus is also having other facilities like library for students.

6.2.6 Defects in school building:

This school building is having lots of defects into building because of the aging of the structure and poor quality of materials used for the construction of the building. There are lots of cracks in the walls and around the openings of the building. Plaster is being chipped of in many places. There is no continuous band provided in the building for resisting any lateral loads. Condition of roof structure and roof covering is better in comparison with the other elements of the building. Veranda is being built with the wooden planks and condition of the same is not good as there are some places where these wooden pieces are missing which reduces the diaphragm effect of the floor. One of the major problems with this building is that there is a bulging of the wall in front face of the building as shown in the picture. This gives a sign that there is no integrity in the structure and in future even a minor earthquake can lead to major disaster in this school building.

This school building can be taken up as one of the school to be retrofitted because of the location and other schools are also in same campus so we can train more students and teachers by doing program in one school. Apart from that this school give be good example for the other schools in surrounding areas.

Chapter 7. Experiences from Indonesia

7.1 Seismic Vulnerability Assessment Results

Prior to conducting retrofitting activities under SESI program, a selection of school buildings to be retrofitted was carried out. The procedure was conducted throughout a series of site visits and preliminary surveys to a number of school buildings considered as the top candidates for the programs. The surveys were conducted by the experts from CDM-ITB with officers of local governments.

Four locations of school buildings were found to be good candidates for retrofitting activities. These are SD Cirateun Kulon II, SD Padasuka II, SD Sukajadi, and SD Legok Jambu. Therefore, a selection process was carried out based on the needs of these schools to determine the two school buildings to be involved in the program. Based on the structural conditions, deficiencies, and locations of the buildings, SD Cirateun Kulon II and SD Padasuka II were selected as the school buildings to be retrofitted. A more detail survey and investigation were then conducted for these school buildings.

7.1.1 SD Cirateun Kulon II

The local govenment of Bandung City affirmed that SD Cirateun Kulon II was the top priority for major renovation at the time the preliminary survey was conducted. The school building was located at Kec. Sukasari, Jl. Dr Setyabudhi KM 10.7, Bandung. The location is in the northern part of the city, and within the vicinity of the main road to North Bandung and Lembang. The school building consisted of 2 buildings, each with 4 rooms. The total area of the school buildings is approximately 223m2. The school has 423 students and 14 teachers, and is occupied from 7AM to 5PM on Monday to Friday.

Figure 80: SD Cirateun Kulon II

Visual observation revealed that the buildings were located in a slope, although no possibility of landslide was seen for the buildings. The structures were likely to be masonry structures or reinforced concrete frames with masonry in-filled walls. The roof trusses were made of timber, and in some places were deteriorated. The finishing exterior showed wear and tear, with loose plasters, missing floor tiles, and leaking roof. Sanitary facilities also needed improvement, especially for toilets and drainage systems.

The school community was found to be very eager to participate in the retrofitting projects. The school committee (parents and teachers) were receptive to earthquake risk faced by the school buildings, and they looked forward to participate in the dissemination activities of earthquake mitigation strategy, which included earthquake drills.

Figure 81: Existing structural condition of SD Cirateun Kulon II

Based on the preliminary survey, experts from CDM agreed that the SD Cirateun Kulon II was a very good candidate for the retrofitting activities under SESI program. A complete investigation of the school buildings were then conducted for next stages of the retrofitting activities.

7.1.2 SD Padasuka II

The local government of Bandung County listed SD Padasuka II as one of their top priorities of school buildings in needs of repair and retrofitting. The school was located at Kec. Soreang, Bandung County. The location is close to the main road from Bandung, and in the suburb area of the Bandung City. The school building consisted of 2 buildings with four rooms each. The school has approximately 400 students, and is occupied from 7AM to 5PM on Monday to Friday.

The preliminary survey showed that the buildings were located on a hill foot, although no possibility of landslide or flood was seen for the buildings. The structures are made of RC frames and masonry walls, and relatively new, built in circa 1990s. The foundation was found to be hanging on some places, due to missing stones/boulders underneath the tie beams. The walls were cracked on some places, and some of the gaps were quite large. The roof trusses were made of timber and showed wear and tear, with visible deflection appeared in the middle part of the roof.

The overall finishing exterior was dilapidated, with loose plasters, broken floor tiles, and leaking roof. Sanitary facilities also needed improvement, especially for toilets and drainage systems.

Figure 82: 6.1.2 SD Padasuka II

Figure 83: Existing condition of SD Padasuka II

The site visit also revealed that the school community was very eager to participate in the retrofitting projects. The school committee (parents and teachers) were receptive to earthquake risk faced by the school buildings, and they looked forward to participate in the dissemination activities of earthquake mitigation strategy, which included earthquake drills.

Based on the preliminary survey, experts from CDM decided that the SD Padasuka II was another very good candidate for the retrofitting activities under SESI program. A complete investigation of the school buildings were then conducted for next stages of the retrofitting activities.

7.2 Retrofitting design and implementation

The retrofitting project was first conducted at SD Cirateun Kulon II. The school buildings consisted of two buildings made of RC frames and masonry walls. Each building has four rooms, and the layout of the school buildings is presented in Figure 1. Based on results from survey and tests, structural analyses were performed on the existing structures using the actual material and structural components. Earthquake risks were introduced to the buildings by applying loads based on potential seismic risks and local soil conditions. The analysis showed that both buildings were considered likely to behave poorly under seismic loadings, thus required retrofitting. With the funding from Hanshin Department Store Labor Union of Japan, the physical works were then conducted to improve the structural quality and reduce the earthquake vulnerability.

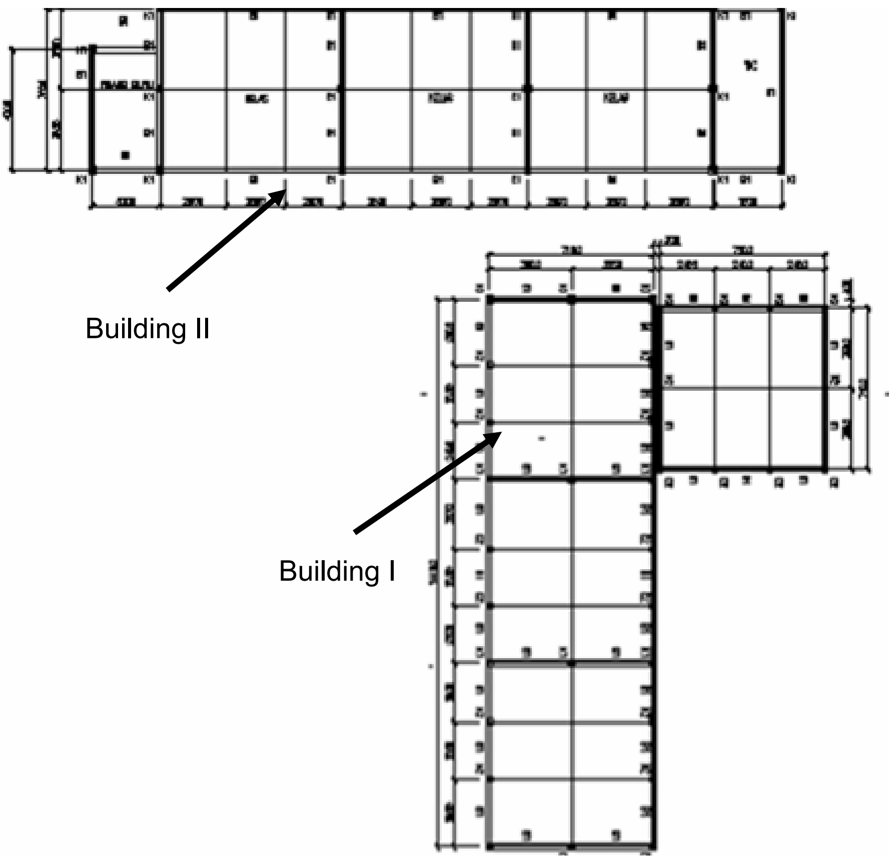


Figure 84: Layout of SD Cirateun Kulon II

Two types of retrofitting strategies were applied to the structures due to different structural qualities, as well as needs and capabilities of the school communities. Figure 3 shows the different approaches for retrofitting strategies. Building I which was considered to have lower quality was retrofitted by adding adequate RC frames with mat footings. Anchorage was provided to connect walls with columns and beams. Building II which was in better condition was retrofitted using wire mesh for strengthening wall elements. Double tie beams were added adjacent to the existing one for better foundation system. For both structures, proper detailing was applied to roof truss systems, and repair was carried out for nonstructural elements such as doors/windows and ceilings. Finishing/cosmetic repair and improvement of sanitary facilities were also conducted for both structures. Figure 4 shows the various stages of the retrofitting work for SD Cirateun Kulon II and the finished projects.

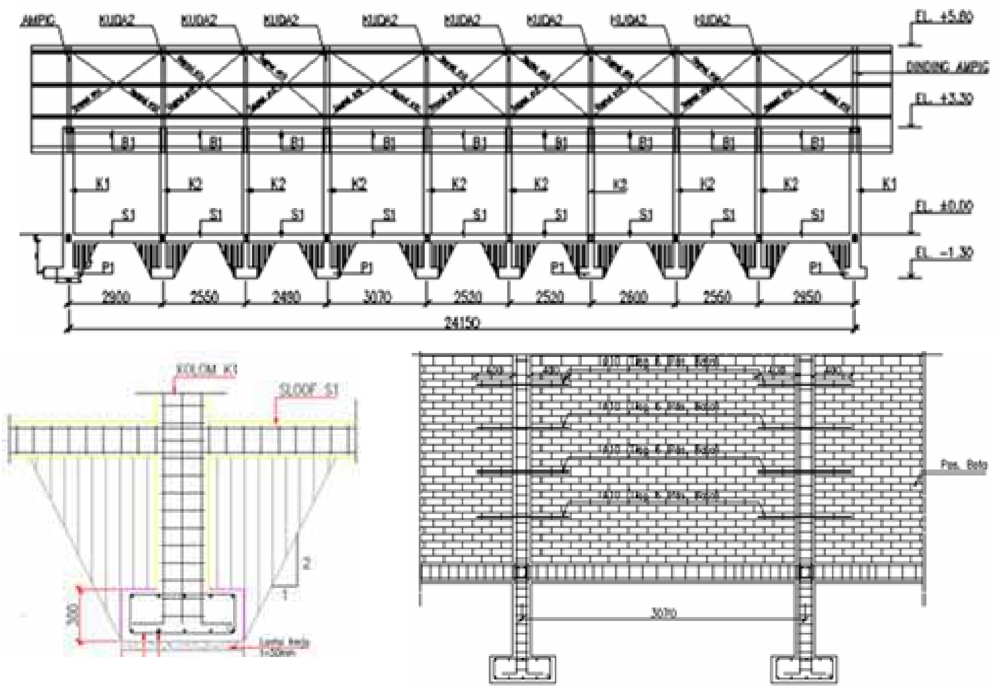


Figure 85: Retrofitting strategy for Building I

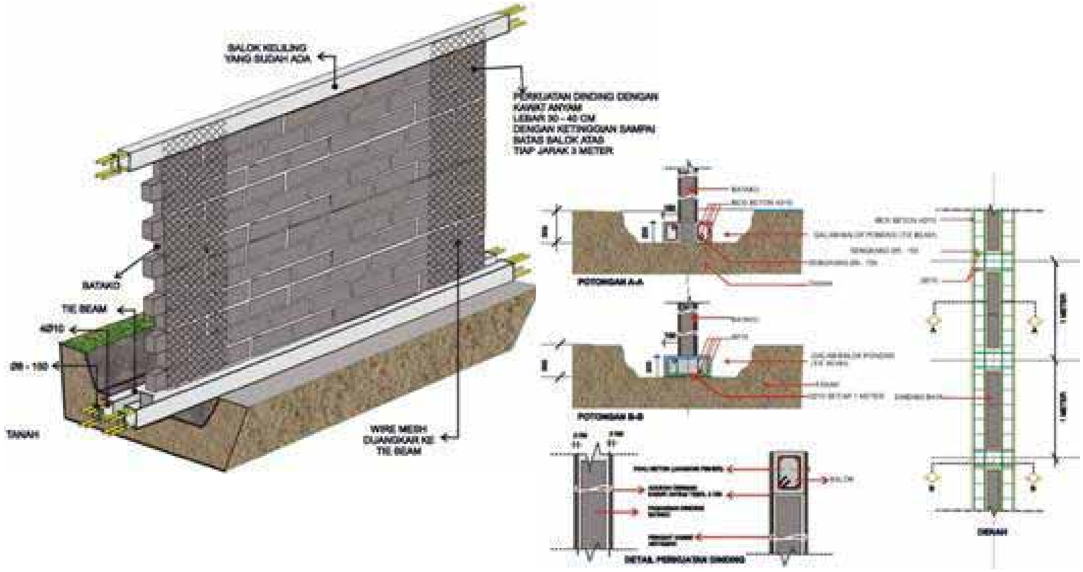


Figure 86: Retrofitting strategy for Building II (courtesy of PT Teddy Boen Konsultan)

Figure 87: Various stages of the retrofitting process

Chapter 8. Experiences from Uzbekistan

8.1 Seismic Vulnerability Assessment Results

Prevailing constructive types of school buildings in Tashkent are schools erected of masonry (retrofitted or not retrofitted with reinforced-concrete elements) and frame-panel schools. Masonry schools were erected since 1934. Frame-panel schools since 1974. Number of floors of school buildings typically 1-4 floors. Frame-panel buildings of schools were erected from modular reinforced-concrete elements. Bearing elements was the frame consisting of modular reinforced-concrete columns by section 30x30 and 40x40 cm and crossbars by section 40x50 cm. As ceilings were used multi-hollow preliminary strained reinforced-concrete plates with height 220 mm. As external walls were used single-layered panels with thickness 30 cm from light concrete with density 1200 kg / m3 which were hung on columns. As partitions were served masonry walls with thickness 12 cm, plaster plates 10x30x60 cm. These two basic constructive types of school buildings were exposed to influence of earthquakes with intensity from 5 up to 9 units by scale MSK-64. As a result of the analysis of consequences of earthquakes the reasons of their damageability were revealed.

8.1.1 Masonry school buildings

Age of a building. If age of building is more senior, it is more possibility of damage as in 40-50 years of the last century building codes for seismic areas practically were absent, and recommendations were imperfect.

Absence of constructive (appointed without calculation) actions for retrofitting of schools buildings (there is no antiseismic belt, building complex in the plan, bearing walls not axial, large distances (more than 9 m) between bearing walls, there is no horizontal reinforcing (through 5-7 lines grid 206 longitudinal plus cross bars with step 30 cm), there are no cores - vertical reinforced-concrete inclusion in walls and frames of window and doorways, not in each compartment between antiseismic seams there are stairways).

By testing calculations it is shown, that actual durability of building equal no more than 50 % from required by building codes.

There are damages in bearing walls as cracks from the previous earthquakes, subsidence and settlement of the basements, watering of basements, and stratification of brickwork. Differences of marks by height in places of crossing of walls are more than 20% from height of floor. A deviation from vertical of walls by height of building is more than 10cm.

Instead of reinforced concrete, ceiling wooden was used. The hard disk, i.e. ceiling pliable is not provided; at presence of modular plates of reinforced-concrete ceiling seams between them are not filled with mortar or fine-grained concrete.

The basements not reinforced-concrete (slag concrete, masonry, concrete blocks).

Strength of cohesion of mortar with masonry in horizontal joints is less than 1,2 kg / cm2 (minimally allowable value), and strength of mortar is less than 25 kg / cm2 and masonry less than 75 kg / cm2. Quality of brickwork is low (vertical seams are not filled with mortar, bad bandaging in bricklaying).

By architectural - planning parameters the building does not correspond to modern requirements, modernization of rooms therefore is required, that will demand increase of seismic stability also.

Reduction of heat isolation properties of external bearing walls also will entail necessity of retrofitting of walls.

8.1.2 Reinforced-concrete frame-panel buildings of schools

Year of construction of schools subject to retrofitting approximately since 1974. Therefore this criterion for all schools identical and it, as a rule, was not taken into account. This criterion can be taken into account, if the building during operation was exposed to influences of earthquakes of small (3-4 units) and middle (5-6 units) intensity.

Building is located in site with soils with strong subsidence properties or subject to liquefaction.

Actual durability of concrete of constructions in the average 30 % below of design.

Durability (seismic stability) of building at testing calculation does not exceed 70 % required by building codes.

As bearing frame designs of series IIS-04, release 1, section of columns 30x30 cm are used. This frame the most vulnerable at earthquakes due to:

- welded joint of column with a crossbar in a zone of the maximal loads at earthquakes;
- support of crossbar on a column is carried out through steel bars releases from crossbar, instead of through reinforced-concrete;
- the welded joint worsens plastic properties of steel, that at earthquake results in fragile destruction;
- the frame is formed only in a cross direction of a building.

The following releases of series IIS -04. Columns - 40x40 cm, and a frame is created in two directions - in cross and longitudinal. These releases are more earthquake resistant. Monolithic frames are even more earthquake resistant, because in it the steel bars is not welded, but tied.

There are damages as cracks on a surface of constructions with width of disclosing more 0,4mm, skews of floors more than 1/200 heights of a floor, a skew of buildings as a whole more than 1/70 from height of all building or more than 15 cm. Differences of vertical marks more than 1 % from length of a crossbar or 2 % from height of a floor. Rare more than 30 cm a step of cross cores in columns.

High collapsibility of sites of construction is more than 20 cm of settlement of the basement under weight of building.

Corrosion of armature with loss of section up to 10-15 %

Between the separate basements under columns there is no connection among themselves with the edges of rigidity for exception of negative influence the basis.

Seams between modular plates of ceiling and coverings are not filled with mortar or fine grained concrete, and filled by building dust. Support of plates on crossbars less than 7 cm.

External hinged wall panels are rigidly connected to bearing elements of frame, thus prevent the frame to be deformed freely.

Between end-faces of partitions and bearing elements of a frame backlashes up to 2 cm for maintenance of free deformation of a frame are not stipulated at earthquakes.

Stairway marches in places of support are not welded on sites.

Presence of the majority of these factors with other things being equal gives advantage at selection of building for retrofitting. At an arrangement of a building in areas of 7,8,9 and more units, the buildings which are located in areas with higher seismicity have advantage.

Presence of these factors were taken into account at a choice of buildings of schools for restoration and retrofitting in Tashkent.

The major factor resulting in serious damages of buildings of schools at earthquakes is the quality of conducting civil and erection works was during construction of object. According to the Project in Tashkent it was supposed to choose two schools: one - masonry, another - frame-panel for realization on them of indicative retrofitting with training of builders to provide technology of correct implementation of works on retrofitting of buildings of schools.

The objects of schools chosen for retrofitting prior to the beginning of development of working drawings of the project of retrofitting carefully in details were surveyed as visually, as instrumentally by specially developed technique. The basic information on a technical condition of constructions of school included the following parameters on reinforcement object:

- Year of construction;
- Engineering - geological data of a site;
- Strength and deformation characteristics of underground and ground constructions;
- Dynamic characteristics of a building (actual period of the basic tone of own fluctuations, decrements of attenuation etc.);
- Data on antiseismic actions and constructive restrictions;
- Sizes and characteristics of constructive elements of a building, joint connections (in view of defects and damages);
- Settlement resistance of soil, concrete to compression;
- Actual seismic stability of a building in view of a condition of constructions etc.

8.2 Retrofitting design and implementation

8.2.1 Basic elements of retrofitting of masonry buildings of schools

1. Implementation of antiseismic belts with application of retrofitting bars or rolling profile steel as angle bars or channel bars.

2. For creation of a hard disk of ceiling replacement of wooden ceiling on monolithic reinforced-concrete.

3. Introduction of additional reinforced-concrete or metal frames for retrofitting of long walls (more than 9 meters) and supported in a perpendicular direction by walls.

4. Implementation of frames for window and doorways by angular steel or monolithic reinforced-concrete.

5. Retrofitting of walls (from one or two sides) for perception of the main stretching loads by means of retrofitting grids in a layer of high-strength mortar M100.

6. If necessary retrofitting of the basements by implementation of reinforced concrete covering.

7. Creation of the irrigational network excluding watering of the basements and blind area around of building.

8.2.2 Basic elements of retrofitting of reinforced-concrete frame-panel buildings

1. Retrofitting of joint connections of columns and crossbars.

2. Retrofitting of columns by the implementation of reinforced-concrete holder or metal structure.

3. Retrofitting of crossbars by escalating by metal structure.

4. Introduction of connections for increase of rigidity of building from reinforced concrete diaphragm, transformation of masonry partitions by retrofitting in diaphragms, metal bracings.

5. Retrofitting of the basements by enlarging or introductions of diaphragm from reinforced-concrete.

6. Increase of rigidity of ceiling by an additional layer of the reinforced concrete.

On the chosen model schools the specified elements of retrofitting were applied: it is masonry school N20, 1939 years of construction and frame-panel school N 116 in Tashkent.

For builders was held technical seminar - training on which the presentation of the Manual on technology of works on retrofitting of masonry and frame-panel buildings of schools was carried out. Special tests « Antiseismic construction » and the questionnaire of the participant of seminar - training were developed. Participated more than 45 experts - builders and designers. Thus, for the first time experts of Joint-Stock Company " UzLITTI " within the framework of the Project UNCRD develop training Manual for builders in which in enough popular form data on nature of earthquake, why buildings of schools may collapse, what is aseismic buildings, principles of designing of aseismic buildings of schools, technologies of "step by step" performance on construction site the most widespread and frequently ways of retrofitting of masonry and reinforced-concrete frame-panel buildings of schools of existing buildings.

Materials are received on an example of retrofitting of exemplary schools in Tashkent. Also positions by the basic criteria of selection of existing schools for prime development of the project of retrofitting and realization of works on maintenance it safety at earthquakes are prepared. All results obtained within the Project are adapted and as much as possible adapted to local conditions.

In the following figures separate illustrations on technology of strengthening of brick and frame-panel buildings of schools are presented, explained in Manual.

Figure 88: Masonry school N20

Figure 89: Frame-panel school N 116 in Tashkent