Earthquake Resistant Construction of Buildings

Curriculum for Mason Training

Guidelines for Training Instructors

Asian Disaster Preparedness Center (ADPC)

National Society for Earthquake Technology-Nepal (NSET)

Kathmandu, February 2005

This Curriculum for Mason Training is an attempt to consolidate the experiences of mason training gained in Kathmandu Valley Earthquake Risk Management Project of the Asian Urban Disaster Mitigation Program. It formalizes the training materials, training exercises, and the approaches of such training that were found useful in the past years. It serves as the curriculum for training the masons, and can be used by local professionals in training the masons on the skills of earthquake-resistant techniques in non-engineered constructions. It can serve as a guide for the house-owner, and also for the mason involved in owner-built constructions in remote villages.

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Preface

Significant proportions of residential and public buildings in developing countries are non-engineered and a majority of them do not conform to the prevailing building codes. Even newer constructions continue to be built without incorporation of minimum standards. This situation prevails even in high seismicity zones of different countries of Asia. In some countries, for example in Nepal, the proportion of non-engineered buildings, constructed by the small contractors, mason leaders and house-owners, is believed to exceed 85%.

Many countries in Asia are yet to make their own seismic codes mandatory. While there have been successful initiatives towards improving seismic performance of new construction by incorporation of seismic designs in the building construction process in many countries, it is generally anticipated that local masons and small contractors will continue to play significant role in the building construction process, and any enhancement in their skills in seismic-resistant construction can significantly help in improving the earthquake-resistance of informal, non-engineered buildings and hence considerable reduction in loss of human lives and properties due to earthquakes.

This was the approach adopted by the Kathmandu Valley Earthquake Risk Management Project (KVERMP), implemented by the National Society for Earthquake Technology – Nepal (NSET) under the Asian Urban Disaster Mitigation Program (AUDMP) of the Asian Disaster Preparedness Center (ADPC) during 1996-2003. KVERMP included both formal and on-the-job training programs of masons as part of its School Earthquake Safety Program (SESP) implemented in Kathmandu, Vyas, and Banepa municipalities. The program was a success, not only because the local masons learned the skills of earthquake-resistant technology in non-engineered construction, but also because they were able to convince the home-owners on the benefits of such approach. Further, the skilled masons could successfully impart their skills to masons of other localities. The Mason Training Program was successful and was implemented beyond Nepal: in several parts of India, Afghanistan, Tajikistan, and Iran.

This Curriculum for Mason Training is an attempt to consolidate the experiences of mason training gained in KVERMP/AUDMP. It formalizes the training materials, training exercises, and the approaches of such training that were found useful. It serves as the curriculum for training the masons, and can be used by local professionals in training the masons on the skills of earthquake-resistant techniques in non-engineered constructions. It can also serve as a guide for the house-owner, and for the mason involved in owner-built constructions in remote villages.

In the current form, it is a generic, regional level curriculum that needs translation into vernacular languages with necessary adaptation to local conditions, especially with respect to the prevailing types of construction materials and technologies.

We firmly believe that this joint effort of ADPC and NSET in bringing out this curriculum will contribute to safer buildings against earthquakes and other hazards.

Dr. Suvit Yodmani
Executive Director, ADPC

Amod Mani Dixit
Executive Director, NSET

Acknowledgments

This Curriculum for Masons Training is based on the extensive experiences gained during the implementation of the seismic retrofitting of school buildings under the School Earthquake Safety Program of the Kathmandu Valley Earthquake Risk Management Project (KVERMP), under the Asian Urban Disaster Mitigation Program of the ADPC, Bangkok with core funding from the Office of Foreign Disaster Assistance (OFDA) of the United States Agency for International Development (USAID). The KVERMP has been instrumental in the development and implementation of several methodologies for earthquake risk management that have been regarded widely as appropriate and successful programs especially in developing countries.

Started under KVERMP, numerous Masons Training programs have been organized in cooperation with several institutions in Nepal, namely, the Department of Urban Development and Building Construction and the Department of Education of His Majesty's Government of Nepal, municipal offices of Dharan, Vyas, Banepa, Pokhara, Madhyapur Thimi, Bhaktapur, Lalitpur and Kathmandu and many other professional organizations. The Masons Training programs could be sustained because of the generous financial support received from Lutheran World Federation Nepal. We gratefully acknowledge the valuable support received from all the above-mentioned organizations.

During the preparation of the materials, the authors received valuable suggestions and critiques from many professionals working in the field and also from the international experts. We acknowledge their contributions. We also would like to express our thanks to the trainee masons who guided the authors to the various problems of earthquake resistant construction in Nepal.

Many photographs, sketches and illustrations have been borrowed in its original form or with some modifications from many publications, photo archives and several internet sites. All these references are mentioned in appropriate places and are gratefully acknowledged.

Special thanks are due to Dr. Buddhi Weerasinghe (ADPC) whose extraordinary pedagogic skills guided the authors in developing the format, template and language used in this curriculum.

We wish to thank also the advisors and reviewers for their patience in guiding the entire process.

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1. Overview of Curriculum

a. Introduction

The first step to improve the construction quality and safety level of buildings is to prepare trained manpower required for earthquake resistant construction technology. A few institutions and individuals have initiated to organize training programs to produce skilled building workers, though in a very small number. The graduates of such training programs are mainly engaged in the supervisory role. To improve the construction quality the trained masons have to work as masons and it is not possible until more skilled/trained masons are produced. Such training programs need to be widened and regularized. A standard training manual to produce new masons as well as upgrade the skill level of the practicing masons is a basic tool to conduct training programs on earthquake resistant construction technology. This curriculum is aimed at facilitating such programs to produce skilled building workers mainly masons.

b. Rationale

Construction of residential buildings in a developing country like Nepal is primarily carried out by the informal sector, mostly the owners/builders. The work-force (masons, bar-benders, electricians and plumbers) employed in this sector does not have any formal training. Most of them acquire skill either through trial and error (*working as a helper to the so-called "skilled ones"*) or through practical experience by hereditary transformation. This system may have been good enough in the past. New materials and technologies are now replacing the old ones in the construction sector of the developing world also, which are different from the existing ones and they demand specific skills for their effective use. It is neither possible nor desirable to stop new materials and technology coming to the construction practice. Improper use of such materials and *monkey imitation* of technology have resulted in high cost, low quality buildings and many a times have lead to loss of life and property. Further, the prevailing construction practice does not incorporate earthquake resistant components and the existing housing stock is highly vulnerable to earthquakes.

Alternative Building Materials and Technology for Nepal, one of the series of reports prepared by National Building Code Development Project, states that only less than 5 % of the residential buildings are engineered. The owner builders construct more than 95 % of the buildings with the assistance of the head mason, who plays both the roles of consultant and contractor. Institutions provide maximum resources to train the engineering manpower in training them for the earthquake resistant construction technology that can only facilitate the construction of a mere 5% of the buildings. Where nothing is done so far for training those who contribute to the 95 % of the buildings. This shows a clear need of producing more trained masons by skill upgrading of the practicing masons as well as new comers in the construction sector.

In this broad context, this course is designed to address the need to transfer the knowledge and skills of earthquake-resistant construction technology to the practicing masons.

c. Aim

Main aim of this course is to train practicing masons with basic knowledge of earthquake resistant building construction technology and equip them with required skills to construct an earthquake resistant building.

Another aim of this curriculum is to facilitate the trainers by providing them a clear and concise framework of the earthquake resistant construction technology for training the masons.

d. Learning Objectives

After successful completion of the training course conducted based upon this curriculum, a practicing mason will be able to:

1. Explain the importance and effectiveness of earthquake resistant elements in buildings.
2. Incorporate earthquake resistant elements in new construction.
3. Outline available methodologies to incorporate earthquake resistant elements in existing buildings.
4. Name relevant Building Codes existing to ensure earthquake safe construction.

e. Scope

This course covers only the residential buildings up to three (3) stories since Nepalese buildings that are owner constructed rarely exceeds this limit. Taller and more advanced buildings need engineering consultation in depth, so they are beyond the scope of this training manual.

Regarding seismic strengthening of existing buildings, this course will provide only an outline of the methodologies to incorporate the earthquake resistant features into existing weak buildings. It will not give detail design concepts and construction technology for retrofitting the buildings. Therefore, upon completion of this course, masons are not expected to carry out the retrofitting works on their own.

Further, as the main aim of this course is to train practicing masons and equip them with knowledge and skill of earthquake resistant construction technology, this course is not for training a fresh manpower in construction business such as a labor. It will not be applicable for training unskilled labors to make them masons.

Currently, it is prepared and distributed in English language. The English language version is basically for the trainers. Presentations and the handouts to the participants should be translated into local language where the training program based on this manual will be conducted.

2. Potential Users

This curriculum can be used by both the trainers as well as the participant masons. The trainer of this course may be anybody practicing as technician, junior engineer or engineer in earthquake resistant design and construction field. However, the potential trainers have to participate in "Training of Trainers" program, coordinated or conducted by ADPC and/or NSET.

The end users of this manual will be the practicing masons who have been involved in building construction as skilled labor. This manual helps to conduct "Mason Training Program" targeting a specific location. Interested masons have to participate in such training programs and they will be provided with the handouts translated into their local language. Participants will use the handouts.

3. Course Schedule

An ideal schedule for conducting "Mason Training Program" based on this manual is also presented here. The ideal course duration will be FIVE days. However, it may run on consecutive days. The days may be staggered to suit convenience. This training course can be ideally participated by 30 participants at a time. Exercises and demonstrations are designed for this number of participants.

Course Schedule

Day	Time	Module	Session	Duration	Demonstration Exercise	Title of the Session	Trainer /Resource Person
Day 1				0.50 hrs		Opening of Training Course (Course overview + Introduction of Participants)	
		M1	S1	2.50 hrs		Overview of Earthquakes and Its Effects	
				Within session	Video 1 - V1	Video on Earthquake Disasters	
				Within session	Demo 1 – D1	Demonstration	
		M2	S1	1.50 hrs		Site Selection, Configuration and Layout	
				3.00 hrs	Exercise 1 – E1	Planning a Building and Layout	
Day 2		M2	S2	1.00 hrs		Masonry Buildings: Foundation Construction	
		M2	S3	2.50 hrs		Masonry Buildings: Wall Construction	
				Within session	D2	Demonstration of Stitch Reinforcement	
				Within session	D3	Demonstration of Brick Masonry Model	
		M2	S4	1.00 hrs		Masonry Buildings: Floor and Roof Construction	
				0.50 hrs	D4	Video Demonstration of Test on Floor Slab	
Day 3		M2	S5	1.00 hrs		RC Buildings: Foundation Construction	
		M2	S6	2.00 hrs		RC Buildings: Beams and Columns Construction	
				3.00 hrs	E2	Exercise on Model Construction of Beam-Column Reinforcement	
Day 4		M2	S7	1.00 hrs		RC Buildings: Floor and Roof Construction	
		M2	S8	1.50 hrs		Quality Control and Workmanship	
		M3	S1	1.00 hrs		Repair and Maintenance of Existing Buildings	
		M3	S2	2.00 hrs		Retrofitting of Existing Buildings	
Day 5						Final Discussion	
						Field Visit (if appropriate site is available) or Case Study Video	
						Evaluation	
						Closing	

4. Course Content

- Material contains technical descriptions for trainers to enable them to understand the depth of coverage. The references mentioned are the sources for detailed study if the trainer wishes to update his knowledge, and are not meant for discussion with masons.
- It provides presentations that can be used in training sessions with clear instructions of how to proceed in each session and what learning outcomes are expected.
- The trainer is expected to translate the material into a local language using phrases that are user friendly to the masons.
- Where learning outcomes are skills-oriented, exercises and demonstrations have been designed with proper details for their correct implementation. They must be strictly adhered to.
- Some checklists and guidelines are also provided. These are for dissemination to participants after appropriate translation.

5. Course Structure

The Course is segmented into **THREE Modules**. A Module is coded as **M**. If you see M1 written anywhere, it means Module 1. Each Module is sub-divided into several **Sessions**. A Session is coded as **S**. For instance, Module 1, Session 1 is coded as M1-S1.

Module 1: Overview of Earthquakes (Introductory Module)

This module has ONE Session.

M1-S1: Overview of Earthquake and Its Effects on Buildings

Module 2: Earthquake Resistant Construction of New Buildings

This Module contains EIGHT Sessions.

M2-S1 Site selection, configuration and lay out

Earthquake Resistant Construction of Masonry Structures

M2-S2 Construction of Masonry Buildings: Foundation

M2-S3 Construction of Masonry Buildings: Walls

M2-S4 Construction of Masonry Buildings: Floor / Roof

Earthquake Resistant Construction of RC Framed Structures

M2-S5 Construction of RC Framed Buildings: Foundation

M2-S6 Construction of RC Framed Buildings: Beam / Column

M2-S7 Construction of RC Framed Buildings: Roof / Floor

M2-S8 Quality Control and Workmanship

Module 3: **Enhancing Earthquake Resistance of Existing Buildings**

This Module contains TWO Sessions

M3-S1 Repair and Maintenance of Existing Buildings

M3-S2 Retrofitting of Existing Unreinforced Masonry Buildings

Each session spells out:

A Goal

Learning Outcomes

Learning Objectives.

The Goal sets the scope of the session in very broad terms. **Learning outcomes** are what the 'Trainer' expects as an end result of the session.; what the Trainer envisages for the learner to achieve. **The Learning Objectives** are what the learner would be able to measure as achievements at the end of the session. These are measurable and discrete so that the learner would be able to self-assess whether he/she has achieved them.

The Goal, Learning outcomes and Learning objectives form a hierarchy that paints what is to come in the session. It provides a mind-map for the learner to provide direction to where he/she would be going in this learning experience.

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Module 1 / Session 1
Overview of Earthquakes and Its Effects on Buildings

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In this session, some of the important information about the earthquakes such as internal structure of the earth, cause of earthquake etc. are discussed.

Learning outcomes

After completing this session, the participants will be able to

- Explain that earthquakes are due to natural phenomena within earth;
- Discuss earthquake risk of Nepal and its neighboring countries;
- History of earthquakes in Nepal;
- Discuss effects of earthquake in buildings and infrastructures; and
- Discuss feasibility of damage reduction.

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Earthquake and its causes

In first part of this session, we will discuss about the structure of the earth, causes of the earthquakes and seismicity of world and Nepal.

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Video on Earthquake Disasters

PICTURE START

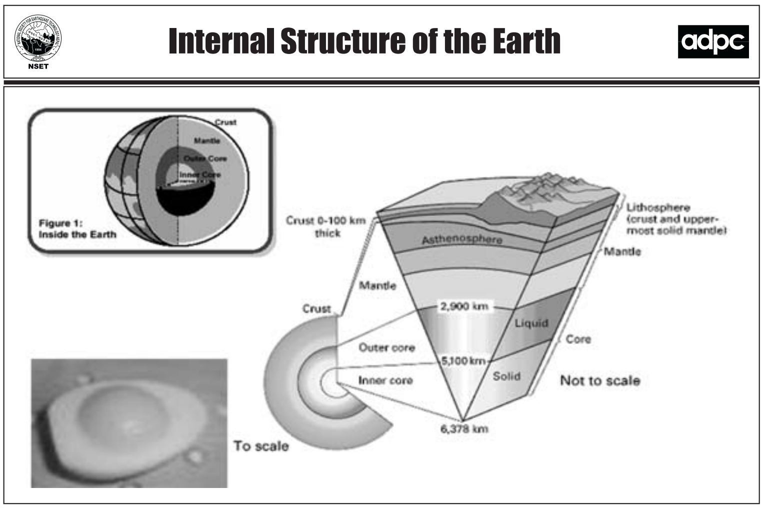
Now, first of all, let's see a video. This video shows earthquakes and other major natural disasters which will help to feel the consequences and possible extent of the disaster.

[for this video, it is requested to contact to NSET, Kathmandu, Nepal]

Image Courtesy: from www.smdc.army.mil/familyprograms/main.html

Simply looking around our surroundings, we may feel that the earth where we are living is a motionless rigid body. Also, we may think that our earth is flat. It is long back proven that our earth is not flat but it is round like an egg and there is continuous movement inside the earth as well as it is moving around the sun and it is also moving/rotating about its own axis. In this sense we can say that our earth is not a motionless rigid body but it is alive with movements inside and outside.

[Please, show in the map where your country and the neighboring countries lie.]



Sketch Courtesy: "This Dynamic Earth: The Story of Plate Tectonics"- Online Edition; USGS

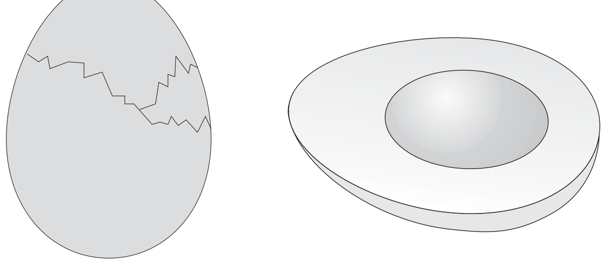
It is already mentioned that our earth is similar to an egg. The interior of it consists several layers of different types as in the egg. The earth consists of the inner core, the outer core, the mantle and the crust. Central part of the earth is called the core; the inner core (of radius about 1290km) is solid and consists of heavy metals like nickel and iron, and the outer core (of thickness about 2200km) is liquid in the form. The mantle (of thickness about 2900km) is in the semi-solid state and has the ability to flow. The crust is about 5 to 40 km thick and consists of light materials like granite and basalt rocks. This layer is usually known as the rock layer which is immediately inside the outermost soil layer. The crust is divided into a number of large pieces and these large pieces of the crust are called the plates.

[Give some examples of distance to feel the relative size/distance/thickness of the different layers]

To better understand the structure of the earth, a demonstration of boiled egg is helpful.

[Please show the demonstration to the participants and try to make the participants actively participate]

Demonstration - D1



Cross section of the boiled egg

Sketch Concept: EVRC course manual, ADPC

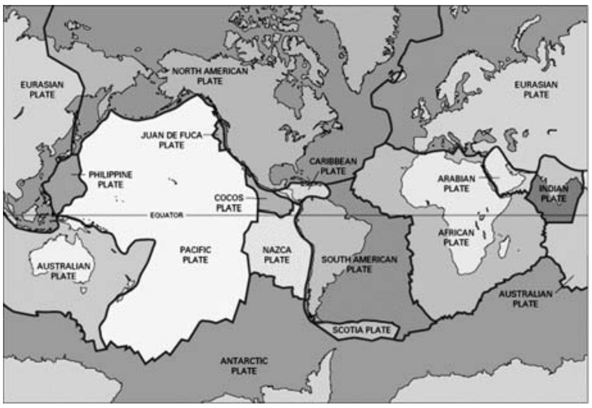
Demonstration

Take a hard boiled egg; the egg can be seen as a tiny model of the earth, although the shape is different. Now, crack the shell, the thin cracked shell represents the earth's crust divided into plates.

Then, take out the cracked shell and cut the remaining boiled egg with a knife. Draw the cross-section of the egg, which will show a white layer at the outer part and yellow yoke at the core. These two layers represent the mantle and the core of the earth.

Now, ask the participants, does it give a feeling of earth's internal structure.

Different Plates around the World

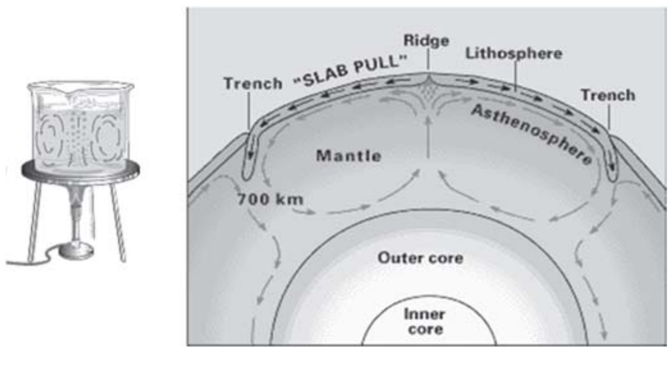


Sketch Courtesy: "This Dynamic Earth: The Story of Plate Tectonics"- Online Edition; USGS

As mentioned earlier and seen in the demonstration, the crust of our earth is not a one unit but it is divided into a number of large pieces, these large pieces of earth's crust or the rock mass are called the plates. There are 7 major and 23 minor plates around the earth. The map in the slide shows different plates around the world.

[Show in the map the location of your country and the neighboring countries and the plate/plates above which your country lies.]

Plate Movement



Sketch Courtesy: "This Dynamic Earth: The Story of Plate Tectonics"- Online Edition; USGS

The sketch in the slide again shows the interior of the earth like that of an egg. Unlike in the egg, there is a huge difference of temperatures and pressures between the inner and outer parts of the earth. The temperature at the core is about 2500°C whereas the temperature at the surface is about 25°C. Similarly, the pressure at the core is about 4 million times more than that at the surface.

This difference in temperature and pressure at the outer and inner parts of the earth creates continuous flow of the semi-liquid mantle in the form of currents. The current of the molten interior can be visualized as similar to that when created in boiling water. While flowing, the molten mantle makes the outer crust (or plates) also to move together. The current may be flowing in different ways as seen in the picture, and also the plates are moving in different directions depending upon the flow of the current. There are different locations in the earth where the plates are converging, diverging or sliding to each other. The boundary between two plates is called the plate boundary.

Plate Movement

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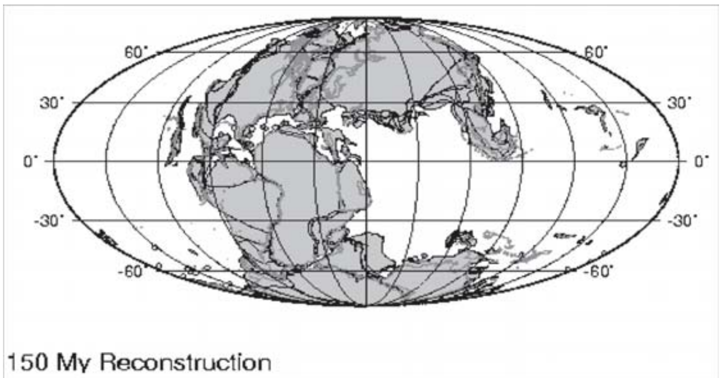

There is a continuous movement of the plates since millions of years ago, which can be seen in the animated slide. In the slide different stages of the earth's plates are shown at different times.

[Note: My: Million years]

What is an Earthquake ?

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An earthquake is a vibration of surface of the earth due to the sudden rupture of the earth's crust or the rock masses.

At the boundaries where the plates are coming close to each other (convergent plate boundaries), the movement of different plates increases the stresses in the plates. In the course of time, such stress goes on increasing and a stage comes when the plates can not bear further stress and they suddenly break producing a strong vibration. This sudden breaking of the earth's plate producing a strong vibration is called an earthquake.

To make it more clear, we can take the example of snapping of the fingers. Before the snap, the fingers are pushed together and sideways. At first, friction keeps them from moving to the side. But when the push sideways is hard enough to overcome this friction, the fingers move suddenly, releasing energy in the form of sound waves that then travels from the fingers to the ear. The earthquake phenomenon can be taken as similar to the snapping of the fingers.

At the boundaries where the plates are going far from each other (divergent plate boundaries), volcanic eruption and earthquakes way occur.

Our Himal

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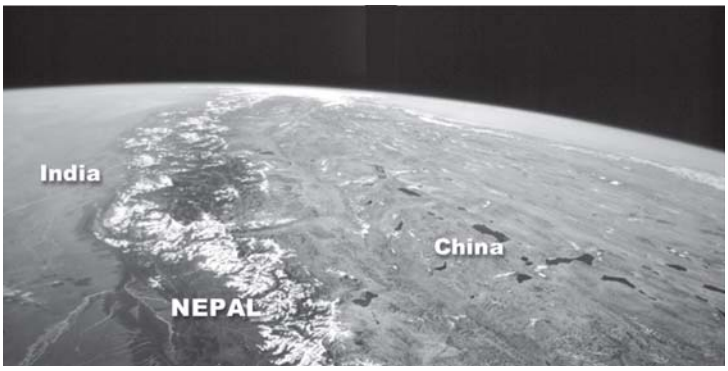

Nepal (and the entire Himalayan belt) is situated at the boundary between two large plates, Tibetan or Eurasian plate at the north and Indian plate at the south. Indian plate is subducting underneath the Tibetan plate at an average rate of 25mm per year. Due to its location at the subducting zone between two large plates Nepal and the entire Himalayan region is highly earthquake prone. In the picture we can see the location of Himalayan region between India and China. This is photograph of earth taken from a satellite.

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Mountain Building

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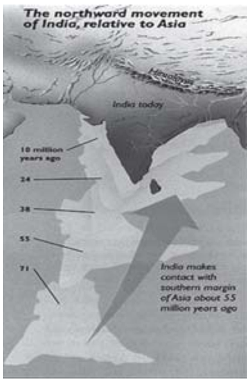

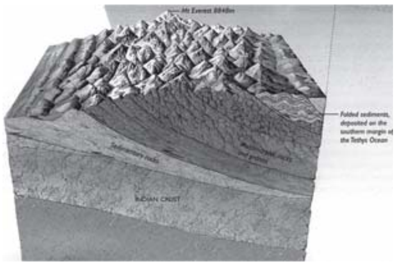

The mountain for which we are very much proud are the products of such tectonic movements and the earthquakes. In the ancient times, our current location used to be a large sea called the Tethys sea and the whole Indian sub continent was far below in the southern part. Different locations of the Indian plate in different stages of time are shown in the slide.

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Principal Earthquake Zone

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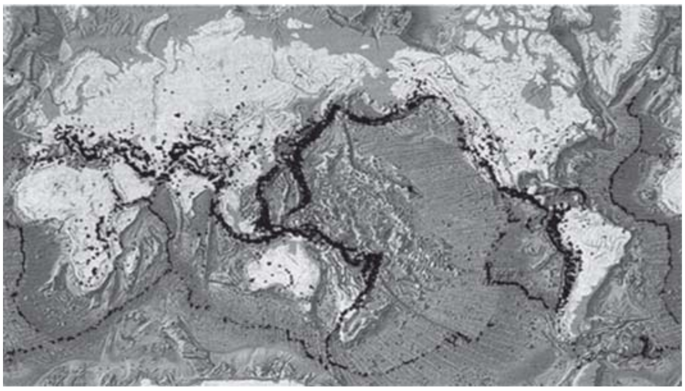

Now, it is clear that all the locations of the earth are not prone to earthquakes, but the boundaries between the plates are the locations that are very much prone to earthquakes. In the picture, Principal earthquake zones of the earth are shown which are obviously at the plate boundaries. The history of the earthquakes also verifies the fact.

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Seismicity and Historical Earthquakes of Nepal

In this part of the session, we will discuss about the seismicity and earthquake history of Nepal.

Seismicity of Asia Pacific Region

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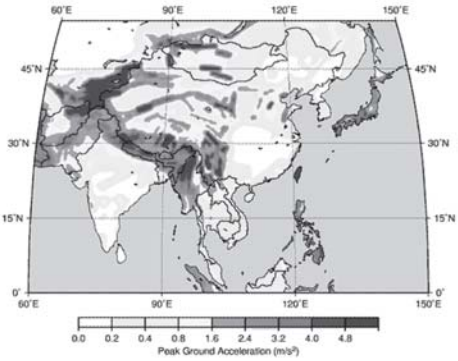

Seismic Hazard Map of Asia

Image Courtesy: Global Seismic Hazard Map, GSHAP

This is a part of world seismicity map which shows the seismicity of Asia Pacific Region. The dark red color shows the highly seismic areas whereas the lighter colors show the lower level of earthquake proneness. The map shows the whole Himalayan region as the highly seismic area. Similarly, Japan and other eastern countries and some parts of Russia are also very highly seismic.

Seismicity of Himalayan Region

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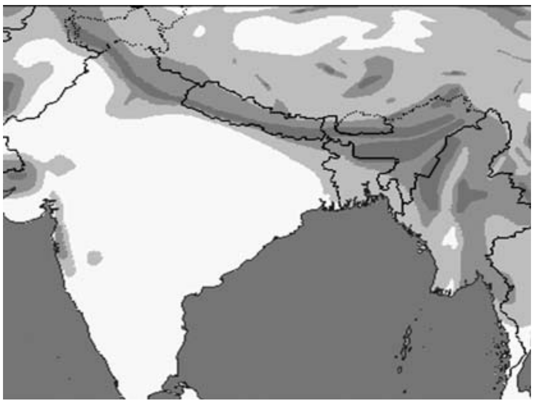

Image Courtesy: Global Seismic Hazard Map, GSHAP

In this map, the whole Himalayan Region starting from Myanmar in the east to the Iran in the middle east including our country is shown. Nepal is in the dark to pale red color and is representing it as seismically very active area. Major parts of India does not lie in the seismic area.

Seismic Hazard of Nepal

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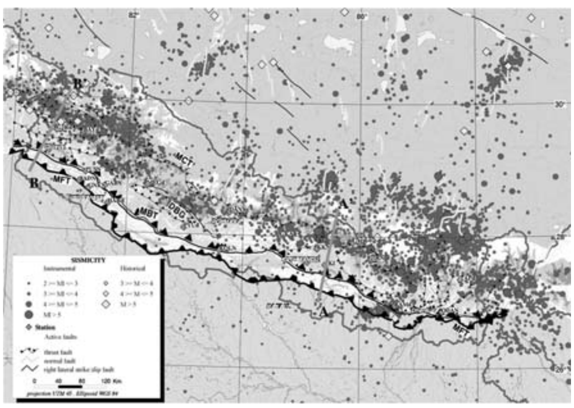

Map courtesy: National Seismological Centre, Department of Mines and Geology, Lainchour, Kathmandou, Nepal

This is a map showing the location and sizes of the recorded and historical earthquakes of Nepal. The whole country seems to be full of earthquakes. Smaller dots show the smaller sized earthquakes and the larger dots show larger sized ones.

Earthquake Record in Nepal (1911-1991)

Magnitude (Richter)	No. of Events	Frequency (years)
5 to 6	41	2
6 to 7	17	5
7 to 7.5	10	8
7.5 to 8	2	40
More than 8	1	81

If we analyze the historical earthquake records of Nepal, there are many smaller, medium sized and large earthquakes. The earthquake record of Nepal over the period of past 90 years, is as shown in the table.

Historical Earthquakes of Nepal

Year	Date	Magnitude	Location	Human		Buildings/temples	
				Death	Injury	Collapsed	Damaged
1255 (1310)	7 June	7.7	NA	One third of total population, including king Abhaya Malla died. Many buildings and temples collapsed			
1260 (1316)	Data unavailable			Heavy loss of life and property			
1408 (1464)		7.0		Heavy loss of life and property			
1681 (1737/38)	Data unavailable			Loss of life and property			
1767 (1824)	June						
1810 (1866)	May			Moderate to heavy loss of life and property			
1823 (1880)	Data unavailable			Minor loss of life and property			

In following few slides we will see the historical earthquakes of Nepal. The first earthquake which is seen as recorded in the history was the earthquake of 1255 A.D. (1310 B.S.), in which the king Abhaya Malla also died. Some major earthquakes recorded in the history are listed in the tables.

Historical Earthquakes of Nepal

Year	Date	Magnitude	Location	Human		Buildings/temples	
				Death	Injury	Collapsed	Damaged
1833 (1890)	26 Aug					18,000 in total	
	25 Sep						
1834 (1891)	11 Jul, 13 Jul, 26 Sep and Many times			Heavy loss of life and property			
1837	17 Jan						
1934 (1990)	16 Jan	8.4	Bihar/Nepal	8,519		80,893	126,355
1980 (2037)	4 Aug	6.1	Bajhang	46	236	12,817	13,298

Out of these historical earthquakes, the 1934 Nepal-Bihar earthquake is believed to be the most devastating in the recent history which is still in the memories of many elderly people and most of us have been listening many times about this earthquake. There are still many buildings, palaces and temples which survived in this earthquake and there are many others which are damaged but repaired or reconstructed later.

Historical Earthquakes of Nepal

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Year	Date	Magnitude	Location	Human		Buildings/temples	
				Death	Injury	Collapsed	Damaged
1988 (2045)	21 Aug	6.6	Udayapur	721	6,453	22,328	49,045
1993 (2050)			Jajarkot			40% of the buildings were estimated to be affected	
2001	17 Jul		Gorkha	None	Few		Many
2003	22 Nov	5	Near Pokhara	None	None		Few

The most recent earthquake to affect the country seriously was the earthquake of 1988. This earthquake hit eastern Nepal and the Kathmandu valley and 721 people were killed throughout the country. This was a medium-sized earthquake.

More recent earthquakes felt in the country were the Gorkha earthquakes of 2001 July and the earthquake near Pokhara of December 2003. Both of these were the minor earthquakes in which no people were killed but many houses were cracked and many non-structural damages were observed.

Scenario after 1934 Earthquake

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“होस-हवास हराएको दुई मिनेटपछि आँखा खोलेर हेर्दा चारैतिर प्रलयको दृश्य, प्रलयको कोकोहलो स्वरले चिच्याउन र कराउन लागेको देखियो, सुनियो । मानिसको ता के कुरो मानिसका शरणमा परेका चराचुरुगींहरु पनि च्याँ-च्याँ र चूँ-चूँ गरेर आकाशमा कराउन लागेका थिए । मूसो जस्तो छरितो जन्तुले पनि भाग्ने मौका पाएन, जहाँको तहीँ थिचिएर मर्नु प-यो ।

छोराको सबै शरीर किचिरहेछ, मुख पक्क-पक्क बाएको इँटका अन्तरबाट अलि-अलि देखिन्छ, आ......मा... भनेको मलीन आवाज अलि अलि सुनिन्छ, इँट काठ पन्छ्याएर छोरो झिक्ने मद्धत पुग्दैन । यस्तो अवस्थामा त्यस अभागिनी आमाको तस्वीर खिच्नुहोस् । जहानमा ११ जना थिए, सबै किचिएर मरे एउटा पाँच वर्षको बालक बाँच्यो । यो टुहुरोको सम्झना गर्नुहोस् । विवाह गरेको वर्ष दिन भएको छैन १५ वर्षकी बाहुनी विधवा भई, उसले छात्ति पिटी-पिटी रोएको करुण क्रन्दनको विचार गर्नुहोस् । जहानमा कसैको टाउको फुटेको छ, कसैको हात भाँचिएको छ, कुनै बेपत्ता छन्, कसैलाई खोस्रेर झिक्दै छन्, कसैलाई पोल्न लगिसके । घ्याम्पो फुट्यो, अन्नको गेडा छैन । घरमा मुर्दा लडिरहेछ, कात्रो किन्न जाने पसल छैन, दाउरा किन्ने पैसा छैन । घर भत्केका काठपातले मुर्दा पोलिए । बाबु म-यो, छोराले किरिया गर्नलाई कपाल खौरने छुरा पाएन । पुरेत बाजेसंग किरिया गराउने पुस्तक छैन, घरले किचिएको छ, अथवा कहाँ छ पत्तो छैन । किरिया पुत्रीले नयाँ धोती नपाएर पुरानै पटुका फेरेर किरिया बस्नु प-यो । सारा शहर भत्क्यो, पसल भत्के, केही किन्न पाइदैन । रात प-यो, माघे झरी पर्ने डर छ, ओत छैन ।

लास जलाउनलाई दाउरा नपाउँदा धेरैले भत्केका घरको काठले जलाए । सबै घाटहरुमा ठेलमठेला भयो । मूर्दाको सद्गत गर्न नसक्नेहरुले घाटमा मुर्दाहरु त्यसै फ्याक्न थाले, गाईवस्तुको त कुरै छाड्नु ।”

(श्री ब्रम्ह शम्शेर ज.ब.रा द्वारा लिखित “९० सालको महाभूकम्प” पुस्तकबाट उद्धृत)

Most destructive earthquake in the history of Nepal was the 1934 Nepal-Bihar earthquake. The scenario after earthquake was well described by Shri Brahma S.J.B. Rana in his book *“Nabbe Salko Maha Bhukampa”* published shortly after the earthquake.

These paragraphs from the book are well enough to describe a scenario after any earthquake.

[Please read these paragraphs loudly so that the participants will get real feeling of what could happen in an earthquake]

Glimpses of 1934 Earthquake

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Clock tower before earthquake

Photo Courtesy: "Images of Century", udle/gtz, Nepal

Few photographs of 1934 earthquake are presented here to give an idea about the extent of damage done by the earthquake.

Glimpses of 1934 Earthquake

The clock tower after destruction by the earthquake. The tower was reconstructed later.

Photo Courtesy: "Images of Century", udle/gtz, Nepal

Glimpses of 1934 Earthquake

Famous Bhimsen Tower before Earthquake

Photo Courtesy: "Images of Century", udle/gtz, Nepal

Glimpses of 1934 Earthquake

The tower after the earthquake. It was reconstructed later.

Photo Courtesy: "Images of Century", udle/gtz, Nepal

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Glimpses of 1934 Earthquake

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The same tower at present.

Photo Courtesy: "Images of Century", udle/gtz, Nepal

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Destruction by Earthquakes

Damage of Buildings

As last part of this session, let's see destructions done by different earthquakes around the world. The main purpose of showing these photographs is to make an understanding of the possible damages of earthquakes and its consequences.

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Photo Courtesy: "Images of Century", udle/gtz, Nepal

This photograph shows the destruction by 1934 Nepal-Bihar earthquake. During that earthquake almost 60% of the Kathmandu valley's building stock was destroyed.

Building Damage by 1988 Earthquake

Photo Courtesy: Department of Information, HMG, Nepal

This is a photograph of building damage due to 1988 earthquake of eastern Nepal.

Building Damage by 1988 Earthquake

Photo Courtesy: Department of Information, HMG, Nepal

This is a photograph showing the building damage in Kathmandu valley due to the 1988 Udayapur earthquake.

Building Damage by 1988 Earthquake

Photo Courtesy: Department of Information, HMG, Nepal

This is a typical damage of rural houses during 1988 earthquake.

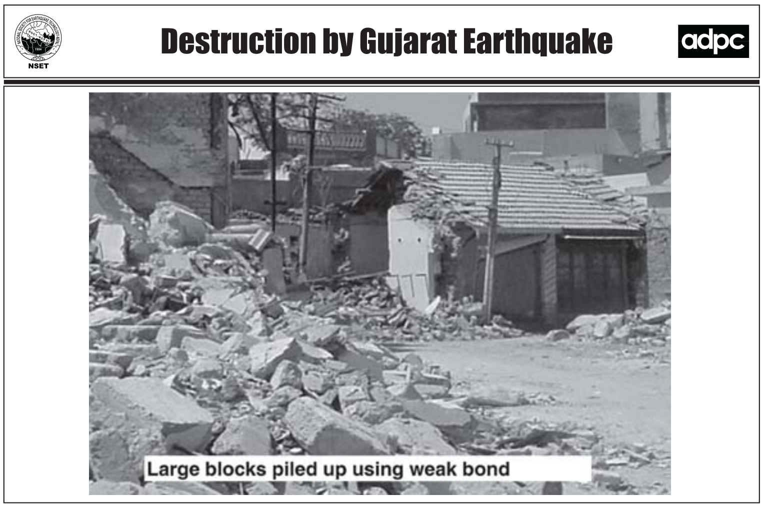


Photo: NSET - Bhuj Earthquake, India

Damage of stone masonry buildings due to Gujarat earthquake of 2001.

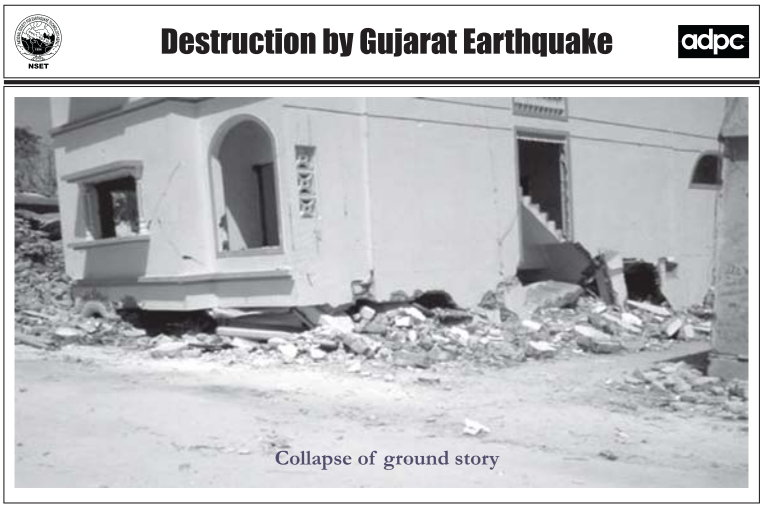


Photo: NSET - Bhuj Earthquake, India

In Gujarat earthquake many buildings of urban areas collapsed due to the failure of ground stories. The failure of ground stories was mainly due to open and weak ground stories.

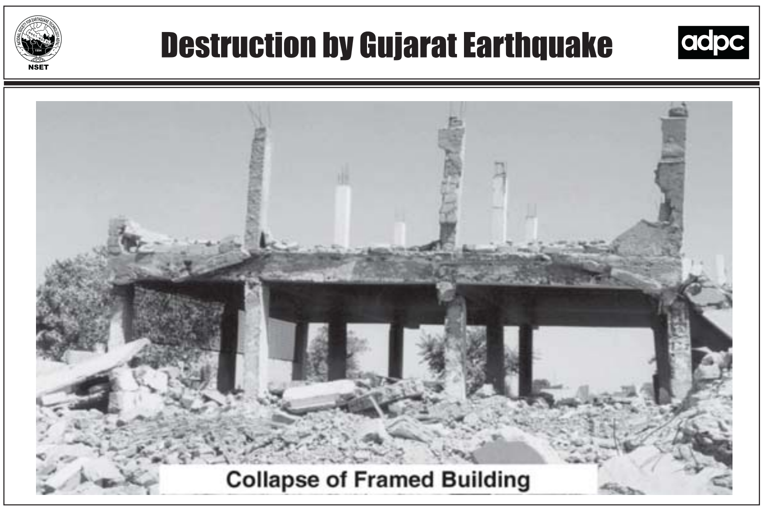


Photo: NSET - Bhuj Earthquake, India

Not only the load bearing masonry buildings are damaged by earthquake but also the RCC framed buildings get damaged if they are not properly constructed. The photograph shows collapse of infill walls in a framed building.

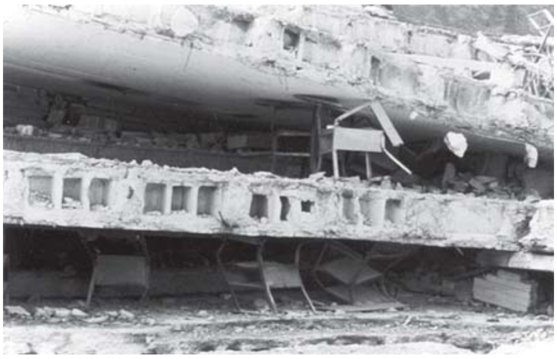
Destruction by Gujarat Earthquake

Complete Collapse of Concrete Building

Photo: NSET - Bhuj Earthquake, India

This is a complete collapse of an RCC framed building.

Destruction by Mexico Earthquake



Pan caking collapse of a School Building

If not properly constructed RCC buildings are more threatening to life than load bearing masonry buildings. The picture shows pan caking collapse of an RCC school building during Mexico earthquake.

Destruction by Mexico Earthquake

Collapse of Apartment Building

Photo Courtesy: Annotated Slide Set, EERI

High rise buildings also collapse during an earthquake if they are not constructed incorporating the earthquake consideration. The picture clearly shows that if a building does not incorporate the earthquake resisting features, then only it collapses during an earthquake and if it does it can withstand earthquake tremors.

Collapse due to Liquefaction

Nigata, Japan

Photo Courtesy: Goddon Collection, Earthquake Engineering Research Center, University of California, USA

Buildings may also collapse due to liquefaction of the soil underneath the foundation. (liquefaction phenomenon will be described in later sessions.)

Tilting of apartment buildings at Kawagishi-Cho, Nigata, Japan

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Destruction by Earthquakes

Damage of Lifeline Structures

Buildings are not the only to be destroyed by an earthquake but other infrastructures are also destroyed by the earthquakes.

Failure of Dam

Taiwan Earthquake, 1999

Shih-kang (Taiwan-China) incident Sept. 1999 after earthquake

Collapse of Bridge

Taiwan Earthquake, 1999

Damage in Electricity Sub-station

Taiwan Earthquake, 1999

Collapse of Tower

Taiwan Earthquake, 1999

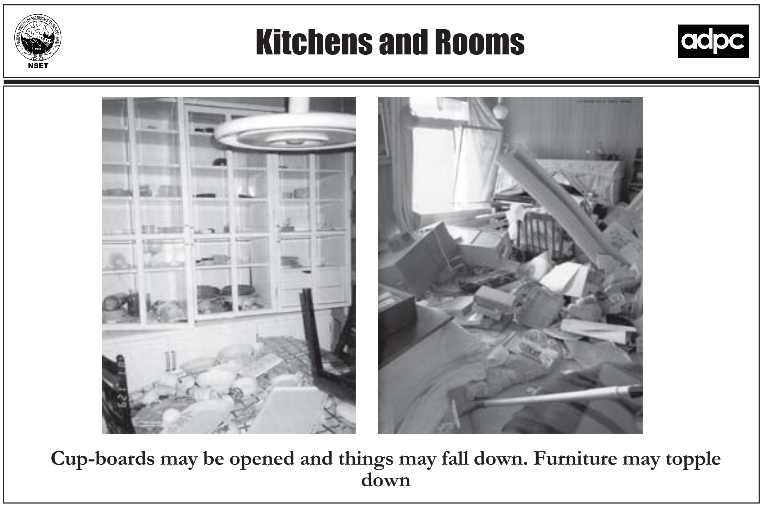
Failure of Railway Lines

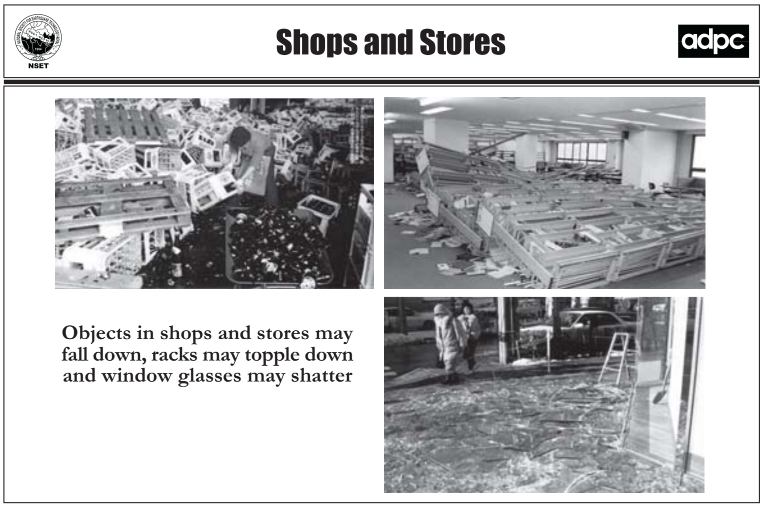
Destruction by Earthquakes

Damage on Non-structural Components

Large earthquakes are not necessary for damaging the non-structural components of a building. If the contents of a building are not placed firmly, even a minor to moderate earthquake can damage these. Only the non-structural damage in a building may cause a heavy loss of property and the falling objects may kill people. Also, due to loss of property and essential facilities, critical structures such as hospitals may loss the functionality and they may be non-functional during most critical hours.

Our room may look like this





This ends the brief presentation on overview of earthquakes. If participants are interested and raise questions further discussion on the issues can be continued.

Module 2/ Session 1

Site Selection, Configuration and Layout

In this session we will discuss about the considerations required during selection of sites for building construction and appropriate shape, size and layout of a building to become strong and earthquake resistant.

Learning Outcomes

After completion of this session; participants will be able to:

- Distinguish between suitable and unsuitable sites;
- Explain the measures available for site improvement;
- Choose appropriate form of building for earthquake safety; and
- Determine layout of columns, walls and openings

Consideration in Site Selection

Location and type of site play important roles in the behavior of a building not only in an earthquake but also in normal conditions too. Therefore, site for a building should be carefully chosen. In this session some basic consideration for good site selection are discussed.

Common Problems

Unequal Settlement

Due to defective site, settlement of foundation may occur in due course of time. Usually such settlement of foundation is likely in most of the common buildings. However, if the settlement is equal, it is not much severe but if the settlement is unequal then it is dangerous. Tilting and overturning resulting many cracks and damages may occur due to unequal settlement. Here are few examples of unequal settlement.

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Common Problems

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Unequal Settlement

Photo Courtesy: Washington Post, Page H05, Wed, Dec 9, 1998 - by Jane Morley

This is another example of unequal settlement of foundation.

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Common Problems

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Liquefaction

Niigata 1964 Japan, Tilting of Apartment Buildings

Photo Courtesy: EERI, 1964 Nigata Earthquake, Japan

This photo shows overturning of building due to liquefaction of foundation soil during Niigata earthquake, 1964 of Japan.

Liquefaction is phenomenon of sandy soil behaving as liquid during earthquake. When sandy soil layer with very high ground water table is shaken due to earthquake vibration, the soil layer behaves like liquid in which buildings may sink or float. This is a serious problem during earthquakes.

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Common Problems

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Liquefaction

Japan Jan 17, 1995, Collapse of the Nishinomiya Bridge

Photo Courtesy: University of Illinois Urban-champaign Civil and Environmental Engineering.

Due to liquefaction buildings tilt and fall down or overturn and structures collapse.

This photo shows collapse of a bridge in Kobe earthquake due to liquefaction.

Common Problems

Landslide and Rock Fall

Photo Courtesy: NSET, 1998 Chamoli Earthquake, India

In a hilly country like Nepal, building-damages due to landslides and rock falls are common. Landslides usually completely wash out buildings lying in its course. Rock fall damages buildings partially or completely.

Factors to be Considered

Following factors should be considered while selecting a site for building construction

- Ground Topography
- Slope Stability
- Rock fall area
- Flood proneness
- Liquefaction Potential
- Fault Zone

In view of these and many other common problems, site for a building construction should be selected carefully. Mentioned are the main factors to be considered while selecting a site. Detail description of these factors are given in the following sections.

Inappropriate Site - Water Logged Area

- Flood Proneness
- Liquefaction Susceptibility

Photo Courtesy: Annotated Slide Set, EERI

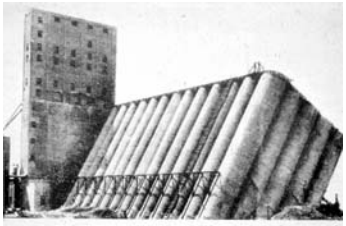
Following area should be avoided while selecting site for building construction:

Water logged area

Water logged area should be avoided for building construction. In water logged area, there may be possibility of flooding, foundation settlement and liquefaction.

Inappropriate Site - Back Filled Area

- Foundation Settlement
- Low Bearing Capacity



Earth filled (back filled) area

No building foundation should rest on uncompacted filled ground. In a back filled area, the bearing capacity of foundation sub soil is low and settlement of foundation may occur. Also, foundation may be exposed due to easy scouring of the backfilled soil. If a building is to be constructed on a filled ground, the foundation should be deep enough so as to rest on the firm ground surface beneath the fill.

Inappropriate Site - Steep Slopes

- Landslide Potential
- Rock fall proneness

Illustration from NSET Calendar

Steep and unstable slopes

No building should be constructed near to steep and unstable slopes. Steep and unstable slope areas are the potential areas of landslide and rock fall; there are potential danger of landslides and rock fall due to rains or ground shaking. Simplest indication of sustained stability of a slope is the upright standing of trees on it. They would be inclined downwards in the case of unstable slopes.

These steep and unstable slopes should be avoided. However, buildings can be constructed in such areas after the provision of proper precaution by retaining walls and green barriers of bamboo grooves is assured. In such case all wall footings should be set back from the edge of slope.

Inappropriate Site - River Banks

- Flood Proneness
- Liquefaction Susceptibility

Illustration from NSET Calendar

Near River Bank

River banks should also be avoided for building construction. River banks are susceptible to frequent flooding and also susceptible to liquefaction. Buildings should be far enough from the flooding zone of river and construction in such areas should be undertaken only after carrying out necessary protection works.

Inappropriate Site - Near Big Trees

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- Roots may damage foundation
- Tree may fall down and damage the building

Illustration from NSET Calendar

Near to big trees

Building should not be constructed close to any big tree. Roots of the tree may penetrate into the foundation and damage the whole building. Also, if a building is near to a big tree, there is always possibility of falling the tree in strong winds and storms.

Local Knowledge

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- If there is any local knowledge for site selection, that should be used
  - Which helps to incorporate local knowledge of foundation construction suited to the particular site
  - History of performance of existing buildings during past earthquakes will be known and this helps to take appropriate corrective measures.
- Assist in
  - Identifying inherent natural dangers like sliding, erosion, land subsidence
  - Identifying other natural / geological hazards

It is a good practice during the construction of a building to examine the existing local knowledge and the history of performance of existing buildings. This will assist in identifying whether there is any potential danger from inherent natural susceptibilities of the land to the process of sliding, erosion, land subsidence and liquefaction during the past earthquakes or any other natural / geological processes likely to threaten the integrity of the building. The local practice of managing such hazards, if any, should be judged against the required level of acceptable risk.

Improvement of Site

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- Improvement of Site
  - Removal of filled material
  - Providing sufficient drainages to control water logging
  - Providing Retaining structures to prevent landslides
  - Controlling the damages by rock falling
  - Control of sand boiling
- Improvement of site
  - Site should be kept well drained
  - Gravel Packing

Whenever it is unavoidable to construct a building in an inappropriate site, extra efforts are to be made for improving the site or enhancing the capacity of normal foundation.

In initial observation, if the site is found unsuitable for building construction, it should be improved and made suitable before starting the construction. Following are common site improvement techniques:

- In backfilled areas, the filled material is first removed and the foundation should rest on a firm ground.
- In case the building is to be constructed on a water logged area, sufficient drainage should be provided and site should be kept well drained. The draining can be done by pumping or providing drains.
- In landslide and rock fall areas, sufficient retaining structures should be constructed before constructing a building.
- In liquefaction susceptible areas or areas of potential sand boiling, the liquefiable soil layer can be removed and packed with gravel.

Mitigation Options

- Site improvement is in general expensive option
- Improvement of Foundation
  - Isolated footing – economical foundation
  - But for end columns problem of eccentricity
  - Adjacent building, during demolishing and new construction may create to our building
  - Strap footing may be effective solution

In general, improvement of site is expensive. Therefore, it will be appropriate in most of the cases choosing a suitable foundation type and improving the capacity of the foundation.

Isolated footings are common and economical foundation for a pillar system (framed) building. For end pillars, there is problem of eccentricity and during demolition of old building and construction of new, there may be problem of effect due to adjacent building. Combined footing or footing with strap beams will be an effective solution.

Mitigation Options

The beam at foundation level give better performances

Illustration from NSET Calendar

Strap beam provided at foundation helps to reduce the problem due to unequal settlement and liquefaction. The strap beam can be provided as shown in the figure. In normal buildings size and reinforcement in the beam may be same as the plinth beams.

Similarly, in a load bearing masonry building spread footing is common foundation type. In this type of footing also, strap bands are effective for increasing the earthquake resistance of the building. The strap bands can be of similar size and reinforcement as of the other bands like plinth band or sill band will be discussed later.

Mitigation Options

- Mat Foundation
  - Expensive option
- Pile Foundation
  - Also expensive option
  - But using locally available timber as piles with simple pile driving techniques may not be so expensive
  - Pile does
- Soil compaction
- Increase bearing capacity from end bearing action
- Increasing bearing capacity from friction action

Mat foundation and pile foundation are advanced type of foundation which suit for even weak soils. However, they are much more expensive. A mat foundation is of concrete slab covering the entire building area. This is suitable for sites of weak soils or low bearing capacity.

Pile foundation is more deeper foundation with long piles or columns inserted deep into the soil. Pile may be of steel, timber or concrete depending upon the type of structure and material available.

Driving Pile

Local solution of specific problems during pile driving

Photo: NSET, SESP-Vidyodaya School, Jhonchhen

Use of locally available material as pile and use of local pile driving technology may help to reduce the cost of pile foundation. Figure here shows the use of locally available timber logs as piles and also the use local pile driving technology in one of the school construction in Kathmandu valley.

Finally, site for a building should be carefully selected so that it is free of any problem. In unavoidable circumstances, inappropriate sites should be improved first and then only building is constructed. Type of foundation should also be carefully selected.

Shape, Size and Layout of an Earthquake Resistant Building

Earthquake Characteristic

During an earthquake building vibrates to-and-fro and upward and downward. The vibration of a building can be viewed as similar to the backward throw of passengers in a vehicle when it starts moving and forward leaning of the passengers when the vehicle suddenly stops.

Building During Earthquake

Illustration: NSET, SESP

Vibration of a building during earthquake is due to weight of the building. When earth shakes during earthquake, the building tries to remain in its original position due to its weight but the foundation changes its position according to the ground; this makes the building to vibrate back and forth. The building may vibrate in any direction. The vibration is due to the weight, therefore heavier buildings vibrate more than the lighter ones. Heavier buildings are hit by more force than the lighter buildings; heavier buildings get more damaged.

Building During Earthquake

Illustration: NSET, Bhuj Earthquake, India

When building vibrates, in a weak building joints between the walls start to open, cracks start from doors and windows and finally the wall and also the floors/roofs collapse. However, in a strong building the walls do not separate and collapse. There are many factors to make a building strong: shape, size and the layout are the primary factors to make a building strong and contribute to make the building earthquake resistant.

Common Shapes of Buildings

Photo Courtesy: TAEC, 1988, Udaypur Earthquake, Nepal & Illustration

We see different shapes of buildings around us, some common shapes being rectangular, square, L, tee, Y, C, circular etc. buildings with different shapes behave differently in an earthquake: irregular shaped buildings behave with more complexity and suffer more damage than a building of regular shape.

Irregular Shape

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Illustration Courtesy: Building Seismic Safety Council (BSSC)

When a building is hit by an earthquake, it is subjected to horizontal force at the floor levels and the whole building is deflected. If the building is regular shaped the deflection is uniform in all the parts of the building. But if it is irregular then the deflection is not uniform, some parts deflect much and some parts less. Due to this difference in deflection the building as a whole tends to rotate leaving the corners and ends at more stresses. This rotation of a building is called the torsion.

Torsion

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Illustration Courtesy: BSSC

To understand this more clearly, let us take an example of a table, the legs of which are fixed at the base. If the legs are of same size, when we push the table at the center of the top, the whole top of the table deflects equally and forces on the legs are equal. But if one of the legs is of larger size as shown in the figure and when we push at the center of the top, then due to the larger resistance of the larger leg, the top near to the larger leg deflects less and that at the far deflects much. This difference in the deflection makes the table rotate as shown in the figure. Due to this rotation the normal legs are subjected to more forces and stresses.

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Illustration Courtesy: Earthquake Tip Series, IITK-BMTPC

A simple example of this rotation can be seen in the swing. In a swing, if the ropes are not equal or the person sitting is not at the center, in both the cases it does not swing in straight direction, but it rotates.

Appropriate Shapes of Buildings

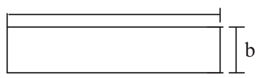
Illustration Courtesy: BSSC

From both the examples, it is clear that shape and weight of a building should be such that the building does not rotate during earthquakes. Regular shaped and uniformly weighted building does not rotate or rotates less. Therefore, a building should be of regular shape and uniform size.

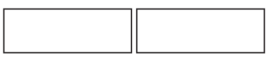
Some Appropriate Shapes

Rectangular, square and circular shapes are some common appropriate shapes and C, L, T, Y are inappropriate.

Long Narrow Buildings



Long narrow building



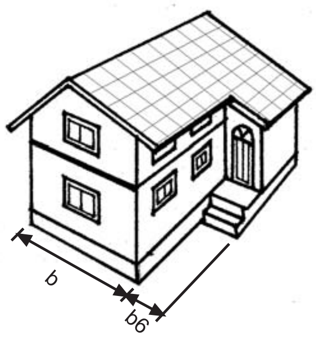
Long narrow buildings are also weak because the long side of the building can easily be damaged.

Photo: NSET, SESP

Separation can be made only in the superstructure.

When length of a building exceeds three times its width we call the building as long narrow building. In a long narrow building the longer sides are usually weak due to its long length and can easily fall down during earthquakes. A long narrow building is also taken as weak building even if the shape is rectangular and regular. Therefore, whenever it is necessary to construct a long narrow building, it has to be divided into two or more blocks providing sufficient gaps between them so that the individual length of separated blocks does not exceed three times its width. Such gaps provided to separate the blocks are known as the seismic gaps. The foundation of different blocks may be connected to each other.

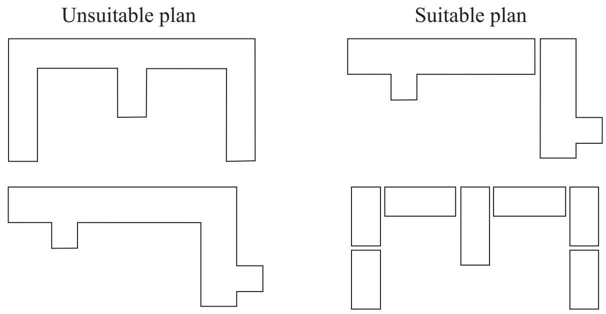
Wings in a building



Small wings in rectangular buildings are permissible. Rotation due to such wings is less.

L shaped buildings are irregular and inappropriate. However, small projection as shown in the figure is allowable. If the wing projection is less than one sixth of the width of the building effect of torsion is not much significant; hence small projection in buildings are allowable.

Complex Shapes

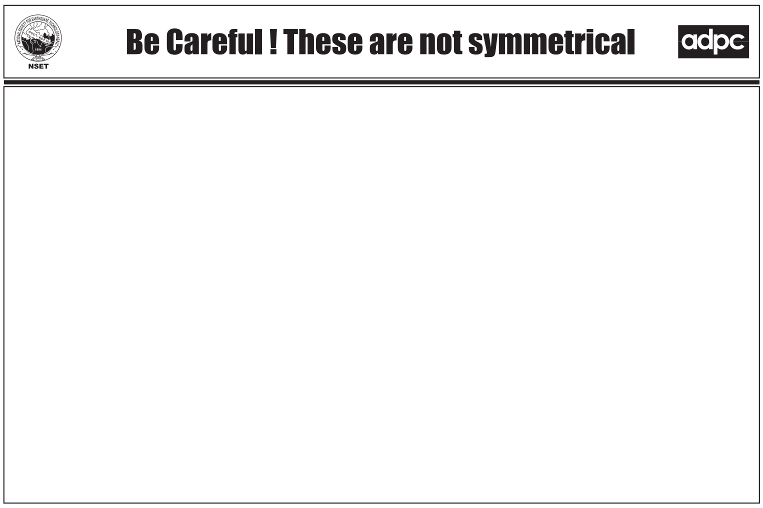


In order to make unsuitable building plans seismically acceptable, they need to be divided into a number of rectangular or symmetrical units.

More complex shaped buildings can also be made simple by providing seismic gaps at appropriate locations. Some complex shapes and their solution are as shown in the figures.

Simple Solution for Complex Buildings

Other complex shapes and appropriate locations for providing seismic gaps to make them simple are as shown in the figure. The proposed building should be viewed in both plan and elevation and if there is any change in elevation, gaps should be provided in that place too.



Some buildings may look symmetrical and regular but actually they may be unsymmetrical and irregular. Buildings with heavy shear walls in staircase or lift wells, buildings with walls in some sides and open in some sides are common examples of such false symmetry and false regularity. This should be avoided as far as possible and care should be taken to make them actually regular both in terms of shape as well as weight and distribution of walls or columns.

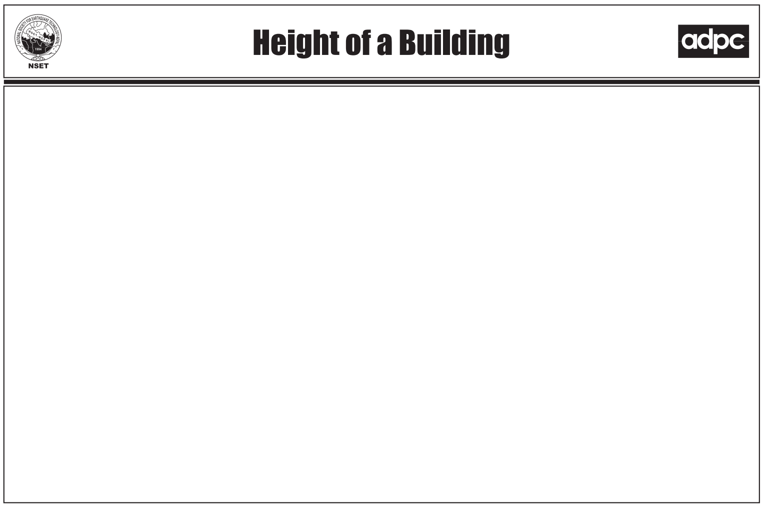
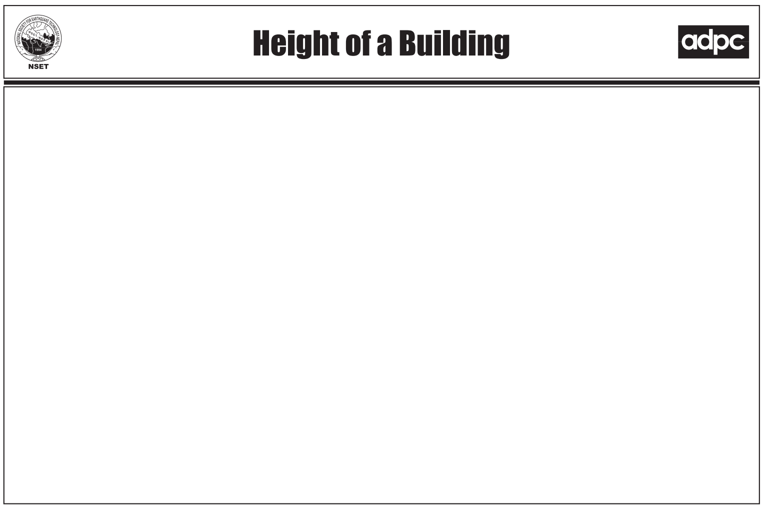


Photo: NSET, SESP

Height also plays important role in earthquake resistance of a building. We can see many tall and slender buildings around us specially in urban areas. Tall and slender buildings are not good in terms of earthquake point of view as well as for normal conditions. Let us see few examples why tall buildings are inappropriate.



Take two sticks of same size but different lengths and put them vertical with their bottom end fixed at some place. Now if we try to deflect them at the top with same amount of force, the shorter one deflects less and the longer one deflects much. In other words we feel easier to deflect longer stick than the shorter one.

Similar to this case, tall buildings deflect much and small buildings less during an earthquake.

Further,when there is some extra weight at the top of the sticks, then it is more easier to deflect them. With the same extra weight the longer stick deflects more than the shorter one. Similarly in a building if the weight near to the top is more as compared to the bottom, then the building can be more easily deflected.

Height of a Building

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Buildings in our surroundings are normally weak and when they deflect they don't overturn as a single unit as the case in an equipment, but they fall apart and pancake or collapse.

Appropriate Configuration

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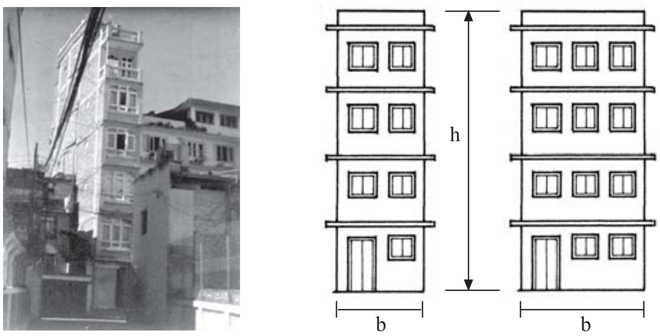

Height of the building should be less than 3b

Photo (Left): NSET & Illustration from NSET Calendar

Therefore, building should not be of excessive height. A good building is that in which its height is not more than 3 times of its width. Height should not be more than 3 times of its width.

Upper Floors - Elevation

adpc

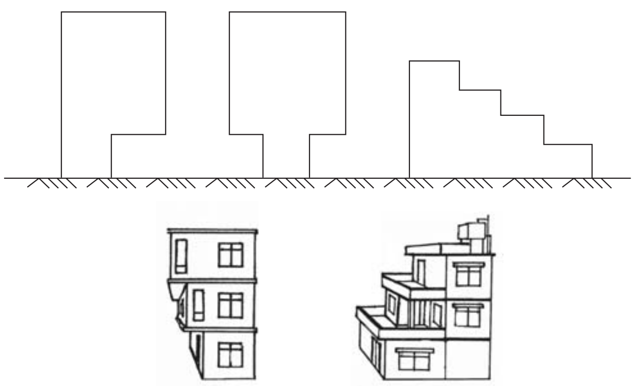

Illustration from NSET Calendar

Form of a building in elevation should also be uniform. Shown are some common forms in elevation. We see many buildings cantilevered and many buildings set back in upper floors. In all the cases the building becomes unsymmetrical and unstable. In first building, upper floors are cantilevered in one side only, making the weight of whole building concentrated in that side. Therefore, this building is quite unsymmetrical and unstable. In second building, the upper floors are cantilevered in both sides and looking symmetrical. But in this building also the whole weight is concentrated more towards the top which again makes the building unstable. In the third example, the building is set back in upper floors and looks good as compared to the pervious ones. However, this building is also not good, weight of the whole building is concentrated towards one side and this again makes the building unstable.

Appropriate Form in Elevation

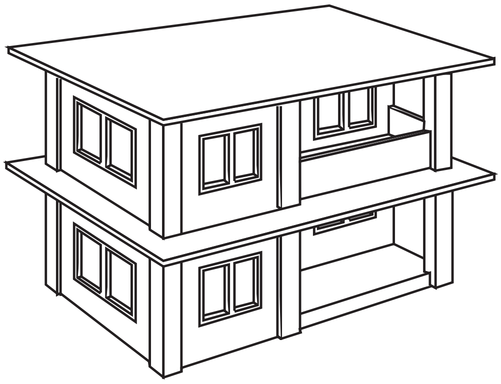

Illustration from NSET Calendar

Irregular and unsymmetrical form in elevation also makes a building weak. Therefore, building should be of uniform shape and regular form in elevation also. Upper floors should be of same shape and same size as in the lower floors. Building should have no walls in cantilever and it should not be excessively set back.

Some Specific Problems in Building Configuration

Here, we discuss some specific problems in building configuration.

Hammering by Adjacent Building

Photo Courtesy: Annotated Slide Set, EERI

When two buildings are attached with each other, during earthquake vibration both the buildings vibrate and they may hammer to each other. Different buildings behave differently in an earthquake. There may be different amount of deflections in each building. In case the floor levels of adjacent buildings are at the same level, the effect of hammering may be less, but if the floors are at different levels then floor level of one building may hit at the middle of the other building. This may be severe.

Adjacent Buildings

Sketch concept from Earthquake Tips Series, IITK-BMTPC

Therefore, buildings should be sufficiently apart. If it is not possible to make them sufficiently apart, then at least making their floors at the same level can reduce the problem.

Vertical Load Path

Sketch concept from Earthquake Tips Series, IITK-BMTPC

Other commonly seen problem is no perfect vertical load path. Weight of occupants, contents and non-structural elements are taken up first by floors or slabs, floors and slabs transfer the loads to beams and then to columns or walls. These columns and walls transfer the whole load to the subsoil below the building through foundation. If there is no wall or columns perfectly in vertical line from top to the foundation, then there will problem of transferring the load. Therefore, all the walls or columns of upper floors should be perfectly above the walls or columns of bottom floors. No walls or columns should start in between the slab or beam.

Soft Story Failure

Illustration: from BSSC

In urban areas, it is of normal practice that ground floors are left open for garages, parking, shops, stores or any other commercial purpose. The walls in ground floors are less than that in upper floors to make it open. When there is significantly less amount of wall in the ground floors the total capacity of ground story to resist the deflection due to earthquake shaking becomes significantly less than the capacity of upper stories. This makes the ground story weaker than the upper story and it can reach to failure stage far before the other stories reach the stage. Hence in such case ground floors collapse first and the whole building may fall down. This phenomenon is called the soft ground story problem because the ground story is more soft than the adjacent stories.

This phenomenon may also happen in other floors, if the floor has significantly less walls or columns than in the adjacent floors.

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Earthquake Resistant Building

We can summarize the basic characteristic configuration of an earthquake resistant building as follows:

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Appropriate Layout of Buildings

For masonry buildings

- Regular shape and appropriate size
- Proper distribution of walls
  - More than two major wall each direction
  - Evenly distributed walls
- Same shape and size in all the floors of the building
- No main walls in cantilever projection
- No significantly less amount of wall in ground floor
- Proper size and place of doors and windows

For a masonry load bearing building these are the main features of good configuration:

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Appropriate Layout of Buildings

For Framed Buildings (Pillar system)

- Regular shape and appropriate size
- Columns (pillars) in grids forming a good lateral load resisting system
- Proper distribution of columns
  - More than two columns (2 or more bays) in each principal direction
  - Evenly distributed columns
- Sufficient size of columns
- Same shape and size in all the floors of the building
- No main walls in cantilever projection
- No columns starting from middle of the slab or beam
- No significantly less amount of walls in the ground floor

For an RCC framed building to be of good configuration it should have the following main features:

Ideal Earthquake Resistant Building

- Small mass
- Low Height-to-base ratio
- Low center of mass relative to the ground
- Balanced lateral resistance
- Direct load paths
- Symmetrical Plan
- Uniform section and elevation
- Uniform floor heights, and
- Maximum rotational resistance
- Short spans

In general, an earthquake resistant building looks like this.

Concept of Stiffness

Member are equally strong but their stiffness is different

Illustration: from BSSC

In an earthquake resistant building the stiffness of different structural elements should be such that they can resist the probable displacement of the structure and the structural members are placed such that their stiffness are proportionately distributed.

Stiffness is a property of a body by which it can resist the deflection. If a body can resist sufficient amount of displacement then the body is called stiff.

The stiffness of a body or a structural element can differ according to its position and direction of the force. For example, let us take a metal plate. When we put the metal plate flat with its width horizontal, supported at two ends and try to put a weight over it, we see the metal plate will deflect. Now, put the same metal plate with its width vertical and try to put the same weight over, then in this case the metal plate can easily resist the weight without any deflection of the plate.

This example gives the idea of stiffness of a structure.

Similar to this example structural elements like beams, columns and walls should be placed in such a position that they will give more stiffness to the structure. A beam should be placed with its longer side vertical so that it will give high stiffness to resist vertical load and posses less deflection.

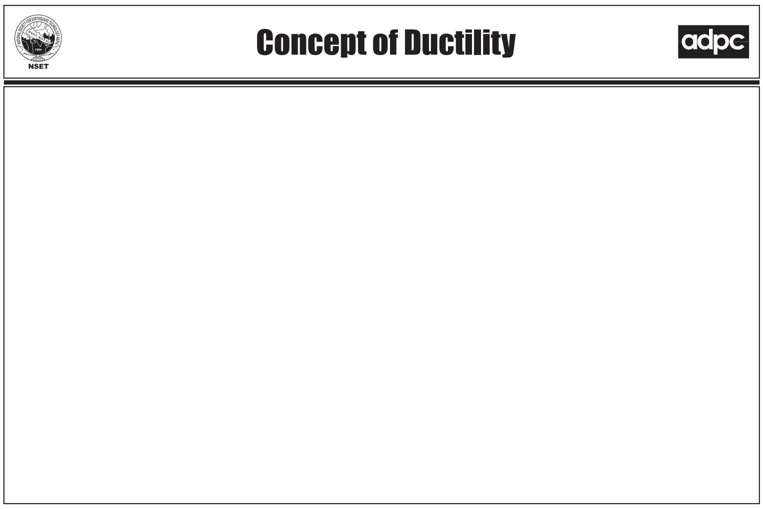
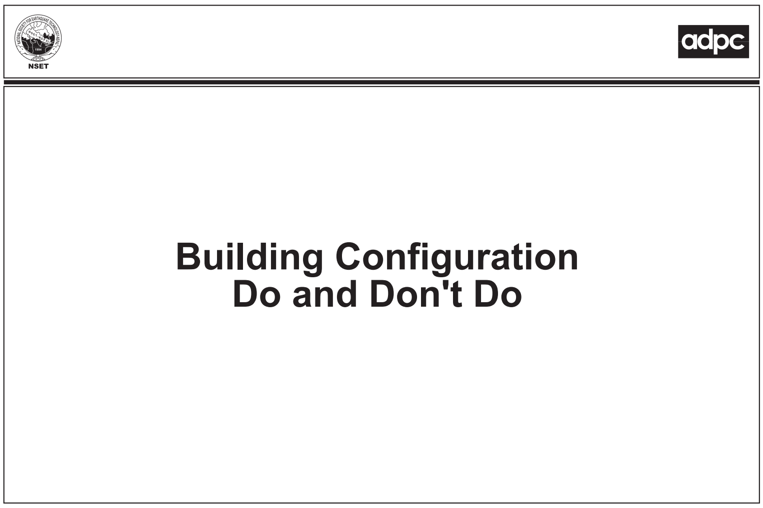


Illustration from BSSC

Similarly, ductility is the other important property of a structure that is assumed to be essential to make a building earthquake resistant. Ductility is a property of a material by which it can take more force without any sudden damage but with the gradual elongation of the material. By ductility an element can absorb larger amount of energy in it without sudden breaking of the element.

When we try to break a steel spoon and apply increasing force to it, in place of sudden breaking it starts to bend with the elongation in its length. It will break only after a number of repeated application of force to bend it back and forth. In contrast to the steel spoon if we try to break a plastic spoon at the certain level of force the plastic spoon suddenly breaks down. In first example, ductility of the steel makes the spoon elongate and prevent the sudden break whereas in the second, the plastic spoon does not have the ductility but it is brittle so it fails suddenly.

In an earthquake resistant building it is tried to make all the structural elements and their joints ductile as far as possible by providing the steel reinforcing bars or any other reinforcement so as to give sufficient ductility to the structure. For this detailing of the reinforcements should be given special attention and they should be constructed as per the requirement of ductile behavior.



Finally, the considerations for good configuration of buildings can be summarized as dos and don’ts as in the following:

NSET **Plan shapes** adpc

NSET **No** **Yes** adpc

NSET **No** **Yes** adpc

No Yes

No Yes

No Yes

Building Systems / Types

- Timber frame
- Load Bearing Masonry – Adobe, Brick in mud, brick in cement, stone (mud/cement), Block
- RCC Framed
- Steel frame
- Composite
- This manual covers the Load bearing masonry with brick/stone and RCC framed buildings

These are the common types of buildings available in Nepal depending upon the building system or the construction material.

Out of these systems and types, this mason manual covers and describes only the construction of load bearing masonry wall buildings and RCC framed buildings. Following sessions of this manual / training program are devoted in describing the various aspects of these building types in detail.

Here are some of the issues for discussion with the participants if they are interested and raise the questions.

EXERCISE

Exercise on Planning and Layout of a Building

- **Task:**
  - A landowner wants to construct a 2-storied building in his existing plot of land with the following requirements. The detail of plot has been given in the attached sheet.
- **Plot detail:**
  - Name of the plot **A**
  - Size of land- **10m (32 feet)** on the road side and **13m (42 feet)** on the back side (L= 13m, B= 10m)
  - A 3-storied building exists on the west side of the plot as shown. The building is constructed adjacent to the boundary line of the proposed land.
  - There is 4m wide road on the south face of the plot

In this exercise, participants will be given plan of a piece of land and required sizes of rooms and facilities for a proposed building to be constructed on the land. Then they will be asked to plan and layout the building appropriately. Main purpose of this exercise is to give the idea of good configuration of buildings and orient them how to make a good plan. For this they will be given papers, pens, hardboard/ plywood, threads, pins, rubber band, board marker, small blocks (similar to bricks but smaller in size) etc. to make the plan. They can use any of the material as per their convenience. The trainer will facilitate them while planning and laying-out. Participants will work in the groups. Each group will make one plan either for framed building or for load bearing masonry building.

Plot of Land

Illustration: NSET

Requirements of the Building

- 2 nos. Bed Room of size 3.00m x 4.50m (10 ft. x 15 ft.)
- 1 Living room of size 3.00m x 4.50m (10 ft. x 15 ft.)
- Kitchen / Dining- 1
- Toilet - inside
- Staircase- inside
- Balcony at the front

Materials to be provided

- Following items will be given to prepare the plan for RCC framed structure
  - Thumb pins
  - Rubber bands
  - Card board/Ply wood/hard board of size 3 feet x 4.5 feet
  - Board marker to mark the size and location of openings
  - Other necessary items
- Following items will be given to prepare the plan for Load-bearing building
  - Blocks (similar to bricks but reduced in size)
  - Small wooden strips for making doors and windows
  - Nails, binding wire, saw, binding materials as required

Exercise

- Prepare two draft plans as per the requirement on the existing land:
  - one for load bearing building and another for RCC framed building
- Provide doors and windows as required and permitted

[Please let the participants prepare the plan and layout. Assist them by giving some clues for better plans. Finally allow them to clief them about their works and tell them good & bad aspects in their plan based on the guidelines provided in the lectures.]

Module 2 / Session 2

Construction of Masonry Buildings: Foundation

NSET

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Learning outcomes

In this session we will discuss about the importance, type and construction techniques of foundation of masonry buildings. Following will be the learning outcomes of this session.

After completing this sessions, participants will be able to

- define relationship between soil type, no. of stories and type of buildings with respect to determining the size of foundation.
- use recommended construction techniques of foundation.
- use appropriate type of material, incorporate EQR components in the foundation.
- use appropriate construction technique for foundation in terrace land

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What is Foundation

- Foundation is a bottom-most part of a structure which transfers the whole load of the structure to the soil beneath it.
- It is a critical part of a structure which plays main role in overall stability of the structure.
- Foundation for a particular structure depends on type of the structure and foundation sub soil.

Foundation is bottom-most part of a structure which transfers all the load of superstructure to the soil beneath it.Loads due to the occupants and contents are first taken up by floors, then by beams, walls or columns and finally transferred to the underlying soil in a wide area through the foundation. Foundation is essential part of any structure, without which loads of the structure can not be uniformly transferred to the soil and the structure will not be stable.

Buildings may have different types of foundation depending upon the type of structure and the material of construction used. It also depends on the type of the foundation sub-soil. For an RCC framed building, the foundation is mostly of isolated spread footing whereas for a masonry building with brick or stone walls it is continuous strip footing of brick or stone masonry. In this session we will discuss about the foundation of masonry buildings.

Foundation for Masonry Building

- For load bearing wall construction, strip footing of masonry, plain concrete or RC is commonly used.
- RC strip footing is most effective for seismic and settlement consideration in soft as well as firm soils
- Masonry footings are most frequently used.

Load bearing masonry building in Nepal and the like countries generally have the continuous strip footing as the foundation. The foundation footing may be of brick or stone masonry or it may be of RCC or PCC depending upon the type of the superstructure, material availability and the economy. RCC or PCC footing is little more expensive as compared to the masonry footing of brick or stone. Seismic performance of RCC footings is better than the others as well as it is good from settlement point of view. However, due to economy, easy availability and easy construction process masonry footings are the most widely used foundation type for load bearing masonry buildings.

Foundation for Masonry Building

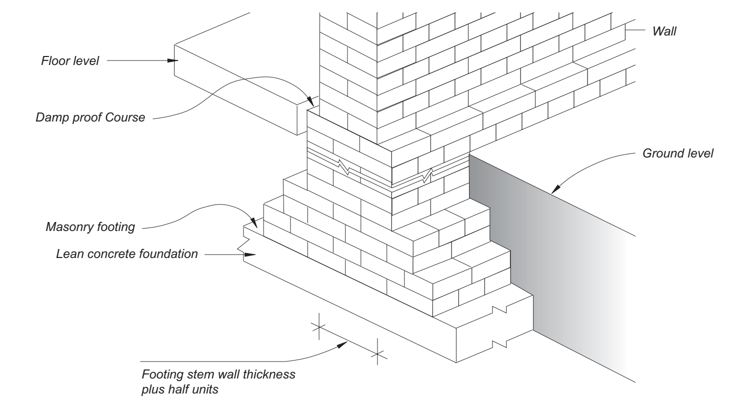

Illustration: NSET, National Building Code

Continuous strip footing for a masonry building looks like as shown in the figure above. This is internal view of the foundation which is covered by the ground and can not be seen from outside. Width of footing at the bottom is made wide enough so that it can transmit the superstructure and foundation load to a wide area.

In following slides we will discuss one-by-one the different types of footings used in load bearing masonry buildings.

RCC Strip Footing

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

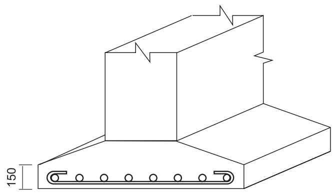

Illustration: NSET, National Building Code

As mentioned earlier, RCC footing is the most suited from seismic and settlement consideration in soft as well as in firm soils. This is due to the capacity of reinforced concrete to resist both tension and compression forces which in the case of masonry, it has little or no capacity to resist tension forces. In case of an earthquake there will not be only compressive forces but there will also be tensile forces coming in the footing.

In this system, required size and no. of steel reinforcing bars are laid over brick or stone soling or lean concrete layer and then concrete is casted over to make the required size and shape of the footing. Width of the footing should be such that it can transmit the load of the building uniformly to the foundation sub-soil without making any part of the sub-soil overloaded or overstressed.

Similarly, the thickness of the footing is made tapered since it requires more thickness near to the superstructure wall and less at the far end of the footing. The area near to the wall is subjected to more punching forces due to the concentrated load from the superstructure wall. Considering this, the minimum thickness of the footing at the far end should not be less than 150mm and it increases towards the center of the footing.

Then above the tapered footing, remaining foundation wall and the superstructure walls rest. The remaining foundation wall may be of the same RCC or it may be of masonry wall.

PCC Strip Footing

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

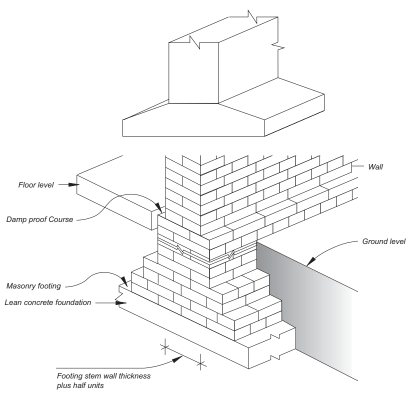
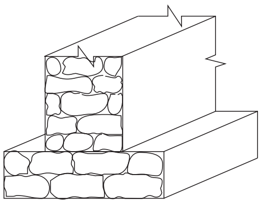


Illustration: NSET, National Building Code

PCC footing is similar to RCC footing; only the difference between these two is the reinforcing bars inside the concrete. In PCC footing there is no reinforcing bars inside. Due to the reinforcing bars placed in the concrete the footing becomes little more expensive but the strength of the footing increases significantly. Therefore. PCC footing is inferior than the RCC footing but is economical.

Plum Concrete Footing



- Suitable where stone or boulders are available in abundance.
- Stones of 200 mm or less are suitable.
- It is basically stone masonry in matrix of 1:3:6 to 1:4:8 concrete which works as both binder and filler material.

Illustration: NSET, National Building Code

Plum concrete footing is another type of footing which can be used where the stones or the boulders are available in abundance. Plum concrete is a kind of concrete in which a major portion of it is filled by stone boulders of about 200mm in combination with lean concrete mix of 1:3:6 or leaner proportion. In this concrete, the voids among the boulders are filled by the concrete mix. This type of footing is not so common.

Brick / Stone Masonry Footing

- It is the most common strip foundation, which can be constructed in cement or mud mortar.

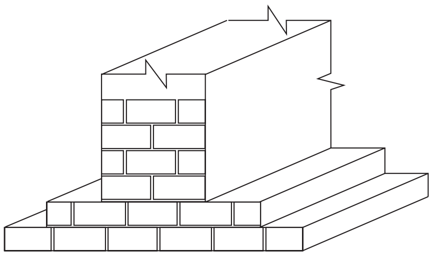


Illustration: NSET, National Building Code

Most commonly used type of foundation for a load bearing masonry wall building is masonry footing of brick or stone. The masonry footing is generally made stepped, the width at the bottom being more and the width at the top of the footing is equal to the width of the wall above. The footing wall may be of brick or stone depending upon the availability of it and the mortar also mud or the cement.

Appropriate Foundation Option

- An RC footing is appropriate from seismic and settlement consideration.
- While most commonly used and economical footing type is masonry footing.
- Therefore, there should be some optimization between these two.
- If we provide an RC band at the bottom and use masonry footing above, this will be an optimized solution.

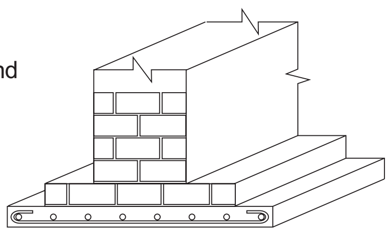


Illustration: NSET, National Building Code

Even though RCC footing is most effective from seismic and settlement point of view, due to its cost it is not commonly used. On the other hand, masonry wall footing is most common but it is weaker to withstand earthquake vibration and ground settlement. Therefore, there should be some optimum type of foundation having both economy and strength. Such optimized solution is masonry footing with RCC band at the base. In this solution, an RCC band as shown in the figure is provided at the bottom and above this band the masonry footing is constructed. Details of this type of footing is discussed in the later slides.

Size of Footing

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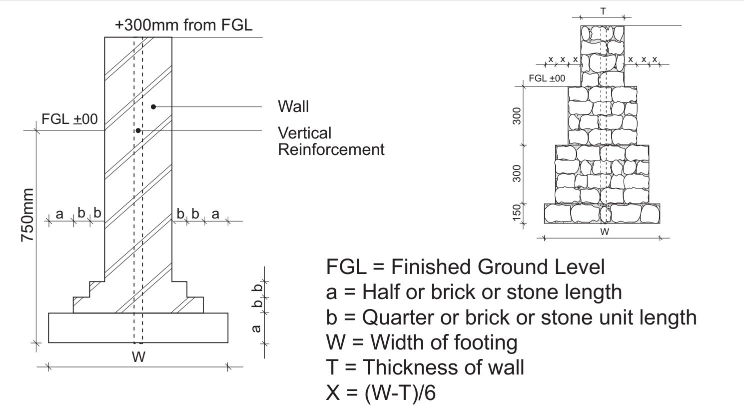

Illustration: NSET, National Building Code

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

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

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

Minimum Size of Foundation

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Soil Type	Size of footing depending upon no. of stories (mm)					
	1		2		2+Attic	
	Width	Depth	Width	Depth	Width	Depth
Hard	**750**	**750**	**750**	**750**	**750**	**750**
Medium	**750**	**750**	**750**	**750**	**750**	**750**
Weak	**750**	**750**	**900**	**750**	**900**	**750**

This table provides the minimum size of foundation for masonry footing in different types of foundation sub-soil and different no. of stories.

Preferable Size of Foundation

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Building Type	Foundation Size					
	Up to 1 story		Up to 2 stories		Up to 3 stories	
	Depth (mm)	Width (mm)	Depth (mm)	Width (mm)	Depth (mm)	Width (mm)
Brick Masonry in Cement mortar	800	750			900	900
Stone Masonry in Cement mortar	800	750	900	900		
Brick Masonry in Mud mortar	800	830	1000	1000		

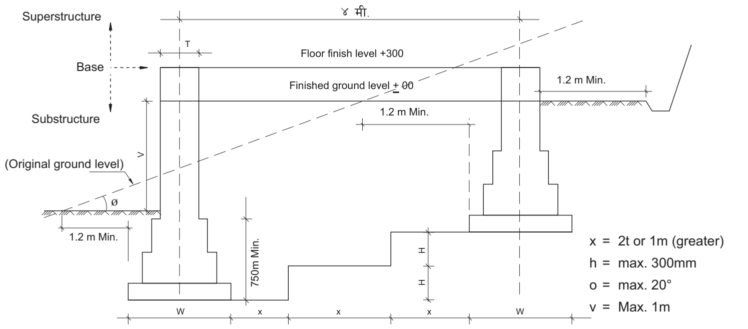
Similarly, this table gives the appropriate size of foundation for different no. of stories and different wall types.

Size of Superstructure Walls

	Floor	Min. Wall Thickness (mm)
Brick masonry in Cement mortar	Second	230
	First	230
	Ground	350
Stone Masonry in Cement mortar or Brick Masonry in mud mortar	First	230
	Ground	350

This table provides the required thickness of superstructure wall for different no. of stories and different masonry wall types. The footing wall just below the plinth level should not be less than the thickness of the superstructure wall. Therefore, this table also gives the minimum thickness of the plinth wall.

Foundation in Sloping Ground



Whenever building on a sloping ground is unavoidable, special care should be taken while constructing the foundation.

Illustration: NSET, National Building Code

As far as possible, building should be on a level ground. But in a mountainous country like Nepal, it is always not possible and building construction on a sloping ground is absolutely unavoidable in some cases. In such condition, if possible it is best to make the ground level first and then to start the construction. However, this is also not possible in most of the cases. Therefore, stepped excavation and stepped foundation as shown is figure is the best option for such circumstances. Width of steps, depth of excavation, distance of side drainage, height of finished ground level etc. should be as shown in the drawing.

Earthquake Resistant Components in Masonry Foundation

Now, we discuss about the earthquake resistant elements that has to be incorporated in the foundation of a load bearing masonry building.

Foundation Band

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- A reinforced concrete band provided throughout the foundation helps to perform better during earthquake.
- It ties the whole building at foundation level and helps to prevent damage due to settlement of foundation sub soil.
- This band is cost-effective solution for normal residential buildings in very weak and liquefiable soils to medium soils.

Of course, as discussed earlier, foundation band of reinforced concrete is the best option as an earthquake resistant element in a masonry building. This band is cost-effective solution for normal residential buildings in very weak and liquefiable soils to medium soils.

This band is provided throughout the entire foundation length and ties the whole building at the foundation level. This helps to keep the building as one unit even during earthquake vibration and prevents the damage of the foundation. This band is also effective to minimize the problem due to settlement of foundation sub-soil. When the sub-soil settles down unequally, even in that case this band helps to keep the foundation at the same level and prevents the cracks and damages due to settlement.

Foundation Band

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- Thickness and width of this band depends on the span of footing between supporting walls and the thickness of the wall at plinth.
- Width should not be less than wall thickness at plinth.
- Thickness should be 75mm minimum.
- Minimum 2 nos. 12mm diameter bars with 4.75mm diameter single legged stirrups at 150mm spacing.
- If the width is more than 350mm, it is preferable to use more than 2 nos. of bars.

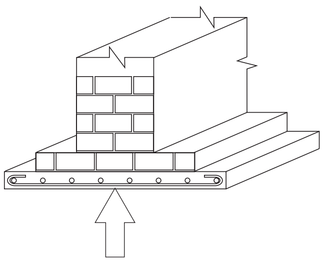

Illustration: NSET, National Building Code

Size of the RCC foundation band depends on the span and the load above it. The minimum width of this band should not be less than the width of the wall at plinth and the thickness should not be less than 75mm. Thickness can be similar to the bands at plinth (plinth band), sill (sill band) or lintel (lintel band) and will be discussed later in the session of masonry wall construction. Also, the reinforcement in this band will be similar to other bands.

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Construction of Masonry Footing with RC Band

In following few slides we will discuss on the construction steps of masonry wall footings with the foundation band at the base.

Construction Steps

- Foundation excavation to true line and level
- Compaction of excavated foundation soil level
- One layer flat brick or stone soling
- P.C.C. (1:3:6) over soling
- Placing formwork or constructing brick wall at sides for required size of foundation band
- Placing reinforcements for the band
- Erecting vertical reinforcement for the wall connecting to the foundation band reinforcement
- Concreting the band with minimum of M15 (1:2:4) concrete mix
- Construction of masonry wall footing above the band

After laying out the building plan, excavation is done to the required depth and width in true line and level. The excavated ground is then compacted well to make a hard base in true horizontal level. Over the compacted base, one layer of flat brick or stone soling is done and again above this soling lean foundation concreting (P.C.C. 1:3:6) is done to make the foundation base uniform and to protect the band reinforcement from the ground moisture.

Above this lean concrete layer, required no. and size of reinforcements are placed. Before placing the reinforcements, formwork should be placed for making required width and depth of the band. This can be made alternatively by constructing brick walls at the sides.

Finally, concrete mix of 1:2:4 proportion (M15) is poured in into the prepared formwork. Hence the concrete foundation band is constructed. After curing for few days, masonry footing is constructed above the band as done in the normal masonry footings.

Making Appropriate Width of Band

Photo: NSET, School Earthquake Safety Program, Kathmandu

In foundation band construction, economy can be achieved by reducing the width of the band.

The band can be made covering the whole width of the footing. However, the full width is not necessary and it can be made at least equal to the width of the plinth wall. This reduction in the width can save a significant amount. In this case of reduced width of foundation band, in place of formwork, brick wall as shown in the picture at the sides can be used. This will also contribute to the economy as wall as the good quality of work.

Placing Reinforcements

Photo: NSET, School Earthquake Safety Program, Nateswori Primary School, Bhaktapur

While placing reinforcements for the foundation band, not only the band reinforcements but also the vertical reinforcements should be placed as shown in the picture. These vertical reinforcements have to be placed at corners and junctions and these are required for giving the tensile strength to the superstructure walls. The superstructure walls will be discussed later in next session. The vertical reinforcements should have sufficient anchorage (L) inserted into the band reinforcement. It should be at least 60 times of the diameter of the vertical bar.

Details of these reinforcements are as discussed in the reinforcements of other bands in the next session.

Concreting

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Photo: NSET, School Earthquake Safety Program, Himalaya Primary School, Bhaktapur

After all the reinforcements are placed in position, concreting is done as shown in the photo. Concrete should be well placed, compacted and cured.

Finished RC Band in Masonry Footing

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Photo: NSET, SESP

The photograph shows the completed RCC band in the foundation of a masonry building. The vertical reinforcements starting from the foundation band are also seen in the picture. Now, above this band the masonry wall footing is constructed.

Finished Masonry Footing

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Photo: NSET, SESP, Shree Krishna Secondary School, Dhapakhel, Lalitpur

These are some photographs showing the views of masonry wall footing with foundation RCC band at the base (now hidden).

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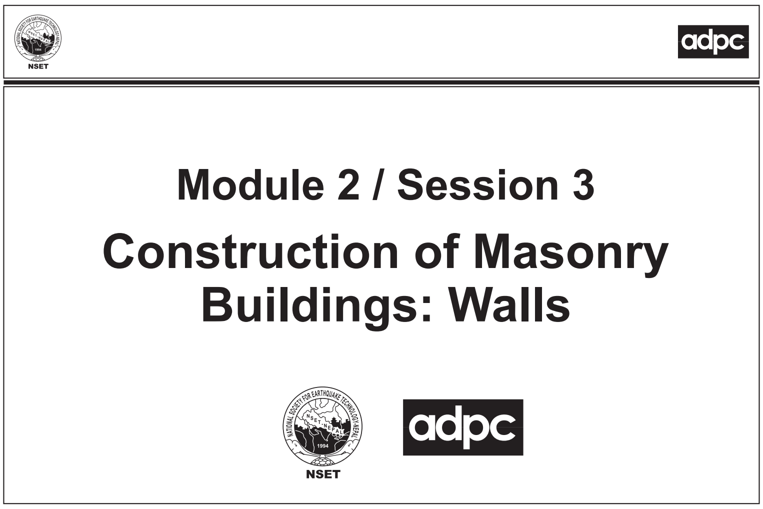
Specific Problems and Solutions

Here, the participants are encouraged to raise specific problems frequently encountered during the construction of masonry foundation and try to find out the solution after discussion.



Masonry wall construction has been a major type of building construction since ancient times. Stones, bricks and blocks of different sizes, shapes and quality have been in use as masonry units and mud, lime and cement as binding materials.

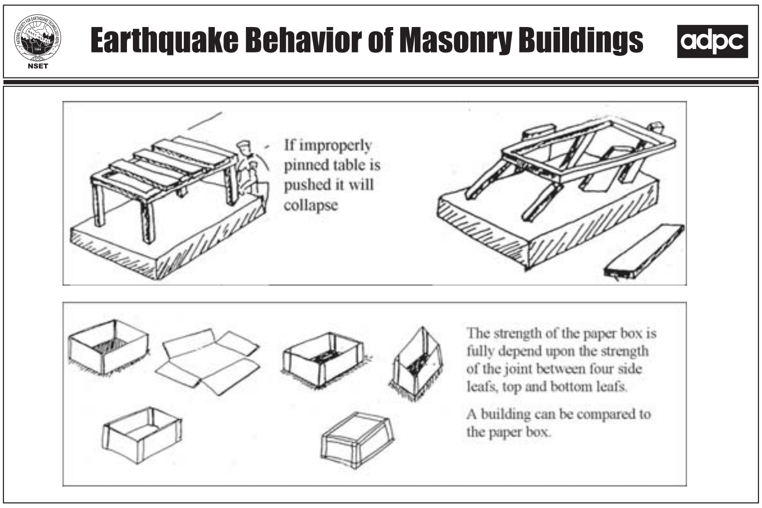
Masonry buildings have been suffering from earthquake damages in which significant number of population have been killed throughout the world. On the other hand, there are many historical cities in the world where a large stock of old masonry buildings still exist surviving after numbers of large earthquakes.

In this session participants will learn about earthquake resistant construction of masonry buildings.

Learning outcomes

After completing this session, participants will be able to:

- Use appropriate bonding of masonry units based on materials use.
- Use techniques of strengthening of corners and junctions.
- Correctly incorporate horizontal and vertical reinforcements



If we study the damages of masonry buildings, we find the failure of joints between different masonry wall elements as the major cause of damage. A masonry building consisting of different wall elements can be viewed as similar to a paper box consisting of different paper pieces joined together. The strength and quality of the paper box depends on the quality of joints between different pieces. Similarly, the quality of masonry building also depends on the joint of the masonry walls.

Further, if we view a table, joints between different elements are the crucial points to give the strength to the table. If the joints are not properly pinned, the table may collapse even in a small push over it. A masonry building can also be compared with a table.

In the following sections you will learn the important factors that make a masonry building strong and earthquake resistant.

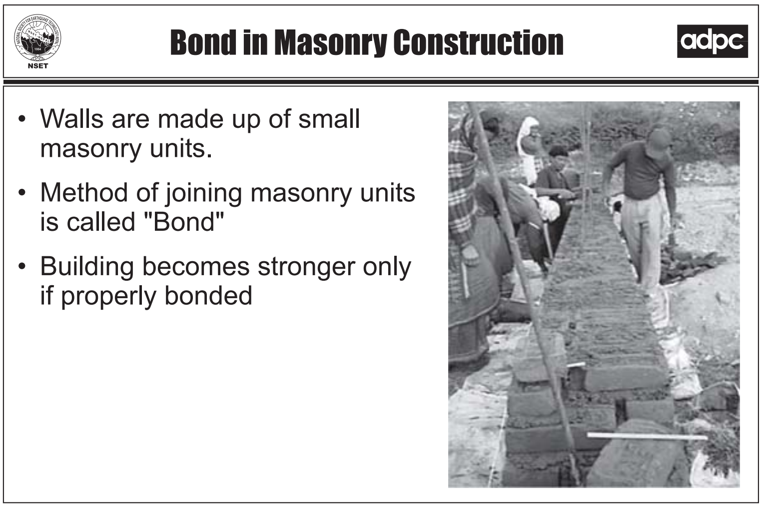
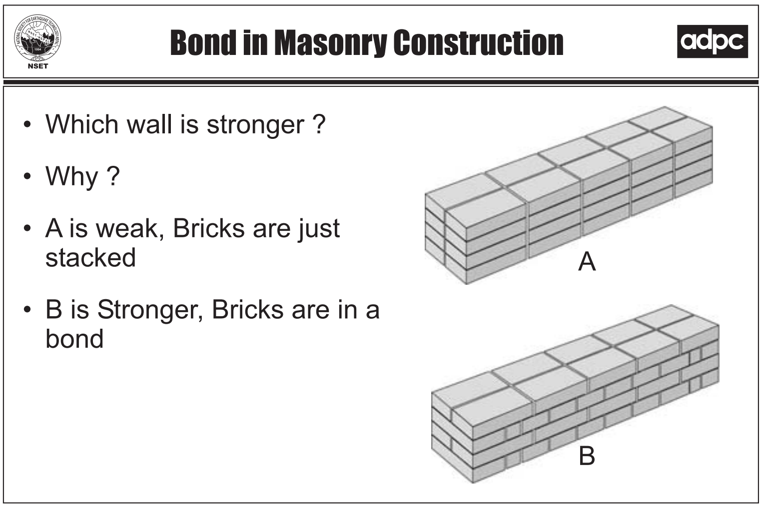


Photo: NSET, SESP

Walls are made up of small masonry units like boulder, stone, bricks, blocks etc. joined together in a systematic way. Method of joining these masonry units is called "BOND" and there are different methods of joining the masonry units. Bond between masonry units is an important factor to make a wall strong. Buildings having properly bonded walls are much stronger and durable and walls with improper bonding are weaker. To join one masonry unit with other mortars of different types are used. Type of bond and mortar used converts individual masonry units into a single homogeneous wall.



In the figure given, we can see two types of brick walls. Can you guess, which wall is stronger and why ?

Of course, wall A is weak and B is strong. Wall A is just a stack of bricks on a straight line in which each brick rests on only one brick immediately below it. It can be easily knocked down. On the other hand, each brick of wall B transfers its load to at least two bricks below it and they are interlocked by staggered brick layers. Wall B is stronger as compared to wall A.

From this, it is clearly seen that each masonry unit must rest centrally on at least two masonry units below it.

As stated earlier, there are different types of masonry units: bricks, stones and blocks are commonly used masonry units. Now, we will go through existing practices, defects and possible corrective measures in the masonry wall construction.

Masonry Wall with Bricks

- Building with bricks
  - Same bricks in all walls
  - Composits brick walls
    - Chinese & Local bricks
    - Brunt and sun dried bricks

Photo: 1998 Chamoli Earthquake, India, NSET

We can find different size and quality of bricks available in the market. According to the availability and quality of construction needed, people use different bricks. In most of the cases, people prefer to use same type of brick in a building, however, due to the economy and availability different types of bricks are also used in a single wall or a building. In some cases, people also use bricks with stones or blocks. These types of walls with different masonry units are called composite walls. The composite of different bricks may be of Chinese and local bricks, different types of local bricks or burnt and unburnt bricks.

In general, walls with same type of bricks are stronger than that of composite ones. They are also easier to construct. The impact of forces coming to different types of bricks vary in a composite wall; the weaker bricks get crushed easily while the stronger bricks do not in the same level of force. In such condition, the wall starts to get separated in two parts (weaker and stronger). This separation causes the wall to bulge out or delaminate. When the wall is deformed it makes the building weaker.

Hence, use of same type of bricks makes easier to construct a stronger building, whereas use of different types of bricks may make a building weaker. Therefore, as far as possible same type of bricks should be used in all the walls of a building; if it is not possible to use same bricks then it should be tried to use similar quality bricks and special care should be taken while constructing so that the bond between different types of bricks will be good enough.

Masonry Wall with Bricks

- Brick Wall

Photo: 1988 Udaypur Earthquake, Nepal, NSET

Another practice commonly seen is the use of broken bricks or brick pieces in the inside faces of the walls. Use of broken bricks makes the vertical joints in a wall to be in a same straight line and hence he wall can easily be cracked. So, care should be taken not to use broken bricks in main wall of a building. Due to economic consideration, it is sometimes unavoidable to use such bricks. In such case, use of excessive volume of such broken bricks should be avoided and there should be no vertical joints in a straight line.

Masonry Wall with Boulder Stones

- Building with Boulder
  - Boulders used as it is available

Photo: NSET, 1988 Udaypur Earthquake, Nepal

Boulder stone is another type of masonry material mostly used near the river banks since rivers and natural streams are the main sources of boulder stones. The history of earthquake damage has shown that a wall made up of boulder stones easily crumble down even in a small earthquake. Boulders are round in shape and do not have flat surface thus making the contact area between two boulders is very much little and difficult to properly bond together. Also, boulders are heavy in weight. These are the reasons why boulder stone walls fall down easily even in a small force.

Boulder stones should not be used as masonry material without dressing the surfaces. The dressing is done so that they can be placed in flat surface and contact surface also increases.

Wall with Quarry Stones

- Building with Quarry Stones
  - Larger stones on sides
  - Packing stone chips in the middle

Photo: NSET, 1988 Udaypur Earthquake, Nepal

The other type of stones used in wall construction is quarry stones. Quarry stones are generally available in hilly areas and they are the common building material used in these areas. As these stones are taken out from the large quarries, they are already broken into pieces and normally flat and cubical in shape. However, further dressing may be necessary to make more regular shape and size.

In stone masonry wall construction, flat surfaces of the stones should be placed horizontal, but we can see many cases around the Nepalese cities that flat surfaces placed vertically. This is done to give the wall or the building a good looking or in other words it is done for good architectural view. In this case, two surfaces of walls are made of the stones with their flat surface placed vertically and inner part is filled with smaller stone pieces and mortar. This practice allows the stones to fall down easily as they are stable only due to the mortar joint but not due to their self weight. Also, during earthquakes these stones can be shattered like a glass and hit the people. Therefore, the use of stones in this manner should strictly be avoided.

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Stone Masonry Walls

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Common Problem in Stone Masonry Works

Photo Courtesy: Left - TAEC, Right - NSET, Baitadi, Nepal

No matter whether boulder stones are used or the quarry stones, it is a common practice that the inner parts of the walls are filled with small stone pieces and mortar. This way of constructing a wall makes the stone units of inner and outer faces not bonded together properly which results in separation of two faces of the wall, bulging and delamination. Such deformation in stone walls may lead to collapse of the building even in normal times whereas they are fatal during an earthquake.

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Failure of Stone Walls

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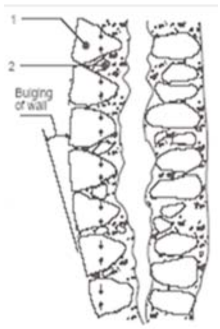

Stone wall delamination with buckled walls

Bulging and subsequent failure of stone wall

Illustration (Left): IAEE, Photo: Righ t) NSET

The figures show separation, bulging, delamination and collapse of stone masonry walls

NSET

Failure of Stone Walls

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Chamauli Earthquake

Failure of outer face of the stone walls

Photo: NSET, 1998 Chamoli Earthquake, India

This is another example showing the failure of outer face of the stone wall.

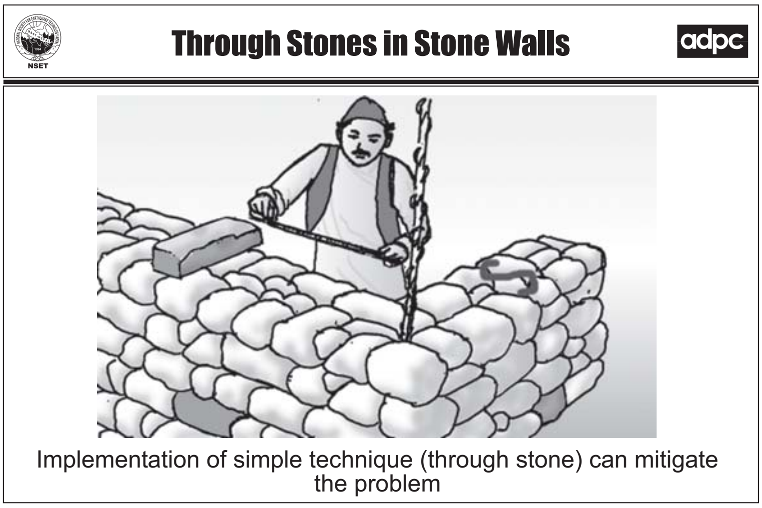


Illustration from NSET Calendar

The problem of separation of two faces of stone walls can be easily mitigated by not using the stone pieces or mortar in excessive volume at the inner part of the wall and by providing through stones at certain appropriate intervals. Through stones are provided at appropriate intervals in both horizontal and vertical direction and they should be provided in staggered fashion.

When there is shortage of large stones to be used as through stones, timber blocks or steel hooks can also be used in place of through stones or in combination with them.

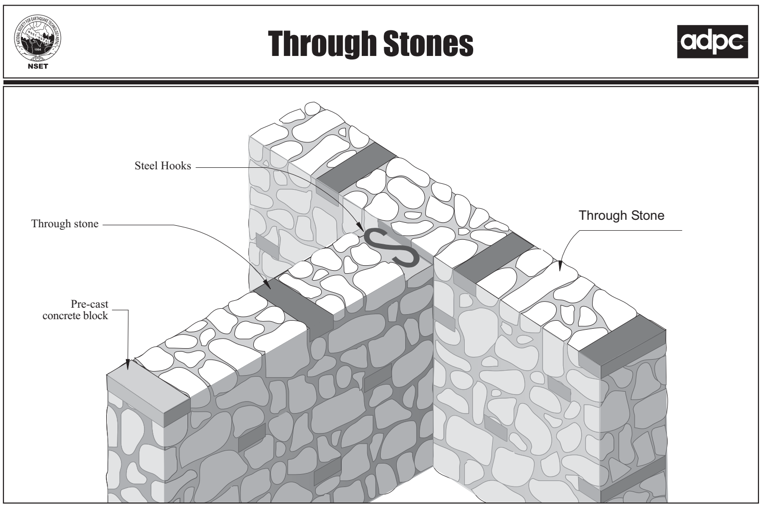


Illustration Courtesy: IAEE Monogram

This figure shows the use of through stones, timber blocks and steel hooks together for tying two faces of stones walls properly.

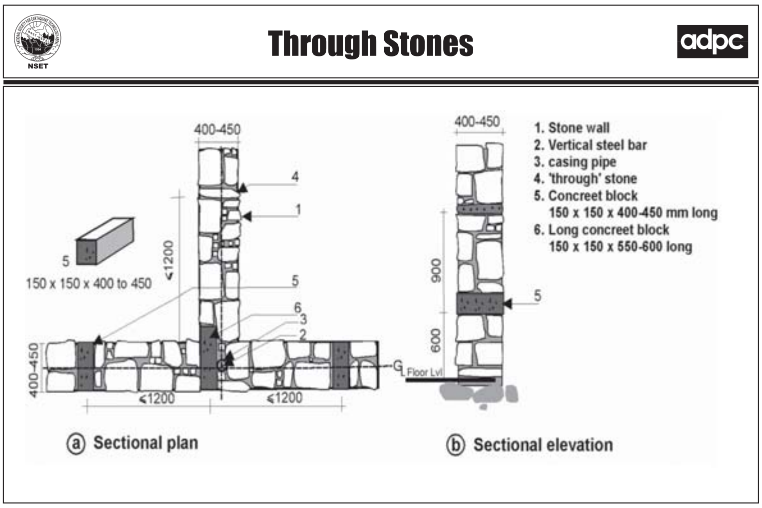
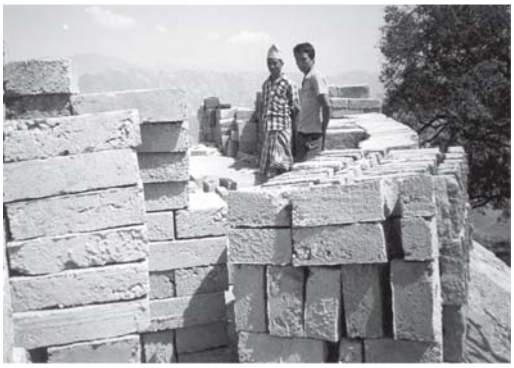


Illustration: NSET, National Building Code

Similarly, concrete blocks of appropriate sizes can also be used as through stones.

Stonecrete Block: A cost-effective option



Stonecrete Blocks ready for use in construction

Photo: NSET, SESP - Kavresthali Lower Secondary School, Kathmandu

Main problem in stone masonry wall is due to the irregular shape and size of stone units. To overcome the problem, use of stonecrete blocks may be easy, cost-effective and appropriate solution.

Stonecrete block is a solid block consisting of stone pieces in the core surrounded by lean concrete mix to give proper shape and size. Significant volume of the block is of stone pieces (40 – 60%) so that it is a low-cost solution for the location where stones of more smaller sizes are available. The strength of such blocks is also good enough to use as main masonry wall material.

This technology have been in use since few years back in the school projects of NSET under the School Earthquake Safety Program (SESP) and is becoming popular day-by-day.

The details of making stonecrete blocks are described in session 1 of module 4: Alternative Building Materials and Construction Technologies.

Stonecrete Masonry Building

Stonecrete masonry building under construction

Photo: NSET, SESP - Kavresthali Lower Secondary School, Kathmandu

This photograph shows the construction of a school building by using the stonecrete blocks made locally in the school.

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Mortar in Masonry Construction

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2 photos of wall being constructed that clearly showing the activities and materials being used (stone and bricks). The photographs should contain masonry units, and mortar in the background.

Photo: NSET, SESP - Shree Krishna Secondary School, Dhapakhel, Lalitpur

Mortar is an important component in masonry construction which joins masonry units (bricks, stones or blocks) to each other to form a masonry wall. Type o mortar and thickness are another factors that affect the strength of a wall.

Mortar may be of cement, lime or mud depending upon the type and purpose of building and the availability, however cement sand mortar is the preferable one to make an earthquake resistant building.

Thickness of mortar plays a vital role in the strength of masonry wall. The mortar thickness should be optimum; thin mortars can not bond the masonry units properly and the thick mortar makes the wall weaker. The optimum thickness of mortar for brick or block masonry is 1 to 1.2 cm (3/8” to 4/8”). It is very much difficult in a stone masonry wall to make the mortar thickness uniform, however it must be ensured that the thickness is not less than 1.2 cm.

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Common Defects in Masonry Buildings and Mitigation Measures for Earthquake Resistance

In the second part of this session, we will discuss about common defects in masonry buildings and corrective measures for reducing the defects.

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Vertical Cracks and Separation of Walls

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Corners in masonry buildings are inherently week and first suffer from horizontal force during Earthquake.

Photo Courtesy: Siddhi Shrestha, TAEC, 1988 Udaypur Earthquake, Nepal

Long vertical cracks and separation of walls at corners and tee junctions are commonly seen defects in masonry buildings. These are seen not only after earthquakes but also in normal life of the weak buildings. Corners and tee junctions are the places where the walls from two orthogonal directions are joined together and these two walls behave differently. Therefore, these locations are inherently weak points in a building.

Here are some photographs showing the vertical cracks and separation of walls in masonry buildings.

Stone Masonry

Wall Separation

Photo: Bhuj Earthquake, India, NSET

Vertical cracks and separation of walls at the corner of stone masonry building.

Brick Masonry

Wall Separation

Photo: Bhuj Earthquake, India, NSET

Vertical cracks and separation of walls at the corner of brick masonry building.

Toothing at Junctions

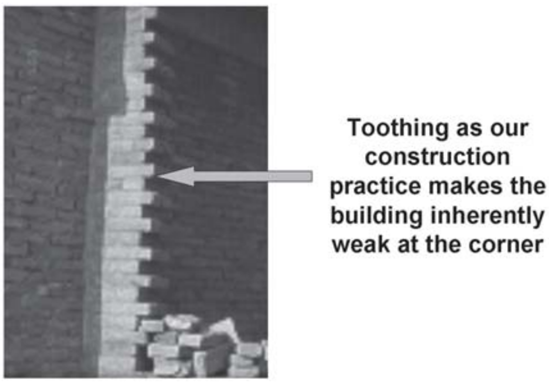


Photo: NSET, Bhairhawa, Nepal

In one hand, the junctions are inherently weak locations, on the other hand we are constructing the junction with toothing joint between the two walls as shown in the figure. Constructing all the walls of a building at once is difficult, so some walls are constructed first and remaining walls joined later. While doing this, it is of common practice to provide toothed joints. In such joints it is not possible to put the mortar everywhere in the joint; vertical and top surfaces can not be perfectly provided with mortar. Also this makes the weak vertical joints in the same location through out the wall height. Ultimately, the inherently weak locations are further weakened by the use of toothed joints.

Joints in Orthogonal Walls

Simple improvement on construction practice give most satisfactory result

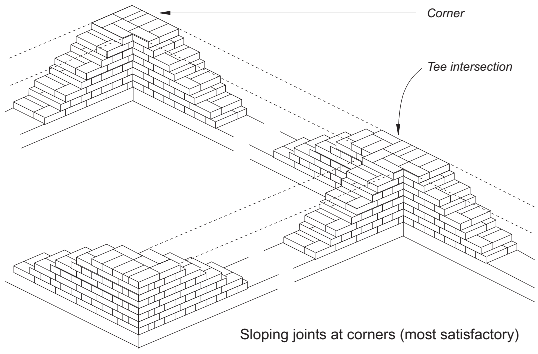


Illustration Courtesy: IAEE Monogram

For mitigating the problem of weak corners and tee junctions, first we have to change the practice of providing toothed joints and second, some extra joint strengthening measures should be provided.

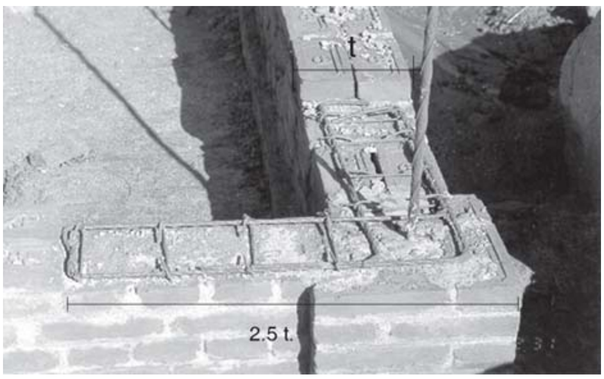
The weakness due to toothed joints can easily be removed by using stepped joints in place of toothed joints whenever necessary. Steps are easy to construct as well as when another wall is to be joined mortar can be placed at all necessary places. Also the joint will not be at the same vertical line. It is a simple method of increasing the strength with no extra cost and extra effort.

Stepping an effective solution

Photo: NSET, SESP, Shree Krishna Secondary School, Dhapakhel, Lalitpur

This photo shows the stepped joints in actual construction of a building.

Joint Strengthening by Stitch



Reinforcement detail view of RCC corner stitch

Photo: NSET, SESP, Himalaya Primary School, Thimi, Bhaktapur

The inherent weakness of wall joints can be removed by just providing stepped joints, for this extra strengthening of corners and tee junctions are necessary. Joint strengthening elements commonly called the stitches have to be provided at the junctions. The stitch is L or Tee shaped element which properly joins two orthogonal walls together. Stitches may be of RCC band, timber or bamboo depending upon the type of building and material available. RCC stitches are suitable for masonry buildings with cement mortar and timber or bamboo stitches are suitable for masonry buildings with mud mortar. However, RCC stitch can also be provided in the mud mortared buildings.

An RCC stitch is L or T shaped concrete band of usually one brick thick and reinforcing bars inside. Length of the stitch on either side is about 2.50 times the thickness of wall or it may be 1.20 to 1.50 m. The stitches should be provided at about 500-700 mm as the vertical interval. The view of reinforcements of RCC corner and tee stitches are as shown in the photos.

Joint Strengthening by Stitch

Reinforcement detail view of RCC T stitch

Photo: NSET, SESP, Nateshwori Primary School, Chhaling, Bhaktapur

The reinforcing bars required are 8 mm diameter torsteel for main bars and 4.75 mm diameter torsteel for ties or hooks (rings). The reinforcement bars are first prepared as shown in the photograph and then placed in appropriate location, tied by binding wire and covered with concrete of 1:2:4 mix.

Joint Strengthening by Stitch

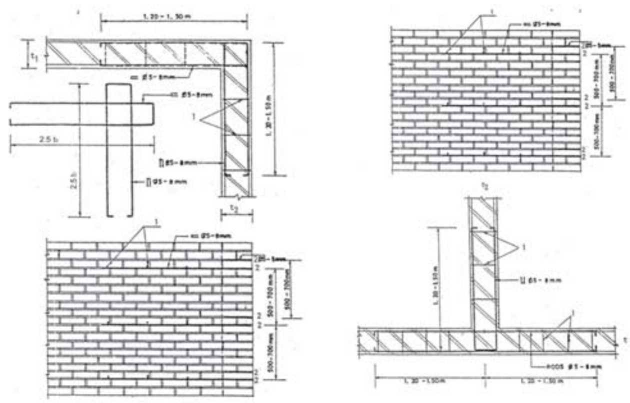
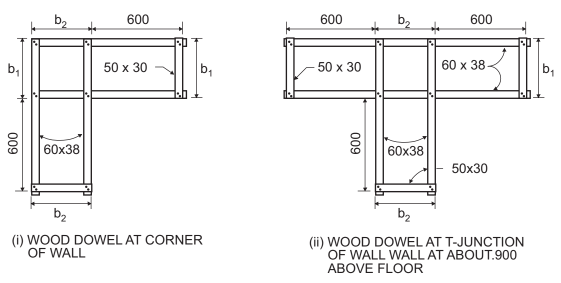


Illustration Courtesy: IAEE Monogram

Details of reinforcements for the stitches are as shown in the figures. 2 longitudinal bars of 8 mm diameter torsteel and tied with 4.75mm diameter rings at a spacing of 150mm (6") center to center.

Timber Stitch



Detail of timber stitches

Illustration Courtesy: IAEE Monogram

For a building with mud mortar, timber stitches can be used in place of RCC stitch. Details of timbers stitch should be as shown in the figure. The joints between different wooden members can be made strong by nailing or by using bamboo keys.

Stitch in Stone Walls

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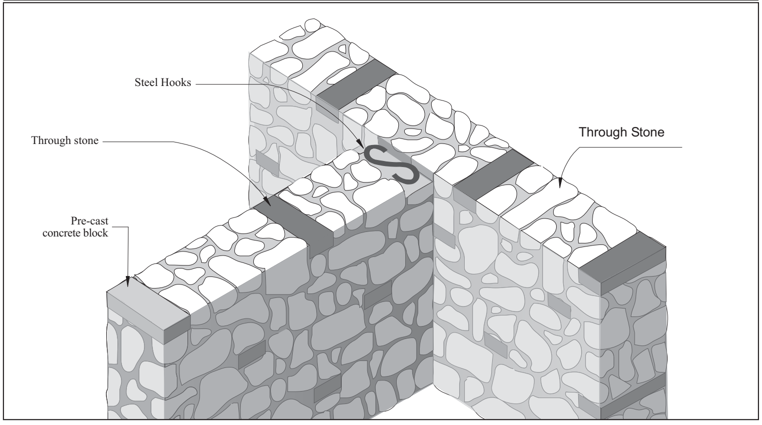

Illustration Courtesy: IAEE Monogram

In stone masonry works, stitches should be provided in combination with through stones or timber blocks or steel hooks. Through stones are provided to properly tie the two wythes of the walls as mentioned earlier.

Failure of Long Walls

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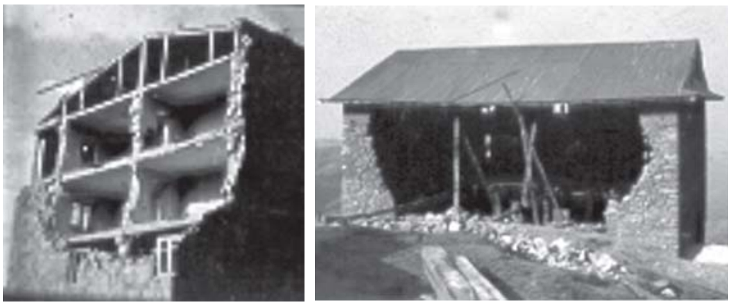

Long and high walls easily collapse during earthquakes

Photo Courtesy: Left - EERI 1988, Spitek Earthquake, Armenia & Right - TAEC 1988 Udaypur Earthquake, Nepal

Failure and falling outside of the wall is another common problem in masonry buildings. Long walls may easily fall down in an earthquake and they may fall even in normal condition if not properly constructed. In an earthquake the horizontal force due to ground shaking hits the wall horizontally throughout the wall and most at the top. This horizontal force to hit the wall is more in the long walls than in the short walls and also more in high wall than in the short walls. If any provisions are not made to resist this force the wall alone can not resist the force and fall down as shown in the photographs.

Cross Walls and Buttresses

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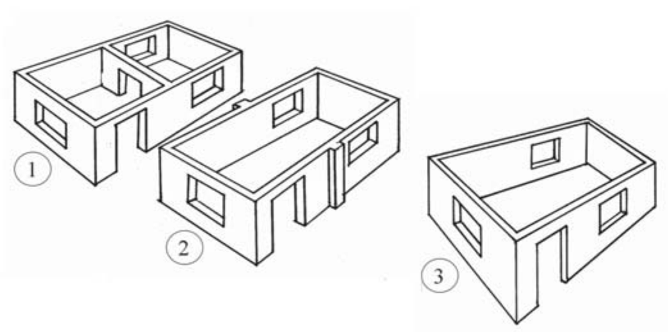


Which wall is stronger and why ?

Illustration from NSET Calendar

In the figures given, three buildings are shown; out of these three, which is stronger and why?

In building 1, the same length of longer side walls are divided into two smaller parts and extra lateral support is given by the intermediate wall. In the second one, the long walls are again divided into smaller parts and lateral support is given by the buttress walls. The lateral support provided by the small buttress walls will definitely be smaller than that provided by full length intermediate wall. The third building has two long walls not supported by any intermediate or buttress wall. Hence, out of these three buildings, building 1 must be the strongest one and building 3 the weakest one.

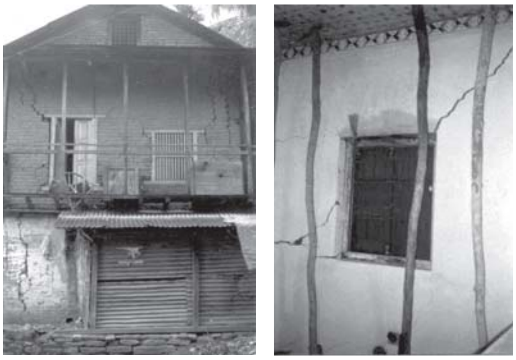
Length and Height of Walls

Photo: NSET

For a building to be strong enough, the length and height of the wall should not be unnecessarily high. The maximum length of unsupported wall shall not be more than 12 times its thickness. If it is necessary to make more than 12 times, buttress walls shall be provided to make the unsupported length less than 12 times. The height to thickness ratio of the walls should be limited to 1:12 for brick or block masonry and 1:8 for stone masonry.

A good building with appropriate length and height of walls and provision of sufficient cross or buttress wall looks like that shown in the figure.

Corners and Sides of Opening



Shear cracks at window openings

Photo Courtesy: Left - Siddhi Shrestha 1988, Udaypur Earthquake, Nepal & Right - NSET 2001, Bhuj Earthquake, India

Another common problem in masonry buildings is long and deep diagonal cracks starting around doors and window openings. Such cracks may also be in the middle of the walls. The problem can be seen not during an earthquake but also in normal times. If such cracks are seen in normal conditions, the building may be severe during earthquakes. Even in normal conditions the cracks may increase and ultimately the wall fall down.

Such cracks are basically due to inability or low capacity of walls to resist horizontal forces coming along the plane of the walls during the earthquakes. In normal times, this may be due to partial settlement of walls and/or foundation and low quality of construction.

Failure of Walls

Cracks originated from corners

Photo: NSET 2001, Bhuj Earthquake, India

In an earthquake there may not be only a single problem but there may be combination of many. Due to the combination of many serious defects, a weak building can easily collapse. If the walls are constructed properly, major problems can be reduced.

Timber Members in Traditional Buildings

Wooden bands in old-type of buildings

Photo: NSET, Basantapur, Kathmandu

If we look at our old and historical buildings, we find many good things in them.

One of such good things is the wooden bandages provided at top and bottom of windows in the shape of snakes. These are not just the architectural and ornamental things but they also have significant role in making buildings earthquake resistant. Due to this and many other measures that our forefathers used to put in the buildings, we have now plenty of traditional building even after many large earthquakes.

Wooden Bands in Traditional Buildings

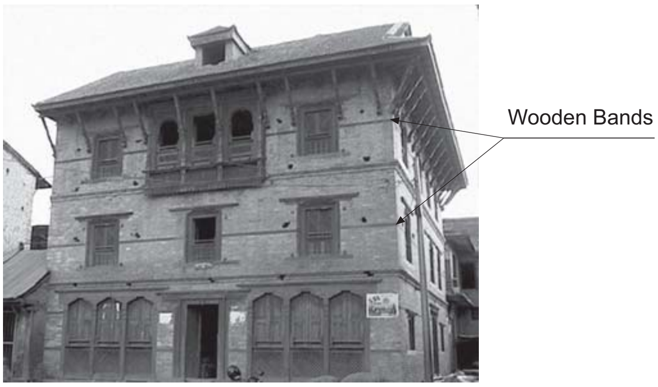
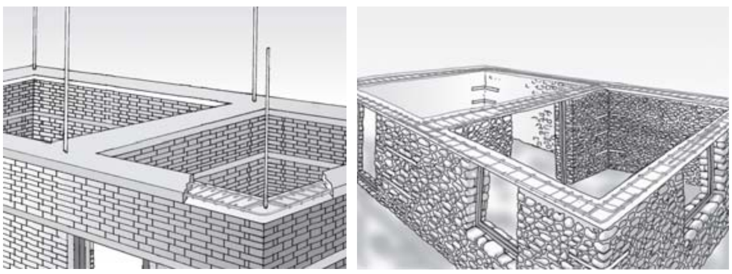


Photo: NSET - Archeological Manual, Lalitpur

This is another example building having wooden bands in the walls.

Horizontal Bandages



Horizontal band at sill, lintel and eve level should be designed for out of plane bending

Illustration: NSET Calendar

To mitigate the problem of diagonal cracks and failure of walls, providing bands below and above the window openings throughout the whole length of wall as also seen in our historical buildings will be an easy and effective solution.

The bandages in brick and stone masonry buildings are as shown in the figures. The band may be of RCC, timber, bamboo or steel strap depending upon the material available and type of the building construction. For a building with cement mortar, RCC band is preferable and for a mud mortared building timber or bamboo band is appropriate. However, RCC band can also be used in mud mortared buildings.

RCC Bands

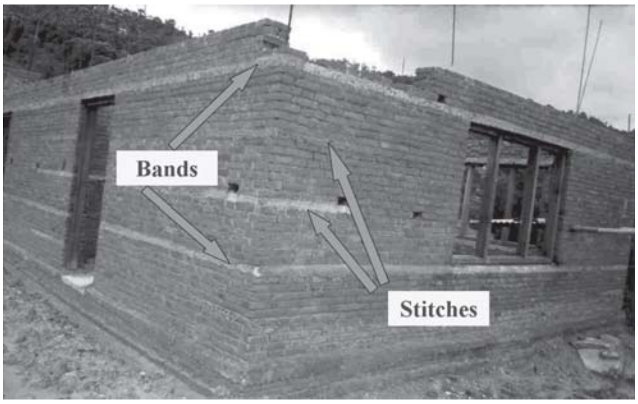


Photo: NSET - Residential Building, Chhaling, Bhaktapur

RCC band is a bandage of concrete with reinforcing bars inside provided throughout the entire length of the wall of a building. A views of RCC bands in a building is shown in the photograph. Corner and tee stitches are also seen in the picture.

RCC Bands

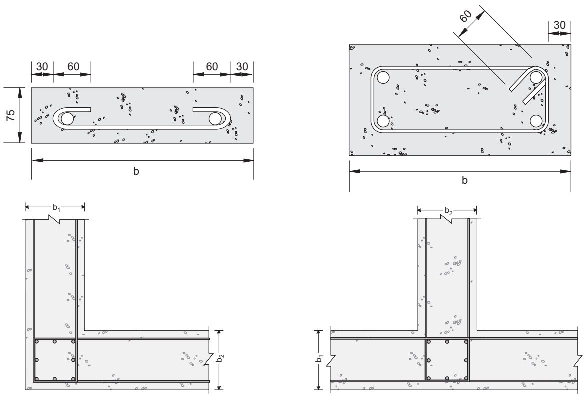


Illustration: IAEE Monogram

The width of RCC band should be same as the thickness of the wall. In other words, the band should be provided in full width of the walls. Concrete for the band should not be less than M15 i.e. the mix of 1:2:4 or richer should be used. Thickness of the band should not be less than 75mm. For a band with 2 reinforcements the thickness may be of 75mm and for a band with 4 reinforcements, the thickness should be of 150mm.

Details of reinforcements are as shown in the figure.

Reinforcements in Bands

Wall Length (m)	No. of Bars	Diameter of bars	
		T	K
5 or less	2	10	9
6	2	12	10

No. and size of reinforcements in bands depends on the length of the walls and the no. of stories in the building. If the building is more than 2 stories minimum of 4 nos. of 12mm diameter longitudinal bars with 6-8mm diameter lateral ties should be provided. The no. and size of reinforcement for different length of walls are as shown in the table.

Timber and Bamboo Bands

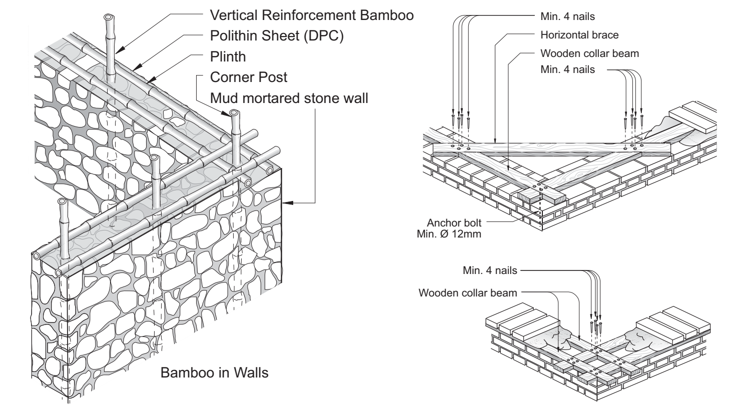


Illustration: NSET, NBC 204

As stated earlier, timber and bamboo bands can also be used in case of mud mortared buildings. The details of such bands are as shown in the figures.

Failure of Gable Walls

Failure of gable walls due to the high height and lack of support at the top

Photo: NSET, 1998 Chamauli Earthquake, India

Other problem in sloped roof buildings is failure of gable walls. Gable wall in a building is at the highest level and the displacement of wall at the top is more than that at the bottom. Usually these gable walls are untied at the top. Also the height becomes more in gable walls so this wall can fall more easily.

Failure of Gable Walls

Complete failure of gable walls

Photo: NSET, Bhuj Earthquake, India

Photograph shown here is the complete failure of gable walls in the rural buildings.

Bands in Sloped Roof

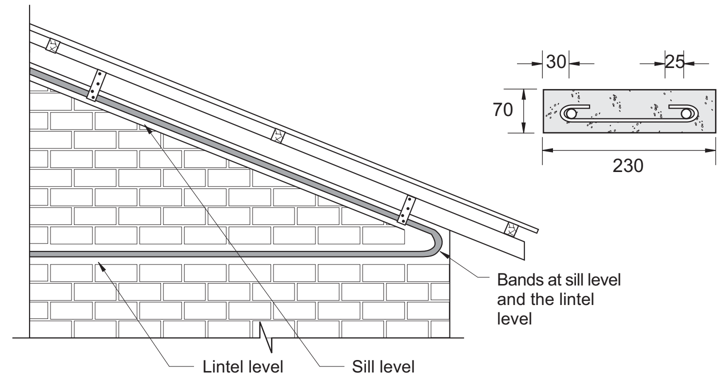


Illustration: NSET

To mitigate the problem of gable wall failure, bandages similar to other bands should be provided at bottom and the slope of the gable wall as shown in the figure. Details of the gable wall is similar to the bands at sill level and the lintel level.

Horizontal Bands

- **Plinth Band**
- **Sill Band**
- **Lintel Band**
- **Roof Band**
- **Gable Band**

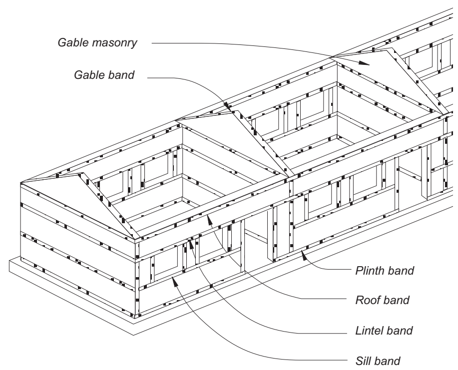


Illustration: NSET

Finally, in a building there should be plinth band at the plinth level, sill band at the sill level, lintel band at the lintel level, roof band at the roof level and gable band at the slope of the gable wall. The structure of all the bands is similar. These bands contribute to create a box effect to a masonry building and helps the building to behave as a composite single unit and hence prevents the damage and collapse.

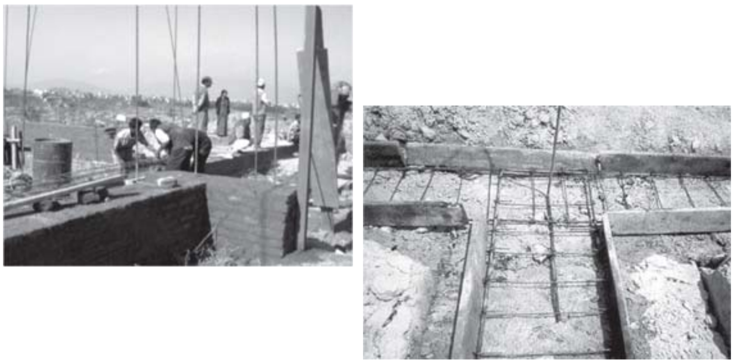
Vertical Reinforcement of Walls

Vertical bars should be inserted at L-junctions, T- junctions, and around openings

Illustration from NSET Calendar

By even providing the horizontal bandages, the problem of tensile failure can not be solved. Masonry walls have the capacity of resisting compression, but they have little or no capacity to resist tension. In earthquake, masonry units are separated at the mortar joints due to tensile failure. This problem can be solved by providing vertical reinforcements at corners, tee junctions and sides of openings. If a wall is long then providing vertical reinforcement at the middle of the wall further enhances the earthquake performance of the building. Vertical reinforcements may be of steel reinforcing bars, timber or bamboo.

Steel Bars as Vertical Reinforcement



Vertical bars should be placed at L-junctions, T-junctions, and around openings

Photo: NSET, SESP, Himalaya P. School, Bhaktapur (Left) & Tinkanya P. School, Benighat, Dhading (Right)

In case of providing steel bars as vertical reinforcement, the bars should be provided at every junctions (L and T joints) and sides of openings. These bars should start from the foundation: at foundation there should be foundation band (as mentioned in the previous session of foundation) and the vertical reinforcement bars should start from this foundation band as shown in the pictures. Such bars should also reach up to the roof level and anchored to the roofing element.

The reinforcement thus provided should be covered with a concrete core of about 2 to 3 inches in the outer periphery of the bars inside the wall. The concrete should be of 1:2:4 mix. After placing the reinforcement, the wall is constructed leaving voids of diameter about 2 to 3 inches around the bars. When the wall reaches up to a height of 300-450mm, the void is then filled with concrete. Again, another lift of the same height is constructed and then filled with concrete. In this way the wall with vertical reinforcement is constructed to the required height.

Size of Vertical Bars

No. of Story	Story	Diameter of Fe 415 bars (mm)
One		10
Two	Top	10
	Bottom	12
Three	Top	10
	Middle	12
	Bottom	12

Diameter of vertical reinforcement bars depends on the no. of stories and the span of the walls between two supports or joints. The required sizes are given in the table.

Vertical Reinforcement in Stone Walls

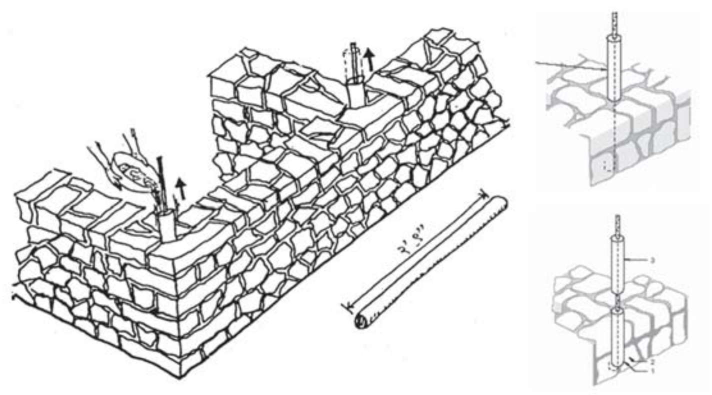


Illustration from IAEE Monogram

In stone masonry wall also, steel bars can be used as vertical reinforcement. However, in stone wall it is somehow difficult to provide void outside the reinforcement in the wall. In such case, polythene pipes of 75mm internal diameter and 300 – 450mm length can be used to make the void around the reinforcement. While constructing the wall the pipe is placed around the bar and wall is constructed up to the height of the pipe. The pipe then lifted up gradually filling the void with concrete mix. Repeating same process stone wall with steel bars as vertical reinforcement is constructed.

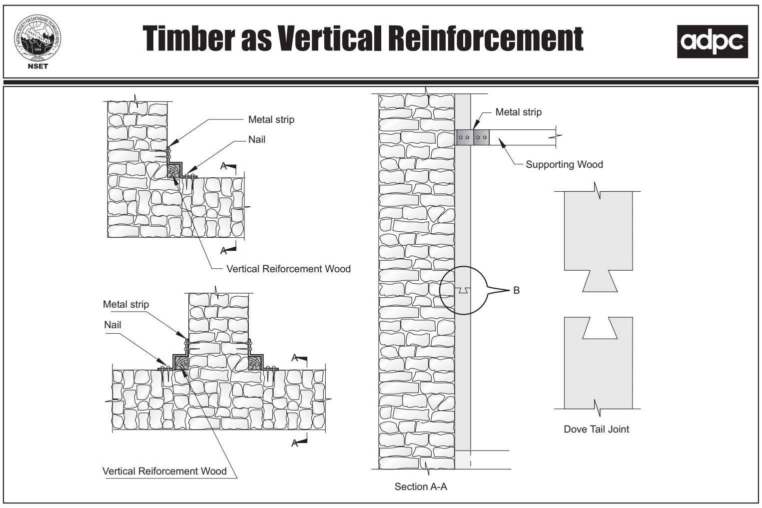


Illustration: NSET, NBC 203

In mud mortared walls normally timber or bamboo are used as vertical reinforcement. Details of timber or bamboo vertical reinforcements are as shown in the figures. In case of timber vertical reinforcement, dove-tail joint should be used to join two timber members and it should be anchored with the walls by metal straps and nails at appropriate spacing as shown.

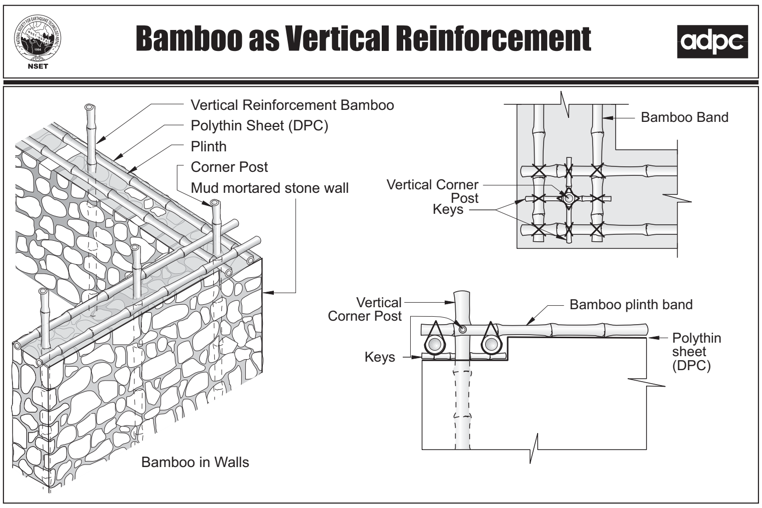


Illustration: NSET, NBC 203

In case of bamboo vertical reinforcement, the vertical bamboo members should be properly joined with horizontal bamboo members with the use of keys and lashings as shown in the figure.

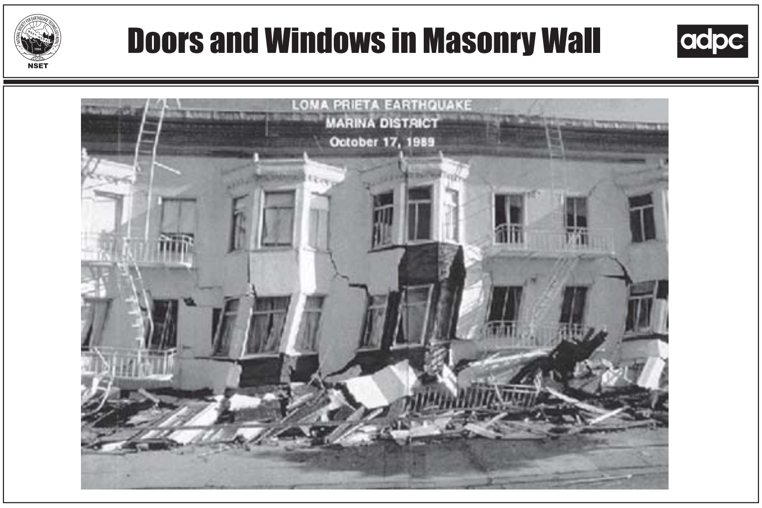


Photo Courtesy: Annotated Slide Set, EERI

Large sizes and inappropriate locations of doors and windows are another cause of severe damage of masonry buildings. Doors and windows are the voids in walls to make them weak. Therefore, their sizes and locations are carefully decided and constructed. These are some rules for size and location of doors and window openings in masonry buildings.

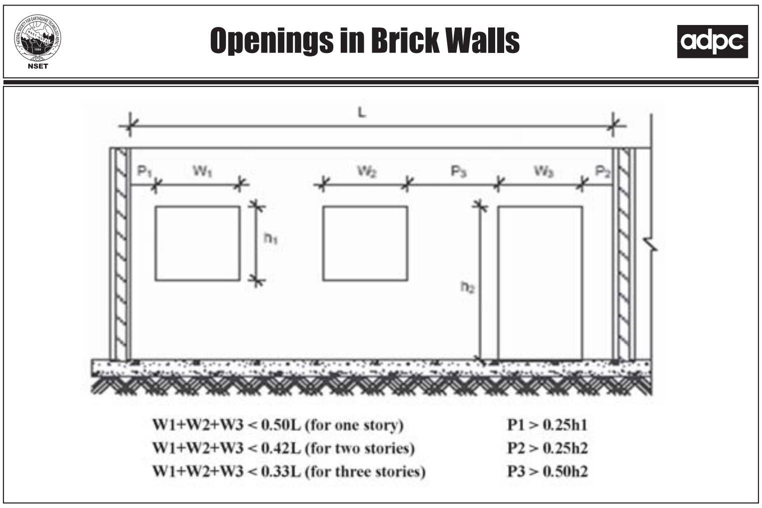


Illustration from IAEE Monogram

The total length of doors and windows in a wall should not be more than 50% of total length of the walls in case the building is of single story. But it should not be more than 42% at ground floor when the building is 2 storied and 33% when it is 3 storied.

Distance of doors and window from the end of a wall should be more than ¼ of the height of the opening.

The distance between two openings should not be less than half of the height of the larger opening.

[Give some examples with numerical values here]

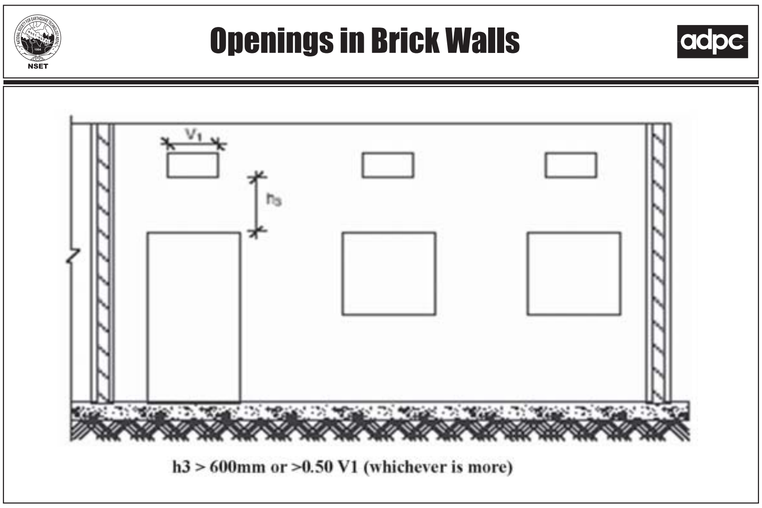


Illustration from IAEE Monogram

If there are two openings in the height of a wall, then vertical distance between the two openings should not be less than 600mm or 50% of the length of the upper opening whichever is more.

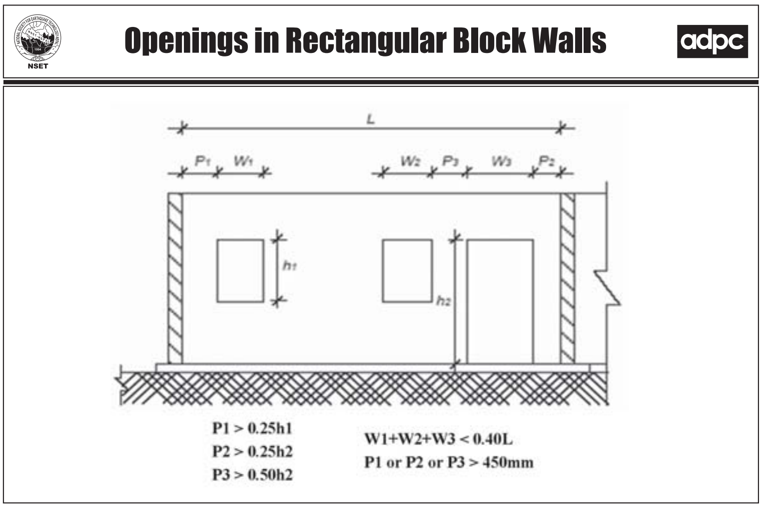
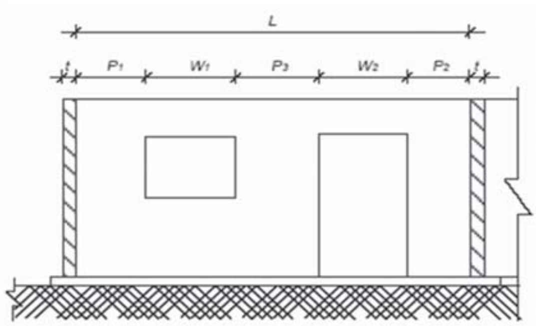


Illustration from IAEE Monogram

In case of wall with rectangular block units, the size of openings should be even less than in brick walls. Total length of openings should not be more than 40% of the total length of the wall.

The distance of an opening from the end of the wall and the distance between two openings should not be less than 450mm.

Openings in Random Rubble Walls



P1+t > 1.20m W1+W2 < L/3
P2+t > 1.20m W1 and W2 < 1.20m

Further, the size of openings are even less in random rubble masonry walls. The total length of openings should not be more than 1.20m and it should also not be more than 1/3 of the total length of wall. Their distances from the ends should also be more.

No. of Stories and Size of Walls

	Floor	Min. Wall Thickness (mm)	Max. Height (m)	Max. Short span (m)
Brick masonry in Cement mortar	Second	230	2.8	3.5
	First	230	3.0	3.5
	Ground	350	3.2	3.5
Stone Masonry in Cement mortar or Brick Masonry in mud mortar	First	230	3.0	3.2
	Ground	350	3.2	3.2

For a good masonry building, the no. of stories, height and length of walls are limited and minimum thickness are specified. The no. of stories, height and length and thickness of walls are as mentioned in the table.

For a building with brick masonry in cement mortar, the maximum no. of stories is 3 and that for stone masonry in cement mortar or brick masonry in mud mortar is 2.

An Example of Good Masonry Building

Photo: NSET, SESP - Himalaya Primary School, Thimi

This is an example of good masonry building. This building incorporates all the earthquake resistant features and follows the rules.

Here are some of the issues for discussion with the participants if they are interested and raise the questions.

Module 2 / Session 4

Construction of Masonry Buildings: Floor / Roof

NSET adpc

Floor and roof in a building are other important elements where the occupants live and which protects the overall building and its occupants from rainfall, snowfall and sunlight. Earthquake resistance as well as the functional use of a building depends also on the construction and type of its floor and roof. In this session we will discuss about the construction of floor and roof of masonry buildings.

Learning Outcomes

After completing this session the participants will be able to:

- choose appropriate type of floor or roof for particular type of building.
- use proper technique of constructing different type of floor and roof.
- use proper technique of connecting floor and roof with supporting walls.
- incorporate earthquake resistant features into flexible roof.

Different Types of Floor and Roof

- Floor
  - Flexible – mud, tile flooring with timber or bamboo as supporting members
  - Rigid – RCC Slab
- Roof
  - Flexible – Tile, jhingati, CGI and thatch roof covering with timber, bamboo or steel as supporting elements
  - Rigid – RCC Slab

Floors and roofs can be broadly categorized as flexible and rigid. Flexible floors or roofs are those in which the deformation in their own plane can take place or we can say they can be twisted. Mud or tile flooring over timber or bamboo supporting elements are the common types of flexible floors and tile, jhingati, CGI sheet or thatch covering over timber, bamboo or steel elements are common flexible roofs.

Rigid floors and roofs are those in which the deformation in their own plane can not take place and they can not be twisted. RCC slabs are most commonly used rigid floor and roof.

Failure of Flexible Roofs and Floors and Their Protective Measures

Out of the two types of floors and roofs, in this session we will discuss about flexible type. Rigid type of floors and roofs will be discussed in RCC construction in later sessions.

Failure of Flexible Roof

Photo: NSET 1998 Chamoli Earthquake, India

Force due to earthquakes in a building is assumed to be applied at floors or roofs. As stated earlier, the load due to earthquake shaking is proportional to the weight of the building. Hence, if the load at the floors/roofs and the load of the walls/columns is more, earthquake load coming at the floor and roof levels is also more and if it is less the force is also less. Therefore, weight of a building should not be made unnecessarily high, they should be as light as possible to make them more earthquake resistant.

If the beams, joists, rafters, purlins and other floor / roof elements are not properly tied with walls or columns and are not made rigid, they may slide from their original position and floor and roof may collapse.

Few examples of roof collapse during past earthquakes are shown in the photographs. In these pictures, the roof has collapsed due to the sliding and failure of supporting elements like rafters, purlins and ridge poles. The rafters and purlins shift from their position mainly due to no or low bearing length into the walls or wall plates and no proper connections at the joints.

Failure of Flexible Roof

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Photo: NSET 1998 Chamoli Earthquake, India

This is another example of failure of flexible roof during earthquake.

Failure of Flexible Roof

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Collapse fo roof due to sliding of rafter

Photo: NSET 1998 Chamoli Earthquake, India

Roofs and floors collapse also due to the lack of structural integrity between different floor / roof elements. Different elements are normally just placed one over another without any anchorage in their joints.

No Connection of Floor Elements

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No connection between floor elements and walls

Photo: NSET Nangkhel, Bhaktapur

No proper connection of different flooring elements like beams, joists to the walls makes the floor flexible and can easily collapse due to sliding and falling of the members.

From all of the above examples it is clear that there are some important factors that help to make a building earthquake resistant. Now we will discuss the main factors in detail.

Light Weight Floors and Roofs

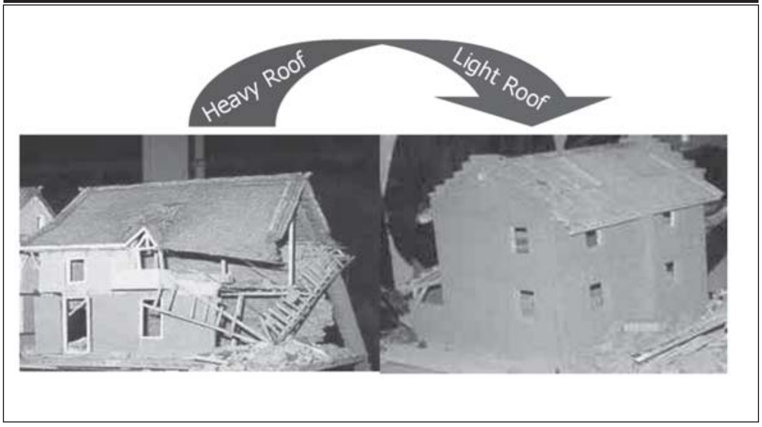

Photo: NSET Shake Table Demonstration

As already mentioned buildings should be as light as possible in order to be more seismic-resistant. The practice of laying thick layers of mud to achieve a firm floor/flat roof is common. This increases the overall building weight and it will be subjected to high seismic force. Therefore, thickness of the mud layer used for flooring/roofing should be kept as small as possible. Reducing the thickness of mud layer can reduce the overall weight of a building significantly. Using light flooring and roofing materials in place of heavy materials can also reduce the weight. For example using CGI sheet roof instead of using tile or *jhingati* roof will significantly decrease the weight of the roof.

Light Floors and Roofs

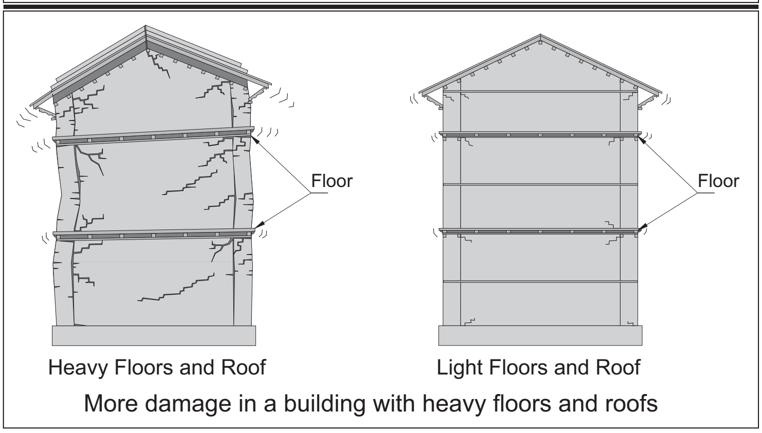

Illustration: NSET Archeological Guidelines

Building with heavy floors/roofs is subjected to higher seismic force as compared to that in a building with light floor/roofs. This higher seismic force causes more damage in the building. Figures show more cracks and damage due to heavy floors and roof than in light ones.

Wooden Beams

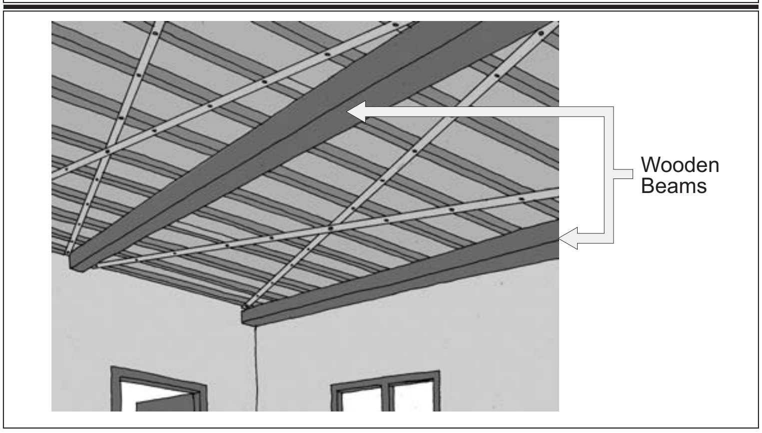

Illustration: NSET

Beams are main structural elements in a flexible floor and wooden beams are most commonly used. Beams take the loads from floors and transfer it to the walls or columns. If these beams are not properly connected with floor joists and the supporting walls it can not properly transmit the loads. Therefore while constructing beams following important points should be considered.

Size of Wooden Beams

- The beams shall be rectangular in section and shall never be laid wider surface horizontal. The minimum dimensions of the beams for different spans shall be as tabulated in Table

Species	Minimum depth of beam according to Span of beam				
	Span = 2m	2-2.5m	2.5-3m	3-3.5m	3.5-4m
Hardwood	190	220	240	270	300
Softwood	230	270	310	340	370

+ The minimum width of beam = greatest of 50mm or 1/50 of span or 1/3 of depth

First of all, beam should be of sufficient size to withstand all forces coming from the floors. Size of a beam depends upon the span of the floor or the span of the beam. The longer the span larger the size of the beam and the shorter the span the smaller. Out of the two dimensions of a beam i.e. depth and width, the depth plays important role to withstand the loads. Therefore, the larger dimension should be placed as depth, it should not be placed/laid wider surface horizontal.

The table gives the minimum required depth of beams for different spans of the floors and for different species of woods. Similarly, the minimum width of beam should be at least 50mm or 1/50 of the span or 1/3 of the depth whichever is more.

Wooden Beams

- The wooden beams should never rest directly over the masonry walls
- A base pad for the beam shall be provided
- This pad should be either of timber or a large flat stone or concrete band covering the whole width of the wall.
- The minimum thickness of such a pad shall be 75 mm.
- The beam shall be long enough to extend beyond both the supporting walls. Timber keys shall be provided on both the external and internal walls

Next important thing to be done while constructing wooden beams is that the beam should not rest directly over the masonry wall. Laying directly over to the masonry wall makes difficult to tie the beams with the walls and it can easily slide or fall down during earthquake. Wooden beams should rest over a base pad which can either be of timber or a large flat stone or a concrete band covering the whole width of the wall. Thickness of such pad should be at least 75mm. The beam should be long enough so that it can extend beyond the walls and can be fixed by providing shear keys or it can be anchored with the base pad.

Wall Plates

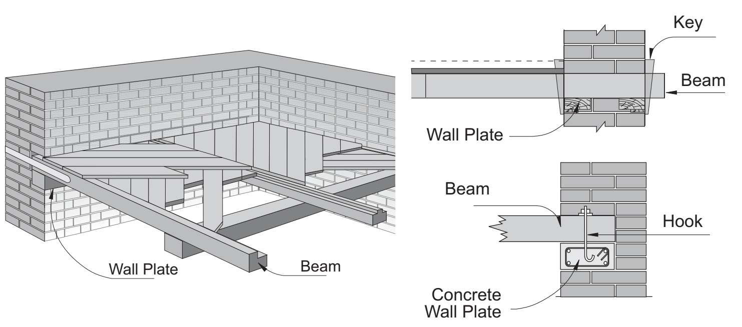

Photo: NSET Archological Guidelines

The base pad provided below the wooden beam is called the wall plate. Wall plates are provided in the walls so that wooden beams can rest over it and the floors can be made more rigid by providing shear keys or anchors. In case of timber wall plates, shear keys as shown in the figure are provided at both inside and outside of the walls and in case of concrete pad, hooks or anchors are provided.

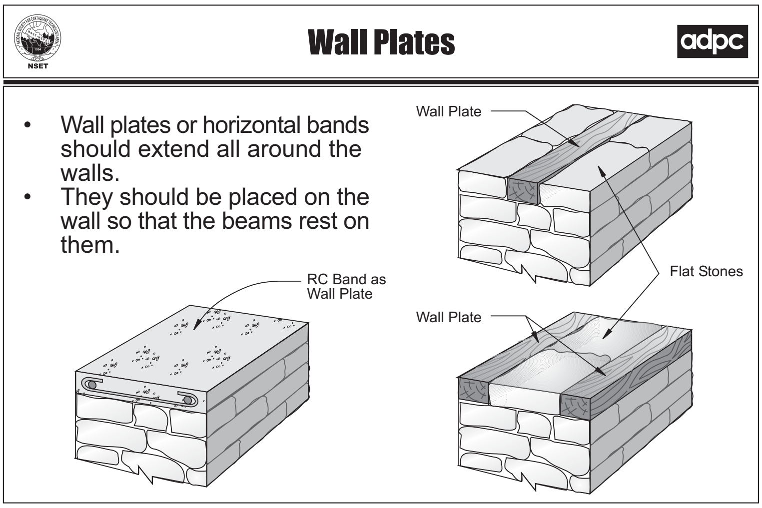

Illustration: NSET NBC 203, 1994

Wall plates should be provided all around the walls to cover the whole walls of the building. Wall plates provided throughout the walls should be at the same level so that beams can easily rest over them. They can be provided as shown in the figure. In case of timber wall plate, it can be provided in full width of the wall or it can be provided at the center and flat stones at two sides or timber wall plate at two sides and flat stone in the middle part of the wall. In case of concrete wall plate (or band), it should cover the whole width of the wall.

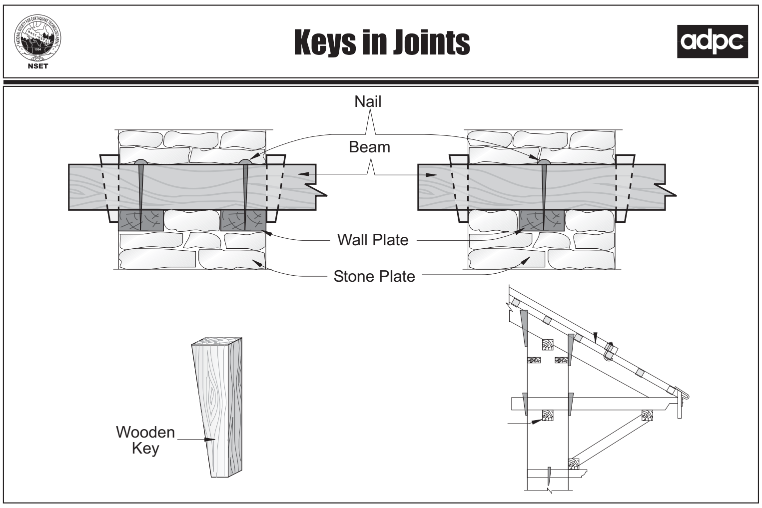

Illustration: NSET NBC 203, 1994

To make the floors or roofs more rigid, the beams should extend beyond the walls and they are tied with the walls by shear keys from both sides of the walls. Additionally, the beams can also be anchored with wall plates by nails. These keys or nails tie the beams with walls or wall plates and do not allow the beams/floors to move. This increases the rigidity of the floors or roofs, Details of the shear key is as shown in the figure.

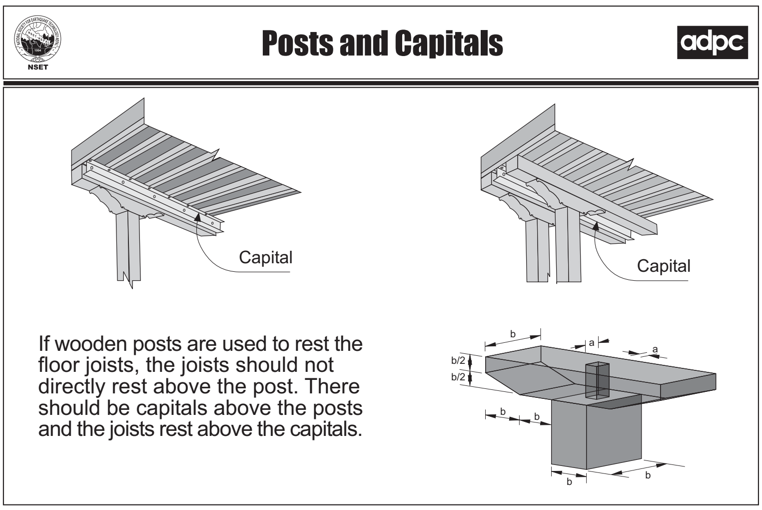

Illustration (top): NSET Archological Guidelines & (bottom) NBC 203, 1994

In traditional buildings we can see the timber posts as vertical as well as lateral load resisting elements besides the load bearing masonry walls. If timber posts are used as main load resisting elements, floor beams or joists should not directly rest over the timber posts. At the top of the posts wooden capital should be provided as shown in the figure and beams or joists rest above the capitals. The minimum required connection detailing of such capitals is as mentioned in the figure. In a building, there may be single post system or double post system, accordingly there may be single capital or double capitals as shown.

Struts

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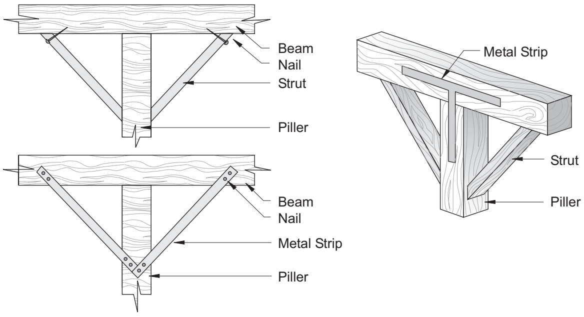
In place of capitals there may be struts



The capitals or struts should be well connected with the posts and the joists with keys, nails or metal strips

Illustration: NSET

In place of capitals, inclined timber struts can also be provided as shown in the figure. Joints between posts, beams and struts should be made strong by using metal straps, nails or keys and they should be well connected to each other. In some cases, metal strut can also be used in place of timber struts.

Rafters

adpc

- Rafters should also be long enough to extend beyond supporting members such as walls and/or beams.
- The extended rafters should have timber keys on both external and internal sides of the supporting elements.

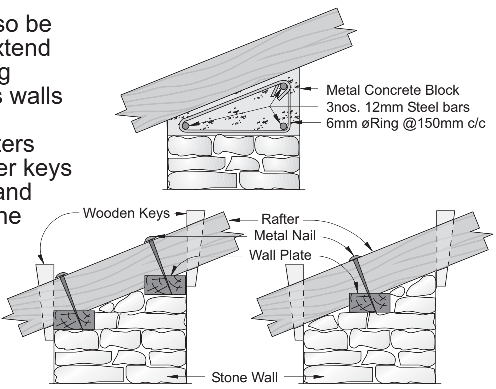


Illustration: IAEE monogram

Similar to beams, rafters should also rest on wall plates or bands. They should also be long enough to extend beyond the supporting walls so that they can also be tied with the wall plates by using shear keys on either sides of the walls or nails or anchors.

Diagonal Bracing of Floors / Roofs

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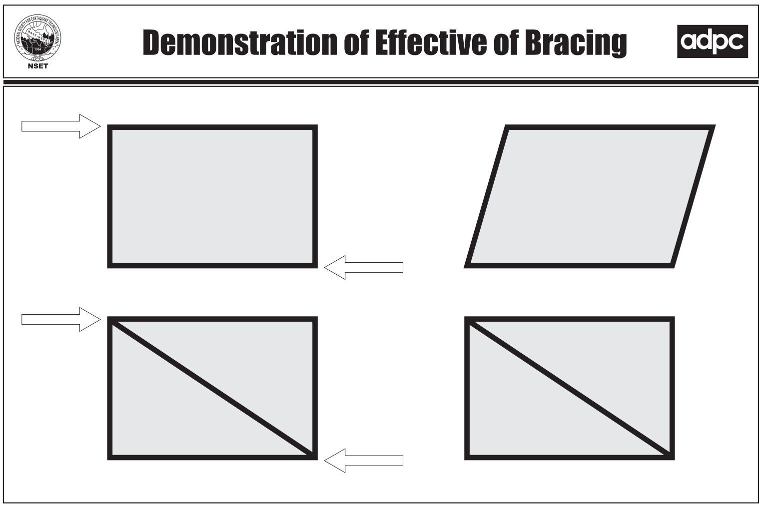
- All flexible structural elements such as beams, joists and rafters should be diagonally braced.
- Each crossing of a joist and a brace should be properly fixed.
- The bracing material could be timber strips, whole bamboo, bamboo strips or metal straps.

Photo: NSET, Kathmandu

The floors or roofs can easily transfer the horizontal load due to earthquake vibration to the supporting walls if they are sufficiently rigid. But in case of timber or bamboo floors/roofs they may not be enough rigid to transfer the load and can easily deflect in their own plane without transferring the load to the supporting walls. Connections of beams, joists and rafters with walls or wall plates by use of keys, anchors or nails helps to provide rigidity to the flexible floors and roofs. For making floors and roofs more rigid, diagonal bracing of the flooring and roofing elements is the most effective solution. Diagonal bracing of beams, joists and rafters gives more rigidity to the flexible roofs and floors. Each joints of bracing with beams, joists and rafters should be properly fixed for better rigidity. Bracing can be done either by timber strips, bamboo or bamboo strips or by metal straps.



To understand the effectiveness of diagonal bracing, here is one simple demonstration. Take a rectangular or square object made of four timber sticks as shown in the figure. Now try to push it at two opposite corners. The object will easily deflect as shown.

Again, take another similar rectangular or square object but with a diagonal member at the middle as shown in the second figure. In this object also try to push at two opposite corners. This time the object will not deflect as was previously.

This shows the effectiveness of diagonal bracing to make a diaphragm rigid and strong.

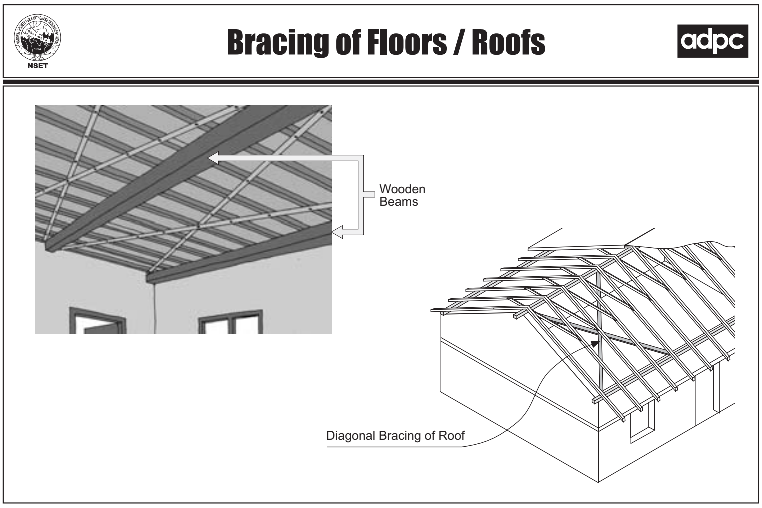


Illustration: IAEE Monogram

Bracings are normally provided at the lower part of floors and roofs as shown in the figures.

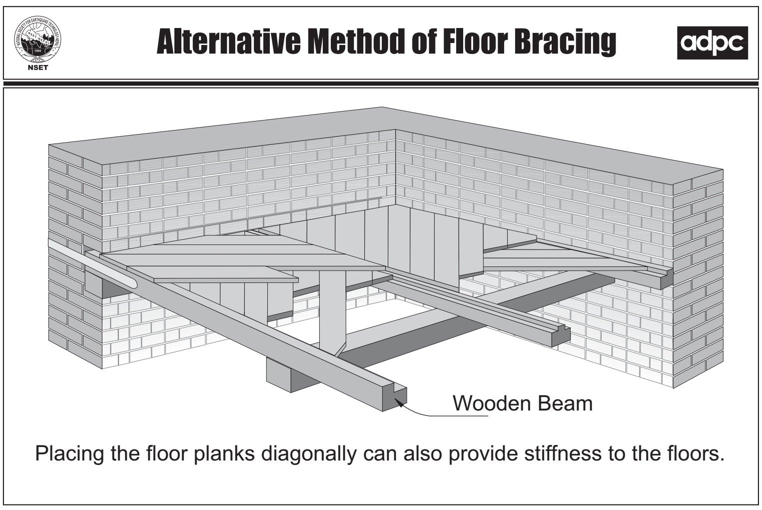
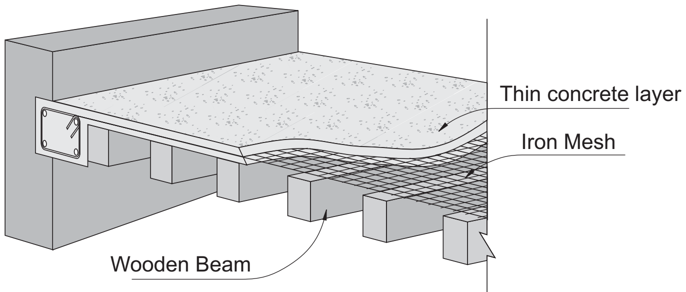


Illustration: NSET Archeological Guidelines

In case of flooring by the use of wooden planks, bracing and hence rigidity can also be provided to the floors without using any separate bracing members. The planks that are generally placed at normal or parallel to the walls or beams/joists, if we place them at some inclination with the floor joists, they can easily behave as bracing element and hence provides stiffness to the floors. but this needs little bit more effort and care while constructing the floors.

Alternative Method of Floor Bracing



Thin layer of concrete over iron mesh can also be an alternative solution to make the floors stiffer.

Illustration: NSET Archeological Guidelines

Another alternative method of floor bracing and providing rigidity to the flexible floors is construction of thin concrete layer with iron mesh inside.

In this method, iron mesh is laid over the wooden planks, bamboo strips or wooden chirpats covering the whole area of the floor and then a thin layer of cement concrete is casted to make a thin rigid concrete slab, this thin concrete slab provides sufficient rigidity to the floors. The iron mesh may be galvanized iron (G.I.) wire mesh, chicken wire mesh or welded wire fabric or mesh of smaller diameter reinforcing bars. For making concrete, smaller sized aggregates i.e. 12mm or down are used since the thickness of the concrete layer has to be as small as possible.

Around the floor, the concrete layer should be connected with the concrete wall plates or concrete beams provided at the walls.

Proper Connection at Joints

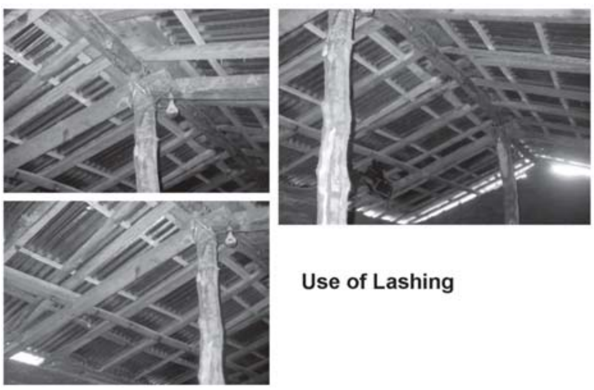
Each joint between two structural elements should be properly joined together by metal strips, nails or lashings

Use of metal strips and nails

Photo: NSET, SESP- Bhuwaneswori L.S. School, Nangkhel, Bhaktapur

There are many joints between different structural elements in flexible floors and roofs. If the joints between these elements are not properly connected, they can easily move from their position, fall down and hence the whole floor or roof fails. Providing bracings, wall plates etc. only can not make a floor rigid if the connections at the joints are not proper and strong. The joints can be made strong by use of shear keys, nails and anchors. Providing metal straps, nailing and lashings are also some ways of making the joints strong. Above picture shows the joint connection of floors joists by use of metal straps and nailing.

Proper Connection at joints



Use of Lashing

Photo: NSET Sindhupalchok

These pictures show the use of rope lashings at the joints between rafters, posts and the ridge beams. These lashings also help to make the floor or roof strong and rigid.

Additional Strengthening

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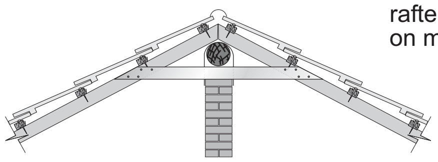
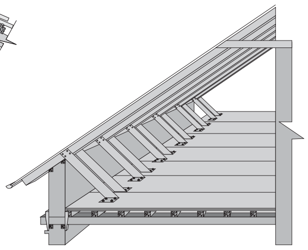
Metal strap connecting two rafters to minimize the impact on middle wall.





Bracing provided at the end of rafter to reduce the force on supporting walls

Photo: NSET Archeological Guidelines

In case of flexible roofs, some additional elements can be provided for increasing the strength. One such element is horizontal metal strap connecting two rafters together as shown in the figure. The strap helps to increase the rigidity of the roof and reduce the impact on the middle wall.

Another extra strengthening element is bracing or strut provided at the end of the rafters. This additional bracing also contributes to make the roof more rigid and helps to reduce the force on the supporting walls.

Flooring and Roofing

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Floor Bridging materials

- Appropriate bridging material
  - allows joists to be spaced wider apart
  - reduce the construction cost
  - make the building lighter
  - helps to achieve stiffer flooring.
- Timber planks and half-cut bamboo are examples of these.
- If chopped (split) wood or planks are used as bridging materials, they shall be nailed to each joist supporting them.
- If bamboo, reed, or any other material is used, it also shall be tied to the joists.

Finally, flooring and roof covering also play important role in the performance of the floors and roofs.

Appropriate bridging material should be selected for applying in the floors. Bridging materials should be such that it allows the joists to be spaced wider apart. This helps to make the building lighter and reduce the construction cost. It should also help to achieve stiffer floors. some commonly used flooring materials are timber planks, half-cut bamboo, chopped (split) wood (chirpat), reed etc. If wooden planks or chopped woods are used, they should be nailed to the floor joists supporting them and if bamboo or reed are used, they should be tied with joists by using nails or lashing. These connections of flooring materials with the joists makes the floor strong and stiff.

Flooring and Roofing

adpc

Roofing

- Stone slabs, slates and mud roofing make a building heavy. These elements should be avoided as far as practicable.
- Tiles or *jhingati* laid over a mud layer are another load-increasing factor and should be avoided. However, it may not be possible to avoid completely these elements owing to various constraints.
- Lighter options such as thin stone slabs, thinner layer of mud and CGI sheet roofing are preferable

Photo: NSET, Kathmandu

Similarly, while selecting roofing material care should be taken to select lighter material so that the roof will become as light as possible. As discussed earlier, heavy roofs are subjected to higher seismic force and suffer more damage. Therefore, stone slabs, slates and mud roofing should be avoided. Tile and *jhingati* laid over a thick mud layer are other roofing types which give heavy load to the roof. Avoiding these tiles or *jhingati* may not be always possible, in such case special attention should be given to make the mud layer thin. In place of heavy roofing materials lighter options like thin stone slabs, thin layer of mud or CGI sheet roofing are preferable.

Additionally, roof should be capable to protect the building from rainfall, snowfall and other adverse environmental effects. Therefore, roofing should be made watertight by providing appropriate joints and connections between different roofing units and also with purlins, battens or rafters.

Wood for Timber Member

- Locally available hardwood species should be preferred to softwood species for the structural elements of flooring
- Using a whole tree trunk as a structural element not only increases the weight, but also makes the wood more susceptible to termite attack. This results in a shorter life for such elements. Hence, only sawn timbers should be used
- Seasoned and treated timber or bamboo are preferred than the untreated ones. Treatment should be carried out prior to the placement of these structural elements

Wood or timber is most widely used material to make flexible floors and roofs. Quality of the timber plays vital role in the strength and durability of roofs and floors. good quality timber gives sufficient strength as well as it can also last for a longer period.

Locally available hardwood species should be preferred than the softwood for making structural elements of roofs and floors. Softwood species have lower strength and can be easily attacked by termites. Instead of using whole tree trunk for structural elements, it is better to use sawn timbers. Using whole tree trunk makes a building heavy and also they are susceptible to termite attack. Unnecessary and weak parts of the tree trunk like the bark, sapwood should be removed and only the sawn hard section should be used. Similarly, unseasoned and untreated timber are more likely to be attacked by termites. So seasoned and treated timber or bamboo should be used. Seasoning and treatment should be done prior to using as structural elements.

Rigid Floors and Roofs of RCC Slab

- Reinforced Concrete Slab (RC Slab) is the most commonly used rigid floor/roof.
- However, till few years back there was a normal practice of constructing Reinforced Brick Slab (RB Slab).

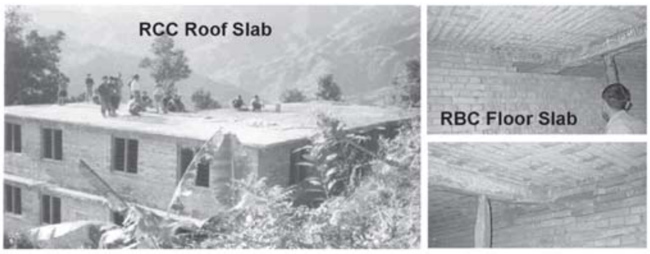

Photo: NSET, School Earthquake Safety Program

RCC slabs as floors and roofs are superior than the flexible ones of timber or bamboo since it gives higher rigidity and helps to improve the integrity of the building. However, defective construction of RCC floor and roof slabs can not contribute to overall strength of the building. We can find many defects in the RCC slab construction. These will be discussed in detail in later session in the RCC construction.

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Module 2 / Session 5

Construction of RC Framed Buildings: Foundation

NSET adpc

Learning Outcomes:

Upon completion of this session, participants will be able to:

- Define relationship between soil type, building type in terms of use, number of stories and grid span with respect to determining the size of foundation.
- Distinguish between different types of foundations.
- Incorporate earthquake resistant features in isolated and combined footing foundation
- Use bars of optimum size and proper placement of reinforcement in foundation
- Use appropriate size of aggregate and mix ratio for the foundation.

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Type of Foundation

- Improvement of site condition is generally expensive therefore, appropriate type of foundation has to be chosen for a particular site and building type.
- There are various types of foundations used in RCC framed building.
- Foundation type depends on size and weight of the building and the sub soil category.
- Some commonly used foundation type for RCC buildings are:
  - Isolated Footing (Pad Foundation)
  - Combined Footing
  - Mat Foundation
  - Pile Foundation

There are various types of foundations used for RCC framed buildings. Foundation for a particular building depends on the size and weight of the building as well as the type of foundation sub-soil. Commonly used foundation types for RCC framed buildings are:

- Isolated Footing (Pad Foundation)
- Combined Footing
- Mat Foundation
- Pile Foundation

Generally, site condition and sub-soil category play vital role while deciding foundation type and its size. We can change the foundation type by improving the site condition if it is very much weak. However, site improvement is generally very much expensive and therefore, it is better to go for a superior foundation type rather than going for improvement of site. Also, partly site improvement and partly using superior foundation type may be optimized solution. In some cases site improvement may be must and which can not be avoided. Hence foundation should be selected carefully to match with site condition and the building type.

In the following slides we will go briefly through all the foundation types.

Pad Foundation

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- Each column of building ends at an isolated pad of reinforced concrete which is called pad footing.
- The pads balance the loads due to gravitational forces and the induced forces due to earthquake shaking.
- This type of footing is appropriate for firm soil condition and smaller buildings with low weight.
- However, most commonly used foundation type in Nepal in all soil conditions.

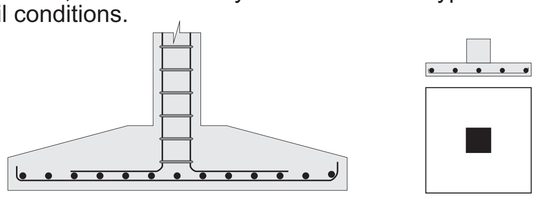

Illustration: NSET

Pad foundation is the most commonly used and most economical foundation type in Nepal. This type of foundation is appropriate for firm soil condition and smaller buildings with low height. However, this is used for smaller and most of the residential buildings in all soil conditions without in-depth consideration of sub-soil category.

In this type of foundation, each column of the building ends at an isolated pad of reinforced concrete which is called the pad or isolated footing. The pads balance all loads due to gravitational forces as well as the forces due to earthquake vibration.

Combined Footing

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- More than one columns end at a combined reinforced concrete pad or footing.
- It is commonly used when the columns are close to each other.
- For medium soil condition and low to medium-rise building this type of foundation is economical solution.
- When isolated footing becomes eccentric due to property line or any other reason, this type of foundation is effective one to minimize the effect of eccentricity.
- Combined footing with grade beam is another solution when the eccentricity and loads from the building is more.
- Combined footing with grade beam is better than the combined footings only, hence it can be used in weaker soils also.

When more than one columns end at a combined reinforced concrete pad, the footing is called combined footing. This type of footing is used when two columns are close to each other or when the pads become eccentric due to property line or any other reason. Combined footings minimize the effect of eccentricity in isolated footings. Combined footings are better than isolated footings and can be used in medium soil conditions. This footings can be effectively used in low to medium rise buildings. Combined footings increase the capacity of foundation and help to reduce the eccentricity in isolated footings.

The isolated footings when provided with grade beams, they become further better type of foundation. This is yet effective to take more eccentricity and more building weight. This type of foundation can be used in medium to weak soils also.

Figures in the following slide give the views of the combined footings.

Combined Footing

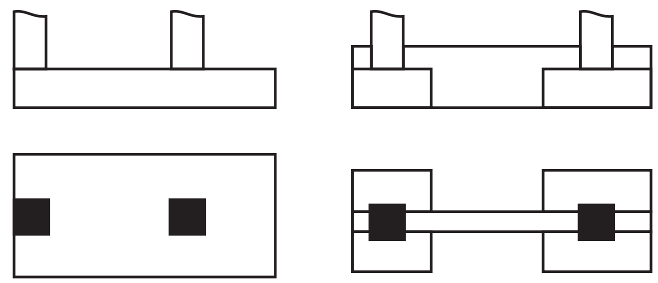

Illustration: NSET

Pad foundation is the most commonly used and most economical foundation type in Nepal. This type of foundation is appropriate for firm soil condition and smaller buildings with low height. However, this is used for smaller and most of the residential buildings in all soil conditions without in-depth consideration of sub-soil category.

In this type of foundation, each column of the building ends at an isolated pad of reinforced concrete which is called the pad or isolated footing. The pads balance all loads due to gravitational forces as well as the forces due to earthquake vibration.

Mat Foundation (Raft)

- All the columns rest on a mat of reinforced concrete slab, also known as raft.
- It is suitable for poor soil conditions.
- This type of foundation is effective to minimize the effects of both unequal settlement of foundation and the earthquake forces.
- It is normally expensive and used when there is basement floor in the building

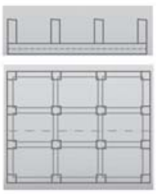

Photo & Illustration: NSET

Mat foundation is another important and a strong type of foundation in which all the columns of a building rest on a common mat floor of reinforced concrete slab. This type of foundation is also known as raft foundation. In poor soil conditions also this type of foundation is suitable since it is capable to minimize the effects of unequal foundation settlement and the effects due to earthquake forces. Foundation slab and beams of required size and reinforcement are constructed covering mostly the whole plinth area of the building for making a raft slab. Therefore, it is costlier than other two previous types of foundations. This type of foundation is suitable and effective when there is basement floor in the building.

Pile Foundation

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- Whole building and the footings rest on numbers of long legs (piles) inserted deep into the foundation sub soil.
- It is suitable for even more poor soils and where the firm soil strata is at higher depth.
- It is also appropriate for liquefiable soils.
- This type of foundation can be used in all kinds of heavy structures like high-rise buildings, bridges etc.
- It is highly expensive therefore, commonly used only in the heavy and important structures.

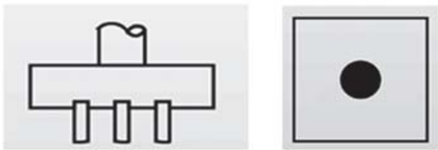

Illustration: NSET

Another further more strong type of foundation is pile foundation. In this type of foundation whole building and the footings rest on numbers of long legs, called piles, inserted deep into the foundation sub-soil. Pile foundation is taken as the strongest type of foundation and suitable for almost all type of structures and heavy buildings. This can be used in all types of soils and specially preferable when the foundation sub-soil is very weak, firm strata is at a higher depth or the soil is liquefiable one. The long legs or piles used in pile foundation may be of different materials such as timber pile, steel piles or concrete piles depending upon the type of structure, type of soil and its condition and availability of the construction material. Pile foundation is extremely expensive and superior type of foundation, therefore it is not commonly used and also not necessary for normal low to medium rise residential buildings. It is generally used in very heavy and important structures like bridge, dam, tall buildings etc.

Appropriate Foundation

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- Although there exists many advanced and strong foundation types, isolated footing (pad foundation) is the most commonly used in normal residential buildings of Nepal.
- However, isolated footing only is not sufficient in weak soils and for settlement and earthquake consideration.
- Therefore, pad foundation with grade beams (connecting all the pads together) is the best option from economical as well as seismic and settlement point of view.
- Combined footing or combined footing with grade beam is equally effective foundation type.

We saw, there are many types of foundations suitable for different soil conditions: weak to firms soils, and for different height and weight of RCC buildings. However, isolated footing or the pad foundation is the most commonly used foundation type in all categories of residential buildings in Nepal. The practice of constructing isolated footings for all types of buildings without any consideration of soil condition and building type is prevailing throughout the country since it is the most economical in cost. Pad foundation may be sufficient for low rise buildings in firm soils but it is definitely insufficient for medium to high rise buildings in medium to weak soils. It is inappropriate both from settlement and seismic consideration. Therefore, there should be some optimum solution so that the foundation is effective from both settlement and seismic consideration as well as it is yet economical. Isolated pad footings with grade beams or foundation beams connecting all the pads together is such type of solution which possesses both economy and sufficient capacity for normal loading condition as well as in earthquake shaking. Another equally or more effective solution is ‘combined footing’ or ‘combined footing with grade beam’.

Isolated Footing with Foundation Beam

- Foundation pads have to be connected by grade beams at the foundation level or just above the foundation pads
- The beam ties the building at the foundation level and helps to maintain integrity of the building during earthquake shaking.
- This also helps in preventing cracks and damage due to unequal settlement of foundation.

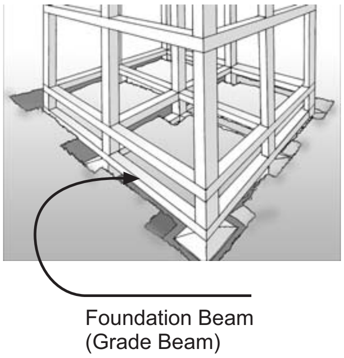

Illustration: NSET Calendar

Internal view of the isolated pad foundation with grade beams is as shown in the figure.

In this type of foundation, the foundation pads have to be connected by grade beams at the foundation level or just above the foundation pads. Size of such grade beams and size/no. of reinforcements in these beams should be similar to that of plinth beams in normal residential building whereas these should be determined after thorough analysis and design for other than normal residential buildings.

The grade or foundation beams tie the building at the foundation level and helps to maintain integrity of the building during earthquake shaking. This also helps in preventing cracks and damage due to unequal settlement of foundation.

Isolated Footing with Foundation Beam

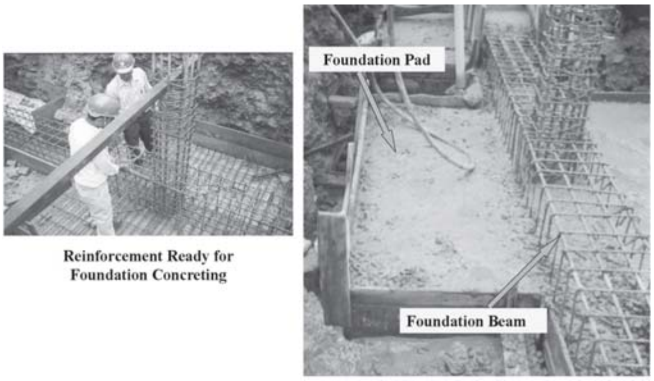

Photo: NSET SESP - Vidyodaya Primary School, Jhochhen, Kathmandu

The view of a typical foundation detail is as shown in the picture. The picture shows the reinforcement details of footing pad, grade beam and the columns. Size of footings, reinforcements in them and size of grade beams and reinforcements in them depend on the type of sub-soil and load in each footing. Also, the detailing of reinforcements should follow the rules of ductile detailing (this will be discussed in detail in next session). In following few slides, we will have a glance of required size of footings and no. of reinforcements for a simple residential building of 3 or less stories in different types of soils.

Size of Pad Foundation

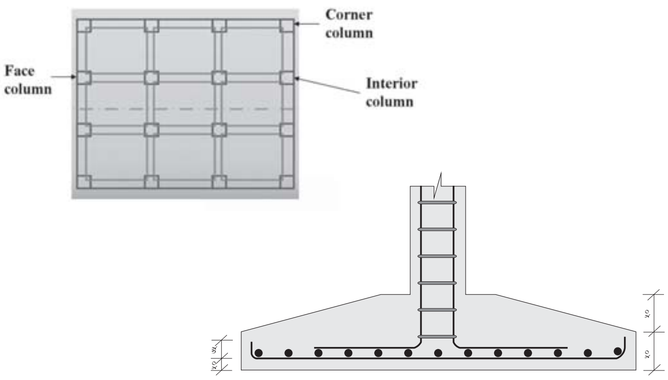

Illustration: NSET

Size of Pad Foundation

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Size and Reinforcement for Medium Soils
(for RCC framed building with masonry infill wall)

Column Type	Column Location			Foundation Plan L x B(m)	Thickness at Edge t_e (mm)	Maximum Thickness t_m (mm)	Reinforcement each way A_s Fe415
	Cantilever side	Along Long Bay	Abutting Infill Wall				
Corner	No	-	No	1.0 x 1.0	150	325	5T10
Corner	Yes	-	No	1.1 x 1.1	150	325	6T10
Corner	Yes/No	-	Yes	1.3 x 1.3	150	425	8T10
Face	No	No	No	1.2 x 1.2	150	450	8T10
Face	No	Yes	No	1.4 x 1.4	175	450	9T10
Face	Yes	Yes/No	No	1.4 x 1.4	175	450	9T10
Face	Yes	No	Yes	1.4 x 1.4	175	450	9T10
Interior	-	-	Yes/No	1.6 x 1.6	250	550	8T12

Size of Pad Foundation

adpc

Size and Reinforcement for Weak Soils
(for RCC framed building with masonry infill wall)

Column Type	Column Location			Foundation Plan L x B(m)	Thickness at Edge t_e (mm)	Maximum Thickness t_m (mm)	Reinforcement each way A_s Fe415
	Cantilever side	Along Long Bay	Abutting Infill Wall				
Corner	No	-	No	1.6 x 1.6	150	300	7T10
Corner	Yes	-	No	1.7 x 1.7	150	300	8T10
Corner	Yes/No	-	Yes	1.7 x 1.7	150	300	8T10
Face	No	No	No	1.9 x 1.9	150	375	7T12
Face	No	Yes	No	2.2 x 2.2	150	400	8T12
Face	Yes	Yes/No	No	2.2 x 2.2	150	400	8T12
Face	Yes	No	Yes	2.2 x 2.2	150	400	8T12
Interior	-	-	Yes/No	2.6 x 2.6	200	500	10T12

Size of Pad Foundation

adpc

Size and Reinforcement for Hard Soils
(for RCC framed building with masonry infill wall)

Column Type	Column Location			Foundation Plan L x B(m)	Thickness at Edge t_e (mm)	Maximum Thickness t_m (mm)	Reinforcement each way A_s Fe415
	Cantilever side	Along Long Bay	Abutting Infill Wall				
Corner	No	-	No	0.80 x 0.80	150	350	5T10
Corner	Yes	-	No	0.90 x 0.90	150	350	5T10
Corner	Yes/No	-	Yes	1.2 x 1.2	200	450	8T10
Face	No	No	No	1.0 x 1.0	200	450	7T10
Face	No	Yes	No	1.1 x 1.1	200	450	7T10
Face	Yes	Yes/No	No	1.1 x 1.1	200	450	7T10
Face	Yes	Yes/No	Yes	1.2 x 1.2	200	450	8T10
Interior	-	-	Yes/No	1.3 x 1.3	250	550	7T12

Foundation Beam

- Depth of foundation depends on the type of soil
- Generally, the foundation should reach up to a depth of firm strata
- It should also be such that the foundation is not scoured by rain water or any other drainage system
- Foundation depth should in general be not less that 90 cm.

Depth of Foundation

- Depth of foundation depends on the type of soil
- Generally, the foundation should reach up to a depth of firm strata
- It should also be such that the foundation is not scoured by rain water or any other drainage system
- Foundation depth should in general be not less that 90 cm.

- Depth of foundation
  - Up to firm strata
  - No Scouring

Special Confining Reinforcement

- Special confining reinforcement should be provided at joints of column and the footing.
- The confining reinforcement should extend at least 300 mm into the footing as shown in the figure.
- The spacing of confining reinforcement should not be more than 100 mm.

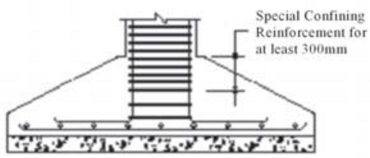


Illustration: NSET

Toe Wall and Plinth Beam

- All plinth beams shall be constructed on the toe walls.
- Toe walls give support to plinth beams and protects the filled materials in the floor from being going out.
- Depth of toe wall - 450mm or 1.5 ft
- Height of plinth – min. 450mm or 1.5 ft

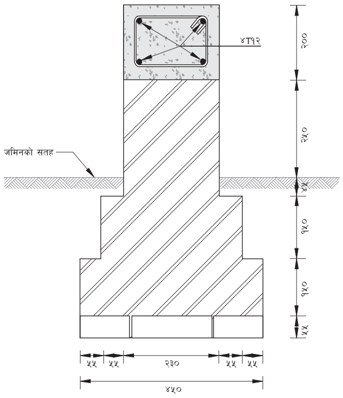


Illustration: NSET

Module 2 / Session 6

Construction of RC Framed Buildings: Beam / Column

NSET adpc

In this presentation we will discuss about the conventional pillared (reinforced concrete framed) building construction. It covers prevailing weaknesses, faulty practices and consequential damage patterns. It also discusses possible mitigation methods to avoid these damages. It also covers an introduction of pre-engineered three story RC framed construction. We will have an exercise as well at the end of the session.

A Tour to Damage: Lessons from Failure

First of all we are going to discuss about global damage to the RC framed construction and then move to local damage. At the same time we will discuss why these damages occurred, what was the problem. Hope, it will help us to learn many lessons.

Pancake Damage

Photo Courtesy: EERI

This picture shows pancake damage of a RC framed hotel building. This building collapsed during Philippine earthquake. It shows RC framed construction are not immune to earthquake damage unless designed and constructed properly.

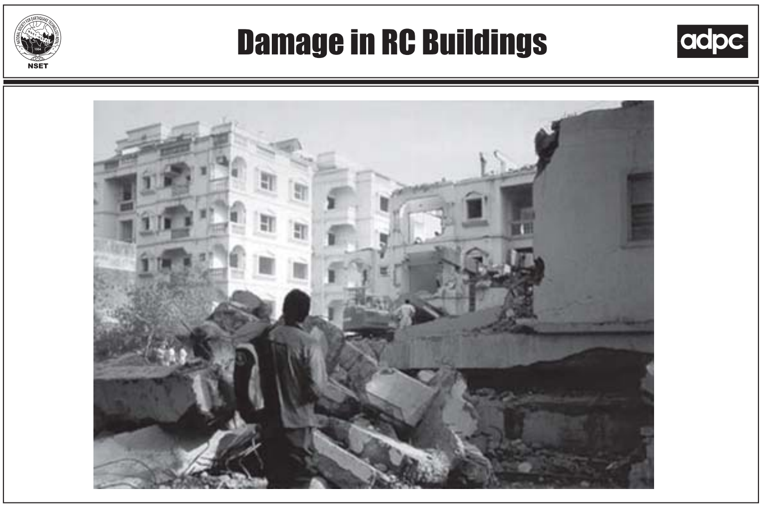


Photo: NSET, Bhuj Earthquake, India

These photographs are from Bhuj Earthquake. Though, RC framed construction is excellent construction system, faulty design and construction has made it more risky than masonry construction because of more number of stories and higher occupancy.

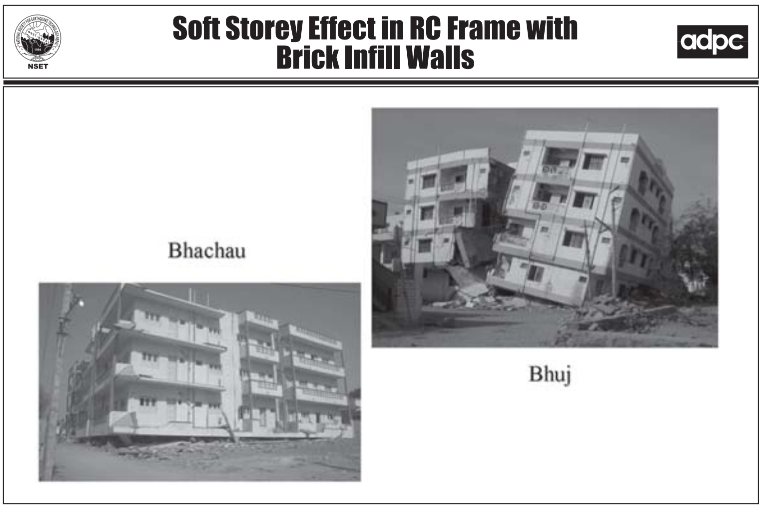


Photo: NSET, Bhuj Earthquake, India

Both the photographs shows “Soft storey” collapse of the buildings. Though the upper stories are still intact, the bottom storey collapsed.

Soft storey effect happens when lower stories are weaker/ less stiffer than upper stories. Examples could be open bottom storey such as shops and more compact upper stories (constructed for residential or office space). More walls in upper stories makes it more stiffer than lower story.

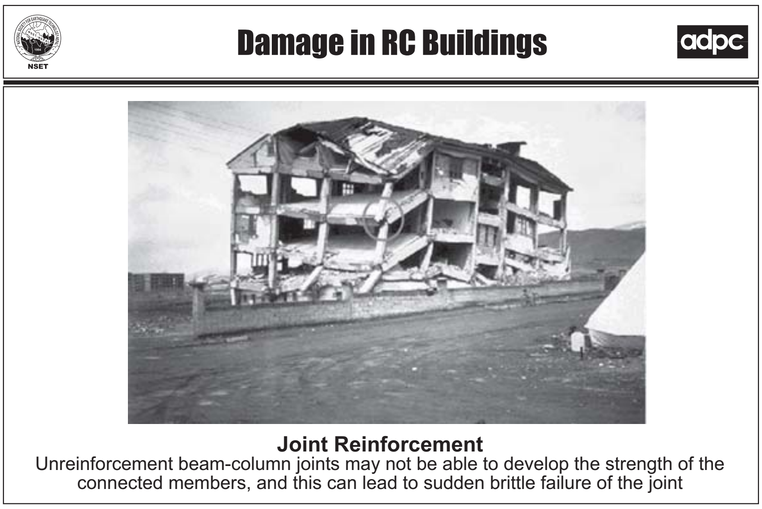


Photo Courtesy: EERI Erzican, Turkey 1999

This picture shows general brittle damage in a RC framed construction. This building has interestingly suffered all types of brittle damages. The red circle shows cold joint/ shear failure of column. Beams could be seen falling apart. The infill walls have already fallen down.

NSET adpc

LOCAL DAMAGE

After discussing global damage of the building, we are going to discuss about local damages, their cause and mitigation measures. We will be discussing about how this damage occurred and how it can be mitigated.

NSET adpc

Eccentric beam column joint

Photo Courtesy: EERI

The picture of this slide shows damage due to eccentric beam column joint. In the picture, interior beam does not frame into column, transverse beam is eccentric with column.

NSET adpc

Indirect Loading to Column

Photo: NSET, Bhuj Earthquake, India

The pictures here shows indirect support for framing beams. The spandrel beam does not frame directly into column - connected on one face only.

Good Beam-Column Joint

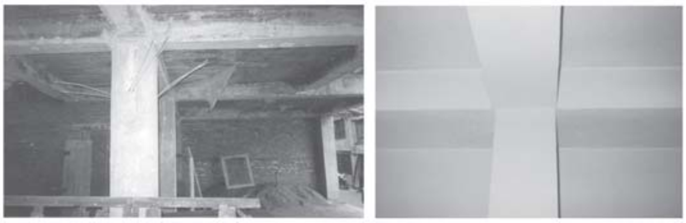


Photo: NSET, SESP, Vidyodaya Primary School

Beam-column joint should be concentric as shown in the pictures. Eccentric beam-column joints creates additional stress in the joint region forcing it to fail.

Column Tie Spacing and Tie Hooks

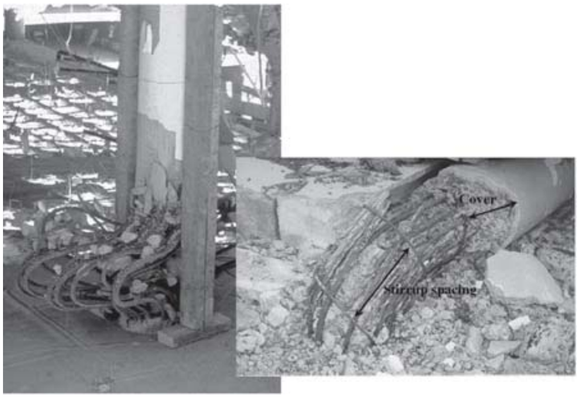


Photo: EERI Maxico Earthquake, Maxico 1985

These pictures show column failure because of lack of stirrups. Because of very little stirrups, the column bursted.

The picture in inset shows too much cover on one side where as almost no cover on other side. Though there are a lot of steel bars in both the columns, the column failed because of lack of stirrups. It shows that vertical bars are not only enough for strength of column. Furthermore, in second picture, all the bars are lapped in one location and at the bottom of the column.

Column Tie Spacing and Tie Hooks

Photo Courtesy: 1971, Jan Fernando. C4, James L. Stralta EERI

Deformability (ductility) of reinforced concrete members is a necessity. Note the obvious differences of capability of concrete columns to take load after earthquake damage. The reinforced column with more stirrups (ductile reinforcing) has an obvious capacity to carry much more load than the column with less stirrups.

This picture shows front column without much stirrups failed where as central column survived because of more stirrups. The stirrups provides shear strength, confinement to the concrete and protects longitudinal bars against buckling. This photo proves this fact. Further, because of adequate stirrups only cover concrete has spalled without much harm to the column.

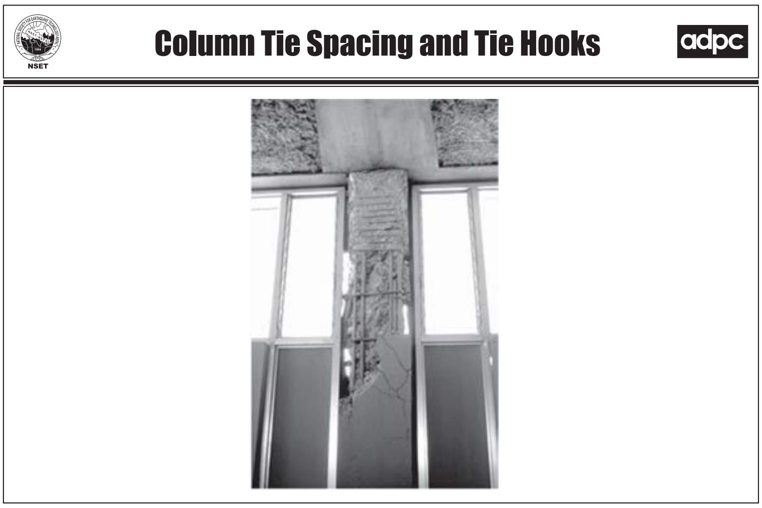


Photo Courtesy: EERI

Ductile vs. Non-ductile Concrete Construction

Reasons as discussed in last slide, upper part of the column suffered very little structural damage compared to middle part. Though the longitudinal bars are same, the difference in quantity of transverse stirrups have made total difference.

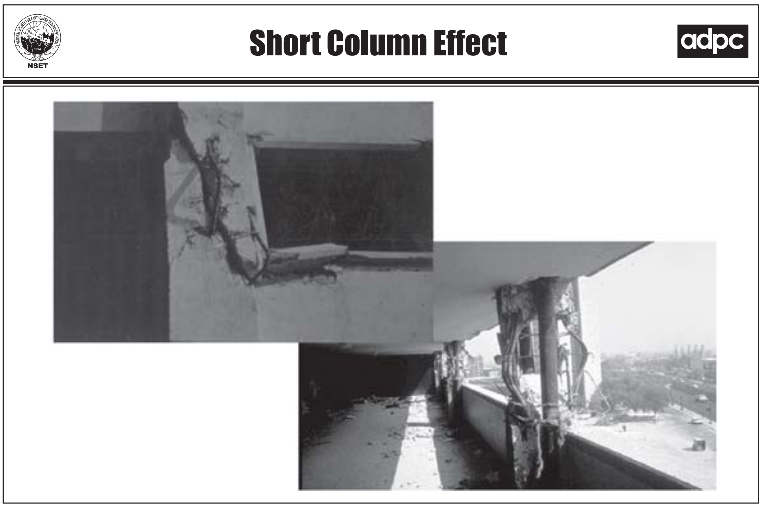


Photo Courtesy: Top - unknown, & Bottom - EERI, J.O. Jirsa, Maxico City, 1985

These photographs show failure of column because of short column effect. What is actually happening is, the walls have effectively reduced the column height. Because of shortened height, the imposed shear load on the column has increased. The column was not designed for this load which led to failure of these columns.

Other problem that can be clearly seen from the pictures is the stirrups were not anchored in the column core concrete that's why these stirrups opened leading to loss of all the concrete.

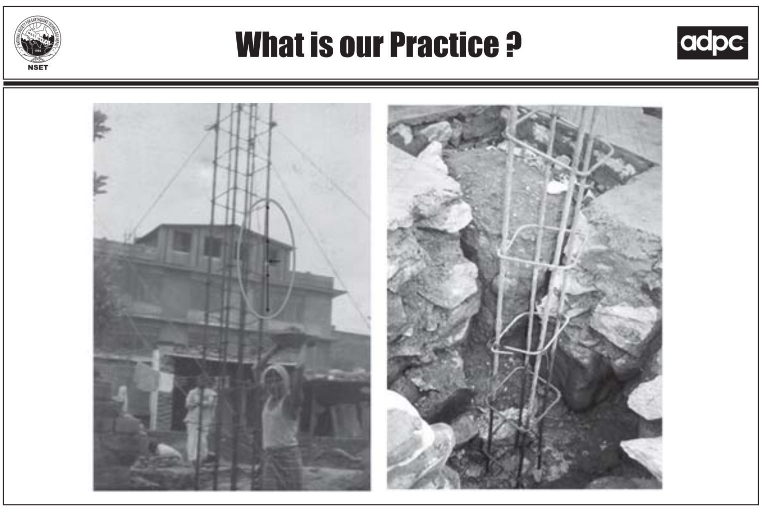


Photo: NSET (Left) Kathmandu, (Right) Baitadi

The slides shown earlier clearly shows shear, confinement failure and buckling of longitudinal bars. These problems are result of lack of stirrups, unanchored end of stirrups in the core of concrete as shown in the above pictures. Use of even open stirrups has been observed as shown in first photograph which is worst possible case.

Beam and Column Stirrups

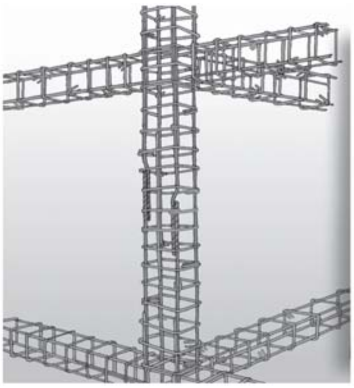
Column Stirrups

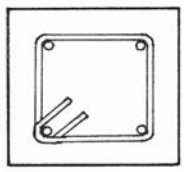
Beam Stirrups

Photo: NSET

Stirrups in beam and column should be closely spaced. At the end of the column and beams stirrup spacing shall not be more than 100 mm till first 600 mm from their ends. In the rest of the mid section the spacing can be increased to half the depth of the section.

Proper Detailing for Ductility





Do Proper detailing to provide proper ductility in RC frame Building

Illustration: from NSET Calendar

This picture shows how a well detailed beam and columns look like. Furthermore, the stirrup ends should be well anchored inside the column or beam core as shown in the right hand picture.

Reinforcement Lapping and Anchorage

Improper Lapping of Column Bars

Photo: NSET, Bhuj Earthquake, India

The pictures show damage concentration in the region of bar lapping. Because of interaction between overlapped bars and concrete for load transfer the overlapping section suffers higher level of damage. This interaction is further coupled with lack of stirrups which has led to buckling of bars, loss of concrete.

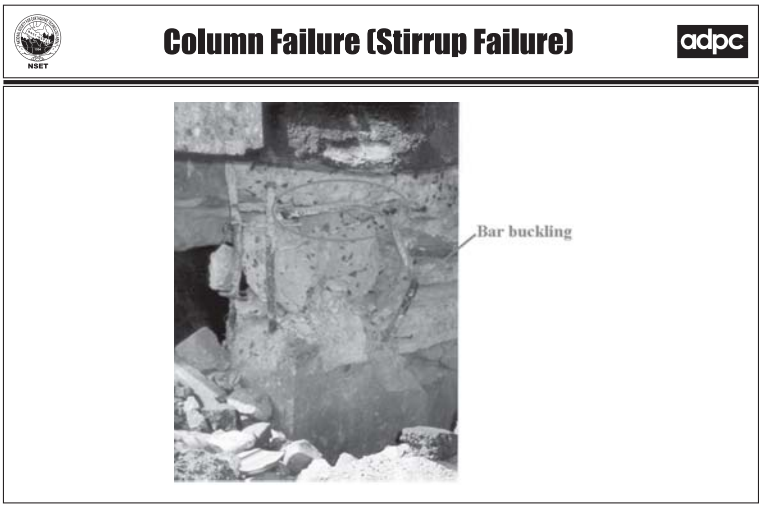


Photo: NSET, Bhuj Earthquake, India

The picture exposes the lack of anchorage of column bars, lack of stirrups. Beam, column ends suffer higher interaction of loads than rest of the member so these need special attention.

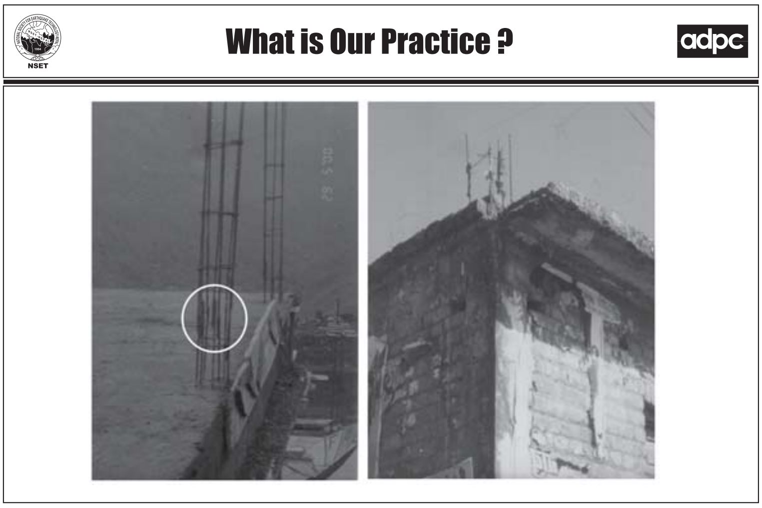


Photo: NSET SESP (Left), Chamoli Earthquake 2001, India & (Right)

These pictures reveals what our practice is and what should we expect if an earthquake strikes. In the first picture overlap is less than 200 mm and spacing of stirrups is more than 400 mm far less than what is required. In the second picture, column bars are left for future extension at the floor level. At one end lap length is too little and other hand this is not a good location to lap bas. Furthermore all the bars should not be lapped at the same location.

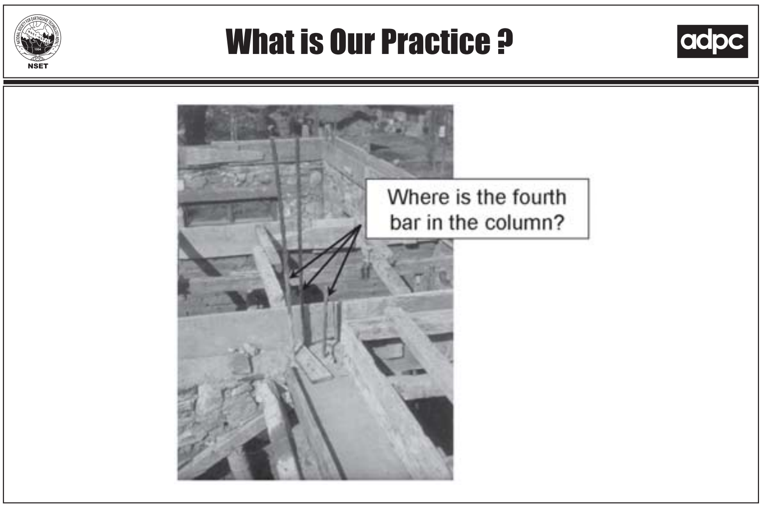


Photo: NSET, Pokhara

This picture reveals one more weakness of reinforcement detailing. Besides weaknesses discussed in earlier slide, this column has only three bars to be lapped. There shall not be less than four bars in a column.

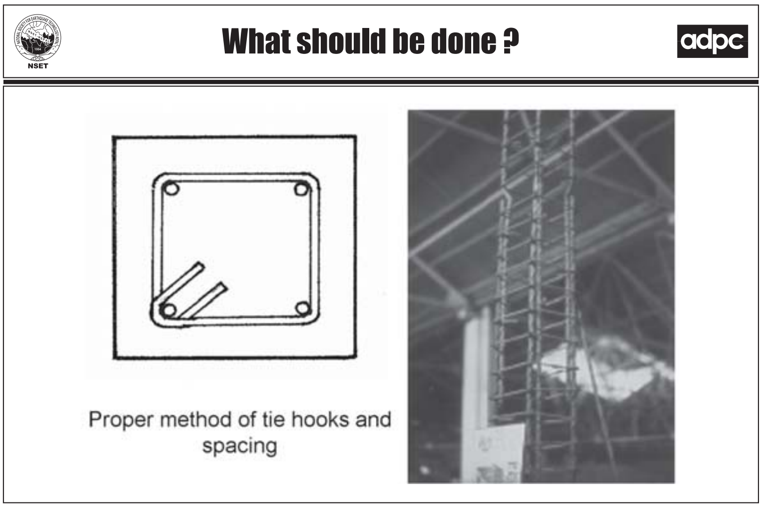


Illustration & photo: NSET, Earthquake Safety Exhibition

The lap length of reinforcement either in beam or column depends on quality of concrete, diameter of bars, surface roughness of bars. However, in general for concrete quality being used, lap length should not be less than 60 times the diameter of the particular bar. Further, lapping should be avoided in beam-column joint region and it should start around 600 mm away from beam or column ends.

As shown in the picture, stirrups should not be more than 100 mm apart over the reinforcement lapping region.

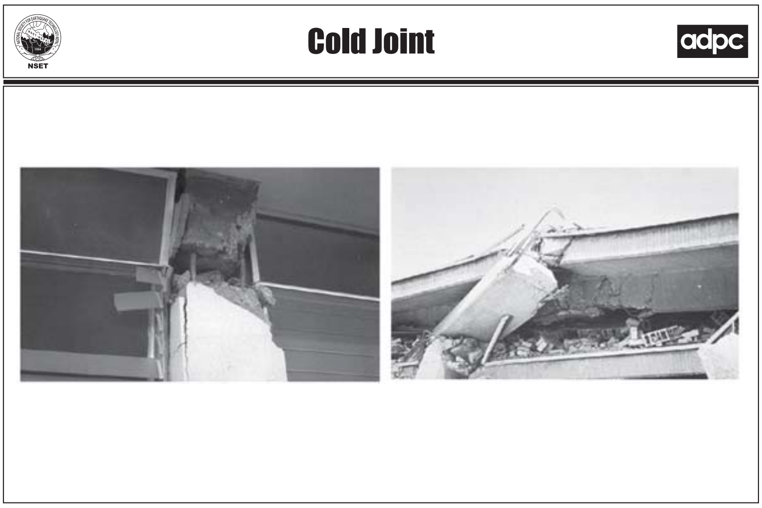


Photo Courtesy: (Lef t) EERI, (Right) 1979, Mexico City EERI CD

Both the pictures show effect of clod joint on seismic performance of the columns of reinforced concrete framed construction. One of the joint is at the mid height of the column and other at the top of the column.

The cold joints are formed when second phase of concreting is done on smooth surface of existing concrete.

Note the failure of roof connection because of lack of transverse reinforcement around hooked bars, cold joint at top of column, insufficient anchorage length for hooked column bars.

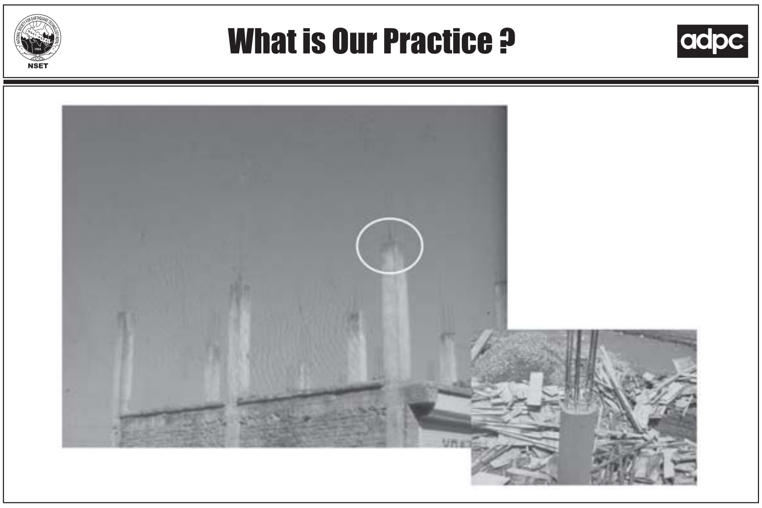


Photo: NSET, Kathmandu

It is common practice to construct columns of full or half height without surface roughening at the top or a shear key. These basically lead to cold joint and should be avoided.

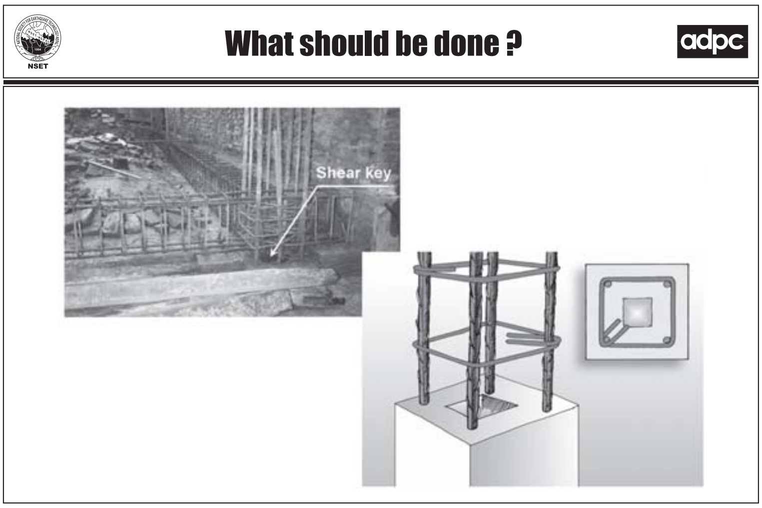


Photo & Illustration: NSET, Kathmandu

The picture shows construction of shear key at the top of the column. The top of the column should be well roughened or shear should be provided at the top of the column.

Also note how beam bars are anchored in the column.

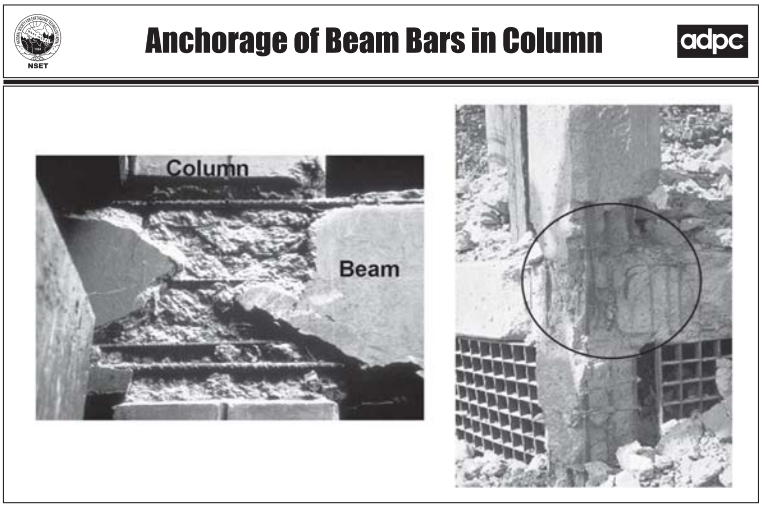


Photo Courtesy: EERI

The pictures presents both the interior and exterior beam-column joint damage because longitudinal beam bars of the beams were not confined within column longitudinal bars and stirrups.

In the second picture, the corner joint failure, the beam bars are not well anchored inside the column, beam bars are not confined by transverse reinforcement through joint.

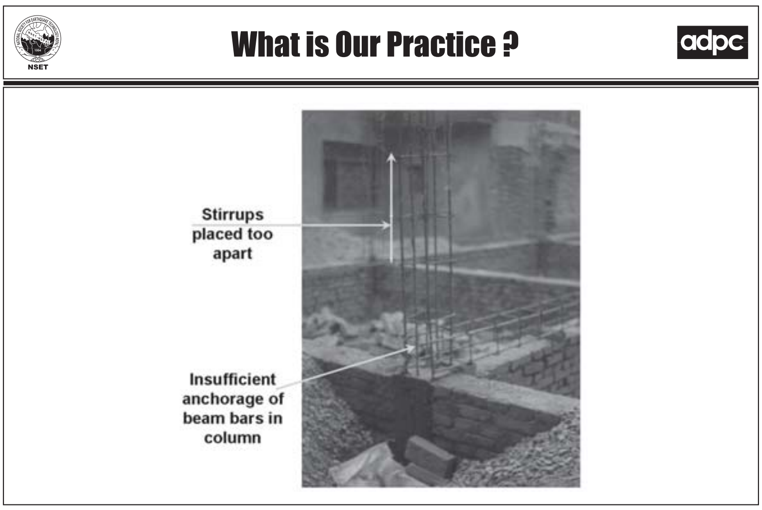


Photo: NSET, Bhaktapur

It is common practice not to provide any stirrup in the beam-column joint region. In addition to it, it is also common to keep one face of beam bars outside the column bars. Furthermore, very short L-bend is provided at the end of beam bar which is not enough for anchorage.

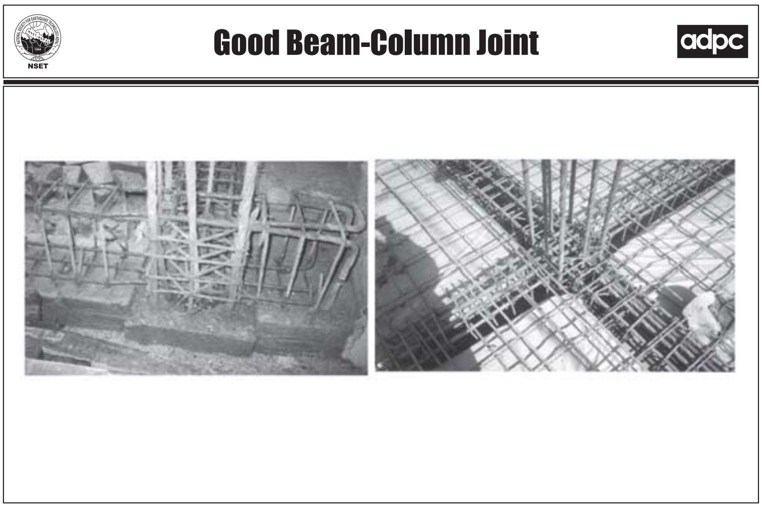


Photo: NSET, SESP, Vidyodaya Primary School, Jhochhen

The beam bars should pass through the column bars and the joint region should be well confined by closely spaced stirrups as shown in the picture (though not visible in second picture).

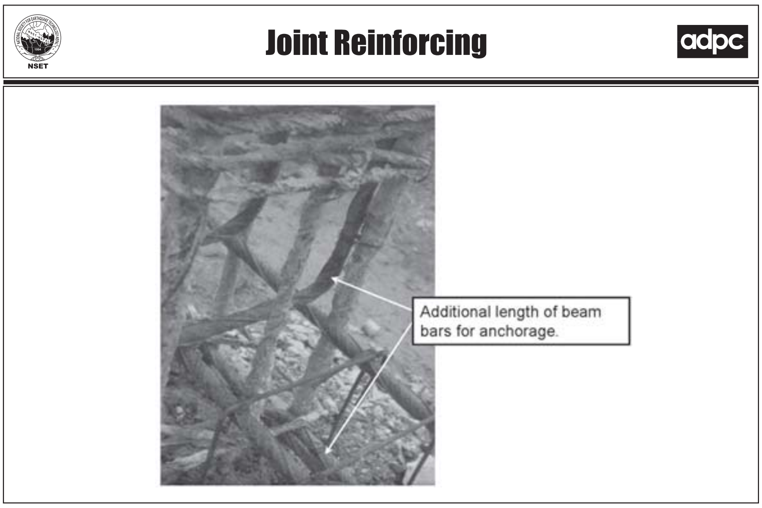


Photo Courtesy: TAEC, Jorpati, Nepal

The picture shows how the beam bars can be anchored in the column.

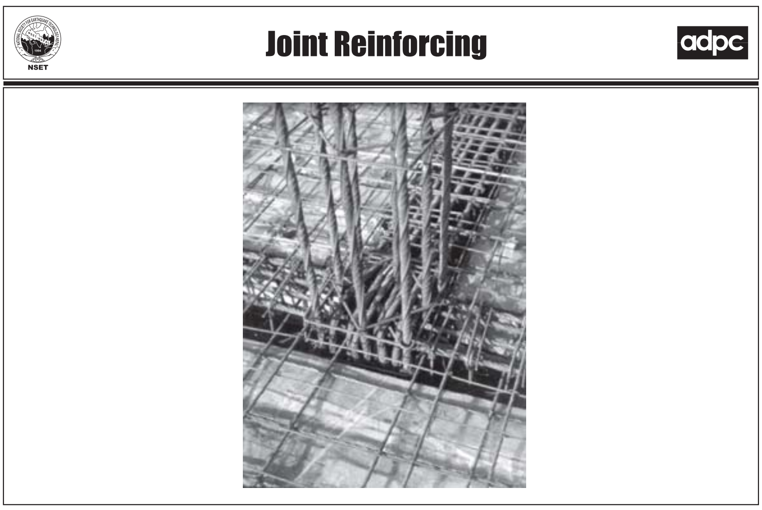


Photo Courtesy: TAEC, Jorpati, Nepal

Note how closely spaced beam bars are in the beam-column joint region, although all the beam bars passes through column. This detail may lead to total honeycombing inside the beam-column joint. Beam-column joint regions are always difficult component of RC framed construction and need special attention.

Good Beam-Column Joint

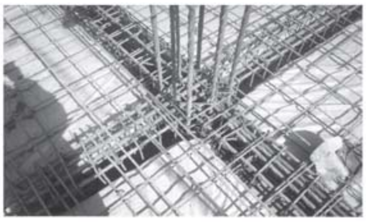


Photo: NSET, SESP - Vidyodaya Primary School, Jhochhen

There should be enough space between reinforcing bars so that concrete can be easily poured in beam column joint region. Also note stirrups in the beam-column joint region.

Detailing at Beam Column Joint

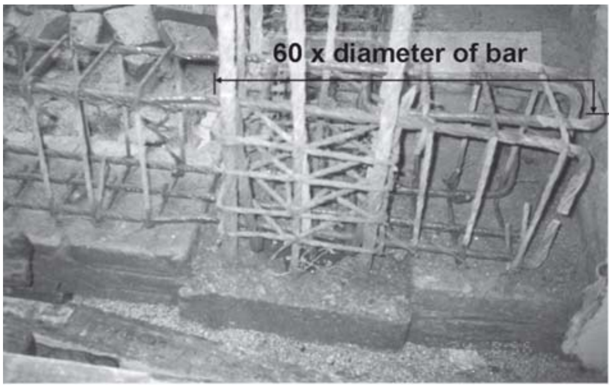


Photo: NSET, SESP - Vidyodaya Primary School, Jhochhen

This slide shows how long the beam bar should be anchored in the column or beyond.

Column Stirrups and Hooks

Placing confining reinforcement at the junction

Photo: NSET, SESP - Vidyodaya Primary School, Jhochhen

This picture shows few of the good practices of the beam-column joint, column, beam construction.

Problem of Infill Walls

Photo: NSET, Bhuj Earthquake, India

Untied infill walls (masonry units of brick, concrete blocks, adobe, or other similar material placed within the confines of a structural frame) usually collapse during earthquake shaking. Though the building may survive, it may cause casualty and loss of property.

Problem of Infill Walls

Photo: NSET, Bhuj Earthquake, India

The infill walls usually create structural problems. As shown in the pictures these may cause shear failure of the framing elements. Since they create a rigid non-flexible element, they attract seismic forces; but being structurally weak, they fail when subjected to these forces. When they fail, they tend to cause a failure in the structural frame as well - often causing collapse of the structure.

What is Our Practice ?

Photo: NSET, Kathmandu

There is hardly any practice to tie-up these infill walls.

Tie-up of Walls

Photo: NSET, SESP

All the infill walls should be tied up with the frame. Walls could be tied up in different ways. One of the method could be to tie-up walls with Reinforced concrete band.

Guidelines

Here is one example for design of a new RC framed construction using pre-engineered design. This design assumes there is no participation of strength and stiffness from the infill walls (cladding or partition walls).

This example is based on NBC201, prepared by Nepal National Building Code Development Project as per Nepalese building code. Precautions shall be taken, if this guideline be used in other regions. The requirements set in following presentation shall be applicable only for buildings complying with specified limitations. The intension is to achieve a minimum acceptable structural safety. The intension of this guideline is not to replace engineers.

Layout

- A or B < 6 bays
  - 7 columns in one direction
- 25m in length
- One bay <4.5m (i.e. 15 feet)
- A<3B and >B/3
- H/A or H/B <3
- H < 11m or 3 stories

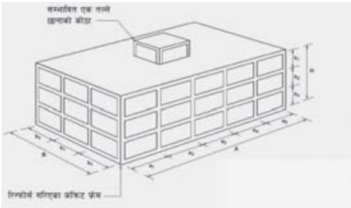


Illustration: NSET, NBC 201, 1994

The general limitations on size of the buildings are:

- The height of the building should not be more than 11 m or three storey (whichever is less). Within an 11 m height, there may an additional storey of smaller plan area. However, plan area of it shall not exceed 25% of the area of typical floor.
- Height to width or height to length ratio of the building should not be more than 3.
- The building should not be more than 25 m long or wide.
- It should not have more than 7 bays in any direction.
- Any one bay of the building should not be more than 4.5 m long.
- This guideline is not applicable if bays are single bay.
- The area of slab panel shall not be more than 13.5 sq meter.
- All the columns of the building shall be vertical. It shall be continue on the same centerline down to foundation.
- No walls other than parapet wall be built on cantilevered slab. This slab should be framed with beams and wall be reinforced and tied up with the slab.
- The foundation shall be at uniform level.
- The building shall not have a soft story.

Layout

- Wings of the structure
  - K1 and K2 < A/4 or B/4
  - The width of wing should be greater than half of K1 or K2

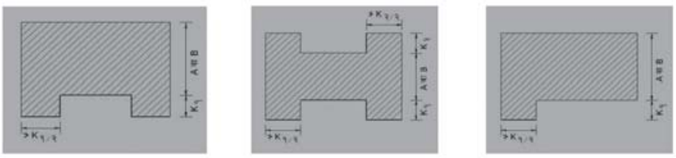


Illustration: NSET, NBC 201, 1994

Regarding the configuration:

- In plan, the wing length should not be more than ¼ of the width of the building.
- At the same time, the width of the wing shall not be less than ½ of its length.

Layout

- The concrete strength shall not be less than 15 MPa at 28 days for a 150 mm cube.
- The longitudinal reinforcing bars used for beam and column shall not have yield strength more than 415 MPa.
- However, for beam or column stirrups bars of yield strength upto 550 MPa can be used.
- 8 mm bars of yield strength are replaceable with 7 mm bars of yield strength 550 MPa.

These are minimum material standard that must be met when this example is used.

Critical Section of Frames

- Ends of beams upto a length of about twice the depth of the beam.
- Ends of columns.
- Joint regions between beams and columns.

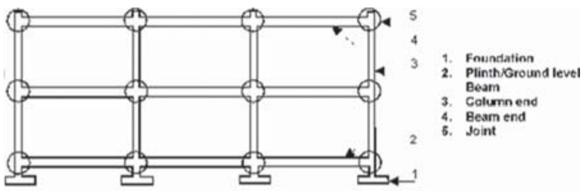


Illustration: NSET, Kathmandu

Column and beam ends, and beam-column joints are the most critical sections during earthquake loading. These need special care.

Size of Reinforcement in Columns

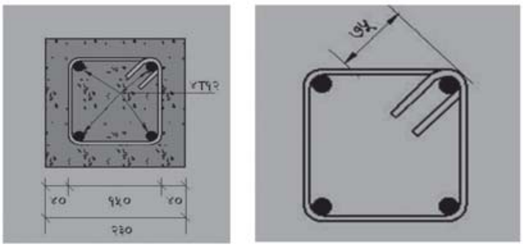
Size of columns and reinforcement depends on the number of stories, span, type of building and the floor

For a residential building as mentioned earlier, following suggests the size of columns and the reinforcements

Story	Corner Columns		Face Columns		Interior Columns	
	Size (mm)	Reinforcement	Size (mm)	Reinforcement	Size (mm)	Reinforcement
III	230 x 230	4T16	230 x 230	4T12	230 x 230	4T12
II	230 x 230	4T16	230 x 230	4T16	230 x 230	8T12
I	270 X 270	4T16	270 X 270	4T16	270 X 270	8T12

This table gives steel bars required in columns. Quantity of steel in a column depends on its location, number of stories, type of loading, beam span etc.

Shear Reinforcement (Rings)



- At the end of columns for 600mm (2 ft) length – T 08 @100 mm c/c
- For remaining height – T 06 @125 mm c/c

Illustration: NSET, Kathmandu

When casting a column, care must be taken to maintain cover to the steel bars. If cover is not well maintained the steel bars start rusting with time and capacity of column is significantly reduced. Cover blocks can be used to maintain cover.

Moreover it, the most important part is shape of column stirrups. The ends of stirrups must be anchored in the column core as shown in picture. These stirrups should also be continued in beam-column joint region.

Beams

- Size :
  - Width = 230 or 240 mm
  - Depth = 325 mm overall
- Reinforcement :

Span	More than 12 ft.				Less than 12 ft.			
Bar type /Level	Regular		Additional		Regular		Additional	
	Top	Bot.	Top	Bot.	Top	Bot.	Top	Bot.
Roof	2T12	2T12	1T12	1T12	2T12	2T12	1T12	1T12
II	2T16	2T16	1T16	1T16	2T12	2T12	2T12	1T16
I	2T16	2T16	3T12	1T16	2T16	2T16	1T16	1T16
Plinth	2T12	2T12	-	-	2T12	2T12		

- Beams are more critical near the supports than at the midspan

This chart presents steel reinforcement required for beams. The quantity of beam reinforcement depends on beam span, type of loading, intensity of loading etc. For vertical loading only, steel reinforcement in all the floors is more or less similar. However, it increases in building designed for earthquake load in lower stories.

Beams Details

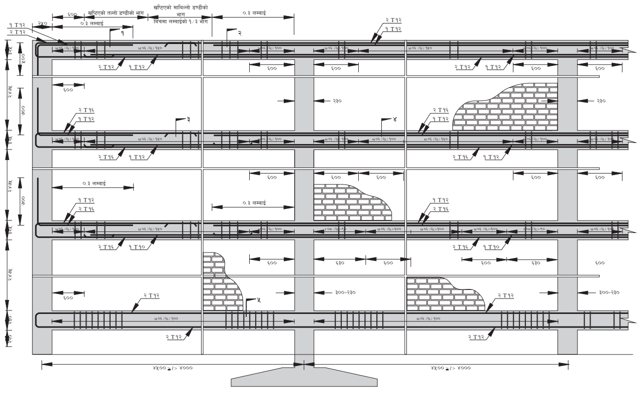


Illustration: NSET, NBC

This drawing presents beam details. Column bars are not shown here for clarity.

Stirrups in Beams

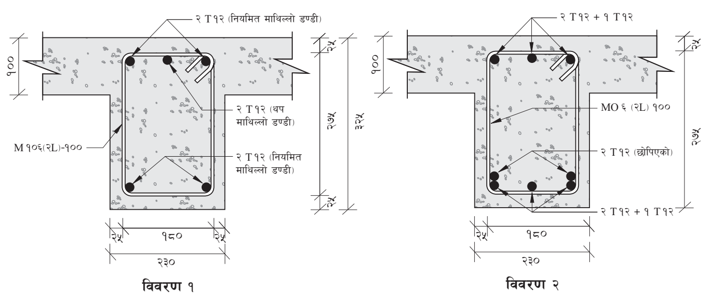


Illustration: NSET, NBC

When casting a beam, care must be taken to maintain cover to the steel bars. If cover is not well maintained the steel bars start rusting with time and capacity of beam is significantly reduced. Cover blocks can be used to maintain cover.

Moreover, the most important part is the shape of beam stirrups. The ends of stirrups must be anchored in the beam core as shown in picture.

Stirrups in Beams

Level/Span	More than 12 ft.	Less than 12 ft.	Remarks
Roof	End 600mm : M06 @100mm	End 600mm : M06 @100mm	In the remaining length of all beams use M06 @ 150mm
II	End 900mm : M06 @100mm	End 600mm : M06 @100mm	
I	End 0.3 L : M06 @80mm	End 0.3 L : M06 @80mm	
Plinth	M06 @100mm	M06 @100mm	

The stirrups shall be provided as specified in the table.

Detailing of Columns

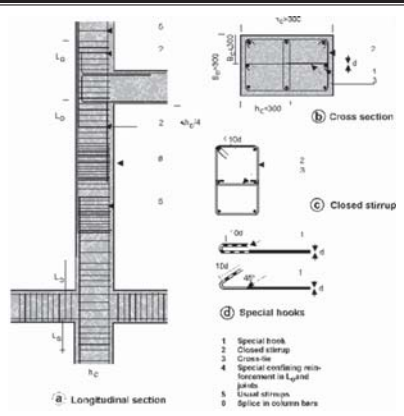


Illustration: NSET, NBC

The spacing between stirrups shall not be more than 100mm at the ends of columns for 600mm. In central region the stirrups spacing can be increased to ½ the width of the column. However, where longitudinal bars are lapped the spacing shall not be more than 100mm.

If spacing between longitudinal bars in column is more than 200 mm and unless it is located in corner of closed stirrup, additional ties, as shown in the drawing, shall be provided to hold these bars.

The lap length of the longitudinal bars shall not be less than 60 times the diameter of the bar. As far as possible, the bars shall be lapped in middle 2/3 length of the column. Further, lapping of all the bars at a section shall be avoided.

Detailing of Beams

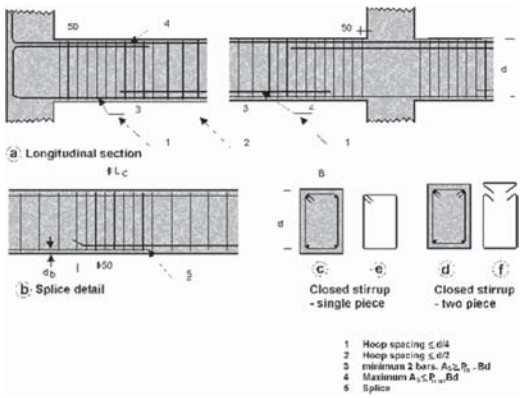


Illustration: NSET, NBC

The lap length of bars shall not be less than 60 times the diameter of the bar.

The top bars shall not be lapped in beam-column joint region. The bottom bars shall be lapped 300 mm away from the column face but lapping in central region of beam shall be avoided. However, the top bars shall be lapped in central region of the beam. Lapping all bars in one section shall be avoided.

Detailing of Beam Column Connections

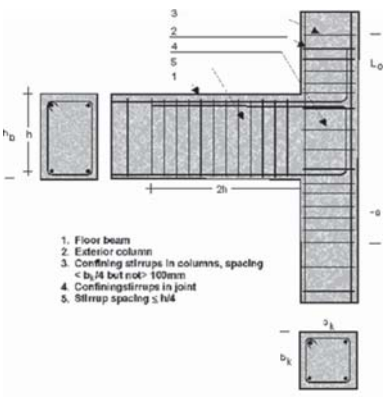


Illustration: NSET, NBC

The beam bars ending over the column shall be well anchored in beam column joint region. The anchorage length shall not be less than 60 times the diameter of the bar.

Further, the column stirrups should also continue in the beam-column joint region.

Detailing of Foundation, Plinth Beam & Column Joints

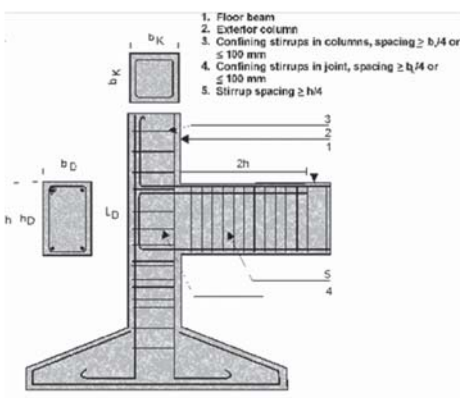


Illustration: NSET, NBC

Individual column footings resting on soft to medium soils should be connected together at ground or plinth level by tie beams. The tie beams shall be a minimum of 200x200 mm in section with 4-10 mm diameter longitudinally bars and 6mm stirrups @ 150mm.

Slab

- Thickness = 100mm
- Reinforcement = T08 or K07 and M06 or K4.75

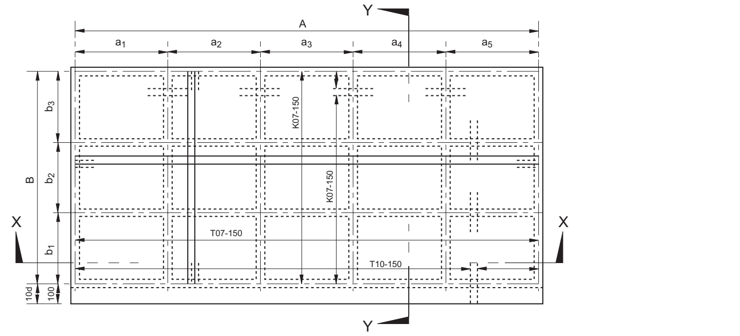


Illustration: NSET, NBC

The drawing presents a typical drawing of a slab where panel area in not more than 13.5 sq m and non of dimension are more than 4.5m. The details are not applicable for single span slab.

Extra bars are required in the slab as top layer along the supports.

Slab Detail

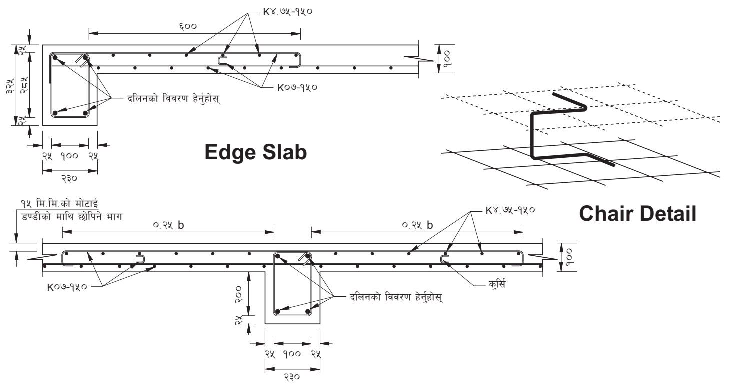


Illustration: NSET, NBC

The top bars and bottom bars shall be well separated. The separation can be maintained using chairs made of steel bars as shown.

In end panel, the top bars along the edge shall be well anchored in the beam.

Slab Reinforcement

Slab reinforcement detail showing chairs

Photo: NSET, SESP, Jhochhen, Kathmandu

This picture presents a typical layout of slab reinforcement details.

Non Load Bearing Walls

- Horizontal reinforced concrete (RC) bands
  - To prevent walls from falling out
  - At one third and two third of the wall height
  - At sill level and lintel level if there is opening
  - Width equal to the wall thickness
  - Thickness equal to thickness of brick or 75mm
- Reinforcement
  - The reinforcement depends on span of the wall.

Bands in Non Load Bearing Walls

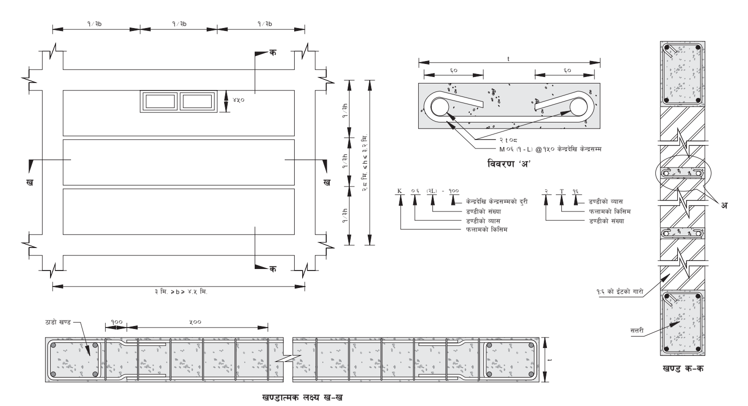


Illustration: NSET, NBC 201, 1994

This picture presents a typical details of wall bands. For span up to 4.5m, two number of 8 mm diameter bars as longitudinal steel with 4.75 mm stirrups at the spacing of 150mm would suffice.

The longitudinal bars can be installed during construction of column.

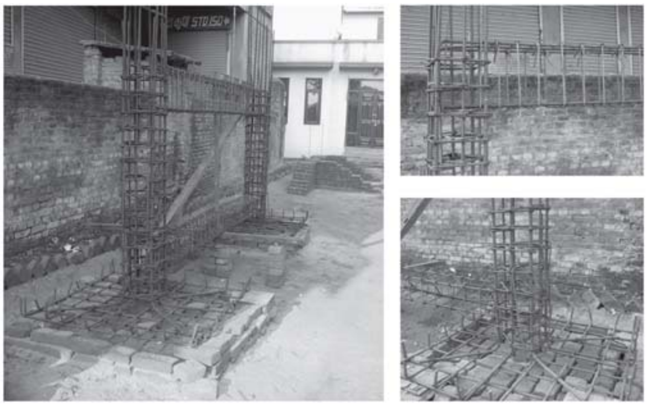
Bands in Non Load Bearing Walls

Photo: NSET, Dharan

This picture presents bars left during column construction for band.

EXERCISE

Exercise on Constructing Reinforcement Models



In this exercise participants will prepare and erect reinforcement models of RCC frame. Models may be scaled down by 1:4.

There will be two types of models: one is column with foundation and another is beam, column and bands. Details of these models are as shown in photographs.

To make the exercise easy and effective, the whole participants (30 nos.) will be divided into 6 groups consisting of 5 persons in each group. The groups will be of three types according to the model they will prepare and for each type of model there will be 2 groups. Hence two groups will construct same type of model separately.

Exercise Groups

- "Column with Foundation" group (2 Nos.)
- "Column and Band" Group (2 Nos.)
- "Beam" Group (2 Nos.)
- These two groups have to work in close coordination because the beams prepared by "Beam" group has to be fixed into the column prepared by the "Column and band" group.

It is better to divide the groups at the beginning of the course so that they will stay in groups and will do everything in groups. This division of groups in the beginning will help better coordination during the sessions as well as in the exercises.

"Column with Foundation" group (2 Nos.)

This group will prepare foundation and column reinforcements and will erect in place.

"Column and Band" Group (2 Nos.)

This group will erect the column reinforcement with proper cutting and bending. Side by side the group will also make the rings and fit them to the main reinforcement but in close coordination with "Beam Group" for proper construction at the joints. This group will also work for making the horizontal band at one location of the columns.

"Beam" Group (2 Nos.)

Preparation of main reinforcement in required length (including that for development length and lapping), placing in required locations and fixing with the rings are the responsibilities of this group. This group will also prepare the rings, in required size. Special joint detailing has to be done in the joints between beams and columns.

These two groups have to work in close coordination because the beams prepared by "Beam" group has to be fixed into the column prepared by the "Column and band" group.

Drawing of Model

Foundation and Column

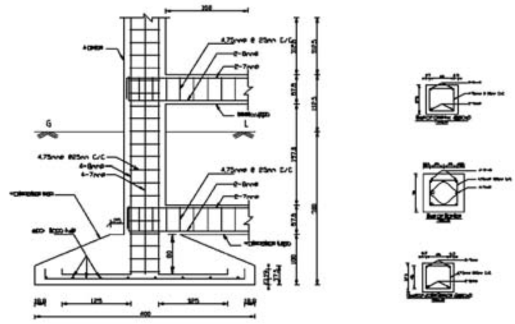


Illustration: NSET

After dividing the whole group of participants into different groups, let them works to prepare the assigned models. It will be better to allow them to work independently without any instruction during the exercise, let them make whatever they received during the lecture. In the critical places where they want any suggestion, some clues can be fixed so that they themselves could try to remember whatever they have learnt in the lectures.

Drawing of Model

Beam, Column and Band

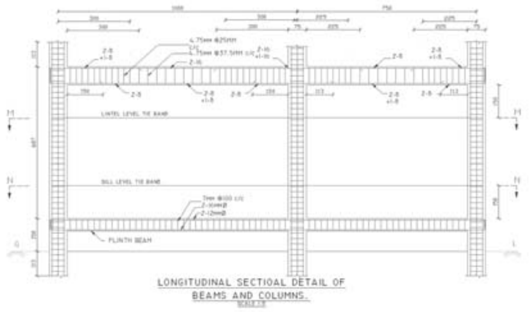
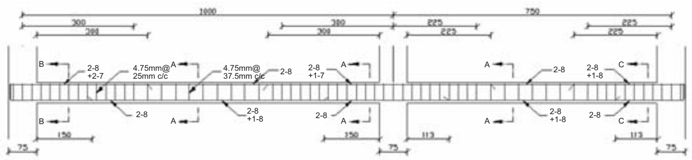


Illustration: NSET, NBC

Drawing of Model

Detail of beam, column and band



L-SECTION OF BEAM OF FIRST FLOOR

Illustration: NSET, NBC

It is expected that this exercise will take 3 hours. Now, ask them to describe/present about their models. Facilitate them to identify the positives & negatives in their models.

Drawing of Model

Detail of beam, column and band

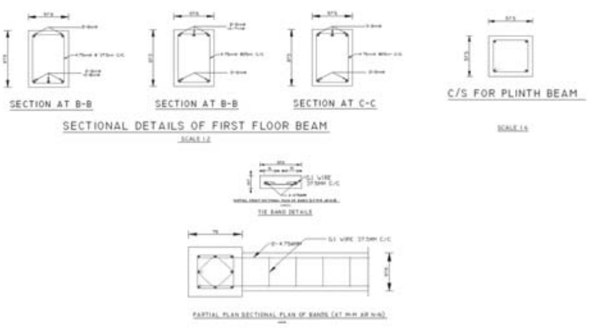


Illustration: NSET, NBC

Finally, from this exercise the participants will have a very good practical knowledge & skill about the required detailing in RCC construction.

Module 2 / Session 7

Construction of RC Framed Buildings: Floor / Roof

NSET adpc

Out of the two types of floors and roofs, we have already discussed in detail about the flexible floors and roofs. Now, in this session we will discuss about rigid floors and roofs.

Rigid floors and roofs are those in which the deformation in their own plane can not take place and they can not be twisted. RCC slabs are most commonly used rigid floor and roof.

Learning Outcomes

Upon completion of this session participants will be able to

- Use bars of optimum size and proper placement of reinforcement in slab;
- Use appropriate size of aggregate and mix ratio for the slab; and
- Use proper technique of connecting floor and roof slab to frames or walls.

Scope

- Importance of floor / roof slabs
  - Rigid diaphragm action
  - Distribute the lateral load to the columns and to foundation
- Common defects and their protective measures in floors/roofs in framed buildings
- Construction of floors/roofs of framed buildings
- Considerations for staircase and sloped slabs
- Practical considerations

RCC slabs as floors and roofs are superior than the flexible ones of timber or bamboo since it gives higher rigidity and helps to improve the integrity of the building. However, defective construction of RCC floor and roof slabs can not contribute to overall strength of the building. We can find many defects in the RCC slab construction. We will discuss now the requirements of a good RCC slab.

Common Rigid Floor / Roof

- Normally, in an earthquake RC slabs fail after the failure and collapse of columns, walls and beams.
- After the collapse of columns/walls, slabs fail as if they are pancakes.
- Failure of slab alone is not seen in an earthquake.

Photo: EERI (Top) & NSET, 2001 Bhuj Earthquake, India (Bottom)

Damage in a Rigid Slab

- However, failure of slab alone can be seen in normal load condition when it can not resist dead loads and imposed loads.
- Therefore, slab should be capable to withstand all possible dead as well as imposed loads and also the earthquake loads.

Photo: NSET, Shaking Table Demonstration

Key Issues in RCC Slab

- Capacity of slab depends on the span, size and reinforcements
- Size of slab should be sufficient enough - thickness of slab and size and no. of reinforcement bars depend on the span of the slab
- It should be properly connected with the masonry wall below it
- For connecting the slab with walls a tie beam below the slab will be good option

Construction of RCC Slab

- Formwork – centering and shuttering
- Placement of reinforcement bars – cutting, bending, placing, binding
  - Top bars, bottom bars and distribution bars
  - Chairs
- Marking lines and levels for finished slab
- Concrete batching, mixing, placing, compacting
- Curing

Placement of Reinforcement Bars

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- At the mid spans of slabs, generally bars are required at bottom face
- Near supports, at the top face also bars are required
- At the locations where top and bottom both bars are required, these two types of bars should be separated by chair bars

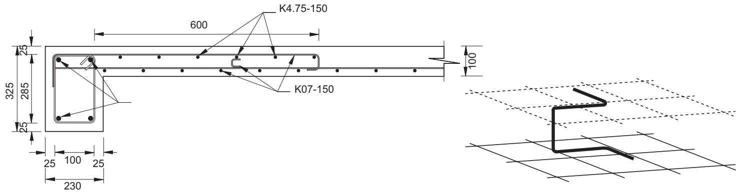

Illustration: NSET NBC 201, 1994

Placement of Reinforcement Bars

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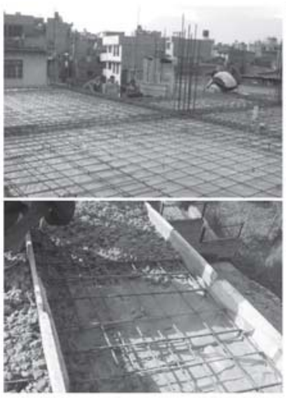

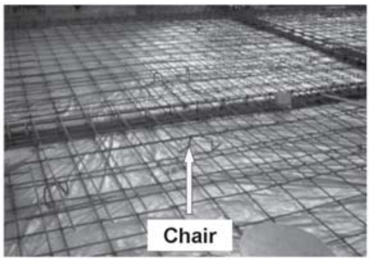

Reinforcements in the projection should also rest on the chair

Photo: NSET, SESP

Reinforcement in RCC Slab

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- Size or dia of reinforcing bars for slab -

  1/8 t >Dia of bars>1/16t ('t' is the thickness or depth of slab)
- Maximum spacing of bars:

  Spacing of bars on slab should not exceed the following
- As designed
- 450mm
- 3 times the effective depth of slab
- 30 times the dia of bar

Reinforcement in RCC Slab

adpc

- Curtailment of bars
  On all continuous edge- **0.25L** from the centre of support
  On discontinuous edge- **0.15L** from the centre of support
- Extension of top bars

For all continuous edge: up to **0.33L** from the edge towards the middle

For discontinuous edge: **0.2L** for discontinuous edges towards the middle

Placing of Reinforcements

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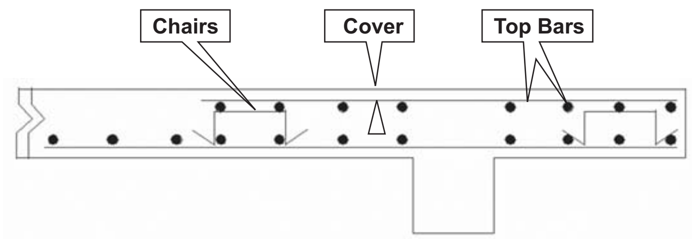
- **Positive reinforcement:** In two way slab bars for bottom mesh should be placed as follows
  - shorter bars (bars along shorter direction) should be placed below the bars along longer direction.
- **Negative reinforcement (top bars):** Main bars for upper mesh (top bars) should be placed above the distribution bars.
- **Bars for cantilevers:** Top bars are the main bars for cantilever slab and should be placed above the distribution bars for cantilevers. All top bars should be resting on chairs and should not be disturbed or relocated.

Cover to Reinforcements

adpc



Proper Placing of reinforcement

In slabs and also in any RCC member the cover outside the reinforcements bars should be provided so that the reinforcement bars are protecter from dampness & other weathering effects.

The cover needed in RCC slabs is as mentioned below.

Cover to Reinforcements

adpc

- Clear cover for reinforcement for slab

Roof Slab

- Bottom and top: 15mm or not less than the dia of larger bar
- Sides or ends: 25mm or twice the dia of larger bar
- Slab on or below the ground level
- Bottom and top: 25mm or not less than the dia of larger bar
- Sides or ends: 25mm or twice the dia of larger bar

Note: Cover blocks of 1:3 cement mortar and appropriate size should be used for proper separation

Placement of Reinforcement Bars

adpc

Floor/roof ready for concreting after shuttering and reinforcement placing

Photo: NSET, SESP

Concrete Casting

adpc

Photo: NSET, SESP, Gadgade Primary School, Nagarkot, Bhaktapur

Concreting

- Procedure for concreting should follow the instructions stated earlier
  - Concrete grade- minimum M15 i.e. 1:2:4
  - well compacted
  - Kept moist atleast for 7 days
  - For slab of size 4.5mx 3m, props of formwork should not be removed before 14 days of concreting

Consideration for Staircase

Typical reinforcement detail of staircase

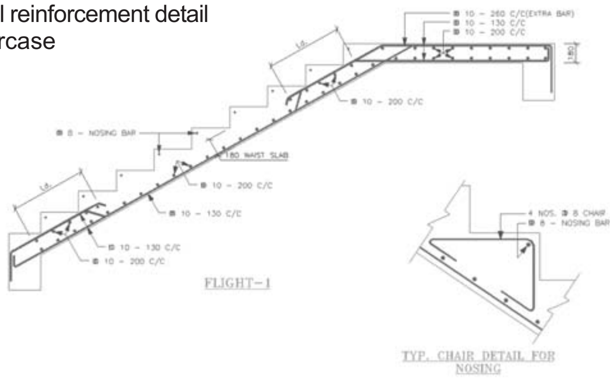


Illustration: NSET, SESP

While constructing staircase, spacial care should be taken. In a staircase slab, reinforcement are placed both at the top and bottom as shown in the figure. Following other points are important:

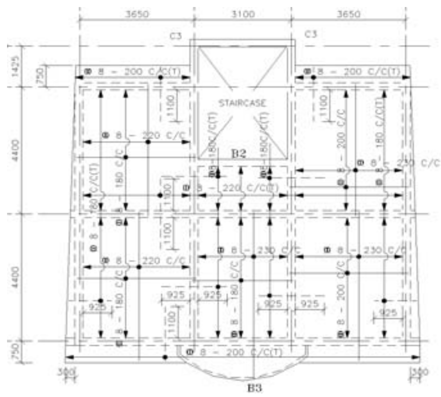
- spacing of bars not less than 150 mm

- concrete grade not less than M15 or 1:2:4 & min

- thickness of slab not less than 120 mm

- removal of framworks not earlier than 14 days of casting

Typical Slab Reinforment Detail



Here is a typical reinforcement detail for slabs. This will give an idea about how to read the drawing of slab reinforcement detail.

Typical Slab Reinforment Detail

- For a panel of 4.5m x 3.0m or less
  - Slab thickness = 100mm
  - Reinforcement = Torsteel of 8mm @150mm c/c
  - Concrete mix = 1:2:4
  - Aggregate = 20mm and below

This is requirements for a typical slab which is vary commonly used size.

The requirements will vary depending upon the size / span of the slabs

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Module 2 / Session 8

Quality Control and Workmanship

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Buildings behave as they are actually constructed not as they are designed or planned. No matter how well a building is planned and designed if they are poorly constructed. Therefore, quality and workmanship during each stage of the construction play a vital role in making a building of good quality, strong and earthquake resistant. Besides good planning and design, quality control should also be given equally high attention during the construction of a building.

In this training manual a session is allocated for discussing about the quality control and workmanship. This session is devoted for that.

Learning Outcomes

Upon completion of this session, participants will be able to:

- Explain the properties of main construction materials and distinguish between good and bad quality materials;
- Explain the effect of quality control measures on the earthquake resistance of building; and
- Assure the quality of materials and processes involved in accordance with the guidelines provided.

NSET **Quality of Construction** adpc

- Major factors affecting the quality of construction
  - Planning and design
  - Quality of materials
  - Quality of construction process (workmanship)
  - Resources available / Time factor (Project period)
- Quality control in each stage, starting from planning to the end of construction, can only produce a good quality building.

First factor to affect the quality of a building is the quality of its planning and designing. If a building is not properly planned and designed, the building can not be of good quality even if it is constructed with greater care and quality control. For a building to be an earthquake resistant, a good quality planning and design means that which follows the basic rules outlined in previous sessions of this manual – appropriate site selection, good configuration and layout, appropriate size and detailing of different structural elements etc.

Another factor affecting the quality of a building is quality of materials used in the construction. Inferior quality materials can not make a higher quality building. Therefore materials used in the construction should be of good quality as mentioned in the specifications.

Next major factor to contribute in the quality of a building is quality of construction process and quality of workmanship. This is the ultimate factor to make a good quality building. Each and every stage of the construction should be in accordance with the provisions and steps mentioned in the standard construction manuals and guidelines.

Resources and time available are also the indirect factors to make a good quality building. Experiences have shown that if the project period is prolonged due to the resource constraints then quality of construction goes on decreasing.

NSET adpc

Quality of Some Important Construction Materials

Now, we will discuss about the required quality of some very popular construction materials.

NSET adpc

Quality of Materials

- Has to be ensured for assuring the final quality of construction
- Should be decided beforehand the construction is started
- In standard practice, is decided during the planning and designing phase
- Differs according to construction type, structural element and location of site

Final quality of any construction is dependent on the quality of construction materials used in the construction. Therefore, the quality of materials should be ensured for using the final quality of construction. The required quality of materials should be decided beforehand the construction is started; generally it is decided during planning & designing phase. The quality of materials required differs depending upon the construction type, structural element & location of site.

NSET adpc

Commonly used Construction Materials

- Cement
- Sand
- Aggregate
- Steel Reinforcement Bars
- Brick
- Building Stone
- Mud
- Lime
- Timber/Wood
- Water
- Roofing and Flooring Materials
- Composite Materials
  - Mortar
  - Concrete

These are the very commonly used construction materials. Out of these, properties and good qualities of most common materials - cement, sand, aggregate, reinforcement bars, bricks, timber and water are described here.

Cement

- Cement is nowadays most commonly used building materials
- Depending upon constituent materials and ultimate features cement are of different types:
  - Ordinary Portland Cement (OPC)
  - Quick Setting Cement
  - Rapid Hardening Cement
  - Slow Setting Cement
- Out of these, OPC is the most commonly used type of cement
- OPC may be of different grades depending upon their strength – 33, 43, 53 (grades) etc.

- Cement is simply a mixture of limestone and clay heated in a kiln to very high temperature and made fine powder by grinding.
- Cement is seldom used alone, it is mostly used as binding materials to make composite materials like mortar and concrete.
- Goes into the voids of aggregates and binds the aggregates when mixed with water and hardened.

Quality of Cement

- Good Quality
  - Hardens/sets within appropriate duration
  - Achieves required compressive strength within specified time period
  - Absorbs appropriate quantity of moisture
  - Fully powder form like talcum powder in well packed slacks.
- Bad Quality
  - Doesn't get strength within specified time duration
  - Absorbs more moisture
  - Not in fully powder form, contains some already hardened particles
  - Defects in packing, transporting and storage.

Selection and Handling of Cement

- Should fulfill the design requirements
  - For RCC and structural elements – cement should not be of less than 43 grade
- Age should not be of more than 2 months at the time of construction
- Air tight bags without any holes should be selected
- Should be free from pebbles or any hardened cement contents
- Handling and storing
  - Bags should be handled with care during transportation so that they will not be torn out by hooks and will not come into contact with moisture/water
  - Stored in dry, air and water tight and moisture free place

Sand

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- Particles of size less than 4.75mm are called sand, it is also known as fine aggregate.
- It is a natural construction material, generally available at river beds, river banks and sand quarries.
- Sand is also not used alone, it is used to make mortar and concrete.
- In concrete sand fills the voids between coarse aggregates and then cement fills the voids between coarse aggregates and sand.

Quality of Sand

adpc

- Many unnecessary and organic things may be mixed with sand since it is obtained from rivers or quarries.
- Therefore, sand should be carefully selected and used.
- should be coarse river sand, well graded grains, clean and fresh
- should be free from foreign particles and minerals (soil, organics)
- Moisture content to maintain minimum bulking

Coarse Aggregate

adpc

- This is obtained from the stones crushed to various sizes or natural sedimentation on river banks. It is used for cement concrete works, pavements etc.
- should be hard enough, durable, clean and granule in shape.
- Minimum abrasion
- should not contain minerals and foreign materials
- should be well graded to various sizes

Photo: NSET

Size of Aggregate

adpc

- Size of aggregates used in construction depends on the thickness of the concrete members, specification and design requirement.
- Size of aggregate for RCC and PCC work
  - For the members having thickness > 100mm - 40mm down
  - For the members having thickness 40mm to 100mm - 20mm down
  - For the members having thickness < 40mm - 12mm down
  - For the members other than specified above – As per design and specification
- Well graded aggregates should always be used (aggregates consisting of different sizes in the mix)

Steel Reinforcement Bars

adpc

- Concrete and masonry have very low tensile strength, so they can not resist tensile forces.
- However, buildings and different structural elements are frequently subjected to tension.
- Steel reinforcement bars are provided to resist the tensile forces.
- Steel bars have very high tensile strength, but have low compressive strength as compared to concrete or masonry.
- Steel bars are characterized by their strength such as MS 230, Fe 415, Fe 500 etc.

Quality of Steel Bars

adpc

- Free from rusting
- Assured standard quality and marked
- should not break while bending
- Uncracked, uniform thickness (dia.) throughout the whole length

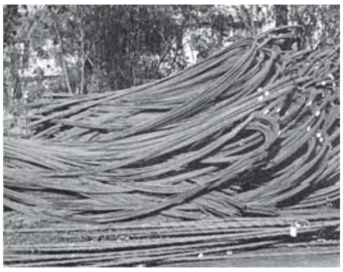


Photo: NSET

Reinforcing bars used in construction should comply with design considerations. should have sufficient strength to resist the stress developed.

These are available in various sizes (diameter).

Diameter of bars to be used for different members depends on the design.

In general, the diameter of bars to be used for various members should be as follows

For columns- minimum 12 mm dia (for rectangular columns- minimum 4 nos. and for circular columns- minimum 6 nos.).

Beam: minimum 12 mm dia. (for rectangular doubly reinforced beam minimum 4 nos.).

Slab: the dia of bars should not be more than 1/8 times the thickness of slab and not less than 1/16 times the thickness of slab.

Stirrups: dia of bars should not be less than ¼ times the dia of main bars (larger bar)

Brick

adpc

- Brick is a clay product. It is produced in a standard mould and burnt in kiln at an appropriate temperature.
- Bricks may be
  - Sun dried only or fired
  - Burnt in standard chimneys or local furnaces
  - Machine made or hand made
- Standard size of modular brick is 240 x 115 x 55 mm
- Depending upon the final quality they are classified as
  - First class - A, Second class - B or Third class – C
  - Class D is overburnt bricks

Photo: NSET

Quality of Brick

adpc

- Minimum compressive strength- 7.5 N/mm2
- Well burnt, uniform red color, smooth surface finish
- Regular and uniform shape and size
- Produce metallic ringing sound when struck each other
- should not absorb too much water (more than 25% of its' weight while soaked in water for 24 hours)
- should not break while dropped from a height of 3 feet

Timber / Wood

adpc

- Timber is used as different structural members like posts, beams, joists, rafters etc. as well as in doors and windows.
- Timber is also used to make formwork for concreting, however their quality differs from those to be used as structural members and doors and windows.
- Timber to be used as structural members should be well seasoned, free from cracks, holes or knots and of hard-wood species.
- Should have uniform surface and should be not be twisted.

Photo: NSET, SESP, Vidyodaya Primary School, Jhochhen

Water

adpc

- Water is most important nutrition for all the living beings.
- Similarly it is an important material in the construction also.
- Water is required in almost every stage of any type of construction from starting to the end.
- Water is used to make mortar, concrete as well as for curing of masonry and concrete.
- As man needs pure and good quality water; concrete, mortar etc. also need pure and drinkable water.
- Impurities in water may lower down the quality of concrete and mortar

- In most of the cases, it is seen that water used in construction is of lower quality. In rural as well as urban areas people use pond water, water from sewerage line, runoff water, ground water for construction.
- It is not possible to use portable water where public is not served enough water even for drinking. In these cases maintaining the quality of construction is very difficult. In such cases, the available water should be first purified then only should be used in construction.

NSET adpc

Quality of Some Important Construction Works

NSET

Quality fo Works (Workmanship)

adpc

- A building to be strong, durable and earthquake resistant, good planning and design and selection of quality materials are not only sufficient, quality of construction process is also equally important.
- Good quality of workmanship at every stage of construction can only assure the final quality of a building.
- Quality and process of each construction work should be in accordance with the standard practice as outlined in specifications and guidelines.

NSET

Common Construction Works

adpc

- Foundation Construction
  - Layout, excavation, compaction and leveling to required surface
  - Soling, P.C.C. and Footing construction
  - Backfilling and compaction
- Masonry Wall Construction
  - Mortar preparation
  - Laying of masonry units (bricks/stones), curing
- Reinforced Concrete Construction
  - Formwork preparation
  - Reinforcement placement
  - Concreting
  - Curing, formwork removal
- Construction of Service Facilities
  - Electricity
  - Water supply and sewerage

Masonry Wall Construction

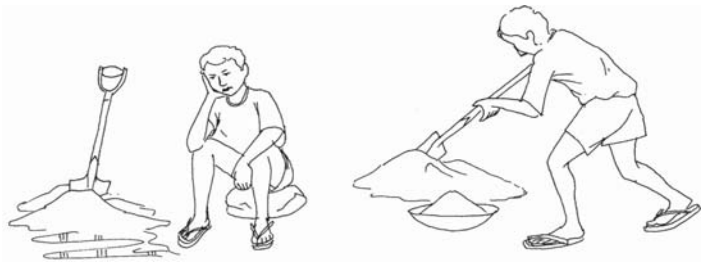
- Mortar preparation
  – Selection of good quality cement, sand and water
  – Batching of cement and sand in appropriate proportions
- For all important superstructure walls the mix should not be less than 1:4
- For foundation masonry the mix may be up to 1:6
  – In case of manual mixing, do not make mortar of more than 1 bag cement batch at a time
  – First put sand, then over that put cement and mix well in dry stage
  – Add appropriate quality of water to the dry mix and stir it until the paste becomes homogeneous.
  – Do not put excessive quantity of water in the mix. Excessive water reduces the strength of the mortar as well as it becomes difficult to use since it flows easily.
  – Carry the mortar to the required place in proper size of trays so that it can be easily handled
  – The prepared mortar has to be completely used within 1-1.5 hours of mixing.

1. The selection of mortar for brick masonry has many consequences. Choosing the right mortar can lead to good performance and a durable masonry wall. Improper selection can lead to leaky walls or deteriorating mortar. Mortar selection is more than picking a mortar type. All aspects of a project including design, material selection and workmanship must be considered to lead to the choice of particular mortar materials and type.

The basic rules of mortar selection are:

- No single type of mortar is best for all purposes.
- Do not use a mortar stronger in compression than is structurally required.

Mortar



Do not use excessive water in the mortar and use it as soon as mixed with water.

Illustration: from NSET Calendar

Laying of Masonry Units

- Bricks and mortar should be as mentioned earlier
- Bricks should be fully soaked in water at least for 7 hours before it is used
- Bricks should be laid in true line and level, vertically in plumb
- Thickness of mortar should not exceed 12mm and joints should be properly racked out
  – Strength of masonry gets reduced as the thickness of bed joint increases. Taking normal thickness of bed joint 10mm an increase of 3 mm may reduce the strength of brick masonry by about 15%
- Vertical joints of bricks in successive courses should not be in one line
- should be uniformly raised and stepping should be maintained for further extension. No vertical toothing is allowed.
- should maintain equal height and level within 2 feet for the whole length.
- Construction of brick wall should be restricted to 1.5m in height in one day.
- All earthquake resistant elements should be incorporated at necessary places.
- should not provide lateral loads before 14 days of construction
- All brick work should be kept wet at-least for 5 days

Plain / Reinforced Concrete Construction

- Concrete is a composite construction material made up of cement, sand, aggregate and water.
- Concrete has very low tensile strength, therefore in the structures/structural members where there is tensile force steel reinforcing bars are used to resist tension.
- Concrete used with steel reinforcement bars is called Reinforced Cement Concrete (R.C.C.) and that without reinforcement is Plain Cement Concrete (P.C.C.).
- P.C.C. is generally used in foundation base, floors, road pavement etc. and R.C.C. is used in beams, columns, slabs and other main structures.

Plain / Reinforced Concrete Construction

- Concrete is generally categorized by its strength (like M15, M20 etc.) but also categorized by mix proportion of the constituent materials (like 1:2:4, 1:3:6 etc.).
- For P.C.C. the concrete should not be of less than M10 or mix not leaner than 1:3:6 and for R.C.C. it should not be less than M15 or mix not leaner than 1:2:4.
- For columns – not less than M20 or 1:1.5:3 and for beams and slabs – not less than M15 or 1:2:4.

Form Work / Centering and Shuttering

Formwork is used to achieve required shape of the concrete products.

Quality
- Hard, durable, enough thickness and of required size
- Water tight, to prevent bleeding
- should not absorb water from concrete.
- Weather free
- Smooth surface
- In true line and level
- Able to withstand the concrete load
- Proper horizontal bracings, props and runners

The forms (where applicable) should be of wood or metal, straight and of sufficient strength to resist springing or deviation during the process of depositing the concrete against them. Wood form should consist of two inches surfaced plank, and metal form should be of an approved section. They should be so designed that devices for holding the form in place will not cause weakness in the concrete or subsequent failure. They should be securely staked and braced, held firmly to the required line and grade and should not permit leakage of mortar. Where alignment includes curves, flexible strips of steel should be used. Form should not be removed for at least 15 days after the concrete has been placed.

Formwork Preparation

- Formwork is used to achieve required shape of the concrete structures.
- Quality of Timber for formwork
  - Hard, durable, enough thickness and required size
  - Water tight, prevent bleeding
  - Should not absorb water from concrete.
  - Smooth surface and in true line and level
  - Able to withstand the concrete load
  - Proper horizontal bracings, props and runners

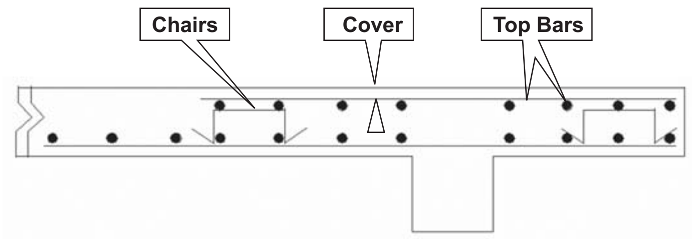
Reinforcement Placement

- Reinforcement should be erected as per detailed design and drawing.
- All horizontal bars should be truly straight on line and level.
- Splicing should be as specified.
- Stirrups should be as specified and placed truly vertical, tied all with longitudinal reinforcement.
- Distribution bars should be placed below the top bars.

Reinforcement Placement

- Top bars and bottom bars should be perfectly separated by using chairs.
- Clear cover on all the sides, top and bottom as specified, use cover blocks
- Cover block should be placed before placing the concrete for maintaining clear cover properly.
- Clear cover for concrete elements
  - Slab - 15mm
  - Beam - 25mm but not less than the dia of larger bar
  - Column - 40mm but not less than the dia of larger bar
  - Foundation - 75mm
  - For other cases - as per the instruction of Engineer

Cover to Reinforcement



Placing of reinforcement

Illustration: NSET

Concrete Batching

- All required materials of appropriate quality and quantity should be ready at site before proceeding to concreting work.
- Batching should be done by weight for good quality of concrete.
- Standard cube box (size 300* 300*375mm i.e. volume of 1 bag of cement) should be used for batching, where weighing is not possible.

Materials should never be batched by empty cement bags or by the means other than standard batching cube box as specified.

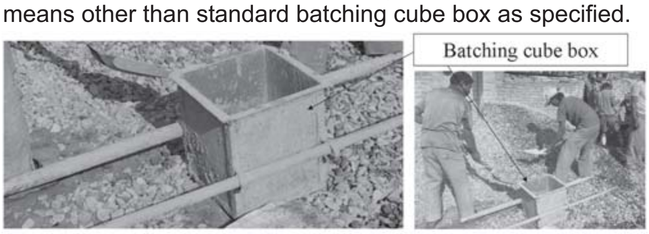


Photo: NSET, SESP

Make sure the grade of concrete required.

For all Reinforced Cement Concrete works, grade should not be lower than M20 (1:1.5:3). In case of plain cement concrete, grade should be of minimum M10 (1:3:6)

The amount of mixing materials can be assured equal if we measure by measuring units.

Always use Cube box for measuring the sand and aggregate.

Size of measuring unit is 1.25 cft which can be obtained by making metal or wooden boxes size 12” X 12” x 15”

Better batching is by weighing the material.

Concrete Mixing

Machine mixing
- The batched materials should be properly mixed in concrete mixer till the mix is homogeneous.

Manual Mixing
- In the cases where machine mixing is not possible, concrete can be mixed manually.
- Add 10% cement extra in case of manual mixing.
- Batching should be restricted to maximum 5 bags of cement
- The batched materials should be mixed in dry till it gets homogeneous, then water should be added. It should again be mixed thoroughly at least 2 times till gets homogeneous.
- Control water cement ratio.
- Mix the concrete thoroughly till it is uniform and place within 45- 60 minutes of mixing.

Concrete Mixing
- Machine mixing of the concrete is preferred for better quality.
- Proper care should be taken in case of manual mixing.
- If possible small batch should be prepared and 10% of cement should be added extra.
- Batching should be restricted to maximum 5 bags of cement.
- Batch should be mixed in dry properly, then water should be added.
- It should be mixed thoroughly before placing.

Concrete Mixing

- Mixing may be done by mixer machine or by hand, preferable is mixing by machine as it gives uniform quality and homogeneous concrete mix.
- In case of manual mixing
  - The area for mixing should be sufficient.
  - Add 10% cement extra in case of manual mixing.
  - Batching should be restricted to maximum 5 bags of cement
  - The batched materials should be mixed in dry till it gets homogeneous, then water should be added. It should again be mixed thoroughly at least 2 times till gets homogeneous.
  - Control water cement ratio.
  - Mix the concrete thoroughly till it is uniform and place within 45- 60 minutes of mixing.

Concrete Mixing

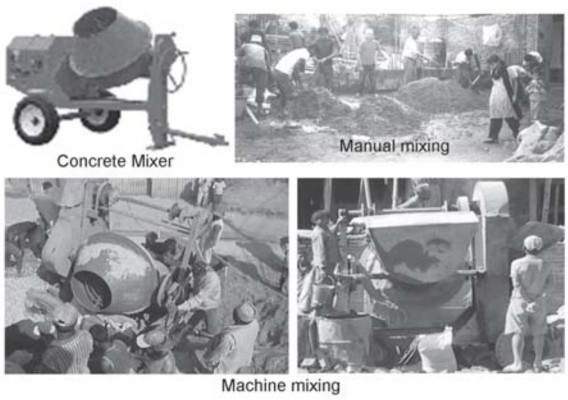


Photo: NSET, SESP

- Picture shows the types of concrete mixing in construction.
- Mixing should be done by mechanical concrete mixer.
- In case if mixture is not accessible to site add 10% cement on hand mixing.
- Use concrete mix within 30-45 minutes after adding water to the mix.

Concrete Placing

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- Mixed concrete should be placed within 45-60 minutes of mixing with water.
- Start placing the concrete from one end to complete another end.
- Concrete should not be spread out or dropped from more than 1.5m in height.
- should not be segregated while placing.
- should be compacted and leveled immediately after placing.
- should not be compacted or vibrated after 5 minutes of placing.

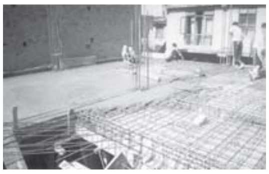

Photo: NSET, SESP

- No concrete should be poured until all reinforcing that is required for the pour is in place.
- Sufficient transporting equipment, clean and in good working order, should be on hand before work is begun. Thoroughly clean forms before placing concrete. Dampen masonry and porus earth to be in contact with the concrete.
- Place concrete as continuously as possible until pour is complete so that no concrete is placed against concrete that has attained its initial set.
- Place concrete as near as possible to its final position. Prevent segregation. Use chutes as necessary. The maximum free drop should be five feet. Compact during placing with internal vibrators. Work around reinforcements, embedded fixtures and into form corners.
- Concrete that has obtained its initial set should not be placed in the forms and should be discarded. Retempering of concrete will not be permitted.
    - Use concrete within 45- 60 mins. after mixing with water.
    - Prevent loss of water from the ground or sub base .
    - While handling, care should be taken not to segregate the concrete particles.

Some Equipments

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Photo: NSET, Web

Compacting the Concrete

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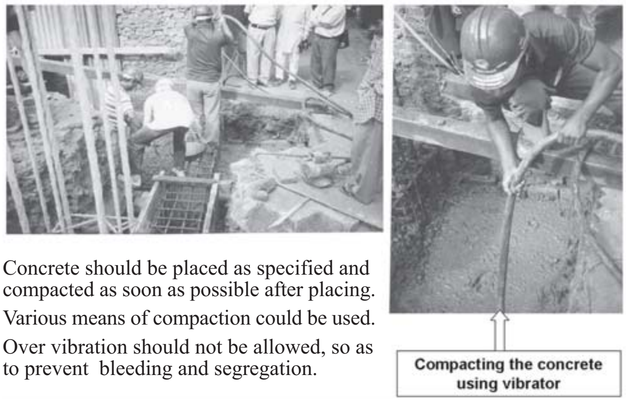

- Concrete should be placed as specified and compacted as soon as possible after placing.
- Various means of compaction could be used.
- Over vibration should not be allowed, so as to prevent bleeding and segregation.

Photo: NSET, SESP

- Use concrete with maximum time of within 1 hr.after mixing with water.
- Prevent loss of water from the ground or sub base .
- While handling, care should be taken not to segregate the concrete particles.

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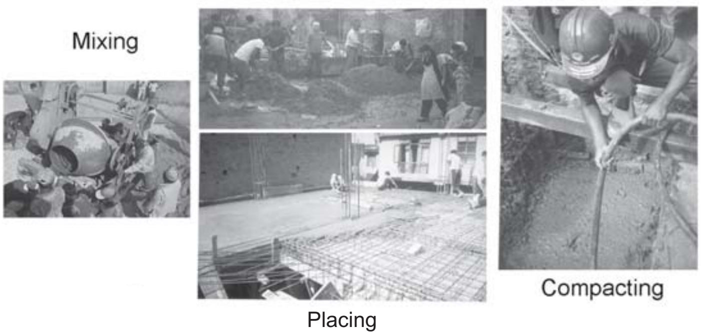

Photo: NSET, SESP

Concrete Curing

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Curing is most important in order to maintain the quality of work-

- The concrete surface should be kept wet or moist atleast for a week.
- It can be done by pounding or covering by jute bags.
- Water for curing should be as used for concrete mixing.

CONCRETE CURING AND FINISH

Maintain concrete in a moist condition for seven days after placement. Freshly poured concrete surfaces should be sealed with clear acrylic curing/sealing liquid membrane within 24 hours of concrete placement. Protect form injury from the elements until full strength is developed. Repair damage/vandalism occurrences as needed.

Formwork Removal

Removal of forms for different elements.

- For vertical members – not earlier than 48 hours.
- For sides of beams, slabs etc- after 24 hours.
- For beams span up to 4.5 m- after 13 days and above 4.5m span - after 17 days.
- Slab- up to 4.5m span : after 11 days
  - Over 4.5m to 6m span: after 14 days
  - Over 6 m span: after 17 days as approval from engineer
  - Cantilevers- after 7 days.

Service Lines

1. Electricity line
2. Plumbing (Water supply and sewerage)
3. Telephone cabling
4. Gas pipe line

Power Supply Line

- Cables: Standard manufacturer, quality assured, well insulated
- Cable laying: Protected from short circuit, possible fire hazard, safe for children,
- Fixtures: Standard manufacturer, quality assured, properly clamped and fixed, hanged fixtures to be assured of fixity.
- Control boards: As per design, of higher quality, height not to reach by children, protected from moisture.
- Auto fuse system
- Switches, sockets and all the fixtures –not to reach by children.
- Be sure of well functioning
- Maintain alarming system in case of short circuit, fires etc.

Plumbing / Water Supply and Sewerage

- Good quality of materials such as pipes, fittings, couplings etc.
- properly connected, no water leakage should be allowed
- Maintain proper head for water supply, bed slope and sufficient bed cushion for drainage pipes
- Sufficient pressure resisting capacity
- Proper clamping of pipes.
- Maintaining flexible joint connections at critical locations
- Construct chambers at every bends for sewerage line in order to reduce chances of blocking.
- Be sure of well functioning

Plumbing / Water Supply and Sewerage

- Provide pressure and air release valves for water supply pipe lines.
- Maintain air vents for sewerage lines
- Overhead water storage tanks should have of standard quality
- Tanks resting on the roof should be fixed and clamped properly.
- Water pumps properly fixed and clamped should be protected from rain, maintain proper air circulation and cables well insulated.
- Provide rain water outlet pipe to protect walls from dampness.

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Module 3 / Session 1

Repair and Maintenance of Existing Buildings

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Learning Outcomes:

Upon completion of this session the participants will be able to:

- Explain the importance of timely maintenance of structural and non-structural elements and utilities
- Able to carryout the maintenance of structural elements

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Rationale

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- Timely repair and maintenance help to remain the original capacity of the buildings
- Defects seen in a building if not repaired or maintained in time the capacity of building further goes on decreasing

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Common Problems in Buildings

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- Cracks
- Dampness
- Bulging and delaminating of walls
- Settlement of buildings - cracks
- Foundation settlement
- Roofing / Slab
- Wearing of surface

Key Issues

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- Identify whether the problems seen are structural or non-structural
- All the defects may not necessarily be structural; they may not be dangerous in some cases

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Common Defects in Masonry Buildings and their Corrective Measures

Diagonal Cracks at Corners of Openings

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Inspection

- Cut ‘V’ grove along the cracked line and remove surface finish and loose materials
- Make it clean
- Identify whether the cracks are structural or surfacial
- If cracks do not appear beyond external surfacial finish, it is called surface defect and not so serious
- If the cracks appear beyond surface finish, then it is structural cracks and might be serious and need structural assessment by qualified structural engineer.
- Prepare flow chart assessment and work accordingly.

Photo: NSET, Chamoli Earthquake, India

The first priority is to identify the cause of any cracking or damage.

Some repair jobs might be simple and straight forward requiring only a day of time to complete. Other jobs might be a lot more involved with major work being necessary together with the coordination of structural engineers.

Cracks

Surface cracks

Though surface cracks may not affect the functioning of the building or parts, it may lead to serious defects if not repaired in advance. Therefore it is also necessary to maintain its original form and functioning.

- In this case, remove all the defected surface, clean exposed and loose materials
- Choose appropriate materials
- Prepare fresh materials and apply new surface finish coat
- Overlaying of new material over defected existing surface shall not be allowed.

Repair of Damanged Floor and Roof

If surface cracks are seen on rigid floor, it shall be repaired immediately, otherwise it will lead to seepage.

- Check the cracks and remove all damaged and loose materials
- Roughen the surface, Wash and clean properly
- Apply neat cement grout, then apply 20 to 25 mm thick cement screed of not lower than 1:4 c/s mixing with appropriate proportion of water proofing admixture, then apply surface finish as desired
- It is also called wearing coat.
- Keep the surface wet at-least for 4 days
- Making small blocks on top finish allows moisture to evaporate and extends the service period.

Cracks

Structural Cracks

If the cracks appear beyond surface, it is called structural cracks. These cracks may lead to serious damage on structure in and also affect on well functioning of the structure.Structural cracks appear when the elements are incapable of resisting forces and stresses acting on to it. If one structural element is defective, it may cause defect to other elements too, if not repaired in time. Therefore it is most important to re-strengthen the defective elements as soon as possible to restore its capacity of withstanding the forces.

Walls

- Remove all the external plasters along the crack line and rack out the cracked surface up to a depth of 10- 25mm.
- Find out the cause of cracks. Check the foundation if any unequal settlement is there.
- If it is minor structural cracks, apply cement grout and fill the gap properly.

Photo: NSET (Web site)

Cracks

Photo Courtesy: AEC, Siddhi Sahr,T es

Cracks

- If these are major cracks, replace part of defected element constructing new one.
- It shall be done part by part.
- While removing in parts, provide temporary supports before removing it and be careful of stability of other parts too.
- If any foundation settlement is there, it is necessary to improve the foundation before repairing the wall.
- Underpinning is one of the process of foundation improvement

Underpinning

- Remove the earth that covered the foundation and clear out the sides.
- It shall be done in parts, shall not be cleared out the whole.
- Provide additional support to the existing foundation, provide more depth and width as required.
- Improving foundation is more technical job so need to involve experienced technical personal.

Repair of RCC Slab

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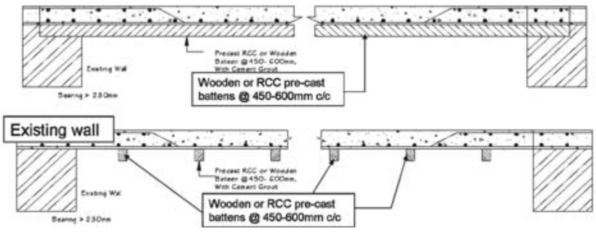

- Inspect the damaged slab.
- Make groves to insert pre-cast battens.
- Insert the battens just below the slab, resting on existing wall to support the slab and grout with cement mortar and apply plaster with 1:3 c/m of 50mm thick.

Illustration: NSET

Repair of Flexible Roof

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Leakage on flexible roof

Roofing system shall be regularly inspected and identify the causes. These leaks shall be repaired immediately otherwise it will case serious damage to the building.

Effects

- Seepage from roof
- Deterioration of surface coating (Interior as well as exterior)
- De-bonding masonry units
- Damage on structure- mucking of wooden members and corrosion of metallic members, reinforcement
- Loosing out nails and bolts

Photo: NSET (Web site)

Repair of Flexible Roof

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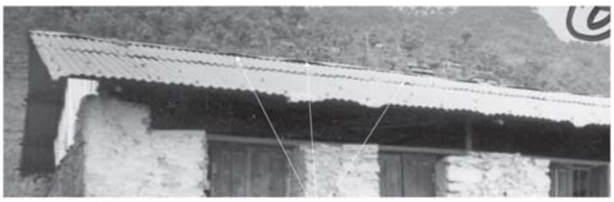

Points of leakage/ wall partially damaged by moisture

Repairs

Identify the points and area of leakage

- In case of clay tile roofing, remove damaged or de-bonded tiles, and seal properly
- In case of CGI sheet roofing, replace damaged sheets, put washers on fastenings, check the overlapping and re-build. If leakage is from small holes or from the fastenings, apply tar coal and seal the leakage

Photo: NSET, Sindhupalchwok

Repair of Damaged Roof

Repair of damaged beam

- Cracked structural elements or deteriorated reinforcement can be repaired by guniting.
- Remove plaster, roughen the surface, open out the cracked surface to maximum depth possibly in 'V' shape, surface cleaned of all loose mortar and foreign matter.
- Reinforcement bars cleaned to remove all scales and rust by wire brush and rubbing with emery paper.
- Coat of neat cement slurry shall be applied on the existing reinforcement before guniting.
- Eject guniting mixture (cement and sand) 12 to 50 mm thick under a pressure of 2 to 3 kg/cm^2.

Dampness

Dampness

On floor and wall

The most common type of damp is **rising** moisture from the ground, it rises by capillary action up the walls on ground floor.

- Moisture seen on the wall surface raising up
- Masonry bricks deteriorated
- Internal decorations are stained and damaged, plaster can debond and become loose.
- Floors cracked and damaged, settled down or lifted up partially

Dampness

Dampness

Types of Damp

- Damp patches on ceilings may be caused by leaking plumbing system or rainwater penetration.
- Damp penetrating from outside will appear only on external walls. Penetration may be apparent near windows or close to gutters or rainwater pipes.
- Try to establish whether the damp appears only when it rains or all the time.

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Dampness

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- Rising damp is caused by water from the ground penetrating damp courses. Signs include peeling wallpaper, lifting floor tiles and discolored patches on lower walls.
- Condensation is caused by water from the air coming into contact with a colder surface. It is recognizable by water drops on windows, mirrors etc, and sometimes mould patches on walls and ceilings.
- Condensation is the third type of damp. This is usually caused by the lifestyle of the occupants, rather than a defect with the property. Lack of ventilation and a tendency to use the radiators for drying clothes are common causes.

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Dampness

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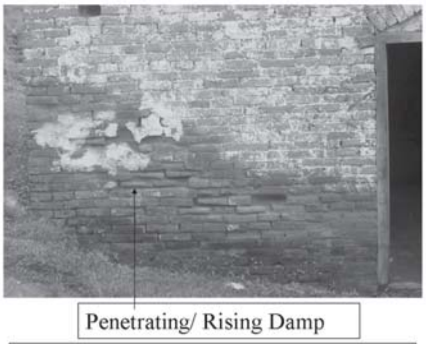
Dampness caused by continuous weathering deteriorates the masonry units and bonding materials.

- Apply protective coating over the existing surface before affected by damp



Lower part of wall damaged due to dampness

Photo: NSET, SESP

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Dampness

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Penetrating damp

It is caused by moisture which penetrates through the roof or walls. Roof problems are usually evident. Damp penetrating through walls, which includes flashings at roof is usually quite evident, but it is usually very difficult to pinpoint and cure the precise cause of the problem and very often there is no quick or easy solution.

Penetrating damp can sometimes be caused by gutter or roof problems which allow rainwater to spill onto and saturate areas of wall.

Condensation

It is the third type of damp. This is usually caused by the lifestyle of the occupants, rather than a defect with the property. Lack of ventilation and a tendency to use the radiators for drying clothes are common causes.

Countermeasures for Dampness

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Repair of Damapness

1. Raising damp

- Repair existing damp proof course by injection or grouting.
- Repair existing floor using water proof compound.
- Provide plinth protection (Apron) work all around the exterior wall.
- Maintain surface and rainwater drainage with proper slope.
- Raise the existing plinth level (floor level) and remove the earth minimum to bottom level of DPC or plinth beam.
- Prevent the surface water to penetrate to the foundation and plinth.
- Remove already mucked plaster surface and apply with new material mixing water proofing agents.

Photo: NSET, SESP

Countermeasures for Dampness

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Repair of Dampness

2. Penetrating Damp

- Prevent rain water to penetrate from roof.
- Provide gutter and rainwater pipe to guide the rainwater towards drain.
- Provide roof projection outwards to the wall
- Apply surface coat of cement plaster with water proofing agents to protect the masonry units and prevent moisture to penetrate interior surface
- Allow the rainwater to drop outside the apron and guide towards drain with proper slope.

Photo: (Top) NSET

Countermeasures for Dampness

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Repair of Damp on Ceiling

- Check the roof, plumbing line of bathroom and Water Supply line passing over roof and floor
- Remove all the finishes over and below the concrete surface and clean properly
- Apply neat cement grout with water proof admixture over the top surface.
- Apply protective coat of minimum 20 mm thick over it
- Let it harden and keep moist by pounding.
- Check weather patches are seen on the ceiling. If not apply surface finishes over and below the surface.
- If patches are seen, employ injection check and apply finishes

Photo: NSET, SESP

Countermeasures for Dampness

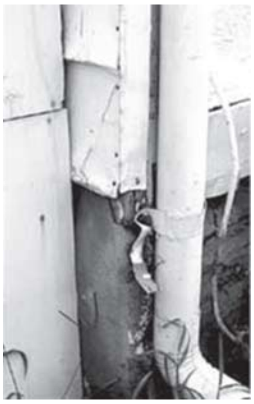

Photo: NSET (Web site)

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Module 3 / Session 2

Retrofitting of Existing Unreinforced Masonry Buildings

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In this presentation we will discuss about seismic retrofitting of unreinforced masonry buildings. We will cover what it is, why it is required, what are basic approach and methods and then elaborate few of the methods.

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What is Seismic Retrofitting ?

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Seismic Retrofitting is Strengthening of Existing House to Improve their Seismic Resilience

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Why Seismic Retrofitting ?

- **Unreinforced masonry buildings are major source of casualty and economic loss in an earthquake event.**
- **Improve seismic resilience -** retrofitting significantly improves buildings' seismic resilience
- **Achieve fail-safe damage -** delayed collapse, if it happens, allowing residents to escape during an earthquake
- **Achieve reduction in the likely damage -** allowing post-earthquake repair and re-strengthening at nominal costs

Most unreinforced masonry (URM) building are highly vulnerable because of weak construction materials, deficient technology. These contribute to major earthquake casualty and economic losses. More than 75% of human casualty can be attributed to unreinforced masonry buildings. it has high probability of sufferring major damage in even in next minor to medium earthquake unless their seismic resilience is improved.

It is economically not possible to improve seismic resilience of URM buildings to codal requirements and it is obvious these may suffer major damage-partial to total collapse-in major event, these can survive medium events. These medium events are more frequent than the major one so these are of major concern for URM houses. Even in large events, the retrofitting measures will delay the collapse time thereby giving time to escape.

Another incentive of retrofitting is that it helps buildings to reduce likelyhood of total collapse during the earthquake and limit the impact to "repairable damage". The repair can be done at nominal cost with local efforts after an earthquake because it will most likely not collapse.

Problem Identification

- Major problems in masonry buildings:
  - Lack of integrity
  - Lack of diaphragm action in timber floor and roof
  - Low shear strength of walling materials
- Configuration problem
  - Plan shape too elongated or with large wings
  - Too many openings
  - Unbalanced openings (too many or big openings in one side)

Major problem of large majority of URM houses is integrity. Practically these does not exists much connection between orthogonal walls, walls and roof or walls and floor. Furthermore, there exits hardly much connections between components of floor or roof among themselves. So these houses are more stacking of materials rather than a sound structure in most of the cases (particularly the traditional houses with timber floor and roof). It is further compounded by weak shear strength of URM.

Because of lack of connection between components of timber floor and timber roof; lack of bracing elements in timber floor/ roof, floor and roof could not provide any in-plane stiffness.

Plan shape or too many openings is not a major problem, in general, in traditional house construction. However, it is becoming a problem in houses with modern construction materials.

Unbalanced openings on different faces of walls is one big problem. Usually, many openings are kept in front and no openings in the back. It makes front much softer than the back wall. It makes building tortionally active.

Basic Solution

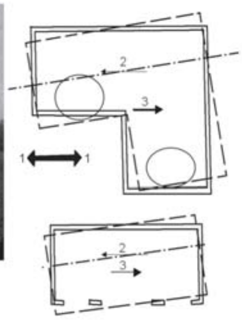
- Improve integrity between different building components:
  - Between walls and walls
  - Between components of floors
  - Between components of roof
  - Between walls and floor
  - Between walls and roof
- Improve shear resistance of the walls
- Improve diaphragm action of floor and roof

Integrity between different building components is the major problem in URM houses constructed of traditional materials (mud, adobe, fired brick in mud, timber floor/or even modern materials (cement, reinforcing bars). It is the major issue that should be addressed whatever retrofitting method employed.

There is not much that can be done to improve shear strength of wall itself unless the walls are grouted. However, the retrofitting method employed may increase shear strength of walls up to an extent.

Improving the in-plane stiffness and strength of the floor and roof and their anchorages with all the walls significantly improves the seismic resilience of the house.

Improving the Configuration

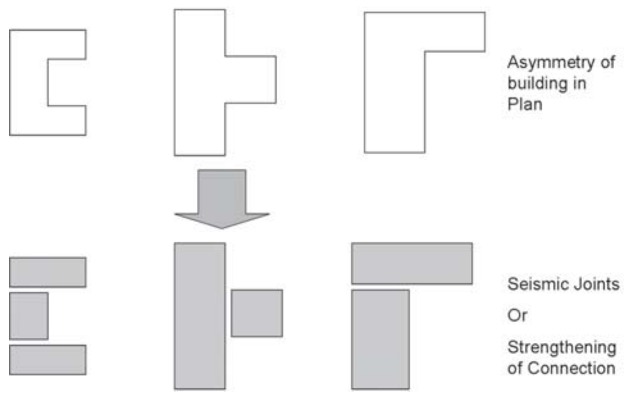


Symmetrical buildings in plan and elevation are better than asymmetrical ones.

Photo Courtesy: TAEC, 1988 Udaybpur Earthquake, Nepal & Illustration: NBC

Large wings and asymmetry in plan causes torsional effects and causes stress concentration and higher damage.

Wings and Symmetry



Unsymmetrical plans can be made symmetrical by breaking building in parts.

Unbalanced Openings

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Photo Courtesy: NSET, Dushanbe, Tajikistan

The picture shows a house with a lot of openings in the front where as no openings in the back. It causes torsional effects there by higher stresses in the corner piers, consequently higher damage.

If the openings are unbalanced (more on one side), the problem can be solved by closing or reducing size of few of the openings. Alternatively, the problem can be addressed by making new openings on the opposite walls or mix of above.

Damage Due to Inappropriate Openings

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Shear diagonal cracks to a building from openings and at corners also lead to collapse during earthquake

Photo Courtesy: Left - IAEE, & Right - NSET, Dshanbe, Tajikista

As shown in the picture, too much openings are sources of weakness. The openings decreases effective wall plan area thereby reducing strength and stiffness of the house.

If there are too many openings as shown in second picture, the problem can be solved by reducing size of openings or closing few of the openings. When doing so, the new material should be well integrated with the original material.

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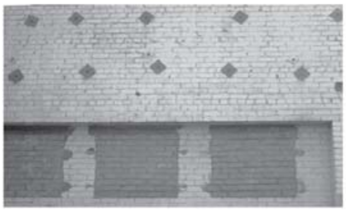
Retrofitting Methods

An URM house can be retrofitted employing different method. Among different methods splint and bandages jacketing of all the walls, beam-column caging of the house, bolting and prestressing are few of the methods to improve vertical structure. These all improve seismic resilience of walls and each method have their pros and cons. Besides above methods, improvement of floor and roof structure is also a must.

Different Retrofitting Techniques ...



Bolting of walls

Jacketing of walls

Photo Courtesy: EERI

Here first photograph presents method for improving integrity of a house using bolting method. These bolts are anchored to wall of other sides. Also note, windows are filled up with new walls to improve strength.

The second photograph presents jacketing technique for strengthening of a unreinforced masonry house. Here all the wall are covered with steel bars. It will be covered with micro concrete.

Different Retrofitting Techniques ...

Beam-column caging

Splint and bandage

Photo Courtesy: NSET

Here, first picture presents a house retrofitted with RC beam and column caging where as second picture is of splint and bandage methods. Splint and bandage is economic version of jacketing.

Different Retrofitting Techniques ...

Photo Courtesy: EERI

Here first picture presents strengthening of a house employing diagonal bracing.

The second picture presents strengthening using vertical bracing.

Different Retrofitting Techniques ...

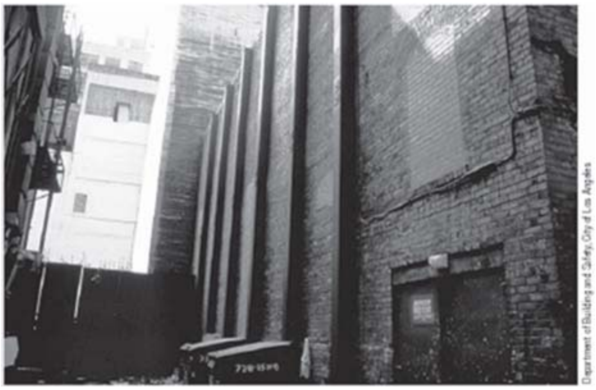


Photo Courtesy: EERI

In this picture wall is strengthened using vertical columns to improve out-of-plane behavior of masonry.

Different Retrofitting Techniques ...

Building and safety. pdf, EERI slides

Plywood diaphragm

Photo Courtesy: EERI

These two pictures presents two techniques to improve floor stiffness and their integrity with vertical-lateral load resisting structure.

In first technique, ties are used where as in second plywood has been used.

Different Retrofitting Techniques ...

Photo Courtesy: EERI

This picture presents strengthening of parapet wall using bracing. Parapet walls are among the first to collapse in an earthquake.

More Methods of Retrofitting

- Steel beam-column caging
- Bolting and prestressing
- Jacketing of walls

Splint and Bandage System of Retrofitting of Masonry Walls

Hereafter we will focus on splint and bandage method for retrofitting of URM house. In addition to it, we will also discuss stitching of the walls, improving floor and roof. First we will try to identify what are the sources of the problem and then we will discuss the possible solutions.

Wall Separation

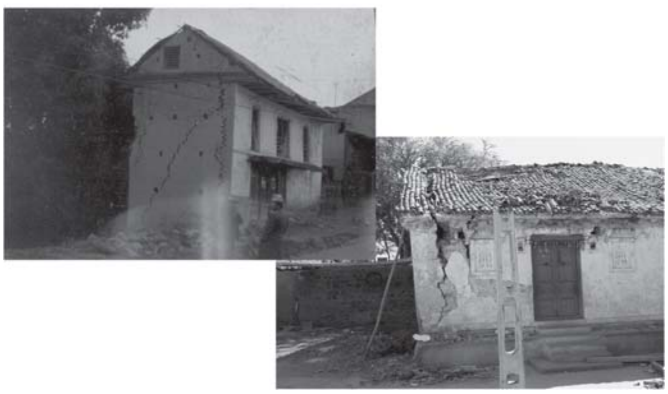


Photo Courtesy: Top - TAEC, 1988 Udaypur Earthquake, Nepal,
Bottom - NSET 2001 Bhuj Earthquake, India

Connections between orthogonal walls are among the weakest links in the URM houses. These weak connections can not hold out-of-plane walls during an earthquake leading them to collapse. Once the floor/ roof carrying walls collapse, obviously the floor and roof will collapse leading to total failure of the building.

Common Defects in Masonry Buildings

Corners in masonry buildings are inherently week and first suffer from horizontal force during Earthquake.

Photo Courtesy: EERI

This picture shows toppling of wall due to weak wall connections though the building was constructed of stone in cement mortar.

It shows vulnerability of a house just due to few weaknesses. Just by improving this weakness the strength of the house can be significantly improved.

Common Weakness at Corners

Toothing as our construction practice make the building inherently weak at the corner

Photo Courtesy: NSET, Bhairhawa

The weak wall junctions are result of wrong method of wall construction. It is common practice to leave toothing for construction of orthogonal walls. What happens is when orthogonal walls are laid, the mortar can not be filled between bricks at the connections.

In addition to it, wall junctions are location of stress concentration. These need special attention.

Wall Stitching at the Corner

Photo Courtesy: NSET, Kathmandu

The connection between orthogonal walls can be strengthened by installing stitches between orthogonal walls. The stitches can be installed

- by drilling a hole at the junction penetrating orthogonal walls. The hole can be filled with cement-sand grout and then inserting the steel bar in the hole forcefully.
- alternatively, the bricks can be taken out as shown in the picture. Steel bar can be installed in the recess and the recess can be filled with the concrete.

Corner Stitch Detail

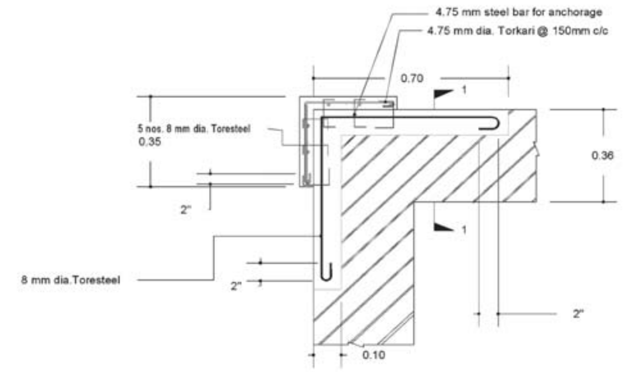
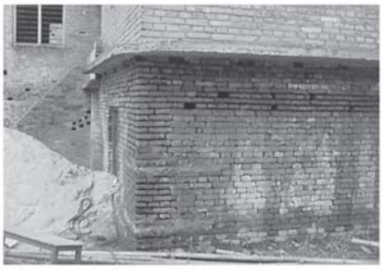


Illustration: NSET

This picture presents the details of corner stitch.

Corner Stitch after Casting



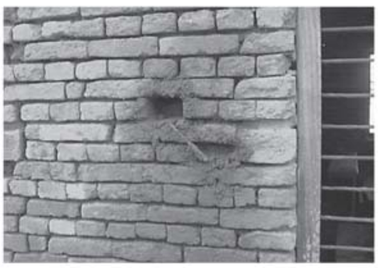
Stitch on outer face

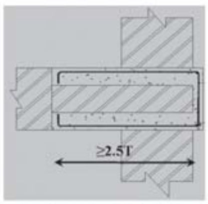
Stitch on inner face

Photo Courtesy: NSET - School Earthquake Safety Program

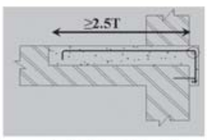
These pictures show completed corner stitches. Corner stitch on one face of the wall is good enough.

Wall Stitching at the T-Junction





For 1 and half brick thick wall



For 1 brick thick wall

Photo Courtesy: NSET - School Earthquake Safety Program

The picture and drawings show stitching at the T-junctions.

Casting of Stitch


Be careful when compacting concrete

Photo: NSET, SESP

When compacting concrete in the recess, special care shall be exercised to fill up the recess.

Long Walls

Photo Courtesy: TAEC, 1988 Udaypur Earthquake, Nepal

This picture shows a house with toppled wall, however the end of the wall are intact. It is because the end connections are strong which are constructed using long stones. However, the central part of the wall toppled because of large unsupported length. The situation can be avoided either increasing wall thickness or providing buttresses at some distance.

Buttress Walls

Photo: NSET

If the free wall length is more than 6 m in weak mortar, or more than 9 m in cement mortar, buttresses should be provided in between. These buttresses should be well integrated with the wall.

It should also be noted free height of wall in weak mortar shall not be more than 10 times the wall thickness.

Cracking of Walls

Photo Courtesy: Left - NSET, Right - NSET 2001 Bhuj Earthquake, India

If the free length between cross walls is large and end connections of the wall with orthogonal walls is good then out-of-plane wall fails in bending as shown in first picture. To avoid it, bands are required. In new construction, new bands can be installed during construction, however, in old construction **bandages** can be employed just above the windows.

The second picture shows how cracks start from opening corners and are extended to wall ends. Unless these pieces of brickwork are hold, these will disintegrate in subsequent shaking. These can be hold by confining windows and providing **splints**.

Micro-Concreting

1 cement : 1½ Sand: 1½ Chips

Photo Courtesy: NSET - School Earthquake Safety Program: Upayogi Primary School, Kathmandu

This picture shows first stage of bandage construction (horizontal elements above window), splint (vertical elements at the wall corners) and confining of windows to avoid significant cracking.

For it the wall mortar needs to be racked, may be 20 mm, and bricks be cleaned. Then the walls can be plastered with micro-concrete (one cement: one and half sand: one and half chips) where new elements are intended.

The surface of the plaster should be kept rough to provide good anchorage for second coat of plaster.

Curing of Concreted Area

Use of Jute bags / mats for better curing

Photo Courtesy: NSET - School Earthquake Safety Program: Upayogi Primary School, Kathmandu

Curing is most important activity for any concrete work. Just by spraying water, as most commonly done, concrete can not be well cured. It is better to hang sacks on the concrete and keep it wet. It continually cures concrete.

Steel Bars at all Bandages and Splints

Photo Courtesy: NSET - School Earthquake Safety Program: Upayogi Primary School, Kathmandu

This picture shows how bars are laid for splint and bandages. These bars needs to be nailed to the wall to keep them in position.

Outer and Inner Bandages are Connected in Certain Interval

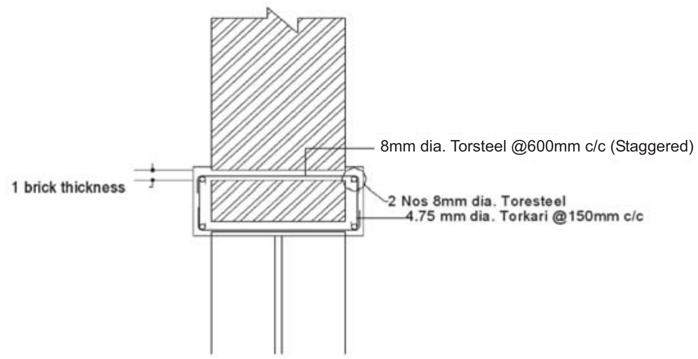


Illustration: NSET

This picture presents a schematic view of bandages and their connections.

Splint Starts from Foundation

Photo Courtesy: NSET, Kathmandu

This picture shows a blow-up of splint reinforcement and presents how these reinforcements should be anchored in foundation.

After laying steel reinforcements, these are covered by second coat of plaster. Mixture of this plaster is same as first coat of plaster.

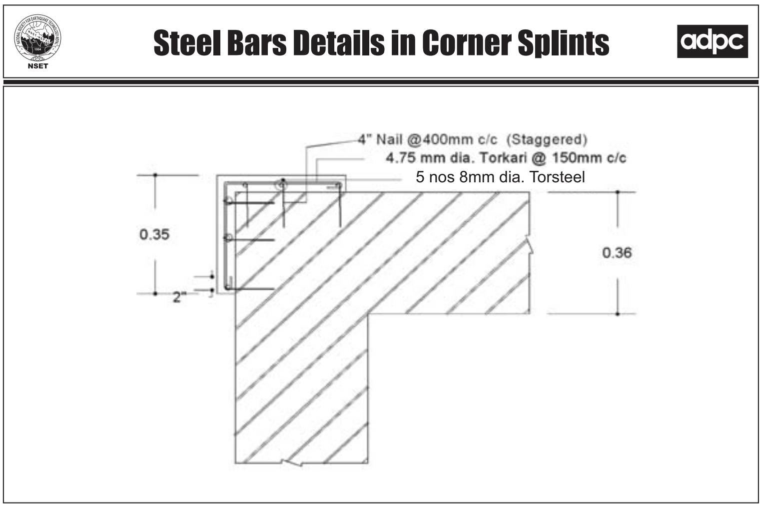


Illustration: NSET

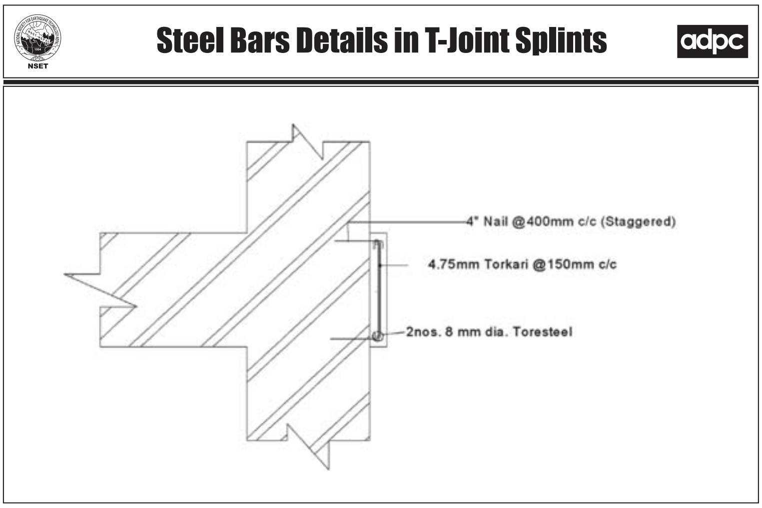


Illustration: NSET

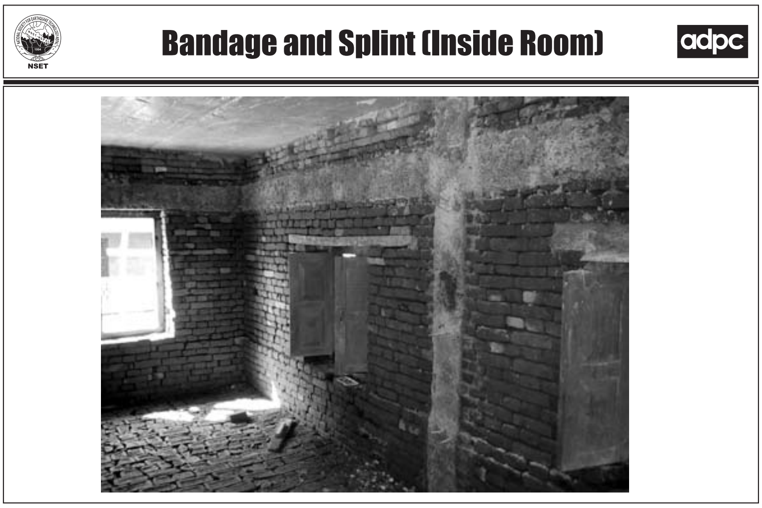


Photo Courtesy: NSET SESP, Kathmandu

The bandages are provided on both the faces of the wall and are tied up together by dowel bars. These dowel bars pass through the walls at around 900 mm center to center staggered and are tiled up with the bandage reinforcement.

Splints are provided on only external face at corners and wall junctions. However, here in the picture splint is visible on internal face as well. In fact, this splint has been provided on both the faces to reduce free horizontal length of the wall.

Bandage and Splint (Inside Room)

Photo Courtesy: NSET - School Earthquake Safety Program: Upayogi Primary School, Bahktapur

This photograph was taken after completion of the retrofitting work. A wall bracing is visible in first story wall. There has been many vertical joints in this wall which could have split during an earthquake shaking. This bracing has been constructed to avoid this splitting.

Furthermore, these sacks are hanged on the concrete elements to avoid drying and curing of the concrete elements.

Retrofitting Techniques for Masonry Buildings

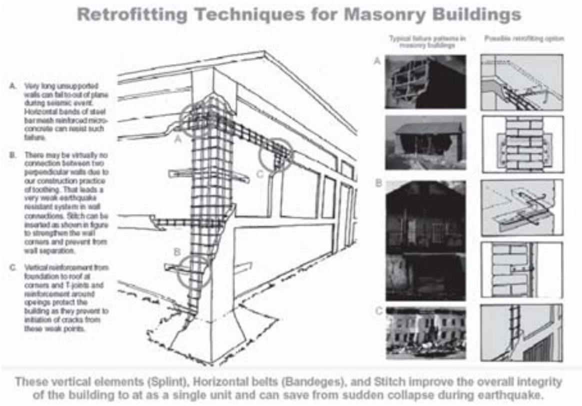


Illustration: NSET Fliers

This schematic diagram presents what we have talked till now. These measures are good for building with reinforced concrete slab as floor and roof. If floor and roof are constructed of timber, these need more measures to improve their integrity and connections with walls.

Strengthening of Floor and Roof

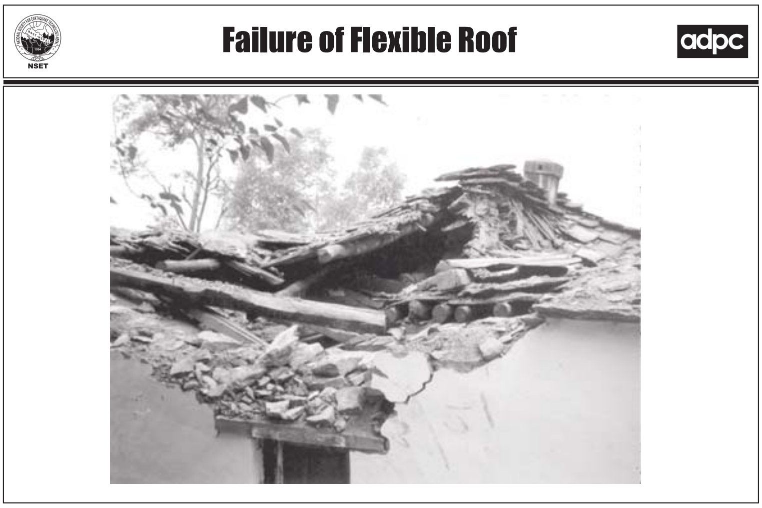


Photo Courtesy: NSET 1998 Chamoli Earthquake, India

The major cause behind failure of roof or floor during an earthquake is lack of integrity between the components of these structures. The picture shows how elements of roof have slide off their original position. Clearly there seems no integrity between them. This damage is further enhanced by heavy load of these structures, lack of integrity between roofing elements.

If the beams, joists, rafters, purlins and other floor / roof elements are not properly tied with walls or columns and are not made rigid, they may slide from their original position and floor and roof may collapse.

Few examples of roof collapse during past earthquakes are shown in the photographs. In these pictures, the roof has collapsed due to the sliding and failure of supporting elements like rafters, purlins and ridge poles.

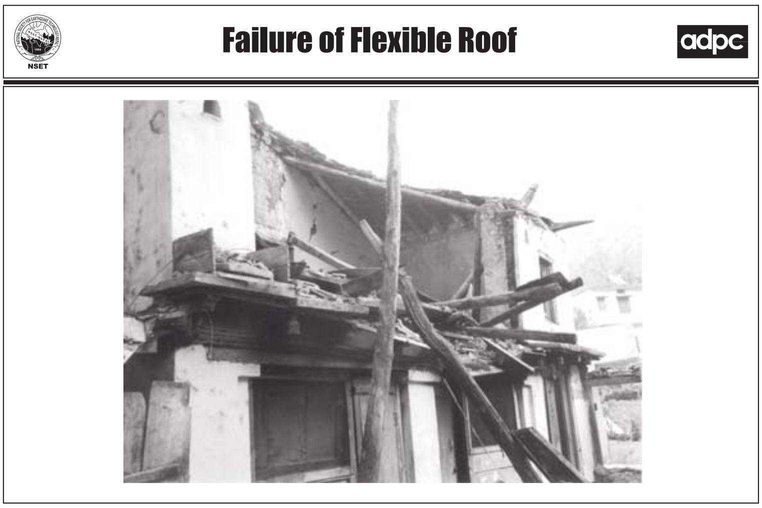


Photo Courtesy: NSET 1998 Chamoli Earthquake, India

This is another example of failure of flexible roof during earthquake.

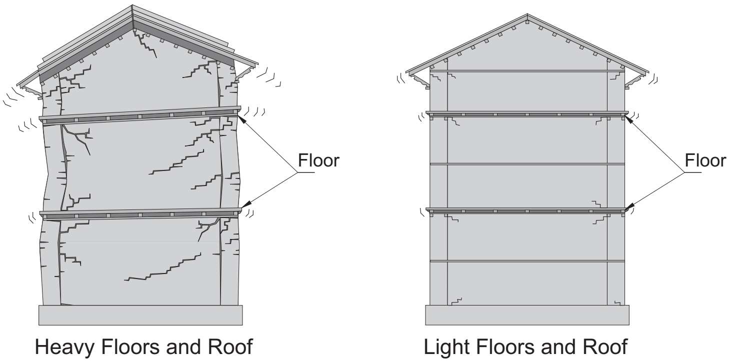
Failure of Flexible Roof

Photo Courtesy: NSET 1998 Chamoli Earthquake, India

Roofs and floors collapse also due to the lack of structural integrity between different floor / roof elements very little bearing of joists/rafter. Different elements are normally just placed one over another without any anchorage in their joints.

The rafters and purlins shift from their position mainly due to no or low bearing length into the walls or wall plates and no proper connections between wall and rafter.

Light Floors and Roofs



More damage in a building with heavy floors and roofs

Illustration: NSET Archeological Guidelines

Building with heavy floors/roofs is subjected to higher seismic force as compared to that in a building with light floor/roofs. This higher seismic force causes more damage in the building. Figures show more cracks and damage due to heavy floors and roof than in light ones.

Light Weight Floors and Roofs

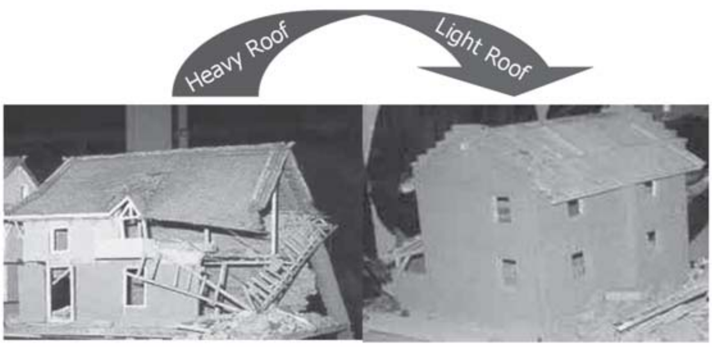


Photo Courtesy: NSET Shake Table Demonstration

Buildings should be as light as possible in order to be more seismic-resistant. The practice of laying thick layers of mud to achieve a firm floor/flat roof is common. This increases the overall building weight and it will be subjected to high seismic force. Therefore, thickness of the mud layer used for flooring/ roofing should be kept as small as possible. Reducing the thickness of mud layer can reduce the overall weight of a building significantly. Using light flooring and roofing materials in place of heavy materials can also reduce the weight. For example using CGI sheet roof instead of using tile or *jhingati* roof will significantly decrease the weight of the roof.

Connecting Floor Joists with Wall

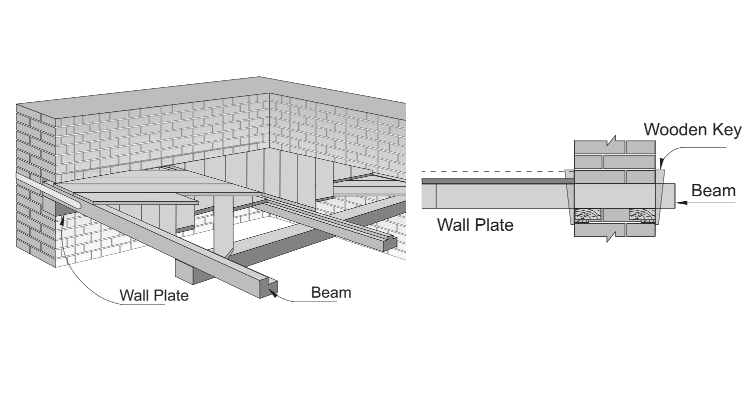


Illustration: NSET Archeological Guidelines

The base pad provided below the wooden beam is called the wall plate. Wall plates are provided in the walls so that wooden beams can rest over it and the floors can be made more rigid by providing shear keys or anchors. In case of timber wall plates, shear keys as shown in the figure are provided at both inside and outside of the walls and in case of concrete pad, hooks or anchors are provided.

Floor Bracing

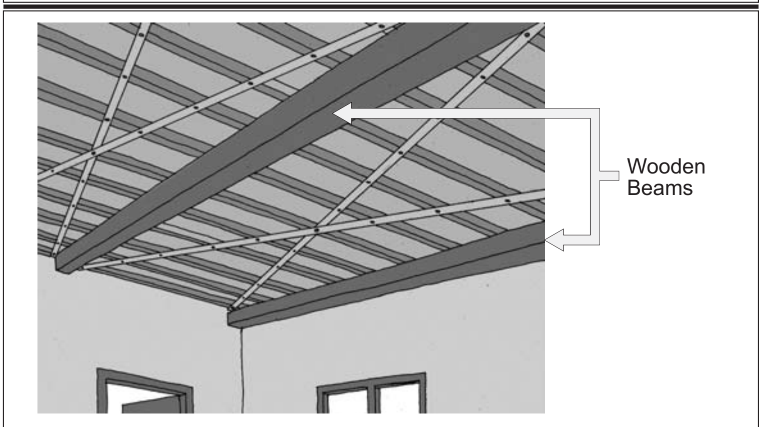
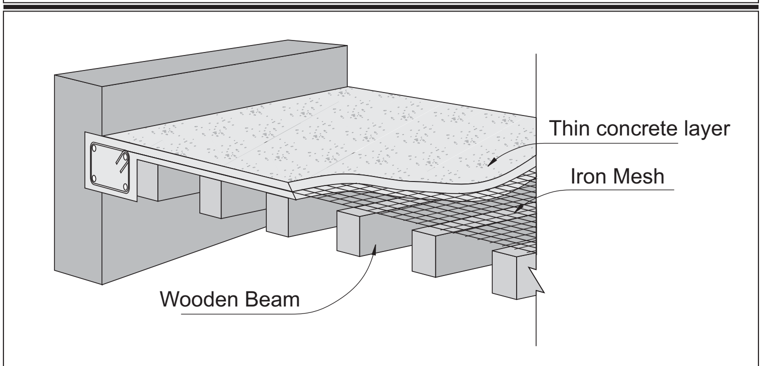


Illustration: NSET

Beams are main structural elements in a flexible floor and wooden beams are most commonly used. Beams take the loads from floors and transfer it to the walls or columns. If these beams are not properly connected with floor joists and the supporting walls it can not properly transmit the loads. Therefore while constructing beams following important points should be considered.

Alternative Method of Floor Stiffening



Thin layer of concrete over iron mesh can also be an alternative solution to make the floors stiffer.

Illustration: NSET Archeological Guidelines

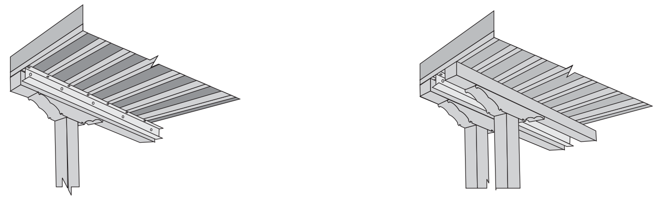
Another alternative method of floor bracing and providing rigidity to the flexible floors is construction of thin concrete layer with iron mesh inside.

In this method, iron mesh is laid over the wooden planks, bamboo strips or wooden chirpats covering the whole area of the floor and then a thin layer of cement concrete is casted to make a thin rigid concrete slab. The iron mesh may be chicken wire mesh or welded wire fabric or mesh of smaller diameter reinforcing bars. For making concrete, smaller sized aggregates i.e. 12mm or down are used since the thickness of the concrete layer has to be as small as possible.

The floor should be well connected with the wall around by making recesses.

Posts and Capitals

adpc



If wooden posts are used to rest the floor joists, the joists should not directly rest above the post. There should be capitals above the posts and the joists rest above the capitals.

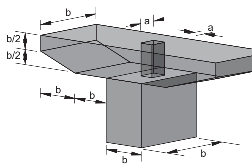


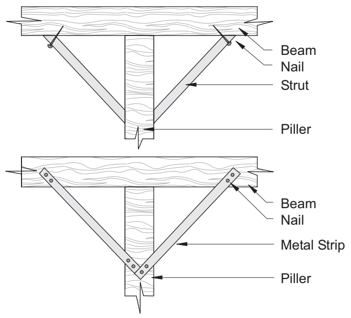
Illustration: NSET Archological Guidelines

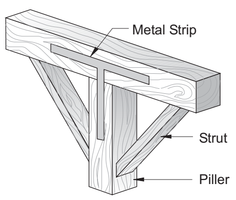
In traditional buildings we can see the timber posts as vertical as well as lateral load resisting elements besides the load bearing masonry walls. If timber posts are used as main load resisting elements, floor beams or joists should not directly rest over the timber posts. At the top of the posts wooden capital should be provided as shown in the figure and beams or joists rest above the capitals. The minimum required connection detailing of such capitals is as mentioned in the figure. In a building, there may be single post system or double post system, accordingly there may be single capital or double capitals as shown.

Struts

adpc

In place of capitals there may be struts





The capitals or struts should be well connected with the posts and the joists with keys, nails or metal strips

Illustration: NSET

In place of capitals, inclined timber struts can also be provided as shown in the figure. Joints between posts, beams and struts should be made strong by using metal straps, nails or keys and they should be well connected to each other. In some cases, metal strut can also be used in place of timber struts.

Connecting Rafters and Wall

adpc

No connection between floor elements and walls

Photo Courtesy: NSET, Kathmandu

No proper connection of different flooring elements like beams, joists with the walls makes the floor flexible and can easily collapse due to sliding and falling of the members.

Rafters

- Rafters should also be long enough to extend beyond supporting members such as walls and/or beams.
- The extended rafters should have timber keys on both external and internal sides of the supporting elements.

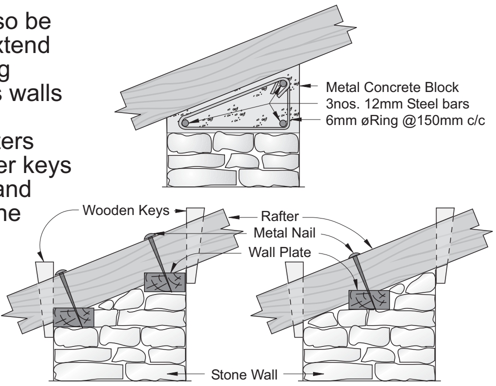


Illustration: NSET

Similar to beams, rafters should also rest on wall plates or bands. They should also be long enough to extend beyond the supporting walls so that they can also be tied with the wall plates by using shear keys on either sides of the walls or nails or anchors.

Proper Connection at Joints

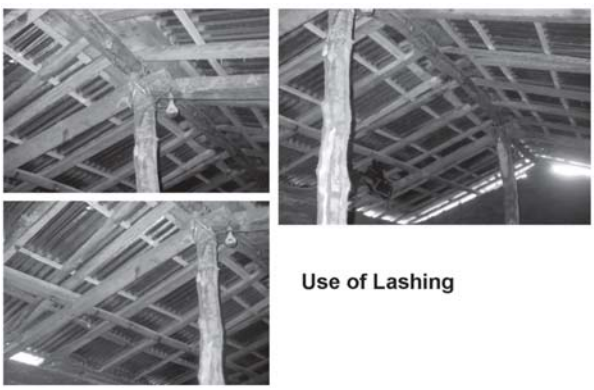
Each joint between two structural elements should be properly joined together by metal strips, nails or lashings

Use of metal strips and nails

Photo Courtesy: NSET, Kathmandu

There are many joints between different structural elements in flexible floors and roofs. If the joints between these elements are not properly connected, they can easily move from their position, fall down and hence the whole floor or roof fails. Providing bracings, wall plates etc. only can not make a floor rigid if the connections at the joints are not proper and strong. The joints can be made strong by use of shear keys, nails and anchors. Providing metal straps, nailing and lashings are also some ways of making the joints strong. Above picture shows the joint connection of floors joists by use of metal straps and nailing.

Proper Connection at Joints



Use of Lashing

Photo Courtesy: NSET, Sindhupalchowk

These pictures show the use of rope lashings/ wires at the joints between rafters, posts and the ridge beams. These help to improve integrity of roof structure.

Additional Strengthening

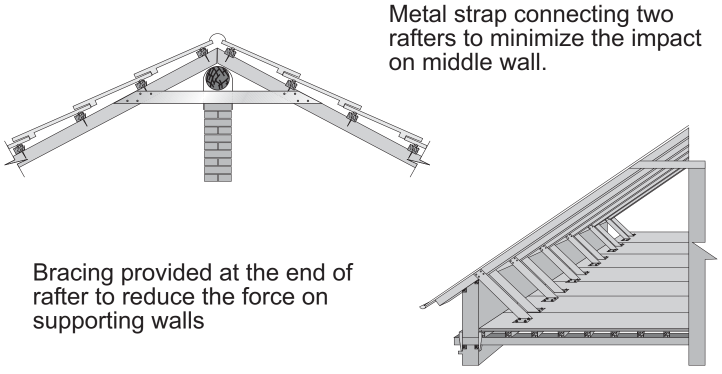


Illustration: NSET, Archeological Guidelines

In case of flexible roofs, some additional elements can be provided for increasing the strength. Horizontal wood strips could be nailed to rafters to improve integrity. These strips help to increase the rigidity of the roof .

Another extra strengthening element is bracing or strut provided at the end of the rafters. This additional bracing also contributes to make the roof more rigid and helps to reduce the force on the supporting walls.

Bracing of Roofs

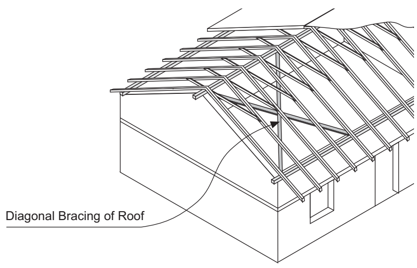


Illustration: NSET

Bracings are normally provided at the lower part of roofs as shown in the figures to stiffen the roof.

Bracing of Roofs

Photo Courtesy: NSET

The roofing materials should be well tied up with the roof structure. Otherwise it may slide-off the roof and cause casualty though the structure may survive.

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