SEISMIC VULNERABILITY OF THE PUBLIC SCHOOL BUILDINGS OF KATHMANDU VALLEY AND METHODS FOR REDUCING IT

A Report on

KATHMANDU VALLEY SCHOOL EARTHQUAKE SAFETY PROGRAM (SES)

OF

THE KATHMANDU VALLEY EARTHQUAKE RISK MANAGEMENT PROJECT (KVERMP)

Implemented by

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

In association with

GeoHazards International (GHI), Palo Alto, CA, USA

Under

Asian Urban Disaster Mitigation Program (AUDMP)

Asian Disaster Preparedness Center (ADPC)

With core funding from

USAID/ OFDA

NATIONAL SOCIETY FOR EARTHQUAKE TECHNOLOGY NEPAL (NSET-NEPAL)

GPO BOX 13775, Kha 2-731, Mahadevsthan, Baneshwor, Kathmandu Nepal
Telephone: (977-1) 474 192
Fax: (977-1) 490 943
E-mail: nset@nset.org.np

August 2000, Kathmandu, Nepal

Acknowledgements

Numerous individuals in various ministries and departments of HMG of Nepal, and the partnering institutions have been invaluable in providing guidance and information that have been important to the successful completion of the School Earthquake Safety Program (SES) of the Kathmandu Valley Earthquake Risk Management Project (KVERMP). Mr. Jaya Ram Giri, Secretary Ministry of Education provided valuable guidance and helped in the formulation of the program and the SES Advisory Committee. Mr. Kamal Prasad Lal Karna, Director, Central Region Education Directorate and Chairperson of the SES Advisory Committee provided overall program sponsorship and continual support. Messer's Ram Pyari Shrestha, District Education Office (DEO), Bhaktapur; Mr. Ashok Aryal, DEO, Kathmandu; Mr. Nayan Singh Dhami, DEO, Lalitpur, all provided important inputs as members of the SES advisory Committee, and assisted in the implementation of the program activities. Other officials of the District Education Offices of Kathmandu, Lalitpur and Bhaktapur districts provided valuable information on the public schools in the three districts of the Kathmandu Valley, and facilitated planning and conduction of School Headmasters' seminar as well as administration of the school survey.

Although many more people were contacted than listed above, the large number makes it impractical to include here. Nevertheless, their contributions to the successful completion of the project are greatly appreciated. In particular, we give sincere thanks to the hundreds of school head masters from Kathmandu Valley for enthusiastically participating in this program. Without their support, the success of this program would have been impossible.

Within the project team involved with the implementation SES Program, Dr. Brian Tucker, President GHI and Mr. Amod Dixit, General Secretary NSET jointly provided leadership. Mr. M. Nakarmi, KVERMP Project Co-Manager assisted by making contacts with individuals within the Nepali government to facilitate the collection of data and implementation of the seminars and meetings. Mr. Jitendra Bothara and Ms. Laura Dwelley-Samant worked ably as integral project team members. The success and completion of the project is directly related to the technical expertise and knowledge of structural / earthquake engineering that they brought to the program. Emeritus Professor Anand S. Arya of Roorkee University, India, who provided technical guidance and inspiration to the SES program, oversaw them.

Working Team for School Earthquake Safety Program (SES) of The Kathmandu Valley Earthquake Risk Management Project (KVERMP)

A. Management

S. No.	Name	Designation
1	Shiva Bahadur Pradhanang	President, NSET-Nepal & Project Principal, KVERMP
2	Amod Mani Dixit	Secretary-General, NSET-Nepal & Project Co-Director, KVERMP
3	Brian Tucker	President, GHI & Project Co-Director, KVERMP
4	Mahesh Nakarmi	Project Co-Manager, KVERMP

B. Technical Group

S. No.	Name	Designation
1	Jitendra Kumar Bothara	Structural Engineer, KVERMP
2	Laura Dwelley- Samant	Project Co-Manager, KVERMP
3	Bishnu Hari Pandey	Engineer, KVERMP/NSET-Nepal
4	Ms. Rinu Basnet	Engineer/Urban Planner, NSET-Nepal
5	Ram Chandra Thapa	Assistant Engineer, NSET/KVERMP
6	Prof. Emeritus Anand S. Arya, University of Roorkee, India	Advisor, Design/Supervision Consultant
7	Amod Mani Dixit	Project Co-Director, KVERMP

Acronyms

ADPC	:	Asian Disaster Preparedness Center
AUDMP	:	Asian Urban Disaster Mitigation Program
BW	:	Brick work
CS	:	Cement sand
DEO	:	District Education Officer
DPTC	:	Disaster Prevention Training Center
DMU	:	Disaster Management Unit
EAARRP	:	Earthquake Affected Area Reconstruction and Rehabilitation Project
GHI	:	GeoHazards International-USA
HFF	:	Himalayan Frontal Fault
IAEE	:	International Association of Earthquake Engineering
INGO	:	International non-governmental Organization
ISZ	:	Indus Suture Zone
KVERMP	:	Kathmandu Valley Earthquake Risk Management Project
MBT	:	Main Boundary Thrust Fault
MCT	:	Main Central Thrust Fault
MHPP	:	Ministry of Housing and Physical Planning
MSK	:	Medvedev-Sponheuer-Karnik earthquake intensity scale
NBCDP	:	National Building Code Development Project
NGO	:	Non-governmental Organization
NSET-Nepal	:	National Society for Earthquake Technology-Nepal
RC	:	Reinforced Concrete
RRM	:	Random Rubble Masonry
UNDHA	:	United Nations Department for Humanitarian Affairs
UNDP	:	United Nations Development Program
WSSI	:	World Seismic Safety Initiative

Executive Summary

Nepal's schools house one of the country's greatest assets: its future. Despite the high risk of earthquakes, school construction in Nepal has largely ignored issues of structural safety. This report presents the findings of the School Earthquake Safety Program (SESP). The first objective of SESP was to survey the public school buildings in the three administrative districts within Kathmandu Valley, namely, Bhaktapur, Lalitpur and Kathmandu. The purpose was to determine how they might behave during earthquakes.

The findings are grim. Over 66 percent of the valley's public schools are likely to collapse if the valley experiences MSK intensity IX shaking in an earthquake. An earthquake producing this intensity of shaking has been experienced on average once every 50 to 100 years in the valley over the past 900 hundred years, the last time in 1934. Such shaking during school hours could kill more than 29,000 students and teachers and injure 43,000 more in these schools. The second objective of SESP was to analyze options for improving the earthquake safety of these schools and to recommend a course of action. Here, the results hold promise. These deaths and injuries can be greatly reduced if programs are put in place to build new schools safe and to upgrade existing schools.

This executive summary presents an overview of the findings and recommendations of this program. Details appear in the full report.

The Condition of School Buildings

There were 643 public schools in Bhaktapur, Lalitpur and Kathmandu districts at the time of this project, ranging from pre-primary to higher-secondary levels. This program collected information for about 60 percent of those schools. Private schools were not included in the program. There are multiple buildings on most school campuses, and in all more than nine hundred (900) buildings were evaluated by the program. Seventy-eight percent of these buildings were built using typical Nepali construction techniques. The remaining 22 percent of these buildings have a standardized plan and structure and were constructed by the Earthquake Affected Areas Reconstruction and Rehabilitation Project (EAARRP) after the 1988 Udayapur earthquake in eastern Nepal.

Schools with Typical Nepali Construction

Approximately seven hundred of the buildings surveyed were built using typical Nepali construction techniques. Over sixty percent of these (about 430 buildings) were constructed of traditional materials (such as adobe, stone rubble in mud mortar or brick in mud mortar) that behave very poorly in earthquakes. Twenty schools built with these weak, traditional materials are three or more stories high and could collapse even with very small earthquake shaking. The remaining 40 percent of schools use more modern materials such as brick in cement mortar or reinforced concrete. Even though modern materials are stronger, these modern Nepali schools are not necessarily safer. Almost all of these schools are built by traditional artisans without any input from an engineer. School buildings built with modern materials are typically taller, have larger rooms and larger windows and doors than buildings built with traditional materials. These features make many modern buildings as dangerous as traditional buildings.

Of the nearly 700 school buildings built with typical Nepali construction techniques, only three buildings are expected to meet the standards of the Nepal National Building Code (draft). An additional four to five percent buildings had some seismic resistant design features, such as reinforced concrete bands at the lintel level. The vast majority of buildings were built without considering seismic forces at all.

These schools are not only built using unsafe construction techniques, but they are also in deplorable disrepair. A structural engineer visited a representative sample of these approximately 700 school buildings and found that about ten to fifteen percent of buildings were in extremely poor condition due to sub-standard material or workmanship, lack of maintenance, or extreme age. Many buildings have floors that are on the verge of collapse or walls that could crumble and fall at any time. These buildings are dangerous to occupy even in normal times. Another twenty-five percent of the buildings were found to have serious maintenance problems, such as decaying timbers or severely cracked walls that, if not repaired quickly, will deteriorate into extremely dangerous conditions.

EAARRP Schools

Twenty-two percent of the buildings surveyed were built by the EAARRP between 1992 and 1995. These buildings all have the same design. They are rectangular, one-story buildings with two classrooms and a light-gauge steel frame and CGI sheet roof. The materials used for walls differ from school to school depending upon local availability. The walls of these buildings could collapse and cause injuries during an earthquake, even though the steel frame of these schools is not likely to be damaged.

Expected Damage to Schools in Future Earthquakes

No one knows when the next earthquake will strike Kathmandu Valley or how large that earthquake will be. It is known that large earthquakes, like the great quake that struck the valley in 1934, shake the valley about once every 50 to 100 years. One way to understand the earthquake risk of Kathmandu Valley's schools is to estimate the potential losses that could occur in schools if the dominant level of shaking under Kathmandu in the 1934 quake, MSK intensity IX, were to reoccur in modern day Kathmandu. The character of the Valley has changed so much in the decades since that earthquake, with the valley becoming ever more crowded and buildings being built more quickly and taller, that the effects of a large earthquake would be very different, and much more devastating than those experienced in 1934.

If shaking of MSK intensity IX were to occur in modern day Kathmandu Valley during school hours, more than 29,000 (12% of total population of school occupants) children and teachers could die. An additional 43,000 (18% of total population of school occupants) could be seriously injured. The direct loss in terms of damaged buildings would be more than 7 million US dollars or 500 million Nepali Rupees More than 66 percent of schools would need to be rebuilt, the replacement cost of the damaged buildings would be more than 10 million US $. Many more buildings would require extensive repairs. The educational system in Kathmandu Valley would be crippled for years, if not decades.

Improving the Safety of School Buildings

Today, the earthquake threat facing Kathmandu Valley's schools is immense, but if actions begin to be taken to improve this situation now, the valley's schools could be considerably safer within only a few years. Two types of actions should be considered: actions to build safe new schools and actions to improve the safety of existing schools.

Building New Schools Safely

Approximately 35 to 40 new public school buildings are built in these three districts every year. An extremely cost-effective way to increase the seismic safety of the valley's schools is to make sure that all new schools are built in accordance with the Nepal Building Code. Generally, building using seismically resistant techniques increases construction costs by only 4 to 6 percent in masonry buildings (building with brick in cement mortar and RC floor and roof slab), and 5 to 8 percent in reinforced concrete frame buildings (for buildings up to three stories).

The Department of Building of His Majesty's Government is on the verge of implementing and enforcing the Nepal Building Code. Only three of the typical Nepali schools surveyed are expected to meet the standards of this code. Schools would be an excellent place to start enforcing this law. Not only would this cause schools to be built safely, but also it could be used as an opportunity to train construction workers in how to use the new code.

The construction of 43 percent of the buildings included in this survey was funded all or in part by an international organization. In most cases, international involvement did not translate into making the buildings safer. In the future, international organizations that support school construction should make sure that all of the schools they fund in the future are built according to the Nepal Building Code. Technical supervision during the construction process should also be provided to make sure that the code is complied with and understood.

Improving the Safety of Existing Schools

The vast majority of Kathmandu Valley's students will continue to use existing schools for decades to come. The high price of land in the valley makes it difficult for communities to build new buildings or expand existing buildings horizontally. Instead, increasing numbers of students are crowded into existing classrooms, or additional stories are added onto already-weak existing buildings. Expected earthquake fatalities in schools will not be significantly reduced until Kathmandu Valley's existing schools are improved.

For 80 percent of the existing schools in the survey area, seismic retrofitting is a cost-effective option. For these schools, the cost of a retrofit would be less than twenty-five percent of the current value of the building. The strength of each building could be significantly improved, significantly reducing the risk of collapse. More importantly, the risk of life loss in schools could be nearly eliminated: properly retrofit buildings will not collapse if exposed to severe shaking or, at worst, will collapse so slowly that occupants can evacuate. The economic damage to retrofitted buildings would be limited to around fifty percent of the current value of the building when exposed to MSK intensity IX shaking.

As explained above, a shaking of intensity IX in Kathmandu Valley today would cause massive loss of life and money in schools. If the recommended 80% percent of schools were retrofit and the remaining 20% of the school buildings reconstructed, more than 29,000 lives could be saved, 43,000 serious injuries could be avoided, and 7 million US$ worth of direct loss due to building damage averted, even at MSK intensity IX level of earthquake shaking in the Valley.

On average, it costs US$ 50-90 per square meter to retrofit a school in Kathmandu Valley. The cost varies depending on structural type and condition of the school. For a typical school serving 200 children, the total cost of a retrofit would be US$ 8,000 (this includes seismic retrofitting, repair and maintenance, environment improvement). This figure is inclusive of the costs for technical inputs and management that comprises about 25% of the materials and labor costs. In case of the retrofit done so far by NSET, the technical inputs for design and construction supervision and management happened to be about 50%. The technical inputs required will be lower once the system of retrofits is developed, manuals prepared and training imparted. To retrofit all of the 80 percent of the schools recommended above and to reconstruct the rest would cost about US$8.7 million (which includes 25% for technical and management cost). The average cost to construct a new, seismically resistant school building for 200 children is US$10,600 (basic cost without any technical and management cost). Assuming that the same rates could apply for all the schools, the reconstruction of all the school buildings (1182) in the three districts of Kathmandu Valley would cost more than US$15 million[1], assuming that the reconstruction would strictly follow the existing comfort and safety standards of the existing building and classroom. It is unlikely, as reconstruction would be accompanied with improved standards, in which case the cost would be much more than US$15 million.

It does not make economic sense to retrofit the remaining 20% percent of school buildings. Some structural measures can be taken to increase the safety of these buildings, but they can never be made as safe as required by the Nepali building code. Over the long-term, these buildings should be demolished and rebuilt.

Earthquake awareness programs could also save many lives in existing schools. School administration, teachers, students and parents need to know how they should behave during an emergency.

The next earthquake to strike Kathmandu Valley could devastate the school system for years and destroy decades of Nepal's development progress. If action starts now, much of this loss can be avoided.

Findings and Recommendations

- 99% of the school buildings are unsafe for intensity IX shaking.
- Of these schools in Kathmandu Valley, 80% should be retrofit and 20% rebuilt. The cost would be around 9 million US$.

[1] The dollar amounts are approximate and based on year 1999 currency values and costs.

- **Responsibility for construction of new buildings and retrofit of old ones should be turned over to a government organization and managed transparently with access to regional technology.**

Table of Contents

List of Tables

Appendices

Annex

- Background -

1 OVERVIEW OF SCHOOL EARTHQUAKE SAFETY PROGRAM

1.1 THE KATHMANDU VALLEY EARTHQUAKE RISK MANAGEMENT PROJECT

The School Earthquake Safety (SES) Program that is detailed in this report is part of a larger project, the Kathmandu Valley Earthquake Risk Management Project (KVERMP). The KVERMP extended from 1 September 1997 to 30 December 1999 and was jointly implemented by the National Society for Earthquake Technology – Nepal (NSET-Nepal) and GeoHazards International (GHI). It was part of the Asian Urban Disaster Mitigation Program (AUDMP) of the Asian Disaster Preparedness Center (ADPC), with core funding by the Office of Foreign Disaster Assistance of USAID.

The KVERMP included a wide variety of activities aimed at beginning a self-sustaining earthquake risk management program for Kathmandu Valley. Project components included the following:

1) Development of an earthquake scenario and an action plan for earthquake risk management in the Kathmandu Valley,
2) A school earthquake safety (SES) program, and
3) Awareness raising and institutional strengthening.

The project activities and objectives were developed and implemented with strong participation by national government agencies, municipal governments, professional societies, academic institutions, schools, and international agencies present in Kathmandu Valley.

This report describes the activities and findings of the second project component, the SES Program. To learn more about other components of the KVERMP, please contact NSET or GHI, or refer to the publication The Kathmandu Valley Earthquake Risk Management Action Plan.

1.2 WHY FOCUS ON SCHOOLS?

The KVERMP decided to place a special focus on schools. Schools are certainly among a community's most important buildings, but many people do not think of schools first when they think of starting earthquake mitigation programs. There are three main reasons that the KVERMP focused on schools rather than on other critical facilities such as hospitals or police stations: the extreme risk of schools buildings, the importance of schools to community in post-disaster recovery, and the tractability of addressing school earthquake risk.

Schools in Nepal, both their buildings and their occupants face extreme risk from earthquakes. School buildings in Nepal are generally constructed without the input of trained engineers, much less engineers with knowledge about seismically resistant construction. Most other critical facilities have at least some level of engineering design and construction supervision. Budgets for school construction are typically very limited, increasing the likelihood that poor materials or workmanship will be used. School children are also particularly vulnerable to natural disasters, especially the youngest children. The loss suffered by a community in the collapse of a school is psychologically much greater than the loss faced by collapses of other building types: schools house an entire generation and a community's future. The vulnerability of schools is illustrated by the events of the 1988 Udayapur earthquake in eastern Nepal. Nine hundred and fifty school buildings were destroyed in this event, luckily during non-school hours [22].

Schools play a crucial role after an earthquake in helping a community to get back on its feet. Since schools are typically well distributed throughout neighborhoods, they are an ideal location for homeless shelters, medical clinics, and other emergency functions. Functioning schools provide a feeling of normality to a community, helping people get back on their feet after a disaster. Schools are also particularly tractable for earthquake safety programs. Schools structures are typically very simple and relatively small, unlike other critical facilities. Therefore it is inexpensive to build new schools in an earthquake resistant fashion and it can be affordable to retrofit existing schools. Also, by raising awareness in schools, the entire community is reached because the lessons trickle down to parents, relatives, and friends.

1.3 OBJECTIVES OF THE SCHOOL EARTHQUAKE SAFETY PROGRAM

The SES program had three principle objectives:

1) To assess the seismic risk of the public school buildings in Kathmandu Valley by
   - Conducting a survey to determine the structural characteristics of all schools in the valley,
   - Analyzing the collected information to assess the vulnerability of Kathmandu Valley's schools, and
   - Estimating the expected losses to schools, both life loss and financial loss, if the 1934 earthquake were to recur in Kathmandu Valley.
2) To identify measures to reduce the earthquake risk by
   - Identifying methods to structurally strengthen (retrofit) existing school buildings,
   - Testing school retrofit methods on one typical school to examine feasibility and cost issues,
   - Estimating the costs of strengthening all schools in Kathmandu Valley,
   - Developing a prioritization plan for improving the seismic safety of Kathmandu Valley's schools,
   - Promoting earthquake resistant construction in school buildings, and
   - Promoting school emergency preparedness measures such as school emergency response plans.
3) Conduct awareness raising while implementing the program by
   - Involving school headmasters in the work of collecting structural information about schools,
   - Providing school headmasters with general earthquake safety information,
   - Involving high-level school officials in this program, and
   - Working actively with community members on the test retrofit of one school.

1.4 BRIEF DESCRIPTION OF SCHOOL EARTHQUAKE SAFETY PROGRAM

1.4.1 School Survey

The first activity of the program was to collect structural information about the schools existing in Kathmandu Valley, as there was no known source of this information. The District Education Office(s) in Kathmandu, Bhaktapur and Lalitpur Districts developed a list of all 643 public schools in the valley, ranging from pre-primary to secondary schools. Faced with such a large number of school buildings (each school has an average of two buildings, also referred to as blocks), the project team decided to get the help of school headmasters to collect information about each school. A survey form was developed to get basic information about each school, such as dates of construction, construction materials, shape of buildings, etc. Headmasters from every school in the valley were invited to participate in a seminar, which informed them about the earthquake risk in Kathmandu Valley and taught them how to fill out the survey form for their school. Fifteen seminars were held, with participation from 69 percent of the valley's headmasters. After a number of months, 630 survey forms were completed properly, although it was necessary to hire additional technicians to aid some of the headmasters in completing the survey form. Nine percent of these schools were visited by a structural engineer to verify that the information collected in the survey forms was accurate and consistent. The results of this survey appear in Chapter 4.

Next, the project team focused on analyzing the collected data (see Chapter 4). All of the schools included in the survey were grouped into 5 different structural types and the vulnerability of each of these types was determined using a variety of methods. An extensive international literature search provided few insights about which method was most appropriate given the non-engineered nature of schools in Nepal. The final method used is simple, but accurate enough to classify the levels of risks facing schools, to identify possible measures to reduce the earthquake risks to acceptable levels, and to make cost estimates for the structural interventions required to bring the school buildings to the standards of the National Building Code.

To conclude, the project team developed information to help the results of this study to be used productively. This included developing conceptual methods to strengthen the different types of structures present in the valley. The project team estimated what it would cost to improve the safety of all schools in the valley (see Chapter 6). A detailed retrofit plan was made and implemented for one typical school in the valley (see Chapter 5). Last, the project team estimated the expected losses to schools, both in terms of lives and money, if strong shaking occurs in the valley. This estimate was made assuming, first, that no changes were made in the valley's schools and, then, assuming that the recommended safety measures in this report were implemented (see Chapter 7).

1.4.2 Study Area

This program originally incorporated all of Kathmandu Valley, which includes all of Kathmandu and Bhaktapur Districts, and the portion of Lalitpur District within the Kathmandu Valley watershed. As the program was underway, the study area was expanded to also include the parts of Lalitpur District that are outside Kathmandu Valley.

1.4.3 Project Team and Advisors

The project team consisted of a project director, a project manager, a structural engineer, a project assistant, and a draftsperson. Appendix-2 lists the names of project team members. In addition, 15 technicians were hired to help gather survey information.

A School Earthquake Safety Advisory Committee was established to oversee this program in close consultation with the Ministry of Education, His Majesty's Government of Nepal. The advisory committee included representatives of the District Education Offices, municipalities, and experts in various technical fields, INGOs and others. The Regional Education Director, Central Development Region, chaired the Committee. Members of the School Earthquake Safety Advisory Committee appear in Appendix-1.

1.5 LIMITATIONS OF THE WORK

This study only examines the safety of public school buildings. No work was done to assess the safety of private schools because, among other reasons, most of them rent private, typically residential, buildings to conduct classes, which complicates seismic retrofit solutions.

Information was collected for approximately fifty-nine percent of public schools in Kathmandu Valley. We have assumed that these data are representative of all public schools in the valley, and extrapolate for some of the estimates in this report. This may not be a realistic assumption.

Some of the data collected in the survey forms may not be accurate due to the method used to complete these forms. Although every effort was made to keep the survey forms simple, some headmasters had difficulty completing them. In some instances, the collected data may not fully and adequately reflect the actual condition of the buildings, as it was not possible for an engineer or technician to visit every school. However, we believe that the majority of information collected is reliable.

Many school buildings in Kathmandu Valley are very structurally diverse, and it was not possible to capture all relevant details about every school with a simple survey form. The survey revealed that most school buildings in the valley have been constructed over many years and vary in construction material and style both horizontally and vertically. As an example, it is common for a school to have a ground floor made of one set of materials, and upper stories made of other materials depending upon the prevailing technology at the time the addition was constructed. A rigid questionnaire form cannot adequately reflect the uniqueness of each building, and we believe that the information collected for many schools gives only a partial picture of the school's structural make-up.

The survey was based on visual inspection only. No parts of buildings were opened for examination. No material testing was conducted. It is likely that non-structural, cosmetic measures, such as building facades, led to misinterpretation of structural building materials in some instances, even in visits by an engineer or a technician.

Building vulnerability was assessed using a very simple method based only on walling materials and number of building stories. The method assumes that two buildings with the same type of walls and the same number of stories, but with different floor and roof structural systems, would have the same level of damage under the same intensity of earthquake shaking. In reality, we know that roof and flooring systems, as well as many other factors such as building maintenance, have a significant impact on building safety. There are certainly some errors introduced in the calculations of vulnerability due to using such a simple method.

The study did not examine the effects of secondary hazards, such as landslide, liquefaction or fire. These hazards could have a significant impact on the level of earthquake damage in the valley.

The estimate of costs to retrofit all buildings in the valley is an order of magnitude estimate only. An average footprint area (also referred to as plinth) based on a few sample buildings was used to estimate the total costs. For example, two buildings of the same structural type with the same number of stories were assumed to have the same retrofitting cost. Factors such as the existing condition of the building were not taken into account.

2 KATHMANDU VALLEY AND EARTHQUAKES

2.1 HISTORY OF EARTHQUAKES

Nepal has a long history of destructive earthquakes. In this century alone over 11,000 people have lost their lives in four major earthquakes. A 1934 AD earthquake produced strong shaking in Kathmandu Valley, and destroyed 20 percent and damaged 40 percent of the valley's building stock. In Kathmandu itself, one quarter of all homes was destroyed. Many of the temples in Bhaktapur were destroyed as well [8]. This earthquake was not an isolated event. Three earthquakes of similar size occurred in Kathmandu Valley in the 19th Century: in 1810, 1833, and 1866 AD. The seismic record of the region, which extends back to 1255 AD, suggests that earthquakes of this size occur approximately every 50 to 100 years [14], indicating that a devastating earthquake is inevitable in the long term and likely in the near future.

Nepal Himalayas are a product of the continental collision of the Eurasian and Indian plates, initiated about 40-55 million years ago. The collision resulted in the subduction of the Indian plate underneath Tibet, which continues today at an estimated rate of about 3 cm per year. The subduction produces tectonic stresses along a series of faults parallel to the Himalayan arc. Numerous earthquakes have occurred in this region, including four major earthquakes of magnitude greater than M8 within the last 100 years [23]. Nepal is one of the most seismically active areas in the world.

A simple loss estimation study for Kathmandu Valley was conducted as part of KVERMP. This loss estimation study examined what the consequences would be if the 1934 earthquake shaking were to occur in modern day Kathmandu Valley. The next earthquake to severely damage Kathmandu Valley will not have the same magnitude and location as the 1934 event. However, it is quite reasonable to assume that the next large earthquake to affect Kathmandu Valley will have approximately the same shaking pattern within the valley due to the nature of the valley's soil.

Some results of Kemp's loss estimation study are presented below to help clarify the extent of the problem faced by the Kathmandu Valley. This loss estimation is not a forecast of what will happen in the future, and should be viewed only as a tool to help make decisions about reducing Kathmandu Valley's earthquake risk.

2.2 LOSS ESTIMATES

The shaking that was observed after the 1934 earthquake is shown in the accompanying map, as it was documented immediately after the event. This shaking is shown according to the Medvedev-Sponheuer-Karnik (MSK) intensity scale. MSK is different from the commonly known Richter magnitude scale. The relevant definitions of the MSK scale are:

X: *Most well built masonry and frame structures are destroyed. Many wooden structures and bridges are destroyed. Landslides occur in sloped areas. People are thrown to the ground.*

IX: *Poorly built masonry structures collapse. All structures are damaged. Underground pipes break. General panic occurs.*

VIII: *Damage occurs to masonry structures. Chimneys and elevated water tanks collapse. Heavy furniture moves or overturns. People are frightened and have difficulty standing.*

The loss estimation study indicates that massive damage can be expected to Kathmandu Valley's buildings, structures and population if the shaking of 1934 were to repeat. The amount of damage expected is strongly influenced by the quality of the valley's soil. Kathmandu Valley is located on the site of a prehistoric lake, which has been filled with the soft sediments that make up the floor of the valley today. These soft sediments tend to amplify earthquake shaking, like a bowl of jelly when it is shaken. In addition, there is a high probability of liquefaction in many of the valley's urban areas, especially near rivers. Liquefaction is a phenomenon in which water-saturated soil changes from a firm material to a semi-liquid material when shaken and loses its ability to support structures. Liquefaction was widely observed during the 1934 earthquake [8].

2.2.1 Damage to Buildings

A rough estimation of damage to buildings was conducted by KVERMP using information about typical construction types found in Kathmandu Valley. Such information on construction types was collected and analyzed while developing the Nepal National Building Code (NBCDP, 1994). As many as 60 percent of all buildings in Kathmandu Valley are likely to be damaged heavily, many beyond repair, if a future earthquake causes MSK IX shaking [20]. Bhaktapur, which suffered the worst damage in 1934, has historically suffered more than the rest of the valley in earthquakes, possibly because of its weak geological conditions. As many as 75 percent of all existing buildings in Bhaktapur are likely to be heavily damaged if the shaking of 1934 (MSK X in Bhaktapur) were to reoccur today.

2.2.2 Damage to Transportation Network

In addition to building damage, it is estimated that almost half of the bridges in the valley could be impassable, and that 10 percent of paved roads will have moderate damage, such as deep cracks or subsidence. In addition, many of the narrowest streets in the valley will be blocked by debris from damaged buildings. The city of Bhaktapur may not be accessible from Kathmandu or Lalitpur because of road and bridge damage. The bridges connecting Kathmandu and Lalitpur to each other are also at risk of liquefaction induced damage. Liquefaction prone areas surround Tribhuvan International Airport. This means that the airport may be isolated from the rest of Kathmandu Valley, limiting emergency aid from outside of the valley [20].

2.2.3 Damage to Utilities

Approximately 95 percent of water pipes and 50 percent of other water system components (pumping stations, treatment plants, etc.) could be damaged seriously. Almost all telephone exchange buildings and 60 percent of telephone lines are likely to be damaged, requiring significant to moderate repair to be operational. Approximately 40 percent of electric lines and all electric substations are likely to be damaged [20]. It could take one month after an earthquake for electricity and telephone utilities to be operational. Water systems will require much more time to repair. It is estimated that most parts of the valley will be without piped water supply for several months and several areas could remain without service for over one year.

2.2.4 Deaths, Injuries, and Homelessness

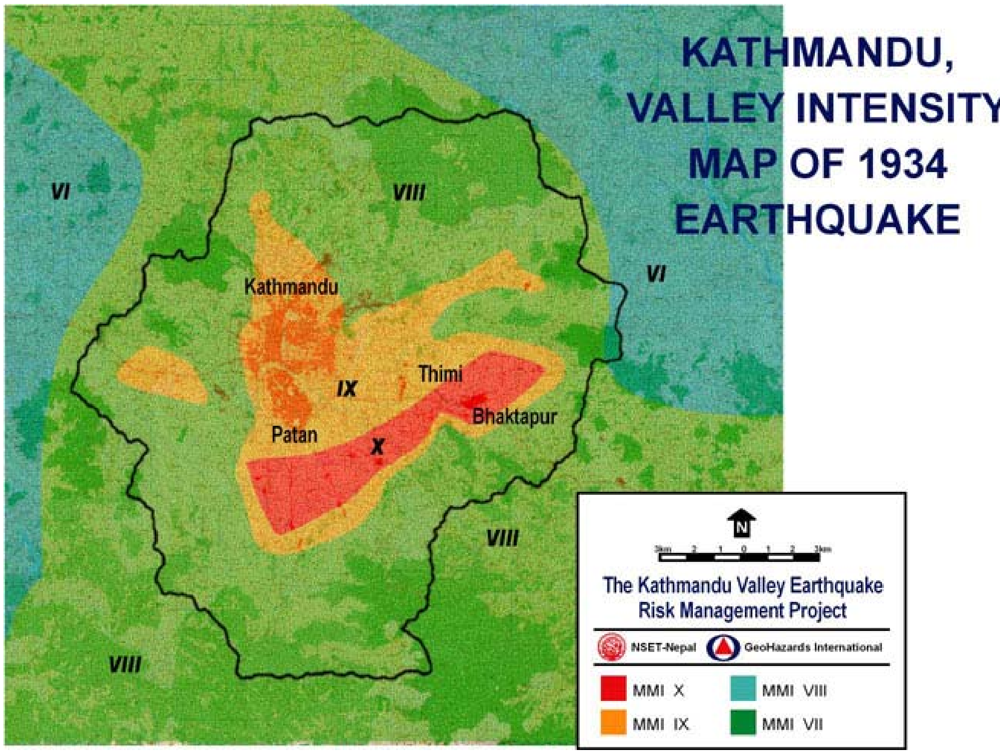
Death and injury expectations are similarly shocking. Simply applying the percentage of the population killed or injured in the 1934 earthquake to the population of the valley today results in an estimate of 22,000 deaths and 25,000 injuries requiring hospitalization [20]. Applying more recent earthquake casualty figures from cities comparable to Kathmandu Valley results in an estimate of 40,000 deaths and 95,000 injuries in Kathmandu Valley’s next major earthquake.

An additional 600,000 to 900,000 residents of Kathmandu Valley are expected to be left homeless by the earthquake due to damaged buildings or fear of being in their homes. The existing government medical facilities in Kathmandu have a total of 2,200 beds, most of which are full under non-emergency conditions. An additional 3,500 patients could be accommodated on floors or outside space around hospitals. In California and Japan, earthquake shaking of MSK IX generally makes at least 50 percent of hospital beds unusable, due to structural problems (building collapse) or non-structural problems (e.g. fallen bookshelves or loss of electrical power). There will be a major shortage of space for medical treatment in Kathmandu Valley.

2.3 CONCLUSIONS

The exact amount of damages or numbers of deaths, injuries, and homelessness are not needed for planning. Kathmandu Valley's current facilities cannot cope with even a small fraction of the estimates that are presented here. This level of devastation and suffering does not need to occur. There are many things that can be done to reduce the amount of risk that faces this community.

Earthquakes do not kill people: building collapses do. Although earthquakes are natural phenomenon that cannot be avoided, or even accurately predicted at this time, the seismic safety of buildings, utilities, and transportation networks and the capability of institutions to respond to an earthquake can be greatly improved. Although the problem facing Kathmandu is large, if work begins now, this problem can be controlled and reduced with time. The School Earthquake Safety program of the National Society for Earthquake Technology - Nepal is one of the initial steps in this direction and focuses on the earthquake safety of schools and school children.



to masonry

lt masonry
ıpse; all
damaged.
ıipes broken.
uilt masonry
ctures and
stroyed.

Figure 2.1: Intensity Map of 1934 Nepal-Bihar Earthquake [5].

- The Condition of School Buildings -

3 DATA COLLECTION AND VULNERABILITY ANALYSIS METHODS

3.1 DATA COLLECTION METHODS

The first step of the SES program was to collect data about the public schools existing in Kathmandu Valley. At the start of this program there was no information available about the types of buildings used for schools, nor the quality and safety of those buildings.

The District Education Offices in Kathmandu, Lalitpur and Bhaktapur informed the program that there were 643 public schools in Kathmandu Valley in 1999. The schools ranged from pre-primary to higher secondary levels. The number of buildings occupied by a single school campus ranged from one to nine.

The project team decided to involve school headmasters in collecting information about the public school buildings in the valley. A simple survey form was designed and school headmasters were trained how to use it. Engineers and technicians verified the results of the headmasters' work. This low-tech approach kept the data collection costs low while simultaneously spreading awareness about earthquake risk to all schools in the valley.

3.1.1 Survey Form

The survey form was designed to be as simple as possible so that headmasters with no technical abilities could easily complete it. Almost all questions were accompanied by simple graphics. While developing the form, the project team tested drafts on ten schools in an effort to make the form applicable to the wide variety of school buildings in the valley. The survey form has the following parts:

Part-A: General Questions

This section included basic questions about each school, such as the school name and address, the number of children using the school, and the number of buildings on the school campus. It also asked about the age of each building, and the source of funds used to build each building.

Part-B: Building Construction Questions for Typical Nepali Schools

This section was distributed to typical Nepali schools, that is, schools built using typical construction techniques found in Nepal (as opposed to EAARRP schools in part C). It included questions on the basic construction materials of each building's walls, floors, roof, and foundation. It asked about the number of stories, building configuration, size and locations of doors and windows, and whether any earthquake resistant features existed. Questions were also included on the location of each building, such as whether it was in a densely populated area, or whether it was on a steep slope.

Part-C: Building Construction Questions for EAARRP Schools

The Earthquake Affected Areas Reconstruction and Rehabilitation Project (EAARRP) implemented following the 1988 Udayapur earthquake in Nepal constructed many school buildings in eastern part of Nepal in a standardized fashion. These schools have an identical light steel supporting structure with a corrugated iron sheet (CGI) roof and are of fixed size and shape. The main variable in these schools is the material used to construct the walls, so questions in Part C were limited to this topic.

Survey Guidelines

Guidelines were developed to explain each survey question in detail and to provide a definition for all terms used in the survey forms.

The survey forms were prepared in Nepali for the fieldwork and in English for review and reporting purposes. The different parts of the questionnaire – A, B, C – were printed in Nepali language in blue, green, and red respectively to make each part distinct. A set of the questionnaires in English is presented in Appendix-2. The guidelines appear as Appendix-3.

3.1.2 Review of Survey Form

A one-day pilot seminar for school headmasters was conducted to test the survey form. Thirty-seven school headmasters from all three districts in Kathmandu Valley attended. These headmasters were requested to comment on the questions and to fill out the forms for their schools. After collecting the completed forms, the project team visited several of the schools to compare the headmasters' responses to their own observations. This process produced many comments from the headmasters and many corrections from the engineers that were used to modify the survey form. International experts further reviewed the forms.

3.1.3 Training Seminar for School Headmasters

After finalizing the survey form, the project team needed to train all of the headmasters in Kathmandu Valley how to use it. Fifteen all-day seminars were organized in different locations throughout the valley. Headmasters were invited to participate in these seminars through mail and advertisements in the newspapers. 25 to 40 school headmasters, school management committee members, and authorities from the district and regional education offices attended each seminar. Headmasters or other teaching staff from 443 of the 643 schools in the valley participated in the seminars. The list of participants is presented in Appendix-4. All of the seminars were held in schools to make a strong impression on teachers, students and the community.

The seminars aimed to instruct the headmasters how to use the survey form for their school buildings and to raise awareness about how to prepare for earthquakes. The first portion of each seminar discussed earthquakes and how to prepare schools and school children. The second portion of the seminars focused on training the attendees to use the survey form.

3.1.4 Response from Schools

Out of the 443 school headmasters, 211 surveyed their schools and returned the filled-up survey form. Out of the returned questionnaires, only 179 forms were filled out adequately. The remaining school buildings were re-surveyed by technicians who completed and corrected the data provided by the headmasters.

3.1.5 Survey by Technicians

Technicians that were engaged by NSET carried out the re-survey work. The aim was to improve the quality of data for all the 443 schools that participated in the seminars. The technicians were given training by NSET prior to their visits to the schools. Fifteen technicians were engaged for this work. NSET engineers provided strict oversight to ensure the quality of the information collected. The technicians surveyed and completed questionnaires for a total of 222 schools, including schools previously surveyed improperly by school officials and schools that had not submitted a survey previously.

Altogether 378 schools (58.8%) were covered by the survey. The final list of surveyed schools is presented in Appendix-4.

3.1.6 Field Verification

In order to measure the reliability of the survey data and to undertake a rapid visual survey for interpretation of the data, the structural engineer visited 34 (9%) of the surveyed schools in-person. Originally, it was envisaged to field-verify only 5% of the schools. This number was increased because the schools turned out to have a much wider variation of structural systems, construction materials, geographic location (urban and rural schools) and construction methods, which the engineer had to understand for a meaningful analysis and development of the applicable retrofit schemes. A list of the field-verified schools is presented in Appendix-5. Schools surveyed by school authorities were the focus of the engineer's visits, and only a few representative school buildings surveyed by technicians were field-verified.

3.1.7 Quality of Survey Data

The quality of data for the buildings surveyed by a school authority such as a headmaster was found to be relatively poor. Very few of the forms submitted by the schools included a building plan. It was very difficult to collect important qualitative data, such as the state of the building's maintenance. This type of information is key to determining building safety, and for this study we can only draw conclusions on this from the few schools that were visited by an engineer.

3.1.8 Preparation of a School Building Database

A computer program has been developed to create the school database and for data analysis. This database includes all of the technical and non-technical information collected by this program and can be a resource for future work.

3.2 INTRODUCTION

Vulnerability of a building can be defined as "the degree of loss to be suffered by it as resulting from the occurrence of an earthquake of a given intensity". It is expressed on scale from 0 (no damage or loss) to 1.0 (for total loss). If a school building collapses fully, the direct losses could be the following:

a) Direct Building Loss
   i) Loss of structure i.e. walls, ceiling and roof;
   ii) Loss of foundations and the ground floor also if the building sinks or tilts or the foundation cracks due to differential settlement.

b) Indirect due to Building Collapse
   i) Loss of lives or limbs of school inmates,
   ii) Loss of furniture, furnishing, equipment's etc.
   iii) Loss of education time.

In the Vulnerability Assessment of School Buildings, only the Direct Building Losses are considered. Here one may or may not consider the savings from the salvaged cost of materials retrieved and used in reconstruction, use of existing undamaged foundations or doors and windows etc. The Vulnerability is therefore taken to approach 1.0 from below even when complete collapse is indicated by the damage category. In case, the buildings are relocated, additional funds are needed for the development of new sites and infrastructures. The resulting cost then will exceed the *in-situ* reconstruction cost significantly. This issue is not considered as a component of the vulnerability of the building. Here, discussions are made only for normally constructed buildings.

3.3 FACTORS AFFECTING VULNERABILITY OF SCHOOL BUILDINGS

The following factors have been considered in the vulnerability assessment of the school buildings:

- Building structural system/ Structural plan density
- Discontinuities of strength and stiffness of structural elements
- Building configuration
- Building height.
- Symmetry
- Horizontal Size
- Proportion
- Vertical setback
- Pounding between adjacent buildings. Table 4.13 shows the position of the surveyed buildings in relation to the adjacent ones.
- Building construction material
- Construction quality

3.4 VULNERABILITY OF INDIVIDUAL BUILDING VS A GROUP OF BUILDING

The performance of similar buildings in the same site could be considerably different. It is due to the random differences in the level of workmanship, material strength, and condition of each structure, the amount of the imposed load present at the time of earthquake, the influence of the non-structural elements, and the response of the foundation soil. The meaning is that buildings of any type say 'A' in a given intensity area will collectively show a degree of damage (say collapse) as qualified by the term Few, Many or Most, although each one may have the same vulnerability of collapse individually. While looking at each of the school buildings from damageability point of view, the vulnerability of an individual building will be more relevant than a large group of similar buildings in the same Intensity areas. But for purpose of this study, buildings in same intensity area are grouped according to their construction materials (walling material), structural system and analyzed in-group.

3.5 METHOD OF VULNERABILITY ASSESSMENT

As no established methods are presently available for the vulnerability assessment of these building types, efforts were made to develop a method that best fits the prevailing types of the building stock. Four methods, notably, i) analytical method ii) rating method, iii) method based on comparison with Building Code provisions and, iv) MSK intensity method (based on walling materials and definition of MSK intensity scale) were identified. These are discussed below.

3.5.1 Analytical method

This method uses the complete load-deflection characteristics of the buildings either employing the intensity- compliant seismic coefficient analysis, or dynamic modal/ time-history analysis using the peak ground acceleration with response spectra or waveform. Whereas, this method works for the engineered frame type buildings, it turned out to be very difficult to model the non-engineered masonry buildings. Again this method fits well for detailed analysis of an individual building and requires significant resources for use. Hence, this method could not be used in general. The analytical method, however, helped to develop an overall pattern of damage, and to do some groundwork for comparative evaluation of the possible application of other methods. Three framed and fifteen masonry buildings with variable parameters were analyzed for this evaluation, and the available building strengths were compared with the stipulations of the Nepal Building Code requirements. The results are presented in Table 3.1 masonry buildings. It is found that frame buildings suffer from a lack of both the strength and ductility. These buildings would suffer brittle type of failures. Out of plane failure of walls would be the most prominent type of failure due to lack of integrity in masonry buildings.

The steel frame structure of *earthquake block* is well designed but the problem is with the walls. The wall up to sill level is tied up with frame but above it, the walls are free. The analysis shows possibility of toppling down of walls specially if these are thin, or constructed of stone masonry without “through” stones (in Chamoli earthquake delamination of even one-meter high wall in second story was observed! [21].

3.5.2 Rating Method

A rating method for masonry buildings has been developed which includes eight most influential building parameters such as structural system, walling material, wall density, floor and roof rigidity, configuration and number of stories. These parameters of the building are given individual vulnerability rating. These factors are presented in Table 3.2. The ratings are then summed up to get a total number, which is interpreted in terms of the final Vulnerability Index. In this scheme, the individual ratings are multiplied by weighting factors before summing them up.

Although the Rating Method could be the best for the vulnerability assessment of a mass of buildings, time and resource constraints did not allow conducting the required research for determining the applicable coefficient and the relative weights of the various factors affecting the vulnerability. So the method could not be used for this study.

3.5.3 Comparison with Safety Provisions in the Building Codes

In this method the component details, method of reinforcing etc, as actually used in the buildings, are compared with those specified in the relevant code of practice. Wherever the actual condition is found deficient, it will indicate damageability. Larger the number and magnitude of deficiencies, higher will be the vulnerability. For example, the provisions required for two-storied brick-masonry building in mud mortar are presented in Table 3.3 [13 &17].

Testing for compliance with the Building Code provisions resulted in only three masonry buildings meeting the Code provisions. Among the remaining, other thirty-two masonry buildings have at least the lintel band. On visual inspection, the frame buildings do not seem meeting the provisions for strength and ductility prescribed by the Nepal National Building Code. From this, it can be reasonably concluded that almost all of the existing school buildings studied is unsafe to withstand a MMI IX shaking.

3.5.4 Method based on MSK intensity Scale

In this method the maximum damageability of a building is related with the Intensity of the earthquake depending on its type A, B or C. It would thus consider one parameter only, namely the wall type or structural frame, but not the other parameters such as the building configuration, number of stories, wall density, size of rooms, and quality of construction, etc.

According to the analysis conducted using the MSK intensity method, the economic loss of surveyed masonry buildings varies from 55% to 90%, depending upon the walling material and the number of stories. The losses under different intensities (MSK) are presented in Table 3.4.

3.6 VULNERABILITY ASSESSMENT OF EXISTING STOCK OF BUILDING

Among the different methods discussed above, the analytical method is good for detailed assessment of an individual building, requires large resources, and does not suit to our needs. The rating method best suits our needs, and also reveals fair results based on visual inspection. But unfortunately the developed ratings could not be trained, and hence, the method could not be made conclusive. Therefore, the method could not be used.

The code comparison method revealed that only three masonry buildings meet the code provisions required for earthquake resistance, and other thirty-two at least have lintel bands. However, this result could not give any lead to the likely losses. Therefore, the MSK intensity method was used for vulnerability assessment. The buildings are grouped according to Table 3.4, and are presented in Table 4.17.

Table 3.1 Stresses in Masonry Buildings by Pier – Method

S. No.	Construction Details	Plan Shape	Total Number of Story	C_d	Story Analyzed	Story Level Coefficient	Stresses (N/mm^2) Wall Bending (Out of Plane)	Pier Bending: Maximum Bending Stress	Pier Bending: Minimum Bending Stress	Pier Bending: Maximum Shear	% of pier cracked
4.3.b1	Rectangular block in 1:6 Cement Sand mortar (CS), Rigid floor-Rigid Roof, 1St story, wall thickness 350mm (1st story), and 230mm Walls (upper).	Rect.	3	0.48	III	0.786	-0.17	0.4672	-0.4224	0.25	74 (14 out of 19)
					II	0.625	-.00056	0.9874	-0.8676	0.507	74%
					I	0.48	+0.1259	0.8937	-0.7027	0.319	63% (12 out of 19)
				0.24	III	0.393	-0.0724	0.287	-0.022	0.195	21%
					II	0.312	0.087	0.634	-0.008	0.253	37%
					I	0.24	0.168	0.6257	-0.0421	0.200	26.3% (5 out of 19)
				0.12	III	0.197	-0.0025	0.22	-0.09	0.063	-
					II	0.156	0.14434	0.5028	-0.164	0.126	5%
					I	0.12	0.1716	0.495	-0.102	0.165	-
4.3 a2	Rectangular block in 1:6 Cement Sand mortar (CS), Rigid floor-Rigid Roof, all wall thickness 230mm.	Rect.	2	0.48	II	0.693	-0.154	0.380	-0.175	0.220	68.4
					I	0.48	-0.045	0.832	-0.217	0.366	63%
				0.24	II	0.346	-0.049	0.282	-0.016	0.109	24%
					I	0.24	0.118	0.587	-0.062	0.123	32%
				0.12	II	.173	0.005	0.21	-0.061	0.054	-
					I	0.12	0.155	0.441	-0.082	0.079	
4.3.a1	Block Work in 1:6 CS mortar, 230 thick Wall, Rigid Roof	Rect.	1	0.48	I	0.48	-0.089	0.338	-0.074	0.15	37%
				0.24	I	0.24	-0.015	0.234	-0.115	0.498	-
				0.12	I	0.12	0.21	0.187	-0.0476	0.024	-
4.b2	Block Work in 1:6 CS mortar, 350 thick Wall in upper story, Rigid floor, Rigid Roof	L-Shape	3	0.48	I	0.48	0.1292	1.142	-0.653	0.61	52 %(15 out of 24)$
				0.24	I	0.24	0.167	0.73	-0.2171	0.213	14 %(4 out of 24)$
				0.12	I	0.12	0.19	0.5241	0.0001	0.106	- $
2.5 b1	Block in masonry in mud mortar First story = 460 mm Upper = 350 mm Rigid floor-Rigid roof	Rect.	3	0.48	I	0.48	0126	0.75	-0.56	0.36	68 (13 out of 19)
				0.24	I	0.24	0.161	0.502	-0.188	0.18	21% (4 out of 19)
				0.12	I	0.12	0.178	0.38	0.003	0.090	-
2.5 b2	Block Masonry in Mud Mortar, First story = 350 Upper- 350 Rigid floor- Rigid roof	Rect.	3	0.48	I	0.48	0.16	0.932	-0.6930	0.2999	100% (14 out of 14)

$: Edge wall of wing of L-shaped building stressed 30-40% higher than its rectangular part.

Table 3.2: Rating Index Method for Load Bearing Walls Buildings

S. No.	Element	Details				Rating Factor R_I	Weighting Factor W_i
1	Building Structural System	a) Well integrated, walls and roof				1.0	1.0
		b) Well integrated walls, but not roof				1.1	
		c) Not well integrated				1.2	
2	Wall material including. Mortar	a) B.W. in good CS mortar				1	6.0
		b) Good RRM in good CS mortar				1.25	
		c) Ordinary RRM in good CS mortar				1.5	
		d) B.W. in Mud mortar				2.0	
		e) RRM in Mud mortar				3.0	
		f) Earthen Walls				3.0	
3	Wall density per Unit area in X or Y direction (of First Story	No. of Stories & Rates					
			1	2	3		4.0
		a)	.066	.077	.088	1.0	
		b)	.055	.066	.077	1.3	
		c)	.0442	0.055	0.066	1.7	
		d)	.033	.044	.055	2.0	
		e)	.022	.033	.044		
4	Floor Rigidity & Weight	a) Rigid heavy				1.0	1.0
		b) Semi-rigid heavy				1.25	
		c) Flexible light				1.25	
		d) Flexible heavy				1.5	
5	Roof Rigidity & Weight	a) Rigid heavy				1.0	1.0
		b) Semi-rigid heavy				1.25	
		c) Flexible light				1.0	
		d) Flexible heavy				1.5	
6	Construction quality	a) Good				1.0	2.0
		b) Average				1.5	
		c) Poor				2.0	
7	Plan Shape	a) Near Symmetrical				1.0	1.0
		b) Acceptable asymmetry				1.1	
		c) L,C,E,F Shape				1.2	
8	Number of Stories	a) One				1.0	1.0
		b) Two				1.25	
		c) Three				1.50	

Total vulnerability Index $\mathbf{V_i} = \Sigma\ \mathbf{R_{i\ x}\ W_i}$

[Prof. A. S. Arya, personal communication]

Table 3.3: Code Compliance

S. No.	Items	Safety Criteria	Vulnerability
1	Mud mortar not permitted	Fails	Yes
2	a) Unit strength (fired brick = 7.5N/mm^2)	Passes	None
	b) Mortar (Mud)	Fails	Damageable
3	Wall thickness (not less than 350 mm, 1/14 of wall length)	Passes	None
4	Story height (2.5 to 3.0m)	Passes	None
5	No of story =2	Passes	None
6	Openings (ratio not more than 33% in 1st story)	Passes	None
7	Horizontal band (not provided)	Fails	Damageable
8	Vertical bars (not provided)	Fails	Damageable
9	Dowel bars to stitch corners (not used)	Fails	Damageable

S. No.	Items	Safety Criteria	Vulnerability
9	Floor (light flexible, no bracing or bandage)	Fails	Damageable
10	Roof bracing (not provided)	Fails	Damageable

Table 3.4: Vulnerability Assessment based on MSK intensity Scale

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

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

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

(3) Loss >70%: destruction to total Collapse, Loss=40-70%: severe damage

[Prof. A. S. Arya, personal communication; and #15].

4 SURVEY FINDINGS AND ANALYSIS RESULTS

4.1 THE BUILDING STOCK

As per the analysis, collected in between fall of 1998 to summer of 1999, there are 909 buildings in the 378 schools. Of these, 202 buildings were constructed under the Earthquake Affected Areas Reconstruction and Rehabilitation Project (EAARRP) during 1992-1997, and the rest (707 buildings) are normally constructed buildings. Of these buildings, three building constructed under EAARRP and 12 normally constructed buildings are either incomplete, or under construction or rented out, and hence are not included in this study. Out of the remaining 695 buildings, 621 are in load bearing masonry and the rest 74 are reinforced concrete frame buildings. Out of 621 masonry buildings, the walling material of 34 buildings is adobe, 114 buildings are rubble stone in mud mortar and five in cement mortar; 281 buildings is rectangular blocks (brick) in mud mortar, and the rest 187 buildings are constructed with rectangular blocks (brick or concrete block) in cement-sand mortar. Drawings of typical Nepali school buildings and earthquake blocks are presented in Appendix-7 and 8 respectively.

4.1.1 Major construction materials

Most of the normally constructed school buildings were constructed over long periods of time may be decades. So there were always changes in the types of materials, workmanship, and technology during the construction of even the same building. It is a common practice to add rooms subsequently as required depending upon the availability of resources. It is extremely difficult, if not impossible, to predict the change in materials, workmanship and technology at different parts of the same building. Connection between different components of a building constructed in different time periods is thus always doubtful and some times it is extremely difficult to distinguish a building as a unit because of the prevailing practice of adding up new rooms laterally or vertically at different levels. For example, a three-room two-story building could have been added with another room with different wall material at its side with a different flooring system but with a single roof. Table 4.1 shows how construction materials have changed over decades in normally constructed buildings.

Table 4.1: Building Construction by Year of construction

Vertical Lateral-Load Resisting Element	Year of Construction#							
	Before 1944 (2000)	1945-1954 (2001-2010)	1955-1964 (2011-2020)	1965-1974 (2021-2030)	1975-1984 (2031-2040)	1985-1994 (2041-2050)	After 1995 (2051)	Total
	>56yr	>46yr	>36yr	>26yr	>16yr	>6yr	<6yr	
1. Adobe or earth building	2	0	6	5	11	6	4	34
2. Random rubble masonry in mud mortar	0	0	2	3	10	13	9	37
3. Quarry/ Semi-dressed stone in mud mortar	4	0	2	9	26	24	12	77
4. Quarry/ Semi-dressed stone in cement mortar	0	0	0	0	1	3	1	5
5. Fired brick in mud mortar	18	1	31	53	93	67	18	281
6. Fired brick in cement mortar	4	0	4	6	33	57	70	174
7. Fired brick in lime mortar	4	2	1	2	0	0	0	9
8. Hollow concrete block in cement mortar	0	0	0	0	1	1	1	3
9. Reinforced concrete framed buildings	1	0	2	2	5	28	36	74
Total	33	3	48	80	180	199	151	694

Years in parenthesis are Bikram Era (BS) which is 56 years ahead the AD.

4.1.1.1 Normally Constructed Buildings

The most common building material used for the construction of a wall is brick, rubble stone in mud mortar; timber, earth for floors; CGI sheet, timber, mud and tile, for roof construction. Cement and steel bars are relatively new construction materials. It is not easy to demarcate the use of traditional and modern materials in a strict manner. The use of modern materials is more concentrated in dense urban areas and urban fringes where affordability and accessibility to materials, information and transport is comparatively easy. The traditional materials are common in old buildings in the urban areas, and in the outskirts and the valley rim or out of the valley mostly where affordability is low. The new buildings are coming up mostly in modern materials, particularly in the urban and urbanizing areas in the valley floor but the process is rather slow in rural areas. Use of pre-cast reinforced concrete sections or steel structures was not observed for construction of public schools.

Drawings of normally constructed building are presented in Appendix-7.

Foundation

Stone is the most prevalent construction material (56%) in all types of load bearing masonry constructions. Reinforced concrete strip is rarely used. Use of lime has become obsolete after the introduction of cement. Isolated pad foundation is used in framed buildings. Table 4.2 presents the types of foundations and the materials used for foundation construction.

Table 4.2: Foundation Material in Normal Buildings

S. No.	Type of foundation	Construction Material	No. of Buildings	Remarks
1	Strip foundation	Stone (mortar unknown)	6	
		Dry stone masonry	4	
		Stone in mud mortar	377	
		Stone in lime mortar	7	This is not a usual practice, so the figure obtained from questionnaire survey is doubtful
		Stone in cement mortar	52	
		Brick (mortar unknown)	3	
		Brick in mud mortar	108	
		Brick in lime mortar	4	
		Brick in cement	54	
		RC strip	6	
2	Isolated Pad foundation	Reinforced concrete	74	
	Total	621 (89%) strip foundations and 74 (11%) isolated pad foundation.		

Walling Material

In the study area, the overwhelming materials are fired brick in mud mortar or cement mortar. The data is rather biased towards use of brick, as the survey was concentrated in valley bottom. Rubble stone is the most prevalent walling material in valley fringe if stone available and in valley rim, out of valleys. Use of cement in wall mortar is rapidly replacing mud. RC frame building is generally preferred over other type of construction as people think these are good to go high and are strong. Table 4.3 presents use of walling materials in normally constructed buildings. The analysis is based on first story walling materials. Again, if brick in mud and cement mortar exists in the first story, brick in mud mortar is taken as the governing attribute (See Photograph 4.1, Appendix-9 for walling materials.)

Table 4.3: Distribution of walling Material by Number of Stories

S. No.	Vertical-lateral Load Resisting material	Number of Stories					Total
		1	**2**	**3**	**4**	**5**	
1	Adobe and earth buildings	23	10	1	0	0	34
2	Rubble masonry in mud mortar	32	5	0	0	0	37
3	Quarry stone in mud mortar	60	16	1	0	0	77
4	Quarry stone in cement mortar	4	1	0	0	0	5
5	Fired brick in mud mortar	150	108	17	6	0	281
6	Fired brick in cement mortar	94	60	16	3	2	175
7	Fired brick in lime mortar	3	2	2	2	0	9
8	Hollow concrete block in cement mortar	3	0	0	0	0	3
9	Reinforced concrete framed building	20	33	15	5	1	74
	Total	**389**	**235**	**52**	**16**	**3**	**695**

Lintel

Most common lintel material constructed in last 25 years in central area of valley is RC where as in old buildings or buildings coming up in valley rim or out of valley timber still controls the scene. Table 4.4 presents use of lintel material in normally constructed buildings.

Table 4.4: Types of Material used in Lintel construction

Lintel Material	Timber	Brick	Reinforced brick	Reinforced concrete
No. of buildings#	265	143	18	119

\# *Out of 695 normally constructed buildings.*

Photographs 4.2 and 4.3 (Appendix-9) presents lintels construction using timber and concrete respectively.

Floor Construction Material

Use of modern materials such as reinforced concrete is most common for suspended floor construction. Table 4.5 shows that 65.3% buildings out of 306 building of more than two stories have RC slab floor. It could be because majority of buildings with two or more stories is concentrated in urban area where modern materials are more common. Buildings in out-skirt or out of the valley are mostly one storied. Many times in old buildings lower floor structure of timber but upper one in RC slab has been observed. RC floor slab is most common in buildings in fired brick with cement or mud mortar. RC framed buildings have invariably used RC floor slabs. Other floor types are more common in buildings with traditional construction materials. Flexible floors are more common in old buildings or in out skirts.

Table 4.5: Types of Material used in Floor construction

Floor Type		Number of buildings
Flexible Floor	1. Planks on timber/ bamboo joist	34

	2. Earth laid on planks/bricks on timber/ bamboo joist	54
	3. Plain concrete laid on planks/bricks on timber/ bamboo joist	18
Rigid Floor	4. Reinforced concrete/ Reinforced brick concrete/ reinforced brick	200
Semi rigid Floor	5. Jack Arch	0
Total		306

Photographs 4.4, 4.5, and 4.6 (Appendix-9) depict the use of bamboo, timber and brick in floor construction.

Roof Material and Shape

In the study area modern material - i.e. CGI roofing sheet on timber structure and reinforced concrete is taken over. Use of both materials is good from seismic point of view. RC roof slab is most common in buildings in fired brick with cement or mud mortar, RC framed buildings. CGI sheet is common in buildings in fired brick or random rubble masonry in mud mortar, adobe. Even use of CGI roofing sheet has been observed in RC framed buildings. RC roof slab is common in valley core area where as CGI sheet is common in core area as well as in out skirts. Use of biomass has not been observed whereas the use of clay tiles is largely replaced by CGI sheet or RC slab. Table 4.6 presents distribution of roof material.

Photographs 4.7, and 4.8 (Appendix-9) depict the use of timber, steel, CGI sheet, and jhingati (clay tiles) for roof construction.

Table 4.6: Types of Material used in Roof construction

Roof Type		**Number#**
Light Flexible Roof	1. CGI/ Asbestos sheet on timber/ bamboo/ steel structure	405
Heavy Flexible Roof	2. Tiles on timber/ bamboo/ steel structure	10
	3. Jhingati on earth laid on timber/ bamboo structure	12
	4. Thatch roof on timber/ bamboo structure	0
Rigid Roof	5. Reinforced concrete/ Reinforced brick concrete/ reinforced brick	267
Semi rigid Roof	6. Jack Arch roof	0
Total		**694**

Out of 695 building. One building is without roof.

Roof shape largely depends upon roofing material. RC slab roof is generally flat where as CGI roofs are mono, double pitched or hipped. Clay-tile roofs are usually duo-pitched and much steeper (around 25^{o} inclination). Roof shapes are presented in Table 4.7.

Table 4.7: Roof Shape

Roof shape	**Flat**	**Mono Pitch**	**Double pitch**	**Hipped**
No. of buildings#	260	258	172	5

Out of 695 normally constructed buildings. All the earthquake blocks are double pitched.

4.1.1.2 Earthquake Block

These buildings are constructed by EAARRP under World Bank assistance. The buildings are one-story sheds of standard shape, size and structural materials. The EAARRP supplied steel framed structure, cement and steel bars required for walls up to sill level. Local community supplied basic walling materials.

The steel frame is made of tubular sections or cold rolled light gauge workshop fabricated sections. The light gauge sections are galvanized. Roofing material is CGI sheet. Drawings of the shed are presented in Appendix-8. Photograph 4.1 (Appendix-9) presents the photographs of Earthquake Blocks under and after construction.

Walling Materials

The common basic walling unit in study area is fired brick. Project supplied cement for wall up to sill level and also provided steel bars and cement for sill band. Although EAARP made it mandatory to provide sill band, but buildings without it have been observed during the survey (Photograph 4.9, Appendix-9). Basic walling materials used are presented in Table 4.8.

Table 4.8: Wall Materials above Sill Level

Walling Material	Adobe	Fired brick in mud	Fired brick in cement	RRM in mud	RRM in cement	Quarry stone in mud	Quarry stone in cement
No. of buildings[#]	2	30	136	4	5	18	1

[#] Data for rest of the 3 blocks not available.

Gable wall

The project, considering out of plane failure of heavy gable walls, supplied CGI sheet for gable. But 27.6% buildings do have replaced CGI sheet with heavy cladding walls, thereby increasing the risk. Table 4.9 presents use of different materials for gable wall. Photograph 4.9 (Appendix-9) presents originally proposed CGI sheet gable wall and masonry gable wall.

Table 4.9: Types of Material used in Gable wall construction

Material	Fired brick in mud	Fired brick in cement	Quarry stone in mud	Quarry stone in cement	CGI sheet
No. of blocks	5	31	5	1	152

4.1.2 Earthquake Resistant Features

Incorporation of aseismic features in buildings in general and school buildings in particular is a rare option. Seismic consideration in even engineered buildings is a rare phenomenon. Out of the normally constructed 695 buildings surveyed, only three load-bearing masonry buildings are expected to meet the Code requirements for aseismic construction (vertical junction bars and lintel band). RC framed buildings depend on ductility of its frame for its survival but ductile detailing is largely ignored. Even very basic steel detailing is not met. RC frames are too light and are only able to carry seismic load of two to three story buildings in strength aspect but again lack ductility.

4.1.2.1 Load Bearing Masonry Buildings

Seismic Bands

Seismic belts at DPC, sill, lintel level and floor or roof levels in flexible floor or flexible roof buildings, is in general not observed. Seismic belts i.e. lintel band are generally not observed even in buildings designed or supervised by technicians. The most common aseismic feature is lintel level belt. Out of 695 buildings only 42 do have lintel bands. Photograph 4.10 and 4.11 (Appendix-9) present the cases of no lintel and existence of lintel band. Table 4.10 reveals that, piece lintel is most common. Lintel level belts are more prevalent in brick buildings in cement mortar. Many times it is also observed, piece lintels in first story and bands in upper story or vice versa. Even if seismic bands exists, the prevailing poor practice of steel bar detailing makes one question the expected positive performance of the bands.

Table 4.10: Types of Lintel

Vertical Lateral-Load Resisting Element	Type of Existing Lintel				Total
	No Lintel	Piece Lintel	Combined Lintel	Lintel Band	
1. Adobe or earth building	9	25	0	0	34

2. Random rubble masonry in mud mortar	5	31	0	0	36
3. Quarry/ Semi-dressed stone in mud mortar	16	56	2	3	77
4. Quarry/ Semi-dressed stone in cement mortar	0	4	1	0	5
5. Fired brick in mud mortar	55	206	10	10	281
6. Fired brick in cement mortar	45	102	9	19	175
7. Fired brick in lime mortar	1	7	0	1	9
8. Hollow concrete block in cement mortar	2	1	0	0	3
9. Reinforced concrete framed buildings	29	34	1	9	72
Total	162	466	23	42	693

The most common lintel material is timber (generally locally available softwood) and reinforced concrete. In many schools crumbling of walling materials has been observed due to decay of timber lintel leading building in hazardous condition.

Corner Stitching

Corner stitching for strengthening of corners with steel, timber or even with long stone pieces in stone buildings has not been, in general, observed. Of course, in few old buildings timber belts at different level has been observed.

Corner bars

Only 32 out of 690 (data for five not available) buildings have corner bars. Among 32 buildings 22 are constructed with fired brick in cement mortar, 6 fired brick in mud mortar, 1 RRM in cement mortar, 1 RRM in mud mortar and one in hollow concrete block in cement mortar.

Floor and Roof Bracing

Incorporation of floor or roof bracing for stiffening of flexible floor and roof has not been observed at all in study area. The flexible floors and roof are generally loose fit structures. Photograph 4.11 (Appendix-10) presents one such roof.

4.1.2.2 Reinforced Concrete Framed buildings

Ductile Detailing

- **Stirrups** used in columns and beams of RC framed buildings are only suitable for vertical loading. Photograph 4.13 (Appendix 9) presents shape of generally used stirrups and their placing in column. Their spacing range between 150-300 mm in general. No stirrups are provided in beam-column joint.
- **Column and beam bar splicing** in general no consideration is paid for location of longitudinal bar splicing in beam and column. Column bars are generally lapped just above the floor slab in plastic hinge region. Lap length generally adopted are far less than the required for stress transfer. Lap length even less than 300-500 mm (1') is common (Photograph 4.14, Appendix-9).
- **Anchorage of bars:** anchorage length of beam bars in end columns is far less than required from development point of view (Photograph 4.13, Appendix-9).

Anchorage of cladding and partition walls

The thickness of these walls range from 115mm (half brick) to 230mm (one brick). These walls are just erected from ground floor upward after completion of frame without any anchorage with the main frame. Their connection with the frame on three sides is quite doubtful.

4.1.3 Building Typology

Building types in study area range from adobe with timber floor and roof (flexible) to RC framed buildings with RC floor and RC roof if analyzed as per their construction material. The number of story range between one to five stories. The plan shape varies from square to tortionally very active shapes. Genealogy of different types of buildings is presented in Figure 4.1A and B.

4.1.3.1 Typology based on Structural System and Construction Materials

Building structures in study area are load bearing to frame structures.

Basic construction material of load bearing buildings is adobe, RRM, fired brick in mud or cement mortar. Framed buildings are reinforced concrete. No timber or steel-framed buildings has been observed. Buildings in load bearing system in fired brick with mud mortar and flexible floor and roof have been observed up to four stories high. Table 4.11 presents occupancy of different types of buildings in study area.

Table 4.11: Building Type

S. No.	**Walling Material**	**Floor & Roof type#**						**Total**	**Remarks**
		FR	**RR**	**FF+ FR**	**FF+ RR**	**RF+ RR**	**RF+ FR**		
A	**Earth/ Adobe in mud mortar**								
A.1	3 Story			1				1	
A.1	2 Story			9			1	10	
A.2	1 Story	22	1					23	
	Total	***22***	***1***	***10***			***1***	***34***	
B	**Field Stone in mud mortar**								
B.1	2 Story			12		2	1	15	
B.2	1 Story	70	3					73	Lintel band=3
B.3	3 story with through stone			1				1	
B.3	2 Story with through stone			3		2	1	6	
B.4	1 Story with through stone	16	3					19	
	Total	***86***	***6***	***16***		***4***	***2***	***114***	
C	**Rectangular blocks in mud mortar**								
C.1	4 story			4		1	1	6	Lintel Band=1
C.1	3 story			6	1	5	5	17	Lintel band=1
C.1	2 story			47	7	28	26	108	Lintel Band=4
C.2	1 story	119	31					150	Lintel band=4
	Total							***281***	
D	**Rectangular Blocks in cement mortar**								
D.1	5 story					2		2	
D.1	**4 STORY**			3		1	1	5	Lintel Band=3
D.1	3 story			5		10	3	18	Lintel Band=2
D.2	2 story			6	1	40	13	60	Lintel Band=8
D.2	1 story	47	57					104	Lintel Band=7

S. No.	Walling Material	Floor & Roof type#						Total	Remarks
		FR	RR	FF+ FR	FF+ RR	RF+ RR	RF+ FR		
D.4	2 story with Building Code reinforcing					2	1	3	
	Total	***47***	***57***	***14***	***1***	***55***	***18***	***192***	
E	**Reinforced Concrete framed**								
E.1	5 story					1		1	
E.1	4 story					4	1	5	
E.1	3 story					14	1	15	Lintel band=3
E.1	2 story					31	2	33	Lintel Band=4
E.1	1 story	1	19					20	Lintel Band=2
	Total	***1***	***19***			***50***	***4***	***74***	
	Grand Total	**275**	**114**	**97**	**9**	**143**	**57**	**695**	

FR: Flexible roof, RR: Rigid roof, FF: Flexible floor, RF: Rigid floor.

Different types of buildings based on structural system and building materials are discussed below:

Adobe or earth buildings

Adobe is one of the traditional materials and still new buildings are constructed of it. It is common in old buildings of valley floor. Use of fired bricks, facia bricks, or plastering of adobe walls with cement sand plaster to protect it from rain and better look is also common. Because of it, some times it is quite confusing to identify basic walling material.

The walls of these buildings are generally thick and range between 450 mm to 600 mm. As it seems, many times no structural connection are made in between the orthogonal walls. Many times, the external walls are constructed first and the internal walls are constructed later on. These buildings are up to three stories in height, but most of them are of one story. Floor height in general is small (around 1.8-2.4 m).

The room size of these buildings is generally small, and the openings are generally few in number and small in size.

Floor in such houses is constructed of mud laid on wooden planks or firewood that are carried by timber joists. The joist ends are just supported on the wall without any anchorage or tie. Generally, the joists do not fully penetrate the full wall width. Most common roofing material is corrugated iron (CGI) sheet supported by timber structure. Roofs are generally duo-pitch.

No anchorage or any other mechanism is used for the integrity of the walls, floor or the roof. The buildings are basically loose fit and behave just as if the materials are stacked.

Stone-Mud Buildings

Rubble stone in mud mortar is most common walling material in the valley slopes, rim of the valley and out of it. These walls are generally 450-600 mm thick. The bond between the walling units of each wythe and between the wythes themselves is not satisfactory. Generally, through-stones are not used and the gap between the wythes is filled with small pieces of stone and mud. Consequently, the thin slender wythes behave as independent members. As it seems, many times no structural connection are made in between the orthogonal walls. Many times, the external walls are constructed first and the internal walls are constructed later on. These buildings are up to three stories in height, but mostly they are of one story. Floor height in general is small (around 1.8-2.4 m). Semi-dressed stone in mud mortar is also in use but rarely.

Floor in such houses is constructed of mud laid on wooden planks or firewood that are carried by timber joists. The joist ends are just supported on the wall without any anchorage or tie.

Generally, the joists do not fully penetrate the full wall width. Most common roofing material is corrugated iron (CGI) sheet supported by timber structure. Sometimes the use of steel trusses has also been observed especially where the construction was assisted by some development projects. Roofs are generally duo-pitch.

The room size of these buildings is generally small, and the openings are generally few in number and small in size.

Use of slate has been also observed. However, their use is rapidly shrinking and CGI sheet is rapidly replacing them. In few other buildings, the timber floor and the roof structure are replaced by reinforced concrete (RC) slab while keeping the same building form. Mixed construction is also common i.e. some parts of the same building are constructed in traditional material and technology, whereas the extension (subsequent addition) to the same building is made in modern materials.

No anchorage or any other mechanism is used for the integrity of the walls, floor or the roof. The buildings are basically loose fit and behave just as if the materials are stacked. The typical stone-mud building is shown in Figure Photograph 4.1 (Appendix-9).

Stone in Cement Sand Mortar

Buildings constructed in stone in cement-sand mortar are not much common, and only few buildings in this walling material exist. Walls are still thick up to 450 mm. Usually, mortar mix is 1:6 or leaner. Floor and roof of these buildings are, generally, cast-in situ reinforced concrete slab or roofs constructed of CGI sheets. The connection between the orthogonal walls is of questionable quality.

There is a significant increase in the number and size of openings in buildings constructed in stone in cement-sand mortar as compared to the traditional construction in mud mortar. The floor height (2.4-2.7 m) is also increased.

Brick or concrete block in cement sand mortar:

Fired brick in cement sand mortar is one of the most common walling materials. In general, the wall thickness is 230mm in case of brick masonry, and 200mm in case of concrete block. Floor and roof are flexible made of timber structure, as well as rigid cast-in-situ reinforced concrete slab. Light roofs made of CGI sheets are also common. Openings are rather large in these buildings. Buildings are generally up to three stories high and the floor height is around 2.7 m. These buildings are common in urban areas or areas accessible by road.

Light Reinforced Concrete Frame:

Some 10.6% of the buildings among the surveyed buildings are reinforced concrete buildings. These buildings are more common in urban areas, and are becoming more popular because they are commonly regarded as stronger than the other type of building. Most of the framed buildings are non-engineered. The most widely used method of construction for such buildings is reinforced concrete frame with in-filled walls of brick or concrete block in cement sand mortar. There are two common construction practices for such building types: 1) construction of frame first and walls next, wall erection starts from bottom story or 2) construction of walls first and then the frames. The former types of construction are more prevalent. These buildings are likely to behave more like a hybrid structure rather than a framed one.

Frames are usually light with column size of 230*230 mm (9”*9”) to 300*300mm with four to six number 12 mm to 16 mm diameter bars (Fe415). Stirrups are generally 6mm diameter bars spaced at 200-250 mm or even up to 300mm intervals. The column spacing in each direction of the building varies from 3.0m to 5.0m. In most cases, the floor heights are 2.7 m, sometimes up to 3.0m. In surveyed buildings number of stories ranged from one to five. Floors of these buildings are constructed of *cast-in-situ* reinforced concrete slab, whereas the roofs are constructed of *cast-in-situ* reinforced concrete slab or CGI sheet supported by steel structure.

4.1.3.2 Plan Shape

Generally rectangular buildings are preferred for school buildings. Among rectangular buildings 38.6% of the buildings are with length to width ratio less than or equal to three and next 26.6% of the buildings are with length breath ratio greater than 3. Next preferred plan shape is L-shape. Table 4.12 presents distribution of plan shape in study area. All earthquake blocks are rectangular blocks, which are not included in this table.

Table 4.12: Plan Shape of Building

No.	Plan Shape	Number
1	Square	30
2	Rectangular (L<=3B)	268
3	Rectangular (L >3B)	185
4	T-shaped	5
5	L- shaped	136
6	C- shaped	42
7	E- shaped	5
8	Courtyard in center	5
9	H- shaped	1
10	Others	18
	Total	695

4.1.3.3 Position of Buildings

Table 4.13 presents position of school building in a group.

Table 4.13: Position of a building Block in Group

S. No.	Position of Building	No. of Buildings
1	Free standing	409
2	Confined on one side	219
3	Confined on two adjacent sides	29
4	Confined on two opposite sides	33
5	Confined on three sides	5
	Total	695

4.1.4 Building Stock

The data collected are largely biased towards urban area, however it is observed that the building stock in the area is mostly in non-engineered materials. The construction methods used are traditional. Even building construction techniques of engineered/ modern materials such as fired brick; cement and steel also are largely of non-engineered nature. Though there exists a good set of Indian and Nepalese Standards on structural design of buildings, these do not seem adopted. Although, Table 4.15 and Table 4.16, shows that some 46.8% and 44.5% buildings received technical input respectively in design and supervision. But the field visit of many of the buildings does not show it. As it seems, design input is limited to preparation of municipal drawings and supervision is superficial.

Majority of school buildings in study area is constructed of fired brick in mud mortar with heavy timber floor and CGI roofing sheet. Use of jhingati is also observed. Stone in mud mortar are more common walling material in the valley rim, foothills, hill slopes and out of valley. Brick, concrete block or stone in cement sand, and reinforced concrete slab buildings and reinforced concrete framed buildings are limited in urban areas or areas accessible by vehicular roads and/ or where the economy is rather good.

4.1.5 Quality Control

Quality control of construction materials and process is largely ignored aspect of construction in all type of building construction.

Use of cement mortar for brickwork is just considered as an extension of mud mortar and curing is ignored. Quality of brickwork is rather poor. Vertical joints at wall junctions receive least attentions (Photograph 4.15, Appendix-9). Even filling of mortar between two walling units is properly not done (Photograph 4.16, Appendix-9).

In reinforced concrete construction, problem starts from preparation of concrete. Grading of aggregate, mixing of concrete is ignored. Concrete is hand mixed and hand compacted. Use of mechanical tool is generally not practiced. Quality of the formwork is always poor. Curing receives least priority as the strength of even uncured concrete is far beyond the traditional materials and craftsman's expectation. As it seems, the requirement of curing the concrete is not well understood by the local masons/builders/craftsman. Enough attention has not been given to provide adequate cover to the reinforcement bars. After striping of formwork, uncovered steel bars can be easily seen in many cases. Additionally, little attention is paid to proper placement of reinforcement resulting in mistakes even in very minor details.

4.1.6 Geographical Variation of building material and typology

It is rather difficult to demarcate the use of construction materials and technology geographically. By far, local availability of construction materials governs the selection of construction materials. Other factors affecting selection of materials are availability of resources, cash flow, and accessibility to the area and technology.

Fired or sun dried brick as walling material are most common in valley floor where as stone is preferred in foothills, valley rim and out of valley. Adobe is more common in northern part of the valley and valley floor. Use of cement and steel based construction such as fired brick in cement mortar, RC construction that requires large cash flow is more concentrated in urban or urbanizing areas but these materials are slowly penetrating remote areas also. Among different roofing materials CGI sheets are more common throughout the study area because of it is light, long lasting, easy to transport and many times it does not require any cash flow as local authorities grant it under their development package.

4.1.7 Effect of modern materials on building stock

Modern materials have rapidly or slowly, replacing traditional materials depending on many factors. With use of modern materials size of rooms have increased where as wall thickness has reduced. Buildings in traditional materials are mostly limited to two stories. With involvement of modern materials number of stories has also increased (ref Table 4.3). Large sized and more openings are common in modern buildings compared to traditional ones. A floor height of 2.1 (or less) to 2.4m (7-8 feet) is common in traditional buildings, whereas this has increased to 2.7 to 3 m (9-10 feet) new buildings constructed with modern materials.

4.1.8 Building Production Mechanism

Major resource for school building production comes out from local sources. Main source of local resources is donations from local community, guthi. Table 4.14 shows that 43.2% of the buildings are constructed from sole community sources and in next 37.2% of the buildings are produced by community participation. The community pays in terms of cash, good, and labor. Government input many times comes in the form of CGI roof sheets for school buildings provided by local authority (DDC, VDC), Ministry of Local Development or in the form of cash grant.

Table 4.14: Funding the School Building Construction

Major Funding Agency	Comm unity	Govt .	International Organizations (Intl. Orgs.)	Community + Govt.	Community + Intl. Orgs	Govt. Intl. Orgs	Community + Got + Intl. Orgs
Number of	289	59	56	135	106	8	16

building s#							

***#	Data for 26 school buildings not available. Earthquake blocks are not included in this table.***

School buildings are mostly produced by owner-builders i.e. community in rural areas. The owner-builders efforts at building production are characterized by a high degree of informality - community members do the decisions. Owner-builders make their own decision, seeks advice from traditional artisans. In urban areas, some input from technicians is also common because of building permit process in municipal areas. The community members themselves deal with materials, suppliers and labor contractors. The labor input by community members themselves is high in rural areas.

Traditional artisans, who generally come from local community, play pivotal role in the construction activity and the community relies heavily on them for all type of advice. They provide overall technical and organizational support even though none of them has formal training. Many of them may be illiterate. Table 4.15 and 4.16 presents the participation of different agents of construction activity in design and supervision.

Out of above listed school buildings, earthquake blocks constructed by EAARRP (22.2% of total surveyed buildings) were designed and their construction supervised by the technicians.

The heading “community” also includes contribution by NGOs. Few school buildings are partially supported by local authorities that provided free CGI sheet roofing, or some cash funds. The school buildings built under the EAARRP were constructed by the joint efforts of the government and the community. The government provided steel structure, door and window frame, roofing sheet, cement, wage of masons, whereas the local community supplied local construction materials, unskilled labor as counter-part contribution.

Table 4.15: Partners in the Design of Normally Constructed Buildings

Walling Material	Com	Mas	Cont	Tech	Com+ Mas	Com+ Cont	Com+ Tech	Mas+ Cont	Mas+ Tech	Cont+ Tech	Com+ Mas+ Cont	Com+ Mas+ Tech	Mas+ Cont+ Tech	Not Available
Adobe or earth building	15	2	-	5	9	-	1	-	-	-	-	-	-	1
RRM in mud mortar	21	1	-	6	5	1	2	-	-	-	-	1	-	-
Quarry/ Semi-dressed stone in mud mortar	36	2	-	16	13	-	6	-	-	-	-	1	-	3
Quarry/ Semi-dressed stone in cement mortar	1	-	-	4	-	-	-	-	-	-	-	-	-	-
Fired brick in mud mortar	82	52	4	77	36	1	13	2	-	1	-	1	-	12
Fired brick in cement mortar	23	13	1	112	7	-	4	1	3	1	1	1	1	7
Fired brick in lime mortar	3	-	-	5	1	-	-	-	-	-	-	-	-	-
Hollow concrete block in cement mortar	-	-	-	2	1	-	-	-	-	-	-	-	-	-
RC framed buildings	3	1	-	61	1	1	4	-	1	1	-	-	-	1
	184	72	5	288	73	3	30	3	4	3	1	4	1	24

Note: Com = Community; Mas = Mason; Cont = Contractor; Tech = Technician

Table 4.16: Partners in Supervision of Normally Constructed Buildings

Walling Material	Com	Mas	Cont	Tech	Com + Mas	Com + Cont	Com+ Tech	Mas+ Cont	Mas+ Tech	Cont+ Tech	Com+Mas+ Cont	Com+ Mas+ Tech	Not Available
Adobe or earth building	16	3	-	5	8	-	1	-	-	-	-	-	1
RRM in mud mortar	24	1	-	6	5	-	-	-	-	-	-	1	-
Quarry/ Semi-dressed stone in mud mortar	36	1	-	11	12	-	11	-	1	1	-	1	3
Quarry/ Semi-dressed stone in cement mortar	1	-	-	1	-	-	3	-	-	-	-	-	-
Fired brick in mud mortar	85	44	6	49	43	2	33	1	2	2	-	2	12
Fired brick in cement mortar	22	13	3	61	13	1	46	-	2	3	1	2	8
Fired brick in lime mortar	3	-	-	5	1	-	-	-	-	-	-	-	-
Hollow concrete block in cement mortar	-	-	-	2	-	-	-	-	-	-	-	1	-
RC framed buildings	5	1	-	41	2	-	21	1	2	-	-	-	1
Total	192	63	9	181	84	3	115	2	7	6	1	7	25

Comm: Community, Mas: Mason, Cont: Contractor, Tech: Technician

4.2 FINDINGS OF VISUAL INSPECTION

4.2.1 Repair and Maintenance Status

The school buildings, like many public structures in Nepal, are poorly maintained generally. Decaying bricks, rotting and broken timber joists/ rafters, sagging floor, leaking roof, broken doors and windows, distorted shape are common in almost all public school buildings. The problem has strong linkage with construction materials and technology used, and the age of the buildings.

The buildings constructed before the introduction of cement do not have any damp-proofing course resulting in the decay of bricks up to 1-1.5m from the ground level.

Many buildings constructed of LSM are old, some even older than 50 years. Because of old age, poor construction technology, and use of weak materials, distress in walling material is also observed.

The timber used for lintels, floor and roof are mostly untreated softwood that are susceptible to termite attack and rotting in moist condition. Overstressing of the rather weak timber leads to sagging failure in lintel and floor structures.

Even in RC components constructed in last 30 years, spalling of concrete due to rusting of bars can be seen because of porous concrete, low/ or no cover to reinforcement bars, and poor grading of concrete materials.

Interestingly, field surveys revealed that generally the buildings seem to be deteriorated more heavily in the southern part of the Valley as compared to the buildings located in its northern part. The root cause, however, could not be understood.

Poor repair and maintenance of the public school buildings is mainly due to fund constraints. Funds allocated by the Government are just enough to cover the salaries of the teachers/staff and the expenses for stationary and other consumables. For all other expenses, including those for repair and maintenance, the schools have to raise funds locally, unless the school is fortunate to be included in specific, preferably externally funded projects. Given the pressing needs for increased classroom space and other facilities, repair and maintenance usually gets lower priority.

Despite the apparently grim situation, there are usually high potentials of community participation in the form of voluntary labor and in-kind contribution for all aspects of running the schools including its repair and maintenance. Lack of technical know-how, suitable and transparent mechanisms, and seed-money are the biggest hindrances to utilize such latent resources.

4.2.2 Condition of Buildings

Visual inspection of buildings during field verification shows that at least 10-15% of the buildings are in severely bad condition and even their use in normal times is hazardous. Crumbling of walls, floors, loss of integrity, and distortion in shape are the common problems in these buildings. These buildings need immediate demolition and reconstruction either in parts or whole.

Around 25% buildings are in fair condition either because of low level of repair and maintenance or structural problems. These include severe cracking in walls, dislodging of material, decayed timber, crumbling of floor and roof. However, the integrity and shape of these buildings are not disturbed. These buildings can be rehabilitated with some efforts if immediate action is taken.

Rest of the buildings is in relatively good condition and usable in some way though more than 99% of these buildings do not meet standards required by the seismic building code. Retrofitting can strengthen these buildings.

4.3 WEAKNESSES IN DIFFERENT TYPES OF BUILDINGS

4.3.1 Material weakness

For the purpose of this study no material testing is conducted so here only qualitative judgments are made based on past experience.

Adobe is inherently a weak material in terms of its compressive, tensile or shearing strength. Stone is rather a good material in terms of its compressive strength but its matrices with mud make its performance extremely bad. Stone shape largely affects its performance as a walling unit. Seismic behavior of dressed stone is far superior compared to boulders but these are not in use. Brick masonry in mud mortar is comparatively a good material but it has low compressive and shearing strength and can not prevent disintegration of walling units due to lack of tensile strength. Brick masonry in cement mortar has rather good properties in strength aspects but all above-mentioned materials are inherently brittle materials.

Reinforced concrete is a good material in terms of strength as well as ductility. But concrete preparation, placing, compaction, curing and reinforcing steel detailing lags the procedure prescribed by standard practice, that makes it inherently a weak material. So, irrespective of the structural system, weak construction materials and improper processing make buildings potentially vulnerable.

4.3.2 Comparative Study of Buildings

The major problem with buildings in study area is the lack of integrity between walls, walls and floors, walls and roof. This causes the buildings to behave as a stack of materials. However, despite such deficiency, there remain some good features that may help a building for survival in an event.

4.3.2.1 Adobe Buildings

Strengths

- Low story height
- Low building height: generally limited to two story
- In general uniform in plan and elevation.
- Generally light roof.
- Openings are generally limited in size, number and symmetrical.
- Old buildings do have some earthquake resistant features (wooden seismic belts etc.).
- High damping ration of the walling material.

Deficiencies

- Weak construction material: low compressive, tensile and shearing strength of load bearing elements.
- Weak wall junctions
- Lack of integrity between load-bearing elements
- Lack of diaphragm
- Long unsupported walls
- Delamination of walls
- Untied gable wall
- Heavy, unstable wall structure.
- Untied gable walls leading to free cantilever.
- Mix (some part in adobe and some part in fired brick) construction.
- Lack of maintenance
- Generally of old age.

4.3.2.2 Stone Masonry in Mud Mortar with or without rigid floor and roof

Strengths

- Low story height

- Building height generally limited to two stories.
- In general uniform in plan and elevation.
- Generally light roof.
- Openings are generally limited in size and number, and symmetrical.

Deficiency

- Weak construction walling material: low compressive, tensile and shearing strength of load bearing elements.
- Due to irregular shape of walling units, blocks are quite unstable.
- Delamination of walls (Photograph 4.17, Appendix-9).
- Non-uniformity/irregularity in plan (e.g. L, T, E shaped) as well as structural system leading it to torsional effects.
- Weak Wall Junctions (Photograph 4.15, Appendix-9).
- Lack of Integrity between Load-bearing elements
- Long unsupported walls
- Large and unsymmetrical opening
- Untied gable wall leading to free cantilever
- Heavy, unstable wall structure.
- Mix (first story in stone masonry in mud mortar but second in brick in cement mortar) construction.
- Lack of maintenance
- Generally of old age.

In addition to these deficiencies buildings with flexible floor (timber floor) have following deficiencies:

- Lack of integrity between the load-bearing elements.
- Lack of diaphragm action.

4.3.2.3 Rectangular Block Masonry in Mud Mortar with or without Rigid Floor and Roof

These buildings are more concentrated in the valley floor, which is mostly accessible by vehicular transport and where population pressure is also high. Because of high population pressure for more rooms is also high but land is scarce here so tendency to go high starts here. Again these buildings also suffer effect of transition of materials and construction technology. The construction is highly mixed.

Strengths

- Low story height.
- Majority of the buildings limited to two stories.
- In general, uniform in plan and elevation.
- Openings are generally limited in size, number and symmetrical.
- Generally light roof.
- Old buildings do have some earthquake resistant features (wooden seismic belts etc.).

Deficiencies:

- Weak construction material: low compressive, tensile and shearing strength of load bearing elements.
- Non-uniformity/irregularity in plan and elevation as well as structural system leading to torsional effects.
- Adjacent buildings.

- Re-entrant corners.
- Weak wall junctions.
- Long unsupported walls.
- New parts have large and unsymmetrical openings.
- Improperly anchored parapets.
- Untied gable wall.
- Heavy, unstable walls.
- Undefined load paths: many times shifting of upper story walls.
- Mix (some part in mud mortar other in cement mortar, few floors flexible where as others rigid) construction.
- Lack of maintenance (Photograph 4.18, Appendix-9)
- Generally of old age.

In addition to these deficiencies buildings with flexible floor (timber floor) have following deficiencies:

- Lack of integrity between the load-bearing elements (Photograph 4.12, Appendix-9)
- Lack of diaphragm action

4.3.2.4 Rectangular Block Masonry in Cement Mortar with or without Rigid Diaphragm

Here the construction materials and technology significantly changes but it can be taken as extrapolation of traditional technology. The deficiencies in the technology can be seen continuing, of course some strength improvement can be felt due to good materials. Due to better materials, tendency to go high is rather high. Increase in floor height, openings and room size also can be seen due to new requirements.

Strengths

- Majority of the buildings limited to two stories.
- In general, uniform in plan and elevation.
- Generally light roof.

Deficiencies:

- Quality of masonry: lack of curing, unfilled mortar joints.
- Non-uniformity/irregularity in plan and elevation as well as structural system leading to torsional effects.
- Re-entrant corners.
- Undefined load paths: shifting of upper story walls.
- Low wall density.
- Large and unsymmetrical openings (Photograph 4.11, Appendix-9).
- Weak wall junctions
- Long unsupported walls
- Improperly anchored parapets
- Untied gable wall
- Thin, unstable walls.
- Mix (some part in mud mortar other in cement mortar, few floors flexible whereas others rigid) construction.
- Lack of maintenance

In addition to these deficiencies buildings with flexible floor (timber floor) have following deficiencies:

- Lack of integrity between the load-bearing elements
- Lack of diaphragm action

4.3.2.5 *Reinforced Concrete Framed Building*

Construction of RC frames has developed a myth that these are infinitely strong and can go to unlimited heights. Such wrong notion has led to severe deficiency in strength of such buildings. The structural section provided, say for a five-story building, for column is only enough for two to three storied building considering the lateral load. The structural components badly lack ductile detailing.

Strengths

- Better construction material.
- Confinement of infill wall.
- Possibility of high damping and energy absorption by infill walls.

Deficiencies

- Quality of materials: condition of concrete, quality of steel.
- Non-uniformity/irregularity in plan and elevation as well as structural system leading to torsional effects.
- Undefined load paths.
- Re-entrant angles.
- Smaller foundation than required.
- Diaphragm openings (especially at staircase).
- Lack of ductile detailing (lack of confining/shear bars, anchorage problem, splicing of bars, ratio of tensile and compressive bars in principal lateral load carrying members not maintained etc.)
- Strong beam and weak column.
- Infill walls not tied up with main frame.
- Soft-story effect
- Splash effect
- Inferior materials as well as workmanship.

4.4 GROUPING OF BUILDINGS

Building are grouped according to their walling material of first story, number of stories and their location according to 1934 Nepal-Bihar earthquake intensity map of the Valley. The result is presented in Table 4.17.

Table 4.17: Distribution of School Buildings by Walling Material[1]

S. No.	Walling Material	Intensity Zone [2]			Total	Remarks
		VIII	IX	X		
A	**Earth/ Adobe in mud mortar**					
A.1	3 Story	0	1	0	1	
A.1	2 Story	4	5	1	10	
A.2	1 Story	9	6	8	23	
A.3	3 Story with Building Code provision	0	0	0	0	
A.3	2 Story with Building Code provision	0	0	0	0	
A.4	1 Story with Building Code provision	0	0	0	0	
	Total	*13*	*12*	*9*	*34*	
B	**Field Stone in mud mortar**					
B.1	3 Story	0	0	0	0	
B.1	2 Story	12	2	1	15	
B.2	1 Story	62	9	2	73	Lintel band=2
B.3	3 story with through stone	1	0	0	1	
B.3	2 Story with through stone	6	0	0	6	
B.4	1 Story with through stone	16	3	0	19	

S. No.	Walling Material	Intensity Zone [2]			Total	Remarks
		VIII	IX	X		
B.5	3 Story with Building Code provision	0	0	0	0	
B.5	2 Story with Building Code provision	0	0	0	0	
B.6	1 Story with Building Code provision	0	0	0	0	
	Total	*97*	*14*	*3*	*114*	
C	**Rectangular blocks in mud mortar**					
C.1	4 story	0	4	2	6	Lintel Band=1
C.1	3 story	3	8	6	17	Lintel band=1
C.1	2 story	28	63	17	108	Lintel Band=4
C.2	1 story	40	78	32	150	Lintel band=4
C.3	3 story with Building Code reinforcing0	0	0	0	0	
C.3	2 story with Building Code reinforcing	0	0	0	0	
C.4	1 story with Building Code reinforcing	0	0	0	0	
	Total	*71*	*153*	*57*	*281*	
D	**Rectangular Blocks in cement mortar**					
D.1	5 story	0	2	0	2	
D.1	4 story	0	4	1	5	Lintel Band=3
D.1	3 story	4	9	5	18	Lintel Band=2
D.2	2 story	25	26	9	60	Lintel Band=8
D.2	1 story	51	40	13	104	Lintel Band=7
D.3	4 story with Building Code reinforcing	0	0	0	0	
D.3	3 story with Building Code reinforcing	0	0	0	0	
D.4	2 story with Building Code reinforcing	1	1	1	3	
D.4	1 story with Building Code reinforcing	0	0	0	0	
	Total	*81*	*82*	*29*	*192*	
E	**Reinforced Concrete framed**					
E.1	5 story	0	1	0	1	
E.1	4 story	0	4	1	5	
E.1	3 story	5	8	2	15	
E.1	2 story	16	12	5	33	
E.1	1 story	10	9	1	20	
	Total	*31*	*34*	*9*	*74*	
	Grand Total	**293**	**295**	**107**	**695**	

[1] Normally constructed buildings.
[2] According to 1934 Nepal-Bihar earthquake.

"Seismic Design of Buildings in Nepal, NBC105-1995" classifies all three districts under a single seismic zone [14 &16]. The zone is equivalent to MSK IX. Actually speaking, none of the document developed by NBCDP reveals this fact but the seismic coefficient provided by the Standard is same as to the seismic coefficient provided by Indian Building Code [12], which specifies that the coefficient is for seismic zone equivalent to MSK IX. To be at par with the building code, all the buildings in these three districts are considered in seismic zone MSK IX and all further analysis are done for the same.

According to Table 3.4, all the earth/ adobe buildings, stone masonry buildings, rectangular block masonry buildings in mud mortar, similar buildings but in cement mortar with more than three story, and RC framed buildings with more than three story may suffer destruction to collapse level of damage and these buildings will have to be reconstructed after an event. This stock constitutes 66% of the normally constructed buildings. Few of the rectangular block masonry buildings in cement mortar and RC frame buildings may suffer severe level of damage and this group constitutes 11% of the normally constructed buildings. Some 23% of the buildings may suffer damage level less than 40% damage.

4.5 SITE SPECIFIC HAZARDS

During the school survey, a study on potential site-specific hazard such as landslide, rock fall, settling or filled ground was also done. Few of these hazards at some sites are active even in normal situation and can be aggravated by a shaking. According to the inventory, sixty-four normal buildings are under landslide threat, and twenty-three are in rock fall area. Twenty-nine buildings are constructed on filled soil, whereas twenty-nine are facing settlement problem. No further analysis on vulnerability of buildings due to site-specific hazard has been done.

4.6 CONCLUSIONS

All the normally constructed 695 masonry buildings in 376 schools are under severe seismic risk as only three out of them are expected to meet the seismic requirements and the other thirty-two have at least lintel bands. Even a simple method as the use of through-stones in stone buildings is rare, which will lead them to delamination in intensity even less than VII leading to severe damage. The integrity would be the major problem during a shaking for the traditional masonry buildings.

The RC framed buildings, especially higher than two storied, would suffer severe loss in a shaking of IX MMI (equivalent to the shaking due to the 1934 earthquake in a large part of the Kathmandu Valley), as these buildings far lag the required strength and ductility. These buildings are also highly vulnerable. Out of plane collapse of partition walls would be one of the major non-structural losses.

Even the in-fill walls of the “earthquake blocks” (constructed under EAARRP) may suffer out-of-plane collapses as the wall is integrated with frame only at the sill level and above the sill, it is just standing as a free cantilever. The steel frame of these buildings, however, is safe for seismic loading.

5 RETROFITTING OF SCHOOL BUILDINGS

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

5.1 PHILOSOPHY AND APPROACH

Philosophy adopted for retrofitting the school buildings considers i) achieving fail-safe damage: delayed collapse allowing pupils to escape during an earthquake, and ii) achieving reduction in the likely damage allowing post-earthquake repair and re-strengthening at nominal costs. Retrofitting schemes are proposed only for those groups of building for which the retrofitting cost does not go beyond 25% of the present value of the building, and which will have, after retrofitting, an economic loss of less than 60% under an earthquake shaking equivalent to MSK intensity IX. Additional requirements as follows are also considered:

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

Emphasis has been placed on the use of locally available materials and local manpower through equipping them with technology.

5.2 DEVELOPMENT OF RETROFITTING METHODOLOGY

Based on the analysis, the building stock has been classified into five groups according to the vertical load bearing system and the walling material. Each of the five groups has been further classified into sub-groups depending on the floor and roof structural system, used construction materials, and the number of stories (refer Table 4.11). This led to the identification of different conceptual retrofitting schemes for each sub-group of the school buildings. The schemes were weighted against their suitability and ease in construction. The most suitable ones have been selected and designed. It is estimated that some 100-school buildings are too weak to be strengthened and need total reconstruction.

5.3 LESSON LEARNT FROM PAST EARTHQUAKES

5.3.1 Masonry Buildings

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

- Non-integrity of wall, floor and roof and their units is one of the major problems.
- Upper parts of the wall of the flexible roof buildings suffer more threat of out of plane collapse due to lack of anchoring elements.
- Cracking at corners (Photograph 4.15, Appendix-9).
- Buildings with rigid floor and roof (RC/ RB floor, roof) suffer diagonal cracking of piers in lower story.
- Delamination of wythes is major problem in round rubble masonry buildings (Photograph 4.17, Appendix-9). Even a meter high stone-masonry wall in second story suffered delamination in Chamoli earthquake [21].
- Collapse of gable wall is common as it behaves as free cantilever.
- Building failures from excessive foundation loading is very seldom. It is because the super structure is too weak and fails much before over stressing of foundation. Some

amount of foundation yielding and movement tends to reduce the forces transmitted the superstructure.

5.3.2 Frame Buildings

Past experiences of earthquakes demonstrate that frames, being flexible, may be affected negatively by the stiff nonstructural components and elements of the building due to interaction.

- Beam-column joint failures, especially for exterior and corner connections, have contributed to many building collapses in past earthquakes.
- Beam failures do not appear to be a major cause of building collapse in past earthquakes, but adequate attention to their details is nonetheless important in design.
- A common problem in the framed building is to artificially "shorten" a column by adding partial-height nonstructural walls that restrict the deformation of the column. The resulting short columns are stiff and attract much higher shear forces than they were designed to carry. There are numerous examples of column shear failure during the past earthquakes. This could be one of most probable causes of column failure in future events.
- The problem of shear strength and confinement are commonly more severe in corner columns especially if the building is tortionally active because of very high bi-axial displacement demand. It has been one of the common phenomena in past earthquakes.
- Failures in column are most commonly related to inadequate strength of the columns, strong beam-weak column. The failure of column leads to a partial- to total collapse of building.
- Large spacing and unanchored ends of stirrups could be of the major causes of column bursting.
- Out-of-plane collapse, diagonal cracking or bed-joint sliding, dislodging of walling units could be the most common behavior of unanchored in-fill walls.

5.4 GENERAL RETROFITTING TECHNIQUES

5.4.1 Configuration Improvement

5.4.1.1 Plan Shape

Majority of school buildings is rectangular in plan with L/B ratio less than three. Next most preferred plan shapes are elongated rectangle or L-shape. Other shapes also exist but in minority. The plan shape of the buildings can be improved by separating wings and dividing it into long elongated rectangular building parts as shown in Figure 5.1 (Appendix-10).

5.4.1.2 Elevation Improvement

School building in general is simple in construction though there remains some problem of stiffness distribution in vertical direction. As the construction process in incremental, upper story could have less covered area than lower one making building look like terrace that may lead to torsional effect. The problem can be solved either by demolition of such terrace or constructing remaining part. The later solution seems more pragmatic.

5.4.2 Retrofitting Techniques for Masonry buildings

5.4.2.1 Floor Improvement

Integrity between different elements of timber floor structured, lack of anchorage between floor joists and wall and lack of diaphragm action are general problems with timber floor. The anchorage between different timber elements can be improved by nailing/ strapping. Anchorage between floor joists can be improved by nailing steel straps to joists and anchoring them in wall. The diaphragm action can be achieved by laying a thin reinforced concrete topping over timber floor or bracing the timber floor as shown in Figure 5.2 and 5.3 (Appendix-10) shows floor topping and bracing respectively.

5.4.2.2 Roof Improvement

The problems identified for floor is also applicable to timber roof structure. Integrity between different elements of roof, and rafters and wall can be improved by nailing and/ or strapping (Ref. Photograph 5.1, Appendix-9). Diaphragm action can be achieved by roof bracing. Figure 5.4 (Appendix-10) shows scheme for roof bracing.

5.4.2.3 Splint and Bandage

Splints are vertical elements, provided at corners, wall junctions, and jambs of openings in external face of the building so as to provide it integrity in vertical direction. Function of bandage is to bind horizontally the various walls together at corners and across the building. The bandage is provided on both faces of the wall just above lintel level. A scheme of splint and bandage for school building is shown in Photograph 5.2 (Appendix-9).

5.4.2.4 Vertical Reinforced Column and Beams

In this scheme, reinforced concrete columns are added at ends of cross and longitudinal walls and horizontal reinforced concrete beams are added monolithic to the added columns. Crossties are used to connect opposite columns. Photograph 5.3 (Appendix-9) presents a general view of strengthening by RC column and beam scheme. Figure 5.5 (Appendix-10) shows a general scheme for use of reinforced column.

5.4.2.5 Prestressing

A horizontal compression state induced by horizontal tendons can be used to increase the shear strength of walls. Moreover this will also improve considerably the connection of orthogonal walls. Figure 5.6 (Appendix-10) shows a general scheme for prestressing.

5.4.2.6 Stitching of walls

The weak connection between orthogonal walls at corners, T-junctions can be improved by stitching these walls with steel bars. The stitching can be done by drilling walls first, filling the drill hole with cement grout and forcefully inserting steel bar. Figure 5.7 (Appendix-10) shows stitching of walls.

5.4.2.7 Stitching of Wythes

The stone walls constructed without incorporating through stones are quite potential to delamination. The problem can overcome by installing through stones in existing walls as shown in figure 5.8 (Appendix-10).

5.4.2.8 Buttressing the Walls

The long unsupported walls are quite susceptible to out of plane collapse due to instability. The seismic stability of the wall can be improved by constructing buttress at intermediate points. The scheme is shown in Figure 5.9 (Appendix-10).

5.4.3 Reinforced concrete building

Reinforced concrete frame buildings in study area severely lack both strength and ductility. 230* 230 mm to 300*300 mm column sizes are common. 230*230 mm size column is most common which is analytically even not enough for three-story building for normal load. These building seem to be standing by hybrid behavior. These buildings need improvement in both in strength and ductility. Following are few of the techniques for strengthening of existing building:

5.4.3.1 Jacketing of Beam and Column

Building frame with inadequate strength and ductility can be strengthened by casting, that is, by providing additional cage of longitudinal and lateral tie reinforcement around the column and beam and casting a concrete jacket as shown in figure 5.10 (Appendix-10). The sections can also be used for the purpose as shown in Figure 5.11 (Appendix-10).

5.4.3.2 Addition of Shear walls

Building frame having enough strength for normal load (i.e. dead load and imposed load) but lacking strength and ductility for lateral load can be strengthened by infilling appropriate bays by in-situ reinforced concrete shear walls with proper anchorage to the existing frame. In this case, the shear walls can be designed to carry the entire lateral load. New foundations will be required for these shear walls. Figure 5.12 (Appendix-10) presents a scheme for introduction of shear wall.

This solutions seems more promising as it will require less time, less resources and will create less disturbance in school operation. For a rough guess, this technique could be applied in three-story building with column size 300*300mm with at least four numbers of 16-mm diameter bars. Monolithic shear walls can be situated either along the periphery of the building as shown in figure 5.12 (Appendix-10) or inside the building. Adding walls along the periphery is often easier as it does not upset the school operation. Providing shear walls in one direction will not be problem as almost all partition or cladding walls in transverse direction are solid where as some intervention with opening will be necessary for shear walls in longitudinal direction.

5.4.3.3 Binding Infill walls to frame

The infill walls are quite potential to collapse during a shaking unless these are tied up with the frame. Bandage is proposed to tie up the walls with frame.

5.5 SELECTION OF RETROFITTING SCHEMES

Table 5.1 and 5.2 recommends selected retrofitting schemes for reinforced concrete framed and masonry buildings respectively to rectify identified deficiencies.

Table 5.1 Selection of Retrofitting Methods for RC Framed Building

Typical Deficiency	Improvement
Plan shape: L, T, C, E, H, elongated rectangle	Separating different wings and making them rectangular with L<=3b
Vertical irregularity	Making elevation more uniform and symmetrical
Undefined load path	Re-plan the working space and rearrange the columns
Inferior construction material	Make-up the weakness by new elements
Insufficient, weak VLLR (Vertical lateral-load resisting) elements	Beam, columns jacketing
Strong beam-weak column	Strengthening column more than beam
Short column effect	Isolating infill walls or strengthening column with more confining steel
Lack of ductile detailing (lack of confining bars/ shear bars, anchorage problem, ratio of tensile and compressive bars in VLLR elements not maintained etc	Adopting ductile detailing during retrofitting
Unanchored infill walls, parapet walls	Using bandage for anchoring infill walls, reinforcing parapet walls.

Table 5.2 Selection of Retrofitting Methods for Masonry building

Typical Deficiency	Improvement	Building Type				
Configuration of Problem		Stone building in mud mortar	Brick Building in mud mortar	Stone building in cement mortar	Hollow concrete block in cement mortar	Brick building in cement mortar
Plan shape: L, T, C, E, H, elongated rectangle	Separating different wings and making them rectangular with L<=3b	Y	Y	Y	Y	Y
Vertically irregularity	Making elevation more uniform, symmetrical	Y	Y	Y	Y	Y
Undefined load path	Re-plan the working space and rearrange the structural walls	Y	Y	Y	Y	Y
Unsymmetrical opening	Reschedule openings and arrange as required	Y	Y	Y	Y	Y
Large and more number of opening	Reduce the size and number of openings, fill the void with new wall anchoring it to existing wall	-	Y	Y	Y	Y
Weak/ no connection at wall junction	Stitch the junctions	Y	Y	Y	Y	Y
Free Gable wall (wall behaving free cantilever)	Provide gable band	Y	Y	Y	Y	Y
Long unsupported wall	Providing piers at intermediate locations	Y	Y	Y	Y	Y
Delamination	Stitching wythes with through stone	Y	-	-	-	-
Lack of integrity between floor/ roof and walls (in timber floor and roof structure)	Tie up different elements of floor/ roof with straps or nails and tie them up with walls with dowel bars/ straps	Y	Y	Y	Y	Y
Lack or tensile vertical reinforcement in wall	Provide splint on outer face	Y	Y	Y	Y	Y
Wall susceptible to out-of-plane failure	Provide bandage	Y	Y	Y	Y	Y
Lack of diaphragm effect if flexible/ semi-flexible floor	Provide a thin RC topping over the existing flexible floor structure or provide bracing. Anchor the topping or bracing with the walls	Y	Y	Y	Y	Y
Lack of diaphragm effect if flexible roof	Provide bracing at rafter level and anchor the bracing with wall	Y	Y	Y	y	Y
Heavy flexible floor and roof	Reducing the weight by removing unnecessary materials, changing materials and stiffening floor/ roof	Y	Y	Y	Y	Y
Unanchored parapet wall	Anchoring parapet walls	Y	Y	Y	Y	Y

Y: Required

5.6 ASSOCIATED PROBLEMS

The majority of the studied school buildings were constructed in parts over long periods of time depending on the availability of resources and the requirements for accommodating a certain number of pupils. This is a common practice in Nepal even for private residential buildings. Due to such extended history of construction, the materials and technology adopted vary significantly in the same building, horizontally as well as vertically. Usually, there is no record of what was constructed and when. Almost all buildings are non-engineered and are constructed by owner themselves using their own experiences. So, the construction would not have followed any set standards. Building configurations are many times controlled by available space and shape of the land lot, especially in the city core areas. Hence, some times, the school buildings are highly complicated in shape. Many times it is extremely difficult even to decide on the number of unit structures within a single building.

These complications may pose serious problems during retrofitting of the buildings. Some of these are listed below:

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

6 COST ESTIMATE AND FINANCING

This section describes the procedure followed for estimating the costs for enhancing structural safety of the school buildings. It also compares two options for seismic strengthening of existing stock of school buildings, namely, i) seismic retrofitting of existing buildings, and ii) demolish and aseismic reconstruction.

The study shows that a part of the buildings needs demolition and reconstruction. Accordingly, the cost estimation is also divided into two parts: estimation of retrofitting cost, and reconstruction cost presuming a seismic-resistant reconstruction. The total cost also includes, apart from the costs for materials and labor, also the costs for management, technical input, mason training, and provision of training to school headmaster/parents for developing school earthquake response plan. These costs for the latter items have been taken as a certain percentage of the basic construction costs.

6.1 RATE ANALYSIS

For the unit rate analysis Norms of work items published by HMG, Ministry of Works and Transport, has been taken as the basis. All the wages for labor and material are based on 2054/2055 Kathmandu Valley rates. However, reasonable local rates are considered for such materials as stones and timber that are available locally at much lower costs. Actually, the rates based on HMG Norms are for new construction only – such Norms are not available for retrofit works.

Based on above, the demolition cost, salvage value, reconstruction cost, cost of aseismic features in new construction, and seismic retrofitting cost of the representative buildings with different structural systems and construction materials have been estimated (Table 6.2). Similarly, reconstruction cost and retrofitting cost are also calculated for per square meter of plinth area of representative buildings, as presented in Table 6.1.

6.2 BREAKDOWN OF BUILDING IMPROVEMENT COST

The cost required for improving structural safety is divided into three components, namely, i) seismic retrofitting, ii) repair and maintenance, and iii) environmental improvements. These are detailed in the following sections.

6.2.1 Seismic Retrofitting

This component includes cost of such elements as splint/bandage, stitching of wall junctions, floor/roof bracing in masonry buildings; jacketing of beam and column, addition of shear walls in framed buildings that are required for seismic retrofitting, and their implementation only.

6.2.2 Repair and Maintenance

A large group of school buildings suffer significant level of deterioration because of age or used weak materials. Therefore, the total cost includes the costs for the replacement of deteriorated walling materials (brick or stone), broken joists and rafters, rusted bars of RC components, and repair of doors and windows. The issue is discussed in 4.2.1 in detail. Seismic retrofitting alone is meaningless unless these building are repaired simultaneously.

Experience shows this cost may go up to 65%[2] of the retrofitting cost. The repairing cost will be higher in buildings constructed of walls in Low Strength Masonry (LSM), floor and roof of timber structure whereas it will be lower in building using cement as one of the construction materials. It is taken as 20% to 60% of retrofitting cost, depending on construction materials used in a particular building.

[2] Experiences of Bhuwaneshwori school building

6.2.3 Environment Improvement Cost

This cost includes cost of environment and non-structural improvement of school buildings. Majority of school building walls are un-plastered and unpainted, and the ground floor classrooms have un-cemented dusty floors, staircases are generally steep and clumsy. Doors of all the classrooms open inside. Schools in fringe, some even in city core areas, are deprived of toilets. At the time of retrofitting, construction of these elements seems justifiable. However, at this stage it is extremely difficult to forecast cost of these elements. The cost of these elements found around 80% of seismic retrofitting cost[2]. For present use the cost is assumed as 60% of the seismic retrofitting cost without further justification.

The costs are presented in Table 6.1.

6.3 COMPARISON OF OPTIONS

The costs of the two intervention options, notably, reconstruction and retrofitting, are compared, as presented in Table 6.2. Comparison has not been made for RC framed buildings, and adobe buildings or those, which are not recommended for retrofitting. Both the options do not include environment improvement cost.

The comparison shows that retrofitting is quite a promising option unless the building has lost its structural value and cannot be saved or the modern days functional requirements of the building have changed.

6.4 PLINTH AREA ESTIMATE

From of the survey data, the plinth area of buildings with different materials and structural system has been calculated and used for estimating total retrofitting and reconstruction cost where required.

6.5 COST ESTIMATE

For cost estimation purpose, two items are identified: a) retrofitting, b) demolition and reconstruction. It is assumed that the masonry buildings that require demolishing, will be reconstructed with brick in cement mortar, reinforced concrete (RC) floor and roof slab with the similar plinth area and number of story as before. Improvement cost of those buildings whose height is reduced is divided into two parts: a) retrofitting of remaining part under Retrofitting Cost heading and b) reconstruction of demolished part as a new building with same plinth area and height as demolished under Reconstruction Cost heading.

It is assumed that salvage value of the demolished buildings' material will be enough to cover up demolition cost and disposal cost of unnecessary materials.

6.5.1 Retrofitting Cost

From the unit rates and plinth area, the total retrofitting cost of groups of buildings with different structural systems and construction materials has been calculated. It also includes cost of retrofitting of those buildings whose height is reduced because of high vulnerability. The cost is presented in Table 6.3. The cost also includes the costs for repair and maintenance, as well as environmental improvement.

Table 6.1: Retrofitting and Reconstruction Unit Rates

S. No.	Building Type		Plinth area (sqm)	Retrofitting Cost					Reconstruction Cost				Cost (NR/Sqm)
	Walling material	No. of Story		Aseismic Retrofitting	Repair & Maintenance	Env. Improvement	Total Cost(NR)	Cost (NR/Sqm)	Reconstruction	Aseismic Features	Env. Improvement	Total Cost	
A	**Stone Masonry Buildings**												
	Flexible floor and flexible roof	2	140	239810	143886	143886	527582	3768					
	Rigid floor and rigid roof	2	140	160767	48230	96460	305457	2182					
	Rigid floor and flexible roof	2	140	214721	96624	128833	440178	3144					
	Flexible roof	1	140	126038	75623	75623	277284	1981					
	Rigid roof	1	140	80254	24076	48152	152483	1089					
B	**Rectangular Block in mud mortar**												
	Flexible floor and flexible roof	2	137	214916	128950	128950	472815	3451					
	Flexible floor and rigid roof	2	137	184242	82909	110545	377696	2757					
	Rigid floor and rigid roof	2	137	164118	49235	98471	311824	2276					
	Rigid floor and flexible roof	2	137	191456	86155	114874	392485	2865					
	Flexible roof	1	137	113447	51051	68068	232566	1698					
	Rigid roof	1	137	71284	21385	42770	135440	989					
C	**Rectangular Block in cement mortar**												
	Flexible floor and flexible roof	4	150	540309	162093	324185	1026587	6844					
	Rigid floor and rigid roof	4	150	368347	73669	221008	663025	4420					
	Rigid floor and flexible roof	4	150	415674	103919	249404	768997	5127					
	Flexible floor and flexible roof	3	150	401796	120539	241078	763412	5089					
	Rigid floor and rigid roof	3	150	279591	55918	167755	503264	3355	1382721	64185	139796	1586702	10578.01
	Rigid floor and flexible roof	3	150	320974	80244	192584	593802	3959					
	Flexible floor and flexible roof	2	146	219007	65702	131404	416113	2850					
	Flexible floor and rigid roof	2	146	194765	48691	116859	360315	2468					
	Rigid floor and rigid roof	2	146	152139	30428	91283	273850	1876	931281	41214	76070	1048565	7181.952
	Rigid floor and flexible roof	2	146	192806	48202	115684	356691	2443					
	Flexible roof	1	134	112190	28048	67314	207552	1549					
	Rigid roof	1	146	73503	14701	44102	132305	906	533304	18432	36752	588488	4030.74
D	**Reinforced Concrete Frame**												
	Rigid floor and rigid roof	5	146	1484844	296969	890906	2672719	18306					
	Rigid floor and rigid roof	4	146	1187875	237575	712725	2138175	14645					
	Rigid floor and flexible roof	4	146	1199315	239863	719589	2158767	14786					
	Rigid floor and rigid roof	3	146	890906	178181	534544	1603631	10984					

S. No.	Building Type		Plinth area (sqm)	Retrofitting Cost					Reconstruction Cost				Cost (NR/Sqm)
	Walling material	No. of Story		Aseismic Retrofitting	Repair & Maintenance	Env. Improvement	Total Cost(NR)	Cost (NR/Sqm)	Reconstruction	Aseismic Features	Env. Improvement	Total Cost	
	Rigid floor and flexible roof	3	146	771543	154309	462926	1388777	9512					
	Rigid floor and rigid roof	2	146	593937	118787	356362	1069087	7323					
	Rigid floor and flexible roof	2	146	475377	95075	285226	855679	5861					
	Rigid floor	1	146	296186	59237	177712	533135	3652					
	Flexible roof	1	146	306276	61255	183765	551296	3776					

Table 6.2: Comparison of Options

S. No.	Building Type	No. of story	Plinth area (sqm)	Demolition and Reconstruction cost (NR.)					Retrofitting (NR)			Benefit (NR)
	Walling Material			Salvage Value	Demolition Cost	Reconstruction cost	Cost of Aseismic Features	Total	Retrofitting cost	Repair and Maintenance Cost	Total	
B	**Fields Stone in mud Mortar**											
	Flexible floor and flexible roof	2	140	157116	28281	598692	139315	609172	239810	143886	383696	225476
	Rigid floor and rigid roof	2	140	86097	68167	706270	68029	756369	160767	48230	208997	547372
	Rigid floor and flexible roof	2	140	114727	48755	658638	108060	700726	214721	96624	311345	538938
	Flexible roof	1	140	72993	15918	334618	72026	349569	126038	75623	201661	147908
	Rigid roof	1	140	44363	60056	391759	30354	437806	80254	24076	104330	333476
	Total		*1120*	*275296*	*221177*	*2689977*	*417784*	*2853642*	*827590*	*388439*	*1216029*	
	Average cost per Sq. m			*424.4*	*197.5*	*2401.8*	*373.0*	*2597.9*	*733.6*	*346.8*	*1085.7*	
	% of reconstruction cost						*15.5*		*30.5*	*14.4*		
C	**Rectangular Block in mud Mortar**											
	Flexible floor and flexible roof	2	137	187760	24060	678592	112698	627590	214916	128950	3438662	283724
	Flexible floor and rigid roof	2	137	159223	47274	744603	60408	693062	184242	82909	267151	425911
	Rigid floor and rigid roof	2	137	119223	65942	787208	41332	775259	164118	49235	213353	561906
	Rigid floor and flexible roof	2	137	148238	44454	742311	81713	720240	191456	86155	277611	442629
	Flexible roof	1	137	92370	13647	379521	58218	359016	113447	51051	164498	194518
	Rigid roof	1	137	63740	35121	434366	19917	425664	71284	21385	92669	332995
	Total		*1370*	*770554*	*230498*	*3766601*	*374286*	*3600831*	*939463*	*419685*	*1359148*	
	Average cost per Sq. m			*562.4*	*168.2*	*2749.0*	*273.2*	*2628.3*	*685.7*	*306.3*	*992.1*	
	% of reconstruction cost						*9.9*		*24.9*	*11.1*		
D	**Rectangular Block in Cement Mortar**											
	Flexible floor and flexible roof	4	146	333926	96033	1760471	214896	1737474	540309	162093	702402	1035072

S. No.	Building Type	No. of story	Plinth area (sqm)	Demolition and Reconstruction cost (NR.)					Retrofitting (NR)			Benefit (NR)
	Walling Material			Salvage Value	Demolition Cost	Reconstruction cost	Cost of Aseismic Features	Total	Retrofitting cost	Repair and Maintenance Cost	Total	
	Rigid floor and rigid roof	4	146	186508	170422	1877830	93066	1954810	368347	73669	442016	1512794
	Rigid floor and flexible roof	4	146	213926	144800	1837388	132910	1901172	415674	103919	519593	1381579
	Flexible floor and flexible roof	3	146	245587	70648	1291001	156805	1272867	401796	120539	522335	750532
	Rigid floor and rigid roof	3	146	138169	133526	1382721	64185	1442263	279591	55918	335509	1106754
	Rigid floor and flexible roof	3	146	165587	107984	1342279	98345	1383021	320974	80244	401218	981806
	Flexible floor and flexible roof	2	146	159277	48741	865200	103500	858164	219007	65702	284709	573455
	Flexible floor and rigid roof	2	146	131859	74283	905642	68937	917003	194765	48691	243456	673547
	Rigid floor and rigid roof	2	146	91859	92951	931281	41214	973587	152139	30428	182567	791020
	Rigid floor and flexible roof	2	146	119277	67409	890839	76142	915113	192806	48202	241008	7674105
	Flexible roof	1	146	74779	30961	482914	18112	457208	112190	28048	140238	316970
	Rigid roof	1	146	47577	57039	533304	18432	561198	73503	14701	88204	472994
	Total		*4610*	*1908331*	*1094797*	*14100870*	*1086544*	*14373880*	*3271161*	*832154*	*4103315*	
	Average cost per Sq. m			*413.9*	*237.5*	*3058.7*	*235.7*	*3118.0*	*709.6*	*180.5*	*790.1*	
	% of reconstruction cost						*7.7*		*23.2*	*5.9*		

Table 6.3: Retrofitting Cost

S. No.	Building Type	No of Story	No. of Buildings	Plinth Area (Sqm)	Unit Rate (NR/Sqm)	Total Amount	Remarks
B	***Stone Masonry Buildings***						
	Flexible floor and flexible roof	3	1	300	3768	1130400	Reduced to 2 story
	Flexible floor and flexible roof	2	15	1126	3768	4242768	
	Rigid floor and rigid roof	2	4	489	2182	1066998	
	Rigid floor and flexible roof	2	2	60	3144	188640	
	Flexible roof	1	86	6628	1981	13130068	
	Rigid roof	1	6	679	1089	739431	
	Total		***114***	***9282***		***20498305***	
C	***Rectangular Block in mud mortar***						
	Flexible floor and flexible roof	4	4	384	3451	1325184	Reduced to 2 story
	Rigid floor and rigid roof	4	1	182	2276	414232	Reduced to 2 story
	Rigid floor and flexible roof	4	1	185	2865	530025	Reduced to 2 story
	Flexible floor and flexible roof	3	6	610	3451	2105110	Reduced to 2 story
	Rigid floor and rigid roof	3	6	1083	2276	2464908	Reduced to 2 story
	Rigid floor and flexible roof	3	5	308	2865	882420	Reduced to 2 story
	Flexible floor and flexible roof	2	47	5580	3451	19256580	
	Flexible floor and rigid roof	2	7	1096	2757	3021672	
	Rigid floor and rigid roof	2	28	3198	2276	7278648	
	Rigid floor and flexible roof	2	26	3133	2865	8976045	
	Flexible roof	1	119	11944	1698	20280912	
	Rigid roof	1	31	3646	989	3605894	
	Total		***281***	***31349***		***70141630***	
D	***Rectangular Block in cement mortar***						
	Rigid floor and rigid roof	5	2	254	4420	1122680	Reduced to 4 story
	Flexible floor and flexible roof	4	3	336	6844	2299584	
	Rigid floor and rigid roof	4	1	164	4420	724880	
	Rigid floor and flexible roof	4	1	88	5127	451176	
	Flexible floor and flexible roof	3	5	403	5089	2050867	
	Rigid floor and rigid roof	3	10	981	3355	3291255	
	Rigid floor and flexible roof	3	3	306	3959	1211454	
	Flexible floor and flexible roof	2	6	539	2850	1536150	
	Flexible floor and rigid roof	2	1	109	2468	269012	
	Rigid floor and rigid roof	2	42	3841	1876	7205716	
	Rigid floor and flexible roof	2	14	1457	2443	3559451	
	Flexible roof	1	47	4861	1549	7529689	
	Rigid roof	1	57	6610	906	5988660	
	Total		***192***	***19949***		***37240574***	
E	***Reinforced Concrete Frame***						
	Rigid floor and rigid roof	5	1	143	18306	2617758	
	Rigid floor and rigid roof	4	4	659	14645	9651055	
	Rigid floor and flexible roof	4	1	97	14786	1434242	
	Rigid floor and rigid roof	3	14	1765	10984	19386760	
	Rigid floor and flexible roof	3	1	120	9512	1141440	
	Rigid floor and rigid roof	2	31	3719	7323	27234237	
	Rigid floor and flexible roof	2	2	232	5861	1359752	
	Flexible roof	1	19	242	3776	913792	
	Rigid floor	1	1	2539	3652	9272428	
	Total		74			73011464	

S. No.	Building Type	No of Story	No. of Buildings	Plinth Area (Sqm)	Unit Rate (NR/Sqm)	Total Amount	Remarks
F	***Earthquake Block#***	1	199		8588	1709012	
	Grand Total,(G=B+C+D+E+F)					202600985	
	Contingency, H=20% of G					40520197	
	Grand Total, I=G+H					243121182	

#: Environmental improvement cost not included.

6.5.2 Reconstruction Cost

It covers up cost of buildings or part of buildings that need to be demolished and reconstructed. The cost is presented in Table 6.4. The cost also includes cost for environment improvement.

Table 6.4: Reconstruction Cost

S. No.	Building Type	No of Story	No. of Buildings	Plinth Area (Sqm)	Unit Rate (NR/Sqm)	Total Amount (NR)	Remarks
C	***Rectangular Block in Cement mortar***						
	Rigid floor and rigid roof	3	1	76	10,578	803,928	Substitute of adobe construction
	Rigid floor and rigid roof	2	10	1,056	7,182	7,584,192	
	Rigid roof	1	23	4,804	4,031	19,364,924	
	Rigid Roof	1	1	300	4,031	1,209,300	Substitute of top story of 3 story stone building
	Rigid floor and rigid roof	2	6	751	7,182	5,393,682	Substitute of top 2 two story of 4 story brick in mud building
	Rigid floor and rigid roof	1		8,592	4,031	34,634,352	Substitute of top story of 3 story brick in mud building
	Rigid floor and rigid roof	1	2	254	7,182	1,824,228	Substitute of top story of 5 story brick in cement
	Grand total					**43,061,562**	

6.5.3 Total cost

The retrofitting and reconstruction cost is summed up here and other cost are added. The total cost is presented in Table 6.5.

Table 6.5: Total Cost

No.	Item	Amount	Remarks
1	Retrofitting Cost	243121182	Table 6.3
2	Reconstruction cost	43061562	Table 6.4
	Total (A)	286182744	
	Adding 70% of (A) to cover up un-surveyed schools (B)	200327921	
	Total, ©	486510665	
	Assuming Cost for management, technical input, training etc @ 25% of ©	121627666	
	Grand total	**608138331**	**$8.7 M**

6.6 FINANCIAL STATUS OF PUBLIC SCHOOLS

The financial condition of schools is rather weak and expected to degrade further in future. It is because of the fact that the financing for education is done by central government, which provides only salary to teachers and very meager fund for stationary as a proportion of the salary. Government does not provide any fund for school construction, repair/ maintenance or furniture unless there is any specific project. There is a restriction on types of fees for public to collect from students.

Such condition has led to the fact that, in general, only those parents, who cannot afford the expenses of a private school, send their wards to government schools. Those who can afford to send their children to private schools do not feel responsibility towards the public schools. This restricts the extent of fund raising for the government schools leading to severe resource deficit in public schools. This phenomenon is more severe in urban areas.

6.7 CONCLUSION

Retrofitting seems to be the most promising option for the improvement of the seismic safety of school buildings provided that the structural condition and present function of the building permit it. This is because of the relatively lesser requirements for funds and time. For retrofitting, the buildings constructed using cement for building components such as wall, floor and roof structure, are more cost effective as compared to buildings with weaker materials such as low strength masonry (LSM), timber floor or roof structure.

Retrofitting of school building with stone in mud mortar, and flexible floor and roof does not seem to be as cost-effective as the cost of retrofitting could exceed 25% of reconstruction cost.

In general, the public schools themselves can not afford to spend cash for strengthening or improvement of school buildings on their own because of extreme lack of resources and other pressing immediate needs. However, there is a tremendous potential for generating resources in terms of in-kind contribution from the community in the form volunteer, collection locally available materials such as sand, aggregate, earth, and bamboos. However, such in-kind contribution could have any meaning only when there is some external fund and resources and there is a sustained program for enhancement of earthquake safety of public schools.

7 POSSIBLE IMPACT OF A SCENARIO EARTHQUAKE

This chapter presents a description of the general consequences likely due to a scenario earthquake (MSK IX intensity of shaking) on educational facilities, and the estimates of casualties in schools for “no intervention” option. It also presents the estimates of the expected damage and casualty if an intervention program such as retrofit is implemented, and provides the comparative benefits of retrofitting existing school buildings and inclusion of earthquake-resistant elements in the construction of new school buildings.

7.1 THE SCHOOL BUILDINGS IN STUDY AREA

The building construction in the study area, except for the newer RC framed buildings, follows the traditional pattern of load bearing walls in burnt bricks, stone or unburned clay blocks (adobe) with sloping roofs.

Table 4.3 shows that the predominant walling materials are burnt brick in mud mortar 40.4%, burnt brick in cement mortar 27.6%, field stone in mud mortar 16.4%, RC framed buildings 10.6%, and adobe 5% among the normally constructed buildings. Among these, fieldstone in mud mortar is highly vulnerable to severe damage in MSK VIII or beyond. RC framed buildings, which are rather safe in moderate earthquake, constitute only about 10.6%.

The predominant floor structure is RC slab, which provides much better binding effect for walls. RC slabs constitute 65.4% of floor structures, whereas flexible floors structures are only 34.6% (refer Table 4.5).

The predominant materials used in the roofs (refer Table 4.6) are CGI sheets (58.4%); RC slab (38.5%) and tile, slate and jhingati (3.1%). Tiled roofs tend to be heavy and cause large earthquake forces on the structure without providing the binding effect on the walls, therefore, unsuitable for seismic zones VIII and higher. Metal and asbestos sheet roofs, which are light in weight, and the concrete slab roof, which have a binding effect on the walls, are both suitable from the seismic safety angle.

Table 4.3 depicts that a majority of school buildings in the study area is one story or two stories in height. One-story buildings constitute 56% of the building stock, two-story buildings are 33.8%, three-story buildings 7.5%, four-story buildings 2.3% where as five-story buildings only 0.4% among normally constructed buildings. The five-story buildings should be expected to be far more vulnerable than the one-story buildings. Fortunately, there are very few five-story buildings in the study area.

From configuration point of view, 38.6% of the buildings are rectangular with length less than or equal to three times the width (refer Table 4.12). Such simple shape of the buildings is in favor of lower losses. 26.6% buildings are elongated - these are not as good in terms of shape, but still not as highly vulnerable as L-shaped. 19.6% of the buildings are L-shaped and the rest are more complicated in shape. These are to be considered as more vulnerable. Cumulatively, one can say that the overall scenario is not very bad from configuration point of view.

The three districts of Bhaktapur, Kathmandu, and Lalitpur suffered earthquake intensity VII to X on MSK intensity scale during the 1934 Earthquake (refer Figure 2.1). The existing school buildings in these districts are grouped according to their walling materials and their location in these different intensity zones (Table-4.5). However, since the National Building Code of Nepal specifies same seismic zone for the entire study area (equal to intensity IX MMSK shaking), the scenario described below has been developed for intensity IX MSK rather than considering the distribution of the 1934 intensities. The following scenario emerges.

7.2 POTENTIAL OF LIFE AND ECONOMIC LOSSES

7.2.1 Building Loss

a. Completely collapsed school buildings: 66%

b. Those partly destroyed and partly having large and deep cracks, which will require reconstruction: 11%
c. Those without total or partial collapse but with large cracks, repairable: 23%

Table 7.1 presents economic loss due to building damage.

Table 7.1: Estimation of Economic Loss due to Building Damage.

S. No.	Building Type	No. Story	No. of Building	Plinth Area	Unit Rate (cost of materials and labor only) (NR/sqm)	Loss ratio	Total loss (NR)
A	**Earth/ Adobe in mud mortar**						
	Flexible floor and Flexible roof	3	1	76	5540	0.8	336812
	Flexible floor and Flexible roof	2	9	842	4121	0.8	2776117
	Rigid floor and flexible roof	2	1	140	4480	0.8	501716
	Flexible roof	1	22	4590	2271	0.7	7296103
	Rigid roof	1	1	214	2478	0.7	371263
	Total		***34***	***5862***			***11282012***
B	**Stone Masonry Buildings**						
	Flexible floor and flexible roof	3	1	300	5863	0.9	1583017
	Flexible floor and flexible roof	2	15	1126	4276	0.9	4333675
	Rigid floor and rigid roof	2	4	489	5045	0.9	2220210
	Rigid floor and flexible roof	2	2	60	4705	0.9	254046
	Flexible roof	1	86	6628	2390	0.85	13465506
	Rigid roof	1	6	679	2798	0.85	1615026
	Total		***114***	***9282***			***23471481***
C	**Rectangular Block in mud mortar**						
	Flexible floor and flexible roof	4	4	384	9019	**0.8**	2770785
	Rigid floor and rigid roof	4	1	182	10145	0.8	1477120
	Rigid floor and flexible roof	4	1	185	9855	0.8	1458522
	Flexible floor and flexible roof	3	6	610	6693	0.8	3266095
	Rigid floor and rigid roof	3	6	1083	7250	0.8	6281179
	Rigid floor and flexible roof	3	5	308	7543	0.8	1858642
	Flexible floor and flexible roof	2	47	5580	4953	0.8	22111202
	Flexible floor and rigid roof	2	7	1096	5435	0.8	4765459
	Rigid floor and rigid roof	2	28	3198	5746	0.8	14700678
	Rigid floor and flexible roof	2	26	3133	5418	0.8	13580498
	Flexible roof	1	119	11944	2770	0.7	23161308
	Rigid roof	1	31	3646	3171	0.7	8091890
	Total		***281***	***31349***			***103523378***
D	**Rectangular Block in cement mortar**						
	Rigid floor and rigid roof	5	2	254	15339	0.75	2922078
	Flexible floor and flexible roof	4	3	336	11736	0.75	2957591
	Rigid floor and rigid roof	4	1	164	12519	0.75	1539821
	Rigid floor and flexible roof	4	1	88	12249	0.75	808451
	Flexible floor and flexible roof	3	5	403	8607	0.65	2254518
	Rigid floor and rigid roof	3	10	981	9218	0.65	5877947
	Rigid floor and flexible roof	3	3	306	8949	0.65	1779862
	Flexible floor and flexible roof	2	6	539	5926	0.55	1756771
	Flexible floor and rigid roof	2	1	109	6203	0.55	371871
	Rigid floor and rigid roof	2	42	3841	6379	0.55	13475190
	Rigid floor and flexible roof	2	14	1457	6102	0.55	4889547
	Flexible roof	1	47	4861	3604	0.45	7883211

S. No.	Building Type	No. Story	No. of Building	Plinth Area	Unit Rate (cost of materials and labor only) (NR/sqm)	Loss ratio	Total loss (NR)
	Rigid roof	1	57	6610	3653	0.45	10865156
	Total		192	19949			57382013
E	**Reinforced Concrete Frame**						
	Rigid floor and rigid roof	5	1	143	20372	0.7	2039220
	Rigid floor and rigid roof	4	4	659	16731	0.7	7718099
	Rigid floor and flexible roof	4	1	97	15755	0.7	1069771
	Rigid floor and rigid roof	3	14	1765	13091	0.4	9241932
	Rigid floor and flexible roof	3	1	120	12114	0.4	581494
	Rigid floor and rigid roof	2	31	3719	9450	0.4	14057698
	Rigid floor and flexible roof	2	2	232	8474	0.4	786371
	Flexible roof	1	19	242	4833	0.4	467853
	Rigid floor	1	1	2539	5809	0.4	5899906
	Total		74	9516			41862344
	Grand Total (A)						237521228
	Adding 70% of (A) to cover up un-surveyed Schools						166264859.5
	Total (A+B)						403786087
	Add management cost @ 20%						80757217
	Total						484543304
	Equivalent to						US$ 6.9 M

7.2.2 Estimate for Loss of lives, Injury

Not all the schools provided data on the number of students and teachers. Available data shows that there are 119,589 students and teachers in 750 school buildings. This figure was extrapolated to cover all the 1514 buildings belonging to the total of 643 public schools of the valley.

For estimating potential loss of lives, a number of assumptions were made:

a. All buildings are assumed having equal number of students irrespective of their size, number of rooms, use, and population.
b. In partially collapsed buildings, the death rate is assumed as half of that of fully collapsed house.
c. Same level of casualty/ injury is assumed in buildings with similar walling material, irrespective of their level i.e. primary or secondary school.
d. No consideration has been made for the number of stories on estimate of death rate .
e. Same rate of casualty/ and injury has been assumed irrespective of the availability of open space. Buildings in the city core areas could suffer higher level of casualty because of generally more number of stories, lack of open space, and indeterminate, labyrinthine, hence confusing, nature of the escape routes, if any.

It is understood that the following factors affect the extent of casualty and injury by an earthquake:

- Season of earthquake: More in monsoon season than in winter, as the mud of the wall is wet and loss of shear strength could result in more damage in buildings.
- Hour of earthquake: More in class hour compared to non-class hour i.e. more in day hours compared to night hours. The situation is in quite contrary to residential buildings. For casualty and injury estimation, earthquake considered striking in class hours.

- Level of schools: More in primary schools compared to higher grade schools. As the students of primary schools are low in age (generally 6 to 10-year age groups) are delicate and cannot escape without guidance.
- Location of school: More in urban, congested area where there is no open space compared to outskirts where there is open space around the school. Chances of entrapment are far high in urban areas.

However, we could not consider the factors because of lack of appropriate models. The effect of season on loss is not well known in quantitative terms. Similarly, no past data exist for the relationship between casualty/injury by earthquake and the level of school (high, lower secondary or primary) or their location (urban/rural).

For the estimation of casualty and injury, the model proposed by Coburn and Spencer [11, Page 277-284, source #7) has been used. This model specifies five factors viz.

Factor M1: *Mortality per building, it is function of population per building (taken as 160 on average).*

Factor M2: *Occupancy at the time of earthquake (taken as 1 in class hour i.e. full occupancy)*

Factor M3: *Occupants trapped by collapsed building (taken as 60% for all masonry buildings and RC buildings).*

Factor M4: *Injury distribution at collapse. It is taken as 20%, 30% and 30% as death, serious injury and light injury respectively for masonry as well as RC buildings.*

Factor M5: *taken as 50% of the community will be incapacitated by the magnitude of the losses, panic; next 25% of the community will be able to organize rescue activity and next 25% of the community will be able to work after receiving help from emergency squad and SAR experts.*

Based on the above assumptions, the number of person likely to get killed works out as followed:

Death = 0.5 * 780 * (160 * 1 * 0.6 * (0.2 + 0.95 * (1 - 0.2)) + 0.25 * 780 * (160 * 1 * 0.6 * (0.2 + 0.6 * (1 - 0.2)) + 0.25 + 780 * (160 * 1 * 0.6 * (0.2 + 0.45 * (1 - 0.2))

= 41658 **(**say **42,000)**

Severe injury = 0.5*780*(160*1*0.6*(0.3+0.95*(1-0.3))+0.25*780*(160*1*0.6*(0.3+0.6*(1-0.3))+0.25+780*(160*1*0.6*(0.3+0.45*(1-0.3))

= 61121(say **61,000**)

Light injury = 61121 (say **61,000**)

7.3 CONCLUSIONS

The likely consequences of the scenario earthquake is quite dreadful:

School Buildings	*66% of school buildings fully collapsed, 11% - structurally destroyed and partially collapsed, and 23% damaged*
Casualties	*42,000 students/teachers killed, 61000 severely injured requiring hospitalization, and 61,000 injured*
Direct Economic Loss	*NR 484 Million or US$ 6.9 Million (1999 prices).*

Post-earthquake emergency response, even if fully prepared for beforehand, can save many lives, but will not be able to reduce property losses and the reconstruction and rehabilitation costs.

8 PRIORITIZATION PLAN

For the rehabilitation program for the hazardous buildings, a prioritization plan has been developed for different types of buildings. Financial constraints and the time necessary to accomplish a program will require that not all buildings identified as hazardous can immediately be incorporated into a rehabilitation program.

The plan identifies the criteria that affect the selection of a particular building. This prioritization plan is first trial and will require further work for refinement.

Table 8.1 Scoring Basis and Scoring Units

S. No.	Criteria	Result	Received Score	Remarks
		Judgement	Score	
1.	Commitment for Participation	Strong	50	
		Very good	40	
		Good	30	
		Fair	20	
		Weak	10	
		No	0	
2	Condition of Building	Bad	20	
		Fair	10	
		Good	0	
3	Craftsman available at local	Yes	10	
		No	0	
4	School visibility	Yes	10	
		No	0	
5	Temporary class room option	Yes	10	
		No	0	
	Total Score			

Local community participation is considered essential in implementation of any rehabilitation program. But it should not be measured in cash / quantifiable terms. An economically weak community has limited options in economic terms. But the community could have high level of enthusiasm and promise of involvement in the retrofit/rehabilitation and in overall school earthquake safety program. Such communities should be given higher priority while selecting a particular school. Perhaps a community motivator /sociologist should work with the local communities during the prioritization process to gauge the relative levels of potential involvement.

The problem of accessibility should be well understood as it affects the process in two ways. Implementation of school rehabilitation works in areas of poor accessibility poses increased difficulties and higher project costs (due mainly to higher transportation costs), at times reducing the visibility of the project in comparison to one in easily accessible areas. But one should understand that such areas generally are neglected and deprived of the fruits of most development activities, and hence should be assigned relatively higher priority while developing the prioritization plan for school retrofits.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 GENERAL CONCLUSIONS

- There is a wide variety of school building structures in the urban or rural areas of the three districts of Bhaktapur, Kathmandu and Lalitpur. These buildings have conveniently been divided into two broad groups, notably, i) normally constructed buildings (ordinary buildings) adopting prevailing materials and technology; and ii) the school buildings (earthquake blocks) constructed during 1989-1993 by HMG/N under EEARRP, which was implemented after the 1988 Udaypur Earthquake.
- Most of the school buildings should be regarded as extremely complex in view of the wide variation in the type of construction materials used and the technology employed.
- The standard Earthquake blocks are two-room, one-story, steel-frame buildings with CGI sheet as roofing. Cladding or internal walls are constructed using the locally available materials.
- Ordinary buildings, constructed 50 years or more ago, are still in use as schools. Construction of schools received a boost in the 1970s and afterwards.
- Highest density of the public schools is in the central part of the valley, in the urbanized areas. Thus, the majority of the school buildings lie in flat terrain. Only a few schools are located in the terraced slopping land in the periphery of the valley.
- Out of the 695 normally constructed school buildings, 64 are located in close proximity of landslides, hence face high landslide risk. Landslide will be the secondary hazard faced by these schools during a significant earthquake.
- A majority of the school buildings are free standing. Most of the confined buildings are within the urban core area.
- Rectangular or L-shaped configuration appears to be the dominating shape of the school buildings.
- 589 out of 695 buildings have open space at least along one side of the building. This allows for collection of the students during emergencies. The remaining school building lack open-space, and they exit right into the street. Poor planning of the building as well as of the exit and egress points are characteristics for the schools in the urban core areas, and hence they are vulnerable during earthquake emergencies. They may lead to entrapment and confusion during an event.

9.2 CONSTRUCTION MATERIAL AND TECHNOLOGY

- Local availability of construction materials and technology dominate the building construction practices.
- Use of cement has rapidly grown up since the 80s. Yet, fired brick in mud mortar is the most common among the different walling materials.
- Only 74 out of the 695 buildings are RC framed buildings.
- Use of pre-cast RC components or structures is non-existent. Similarly, steel structures are not seen except for the earthquake blocks that were constructed following the 1988 Udaypur Earthquake.
- Construction of rigid floor construction (RC/ RB/ RBC slabs) is becoming more common. Like-wise, ‘new’ material such as CGI sheet is gaining popularity and replacing the traditional roof tile and jhingati. Both are good indicators from seismic safety point of view.
- Strip foundation with stone in mud mortar is the prevalent foundation type.
- In most of the cases, the technical input in normal building construction is limited only to the preparation of municipal drawings. While the building permit process does appear to be requiring technical inputs, but in practice this is not followed. Such reality makes the construction control and compliance monitoring difficult.
- Incorporation of seismic strengthening features in buildings is almost none. People even do not know about it.

- The technology in use is rather poor.

9.3 VULNERABILITY OF THE EXISTING BUILDING STOCK

- Four methods for vulnerability assessment were identified and preliminary work done. However, these methods could not be developed to a satisfactory stage due to time and resource constraint, and lack of adequate data and experiences of earthquake damage assessment. This study used the method that is based on the definition of MSK intensity scale.
- The traditional as well as the modern buildings face very high levels of earthquake risk. Even after the introduction of modern materials such as cement and steel in construction, the vulnerability of buildings seems not much reduced because of over-confidence on these materials, inappropriate use, and lack of understanding of the materials' behavior.
- At least 10-15% of the buildings are in severely bad condition- their continuous use is hazardous. These buildings should be subject to immediate demolition and reconstruction in parts or whole.
- Around 25% buildings are in fair condition. This is either because of poor or non-existent repair and maintenance practice, or due to structural problems. These buildings can be rehabilitated, albeit with some extra efforts and resources, and if action is taken without delay. Any delay would further worsen the situation because of deterioration of the constituent elements.
- The remaining 60-65% of the school buildings is in relatively good condition and usable in some way, although more than 99% of them do not meet the aseismic criteria prescribed by the Nepal National Building Code. These buildings can be strengthened by using simple retrofitting techniques.
- Around two hundred thousand students are under risk. A scenario earthquake during day hours when classes are running, will have terrible effect. Risk to the inhabitants in the urban core areas is higher because of clumsy plan, confusing entry and exits resulting in possible entrapment.

9.4 RETROFITTING

- Retrofitting of a large group of the existing stock of public school buildings is economically affordable, cost effective and technically feasible.

9.5 AWARENESS LEVEL

- The knowledge regarding seismic safety among the school family is rather low. But the people are very enthusiastic to learn more about the physical phenomena.
- The general notion about earthquake resistant construction practice erroneously presumes that seismic resistant construction is not affordable in Nepal. Fatalism is still very high.

9.6 RECOMMENDATIONS

To reduce the disastrous effects of earthquakes on buildings, infrastructure, life and the economy, the following recommendations are made:

- Existing buildings should be assessed regarding their structural vulnerability to earthquakes.
- A time-bound program should be implemented to retrofit all weak buildings or their reconstruction with incorporation of seismic resistant measures, as the case may be.
- Earthquake resistant design codes must be implemented in all new buildings.
- School family (students/ teachers) should be provided with drill programs.
- Schools in urban core areas not only need building retrofitting but also improvement in planning. There is an urgent need to reduce potential entrapment, clearly define the confusing points and exit/escape routes for each school.
- Effective awareness raising programs needs to be conducted.

- R & D should be given priority to develop refined and reliable models for vulnerability assessment of different group of buildings. There is a need to invest in R & D on retrofitting of buildings.
- Develop manuals/ Guidelines, to cater to the needs of different groups of people such as designers, supervisors, and masons, for retrofitting of different types of buildings.
- Develop strategy for improvement of seismic safety of schools.
- Before taking up any large-scale retrofitting program, a detailed survey of school buildings by technicians is recommended.

10 REFERENCES

10.1 MAIN REFERENCE

1. Arya, A. S.; 1997, *Guidelines for Damage Assessment and Post Earthquake Action* (Part I: Brick House with Clay Tile Roofing, Part II: Brick House with RC Slab or Stone Patti Roofing or CGI Roofing or with RC Roof), Building Materials and Technology Promotion Council (BMTPC), Ministry of Urban Development, Govt. of India, New Delhi, India.
2. Arya, A. S.; ---, *Retrofitting of Stone Houses in Marathwada Area of Maharastra (First Case: Stone Houses with complete wooden frame inside)*, Building Materials and Technology Promotion Council (BMTPC), Ministry of Urban Development, Govt. of India, New Delhi, India.
3. Arya, A. S. et al; 1986, *Guidelines for Earthquake Resistant Non-engineered Construction*, International Association for Earthquake Engineering.
4. Arya, A. S.; 1987; Protection of Educational Buildings against Earthquakes, Educational Building Report #13, UNESCO Principal Regional Office for ASIA and the Pacific, Bangkok, Thailand.
5. Auden, J. B., 1939, *The Bihar-Nepal Earthquake Of 1934, Memoirs Of Geological Survey Of India*, V. 73, Geological Survey of India, Calcutta, India.
6. BMTPC, 1997, *Vulnerability Atlas of India*, Building, Building Materials and Technology Promotion Council (BMTPC), Ministry of Urban Development, Govt. of India, New Delhi, India.
7. Bothara, J. K., Sharpe, R.; 1996, *The Derivation of Design Seismic Loads for Nepal*, paper presented in First Seminar on Earthquake Design Criterion for Nepal organized by Nepal Engineering. College, Kathmandu.
8. Brahma Samsher JBR, 1936, *Nepal Ko Maha Bhukampa* (The Great Earthquake Of Nepal (In Nepali)), Sahyogi Prakashan, Kathmandu, Nepal.
9. Building Construction Under Seismic conditions in Balkan Region, 1983, *Repair and Strengthening of Reinforced Concrete, Stone, Brick-masonry Buildings*, UNDP/ UNIDO/RER 79/015, Vienna.
10. Chitrakar, G. R., Pandey, Mr. R.; 1986, *Historical Earthquakes of Nepal* , Nepal Geological Society News Bulletin, V. 4, No. 1.
11. Coburn, A., Spencer, R.;-----, *Earthquake Protection*, John Wiley & Sons,
12. IS 1893-1984, *Criteria for Earthquake Resistant Design of Buildings and Structures*, Bureau of Indian Standards, New Delhi, India.
13. IS 4326-1993, *Earthquake resistant Design and Construction of Buildings-Code of Practice*, Bureau of Indian Standards, New Delhi, India.
14. NBCDP, 1994, *Seismic Hazard Mapping And Risk Assessment For Nepal*, His Majesty's Govt. Of Nepal, UNDP/UNCHS (Habitat), Subproject 88/054/21.03.
15. NBCDP, 1994, *Seismic Vulnerability Assessment For Nepal*, His Majesty's Govt. Of Nepal, UNDP/UNCHS (Habitat), Subproject 88/054/21.03.
16. NBC 105-1994, *Seismic Design Of Buildings In Nepal*, His Majesty’s Govt. of Nepal, Ministry of Housing and Physical Planning, Department of Buildings, Nepal, 1995.
17. NBC 109-1994, *Unreinforced Masonry*, His Majesty’s Govt. of Nepal, Ministry of Housing and Physical Planning, Department of Buildings, Nepal, 1995.
18. NBC 203-1994, *Guidelines for Earthquake Resistant Building Construction: Low Strength Masonry*, His Majesty’s Govt. of Nepal, Ministry of Housing and Physical Planning, Department of Buildings, Nepal, 1995.
19. NBC 204-1994, *Guidelines for Earthquake Resistant Building Construction: Earthen Buildings*, His Majesty’s Govt. of Nepal, Ministry of Housing and Physical Planning, Department of Buildings, Nepal, 1995.
20. NSET-Nepal, GHI-USA; 1999, *Earthquake Scenario of Kathmandu Valley*, NSET-Nepal, Kathmandu, Nepal.

21. NSET-Nepal, University of Roorkee; 2000, *Reconnaissance Report: Chamoli Earthquake of 29th March 1999, India*.
22. Thapa, N.; 1989, Bhadau Panch ko Bhukampa (Earthquake of 1988, Udaypur (in Nepali)), Central Disaster Relief Committee.
23. Valdia, K. S.; 1986, *Dynamic Himalaya*, Jawaharlal Nehru Centre for Advanced Scientific Research, University Press (India) Ltd., Hyderabad, India,

10.2 ADDITIONAL RELEVANT PUBLICATIONS

1. ATC; 1996, *Seismic Evaluation and Retrofit of Concrete Buildings*, ATC-40 (Vol. 1and 2), Report No. SSC96-01, Seismic Safety Commission, State of California, USA.
2. Bothara, J. K. and et. al.; 2000, *Seismic Safety in Owner Built Buildings*, 12th World Conference on Earthquake Engineering, Auckland, New Zealand.
3. CBS, 1991, *Statistical Yearbook*, Nepal Central Bureau Of Statistics, His Majesty's Govt. Of Nepal. Chitrakar, G. R., Pandey, M. R., 1986, Historical Earthquakes Of Nepal, Nepal Geological Society News Bulletin, V. 4, No. 1.
4. Dixit, A. M., 1991, *Geological Effects And Intensity Distribution Of The Udaypur (Nepal) Earthquake Of August 21, 1988*, Journal Nepal Geological Soc., V. 7, P. 1-17.
5. Dixit, A. M., Dwelley-Samant, L., Nakarmi, M., Pradhanang, S., Tucker, B.; 2000, Kathmandu Valley Earthquake Risk Management Project: An Evaluation, 12th World Conference on Earthquake Engineering, Auckland, New Zealand.
6. Federal Emergency Management Agency, (FEMA 274), NEHRP Guidelines For The Seismic Rehabilitation Of Buildings, Building Seismic Safety Council, Washington D. C., 1988.
7. Federal Emergency Management Agency, (FEMA 274), *NEHRP Commentary On the Guidelines For The Seismic Rehabilitation Of Buildings*, Building Seismic Safety Council, Washington D. C., 1988.
8. Federal Emergency Management Agency, *Earthquake Hazard Reduction Series 41 (FEMA 154), Rapid Visual Screening Of Buildings For Potential Seismic Hazard: A Handbook*, Building Seismic Safety Council, Washington D. C., 1988.
9. Federal Emergency Management Agency, *Earthquake Hazard Reduction Series 42 (FEMA 155), Rapid Visual Screening Buildings For Potential Seismic Hazard: Supporting Document*, Building Seismic Safety Council, Washington D. C., 1988.
10. Federal Emergency Management Agency, *Earthquake Hazard Reduction Series 45 (FEMA 174), Establishing Programs and Priorities For Seismic Rehabilitation Of Buildings: A Handbook*, Building Seismic Safety Council, Washington D. C., 1989.
11. Federal Emergency Management Agency, *Earthquake Hazard Reduction Series 46 (FEMA 173), Establishing Programs and Priorities For Seismic Rehabilitation Of Buildings: A Supporting Report*, Building Seismic Safety Council, Washington D. C., 1989.
12. Federal Emergency Management Agency, *Earthquake Hazard Reduction Series 47 (FEMA 178), NEHRP Handbook for the Seismic Evaluation Of Existing Buildings*, Building Seismic Safety Council, Washington D. C., 1992.
13. Fujiwara, T., Sato, T., Kubo T., And Murakama, H. O., 1989, *Reconnaissance Report On 21 August 1988 Earthquake In Nepal-India Border Region*, Japanese Group For Study Of Natural Disaster Science, No. B-63-4.
14. IS 1905-1987,?
15. Kuroiwa, J.; 1993, *Reducing Earthquake Risk*, INCEDE Report 4, VII Pacific Science Inter-Congress, Okinawa, Japan.
16. New Zealand National Society for Earthquake Engineering, 1995, *Guidelines for Assessing and Strengthening Earthquake Risk Building: Unreinforced Masonry* (Draft Copy), New Zealand National Society for Earthquake Engineering.
17. NSET, 1997, *Project Document For The Kathmandu Valley Earthquake Risk Management Project*, Document (Unpublished) Prepared By The National Society For Earthquake Technology - Nepal (NSET-Nepal) And GeoHazards International (GHI).

18. Parajuli, Y. K., Bothara, J. K., Dixit, A. M., Pradhan, J., Sharpe, R.; 2000, *Nepal Building Code: needs, concepts and implementation* , 12th World Conference on Earthquake Engineering, Auckland, New Zealand
19. Sobaih, M.; 1999, *Seismic Hazard and Counter Measures in Giza City*, Bulletin of International Institute of Seismology and earthquake Engineering, Vol. 33, Building Research Institute, Ministry of Construction, Tsukuba, Japan.
20. Yadav, R. P.; Singh, P. L.; Dixit, A. M.; Sharpe, R. D.; 1994, *Status Of Seismic Hazard And Risk Assessment In Kathmandu Valley, Nepal*; Issues Of Urban Earthquake Risk, NATO ASI Series E: Applied Science-Vol. 271; Ed. Tucker, B. E.; Erdic, M.; Hwang, C. N.; Kluver Academic Publication.

Appendix-1: List of Members of School Earthquake Safety Advisory Sub-committee

1.	Mr. Kamal Prasad Lal Karna	Regional Director	Central Regional Education Directorate / Ministry Of Education	Chairman
2.	Mr. Ashok Aryal	Chief,	District Education Office, Kathmandu	Member
3.	Mrs. Ram Pyari Shrestha	Chief,	District Education Office, Lalitpur	Member
4.	Mr. Nayan Singh Dhami	Chief,	District Education Office, Bhaktapur	Member
5.		Representative	Kathmandu Metropolitan City	Member
6.		Representative	Lalitpur Sub-metropolitan City	Member
7.		Representative	Kirtipur Municipality	Member
8.		Representative	Madhyapur Municipality	Member
9.		Representative	Bhaktapur Municipality	Member
10.		Representative	District Development Committee, Kathmandu	Member
11.		Representative	District Development Committee, Lalitpur	Member
12.		Representative	District Development Committee, Bhaktapur	Member
13.		Representative	Department of Building/Ministry of Housing & Physical Planning	Member
14.	Mr. Ramesh Jung Rayamajhi	Chief,	Valley Building Office, Kathmandu	Member
15.		Chief	Department of Housing & Urban Development Bhaktapur Section	Member
16.		Representative	Headmaster, Kathmandu	Member
17.		Representative	Headmaster, Lalitpur	Member
18.		Representative	Headmaster, Bhaktapur	Member
19	Mr. Hemanta Gyawali	Executive Director	Town Development Fund Board	Member
20.	Mr. Murari Binod Pokhrel	Director, DRP	United Mission to Nepal	Member
21.	Mr. Santosh Gyawali	System Manager,	USAID	Member
22.		Representative	UNICEF	Member
23.		Representative	UNESCO	Member
24.	Mr. Jyoti Prasad Pradhan	NSET-Nepal		Member
25.	Mr. Mahesh Nakarmi	Project Manager	Kathmandu Valley Earthquake. Risk Management Project	Member Secretary

Appendix-2: School Inventory Questionnaire

Appendix-3: The Guidelines

Appendix-4: List of Existing, Participated and Surveyed Schools in the Three Districts

Appendix-5: Field Verified Schools

S. No.	Name of School	School Code	Number of Blocks		Remarks
			Normal	Earthquake	
1	**Kathmandu**				
1.1	**Primary School**				
1.1.1	Jhor Mahankal L. S. School	KGP68	1		Active land slide in up hill
1.1.2	Champak Binayak P. School	KGP32	-	2	
1.1.3	Chaul Narayan P. School	KGP35	1	1	
1.1.4	Ban Devi P. School	KGP17	1	1	
1.2	**Lower Secondary**				
1.2.1	Bal Uddhar L. Sec. School	KGP10	2	1	1 building severe, 1 fair
1.2.2	Bal Bikash L. S. School	KGLS7	4	-	1 building fair
1.2.3	Kabhresthali L. S. School	KGLS24	1		1 building fair
1.2.4	Sarda Lower Sec. School	KGLS37	3	-	1 no. one story building is in mixed type construction (nogged brick in front and plain masonry in back in fair condition.
1.3	**Secondary School**				
1.3.1	Boudeshwor Sec. School	KGS11	3	-	1 building in severe condition, 1 building has stone in mud mortar in 1st story where as brick in cement mortar in 2nd story.
1.3.2	Chamunda Sec. School	KGS16	4	-	3 masonry building suffer few cracks (fair). The hybrid building structure has some conceptual mistake in structural planning.
1.3.3	Gandhi Aadarsh Sec. School	KGS20	4	-	Generally buildings are in good condition
1.3.4	Kali Devi Sec. School	KGS38	2	1	1 building fair
1.3.5	Nepal Rastriya Nirman S. School	KGS68	2	-	1 building severe
1.3.6	Prabhat Sec. School	KGS78	3	-	Construction mixed type. Two masonry buildings seem quite vulnerable (fair).
1.3.7	Tej Binayak Sec School	KGS104	1	-	Upper story walls shifting, floors badly sagging. Recommended for reconstruction of floor and of 2nd story (fair condition).
2	**Lalitpur**				
2.1	**Primary School**				
2.1.2	Baloday P. School	LGP14	1	-	1 building fair.
2.1.1	Swatantra Shiksha Sadan	LGP123	1	-	-
2.3	Secondary School				
2.3.1	Patan High School	LGS31	6	-	General condition of buildings OK
2.4	Higher Secondary School				
2.4.1	Kitini Higher Sec. School	LGHS4	5	2	1 building fair
3	**Bhaktapur**				

S. No.	Name of School	School Code	Number of Blocks		Remarks
			Normal	Earthquake	
3.1	**Primary School**				
3.1.1	Bal Binayak P. school	BGP7	2	-	Building ok except few cracks
3.1.2	Bhairab P. School	BGP13	1	-	1 building in fair condition
3.1.3	Bramhayani P. School	BGP16	1	-	School running in community building
3.1.6	Chandra Suryodaya P. school	BGP18	1	-	
3.1.5	Gyan Bikas P. School	BGP38	2	-	1 Building in fair condition
	Himalaya P. School	BGP40	1	-	Recommended for reconstruction
	Nateshwory P. School	BGP60	1	-	Floor and roof in need of immediate reconstruction
2.1.3	Shanti Bhairabi P. School	BGP75	1	-	-
3.1.8	Shishu Shyahar P. School	BGP80	1	-	1 building in fair condition
3.1.4	Shushil Bhairab P. School	BGP83	1	-	1 building in severe condition
3.1.7	Upyogi P. School	BGP89	1	-	-
3.2	**Lower Secondary School**				
3.2.1	Tara Lower Secondary	BGP84	1	-	
3.2.2	Bhairabi Lower Secondary School	BGLS8	3	-	Two buildings in stone masonry in mud mortar need immediate demolition.
3.2.3	Bhuwaneshwory Lower Sec. School	BGLS10	2	-	1 severe
3.2.4	Binayak Swarswoti L. S. School	BGLS11	1	-	
3.2.5	Jyan Bijay L. S. School	BGLS17	1	-	-
3.2.6	Gyan Jyoti L. S. School	BGLS18	2	-	1 building severe
3.2.7	Mahendra Gram Lower Sec. School	BGLS20	1	1	1 building severe
3.3	**Secondary School**				
3.3.2	Bageshwori S. School	BGS7	5	-	
3.3.3	Janak Siddhi Kali Sec School	BGS15	4	-	1 building fair
39	**Total**		**78**		

The buildings are constructed using the commonly available materials and technology available in the area.

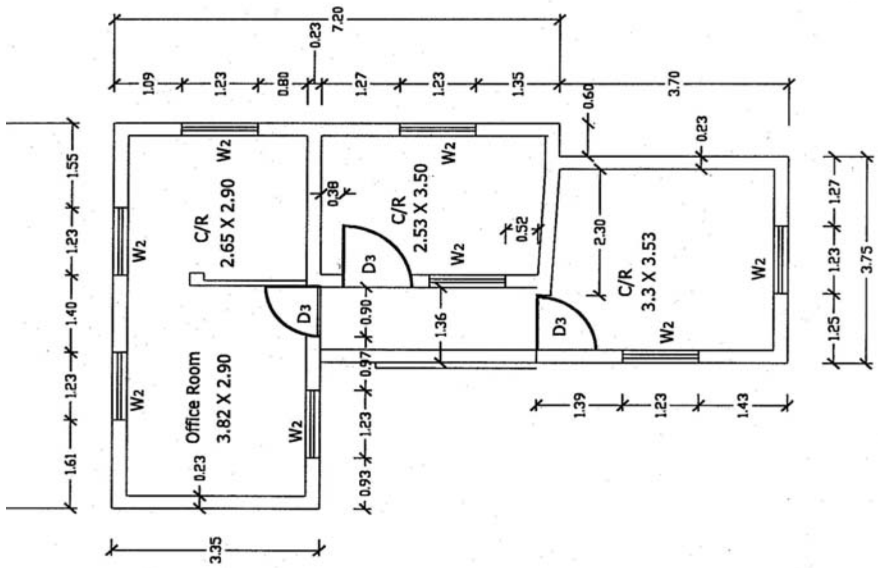
Severe: Hazardous, demolish and reconstruct; Fair: can be saved and strengthened if immediate action is taken.

Appendix-6: Building Category according to MSK Intensity Scale

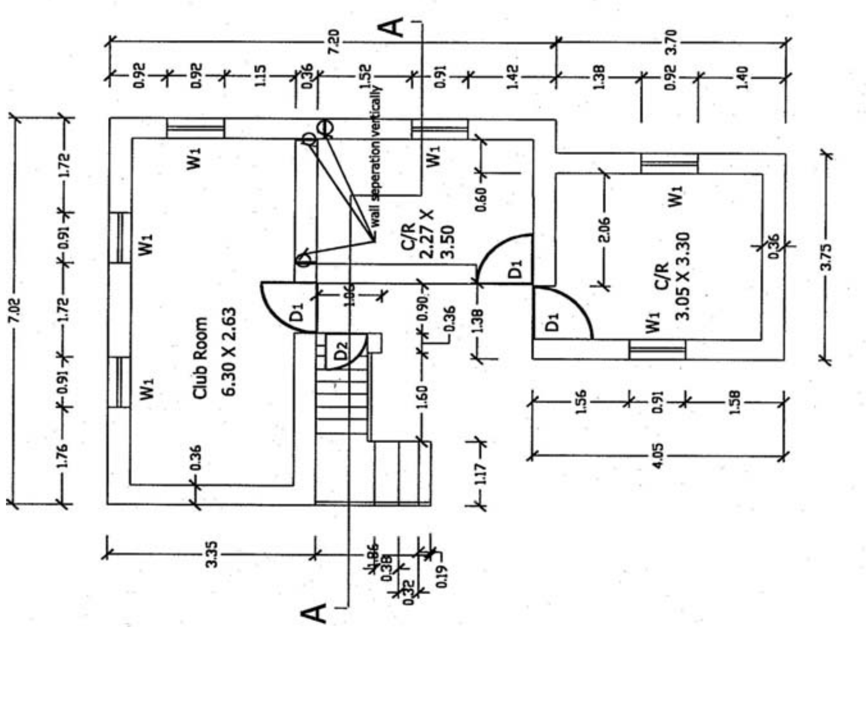
Building Type		Intensity (MSK)		
		Intensity VII	**Intensity VIII**	**Intensity IX**
A	Mud and Adobe houses, random-stone constructions	Most have large deep cracks Few suffer partial collapse	Most suffer partial collapse Few suffer complete collapse	Most suffer complete collapse
B	Ordinary bricks buildings, buildings of large blocks and prefab type, poor half timbered houses	Many have small cracks in wall	Most suffer large and deep cracks Few suffer partial collapse	Many suffer partial collapse Few completely collapse Few Minor crack
C	Reinforced buildings, well built wooden building	Many have fine plaster cracks	Most may have small cracks in walls Few may have large deep cracks	Many may have large and deep cracks Few may have partial collapse and the rest may have small cracks

- Most = about 75%, Many = about 50%, Few = about 5%

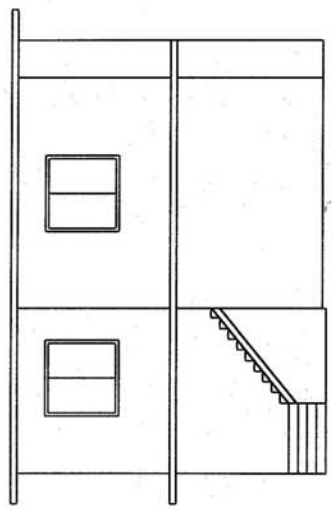
Appendix-7: Drawings of Typical Nepali School Buildings



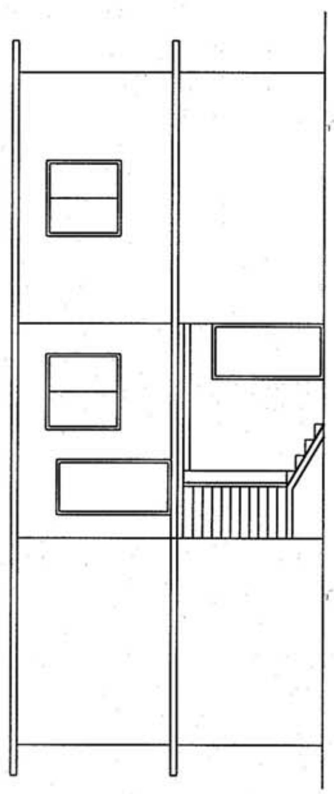
First Floor Plan
Upayogi, Sirutar



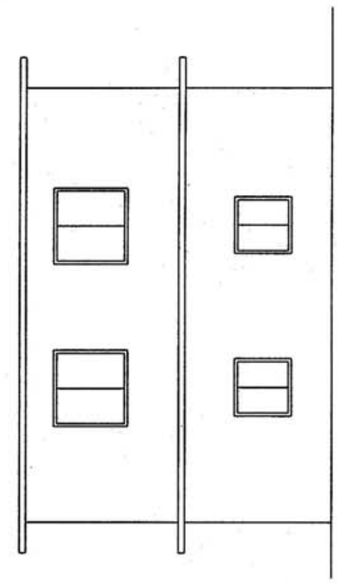
Ground Floor Plan
Upayogi, Sirutar



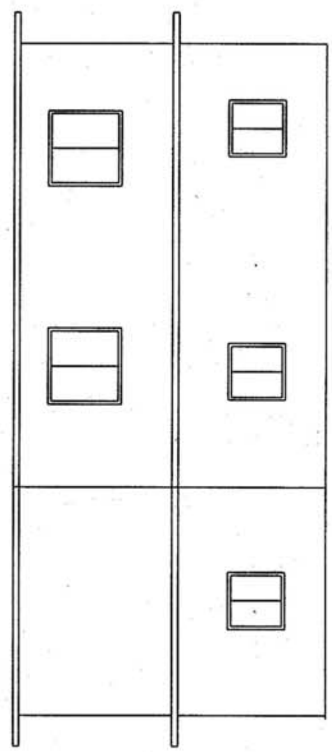
South Elevation
Upayogi Sirutar



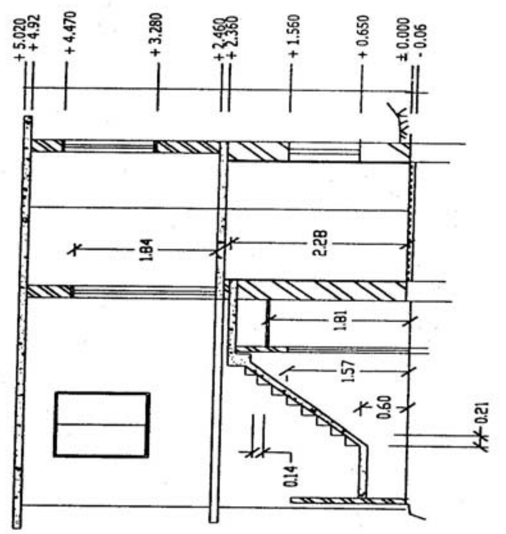
West Elevation
Upayogi, Sirutar



North Elevation
Upayogi, Sirutar

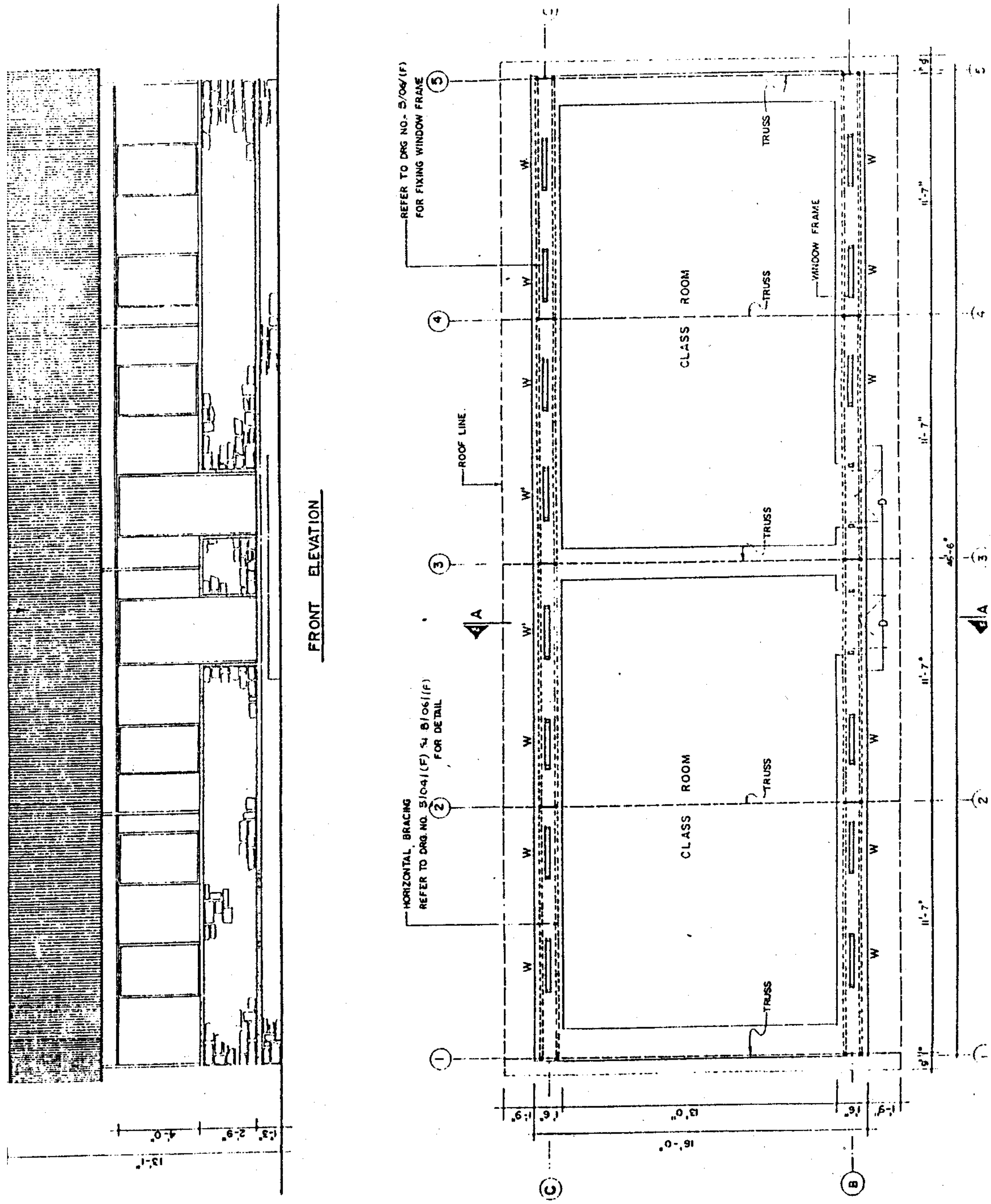


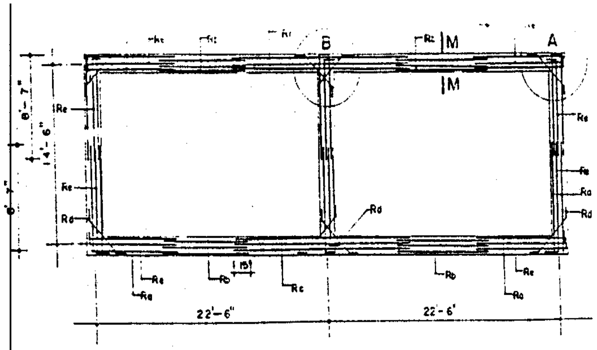
East Elevation
Upayogi,Sirutar



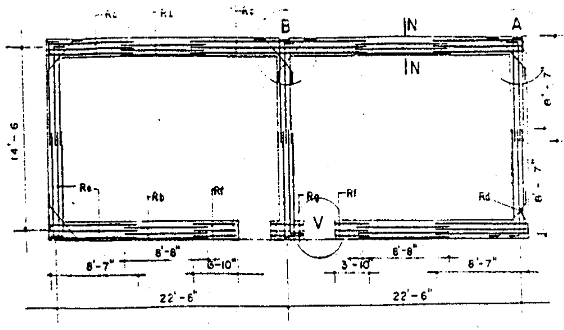
Section at A-A
Upayogi, Sirutar

Appendix-8: Drawings of Earthquake Block

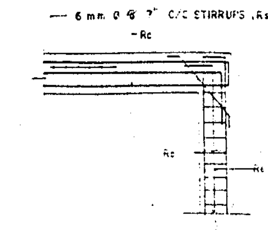

FRONT ELEVATION
CLASS ROOM
CLASS ROOM
TRUSS
ROOF LINE
WINDOW FRAME
HORIZONTAL BRACING
FOR DETAIL
FOR FIXING WINDOW FRAME



PLAN OF PLINTH BAND

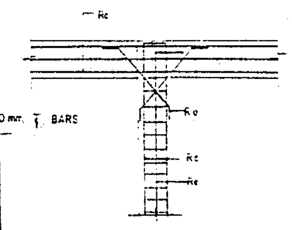


PLAN OF SILL BAND



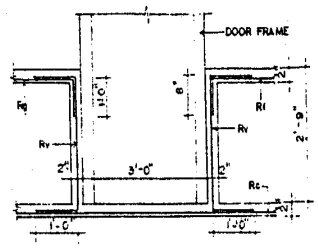
DETAIL AT A

SCALE 1 = 4 - 0



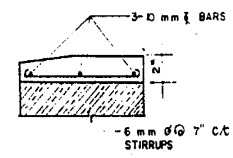
DETAIL AT B

SCALE 1 = 4 - 0



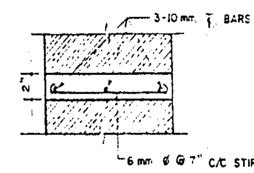
VERTICAL REINFORCEMENT DETAIL AT V

SCALE : 1/2" = 1'-0"



DETAIL AT N-N

SCALE 1' = 1'-0"



DETAIL AT M-M

SCALE 1 = 1-0

R/F BAR SCHEDULE (PLINTH BAND)

S.NO	SYMBOL	Ø in mm	BENDING SHAPE	NO	LENGTH	TOTAL LENGTH	Kg/m	TOTAL WEIGHT
1	Ra	10	6'-7"	10	18'-6"	185'-0"(56.40m)	0.62	34.97
2	Rb	10	8'-8"	12	8'-8"	104'-0"(31.71m)	0.62	19.66
3	Rc	10	16'-10"	6	16'-10"	10'-10"(30.79m)	0.62	19.09
4	Rd	10	3'-5" 135°	8	4'-9"	36'-0"(11.58m)	0.62	7.18
5	Re	10	6'-7"	10	9'-10"	96'4"(29.98m)	0.62	18.59
6	Rv	10	2'-9"	12	4'-9"	57'-0"(17.38m)	0.62	10.78
7	Rs	6	1'-4"	251	1'-9"	439'-3"(133.92m)	0.222	29.73

TOTAL WEIGHT = 140.00 Kg

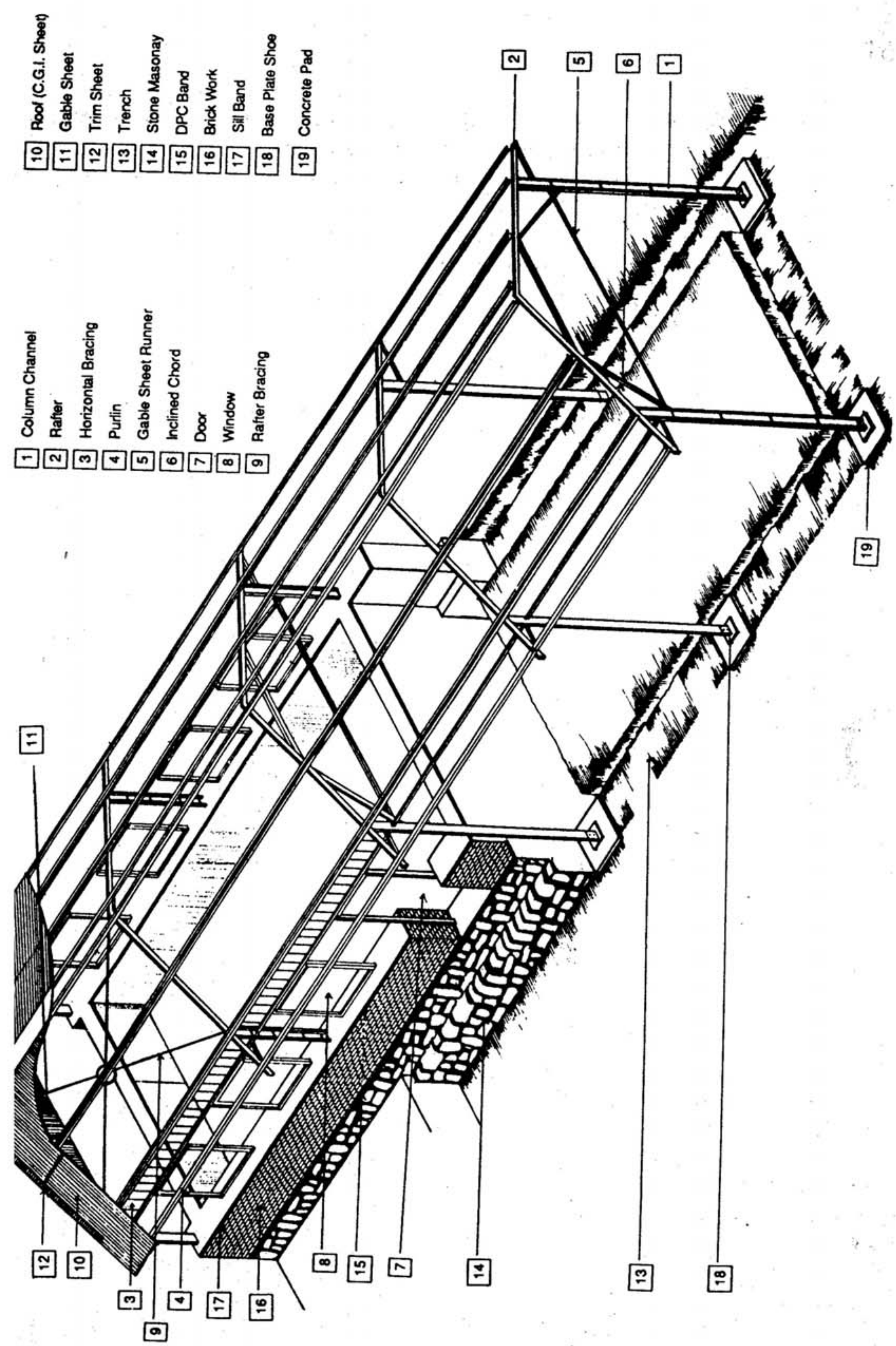
G.I. BINDING WIRE 1.40 Kg

R/F BAR SCHEDULE (SILL BAND)

S.NO	SYMBOL	Ø in mm	BENDING SHAPE	NO	LENGHT	TOTAL LENGTH	Kg/m	TOTAL WEIGHT
1	Ra	10	6'-7"	10	18'-6"	185'-0"(56.40m)	0.62	34.97
2	Rb	10	8'-8"	12	8'-8"	104'-0"(31.71m)	0.62	19.66
3	Rc	10	16'-10"	3	16'-10"	50'-6"(15.40m)	0.62	9.55
4	Rd	10	3'-5" 135°	6	4'-9"	28'-6"(8.70m)	0.62	5.39
5	Re	10	6'-7"	10	9'-10"	98'-4"(29.98m)	0.62	18.59
6	Rf	10	3'-10"	6	4'-6"	27'-0"(8.23m)	0.62	5.10
7	Rg	10	2'-9"	3	4'-9"	14'-3"(4.34m)	0.62	2.69
8	Rs	6	1'-4"	210	1'-9"	367'-6"(112.04m)	0.222	24.87

TOTAL WEIGHT = 120.82 Kg

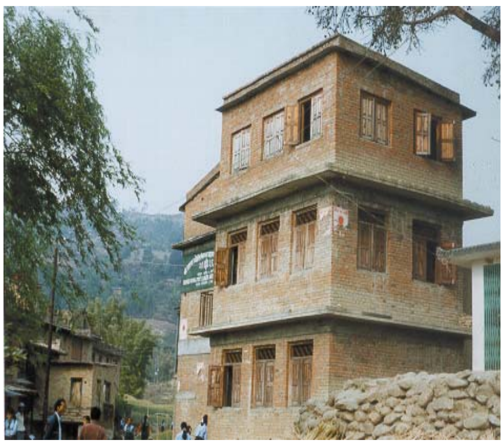
G.I. BINDING WIRE 1.21 Kg


1 Column Channel
2 Rafter
3 Horizontal Bracing
4 Purlin
5 Gable Sheet Runner
6 Inclined Chord
7 Door
8 Window
9 Rafter Bracing
10 Roof (C.G.I. Sheet)
11 Gable Sheet
12 Trim Sheet
13 Trench
14 Stone Masonay
15 DPC Band
16 Brick Work
17 Sill Band
18 Base Plate Shoe
19 Concrete Pad

Appendix-9: Photographs

Single Pitched CGI Sheet roof and timber floor in red brick in mud mortar.

RC floor and roof slabs supported by fired brick wall. All walls of first story and partly of second story are in mud mortar and rest in cement mortar



Two storied RC Slab floor and roof on brick in cement mortar wall.

Multistoried RC framed building with CGI sheet roof and RC floor Slabs.

CGI Sheet roof on brick in mud mortar wall.

A four –story masonry building with RC roof and floor slab. Mind first two stories are in brick in mud mortar where as upper one are in brick in cement mortar.

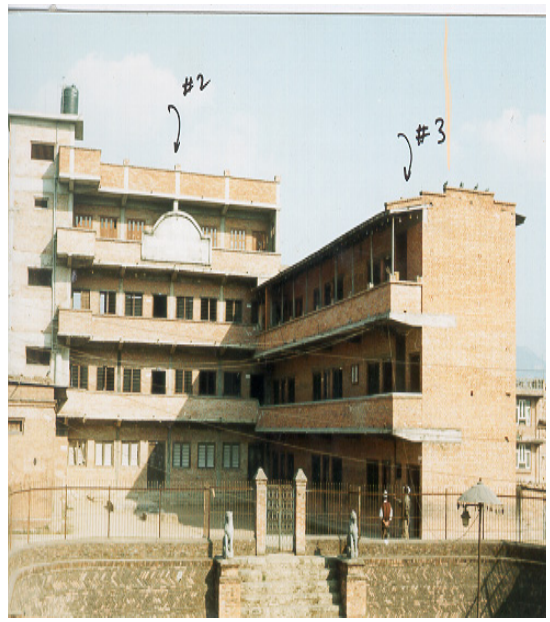
Single storied RC slab roof on brick in cement mortar wall.

RC framed building under vertical extension.

CGI Sheet roof on brick in mud mortar wall.

CGI Sheet roof and RC floor slab on fired brick in cement mortar.

A three- story masonry building in brick in cement mortar with flexible roof.



Multistoried RC framed building with RC floor and roof slabs. Adjacent is three storied brick building in cement mortar, RC floor slabs and CGI Sheet roof.

A school building in dense urban area. Clay tile roof and Timber floor resting on fired brick in cement mortar (constd. By Bhaktapur Development Project)

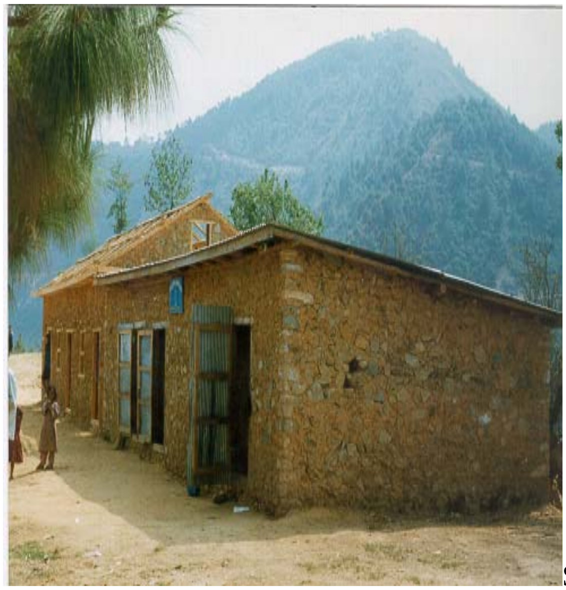
A Rana Era three story building. Walls in fired brick in mud mortar, floor made of mud laid on brick supported by timber structure, CGI sheet roof on timber structure.

Single pitched CGI Sheet roof on one story stone and sun dried brick mixed wall in mud mortar. Floor is constructed of timber.

Earthquake block with masonry infill in brick cement mortar.

Pragti Siksha Sadan, Kupondole, Walls in fired brick in mud mortar, timber floor, Clay tile roof on Timber structure medieval architecture, Constructed much before (2000 B.S.)

A Rana Era Victorian style one story school building. Walls brick in lime, CGI sheet roof on timber structure (Constd. Befor e 2000 B.S.)

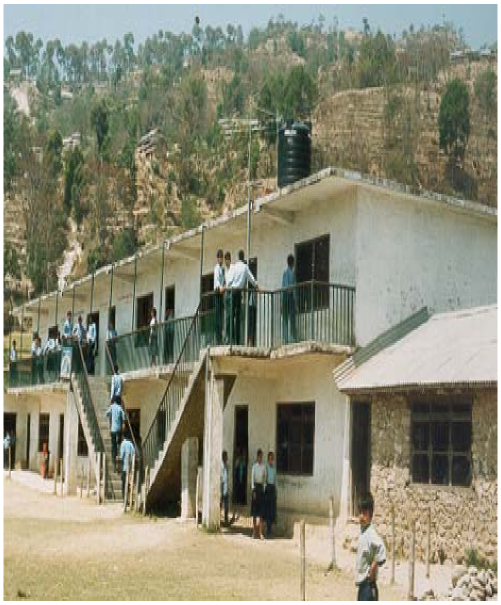


Single pitched CGI sheet roof on stone walls is mud mortar.

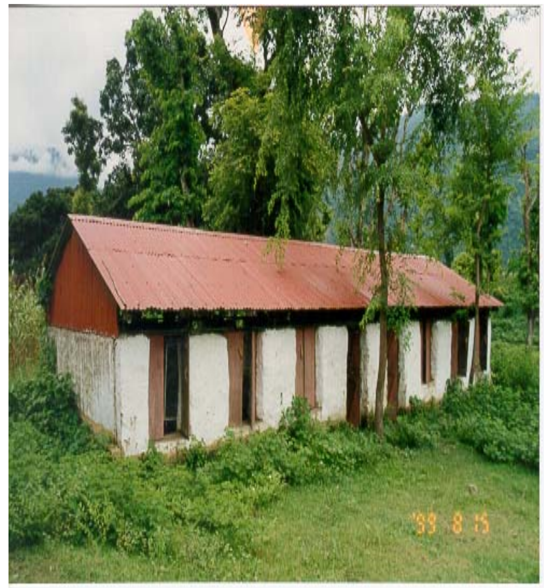
Earthquake block skeleton

Courtyard type building, walls in brick in cement mortar, timber floor and tile roof on timber structure (const. By Bhaktapur Dev. Project)

A masonry school building shed in hollow concrete block in cement mortar, mind the cracks.



RC roof resting on brick in cement mortar. Second story wall where as first story wall is in stone in mud mortar. One story building adjacent to main building is part of the main building without addition of new story.



Earthquake block with masonry infill in stone mud mortar.

Photograph 4.1A: Major School Building Type in the Study Area. [NSET-Nepal's Archive]

Photograph 4.2: Timber lintel in masonry building. [NSET-Nepal's Archive]

Photograph 4.3: RC lintel in masonry building. [NSET-Nepal's Archive]

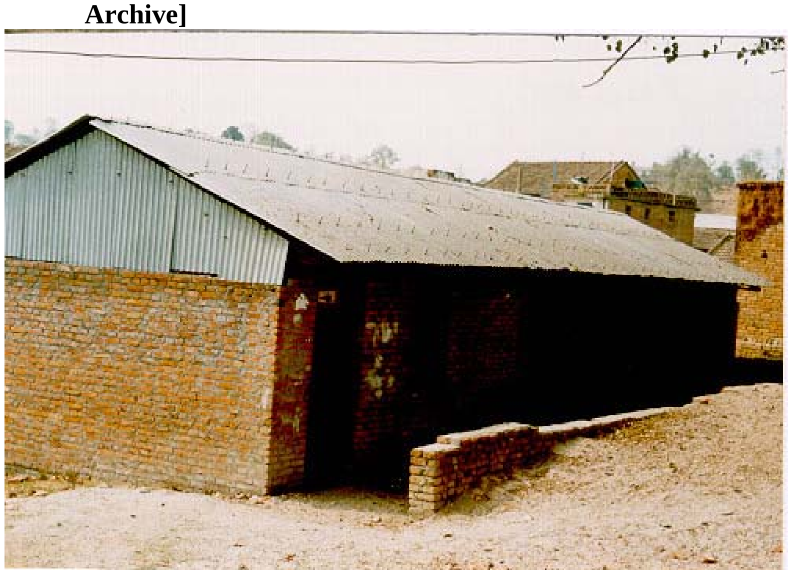
Photograph 4.4: **Flexible floor construction of earth laid on bamboo, timber structure. Note the sagging the timber beam. [NSET-Nepal's Archive]**

Photograph 4.5: **Floor constructed of plain concrete laid over brick supported by timber joist. [NSET-Nepal's Archive]**

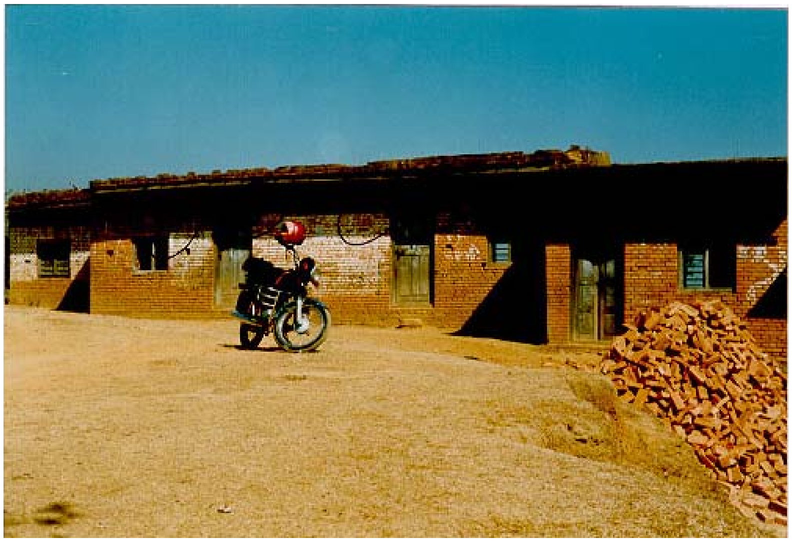
Photograph 4.6: **Floor constructed with earth laid on brick supported by timber joist. [NSET-Nepal's Archive]**

Photograph 4.7: **CGI sheet laid over Timber truss. [NSET-Nepal's Archive]**

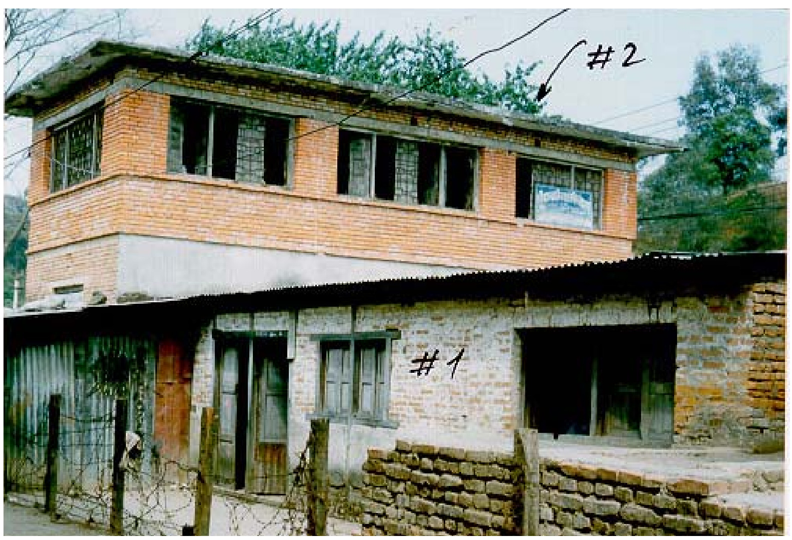
Photograph 4.8: **Jhingati (clay roofing tiles) laid over timber structure. [NSET-Nepal's Archive]**



Photograph 4. 9: **Gable walls are constructed of CGI sheet in *earthquake block*. Note the free standing masonry walls and omission of sill level band (though existed in design). [NSET-Nepal's Archive]**

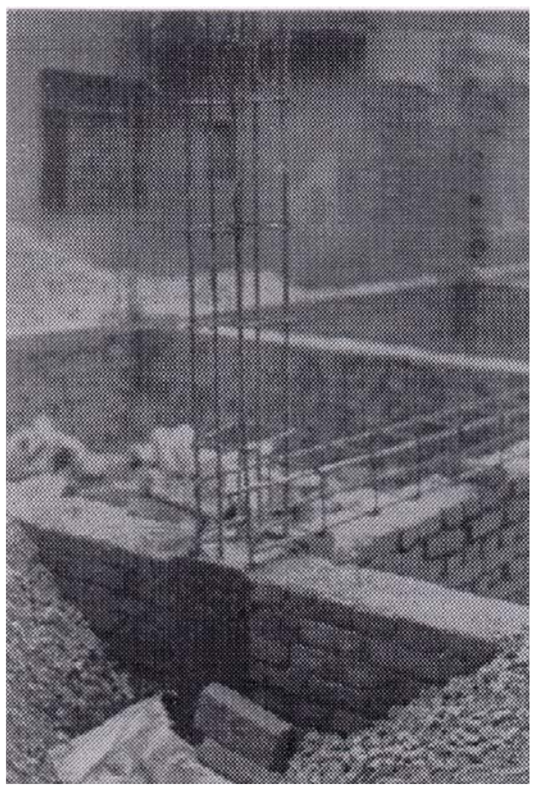


Photograph 4.10: **No lintels at all over openings. [NSET-Nepal's Archive]**



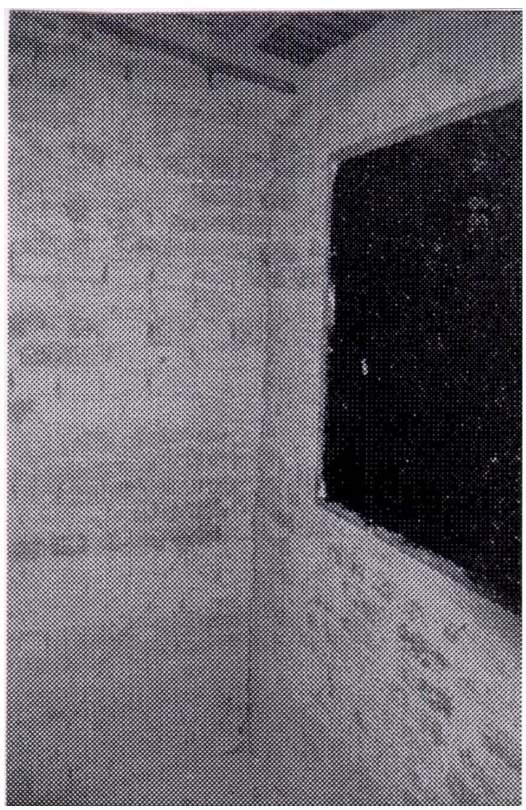
Photograph 4.11: **Lintel band in 2nd story but the same is ignored in 1st story. [NSET-Nepal's Archive]**

Photograph 4.12: **Loose fit timber roof structure. [NSET-Nepal's Archive]**

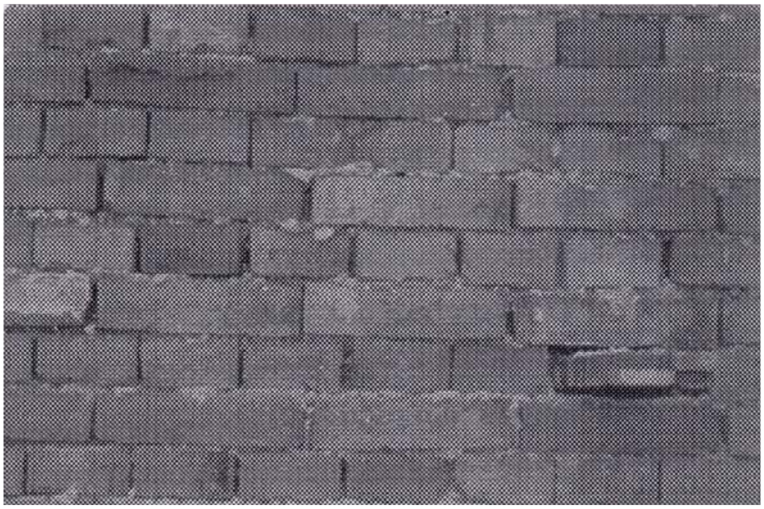


Photograph 4.13: **Shape and spacing of stirrups in a column and beam. Also note beam bar anchorage in column. [Courtesy: Jitendra K. Bothara]**

Photograph 4.14: Available lap length for splicing. [Courtesy: Jitendra K. Bothara]



Photograph 4.15: No connection between two orthogonal walls made of brick in cement mortar. [NSET-Nepal's Archive]



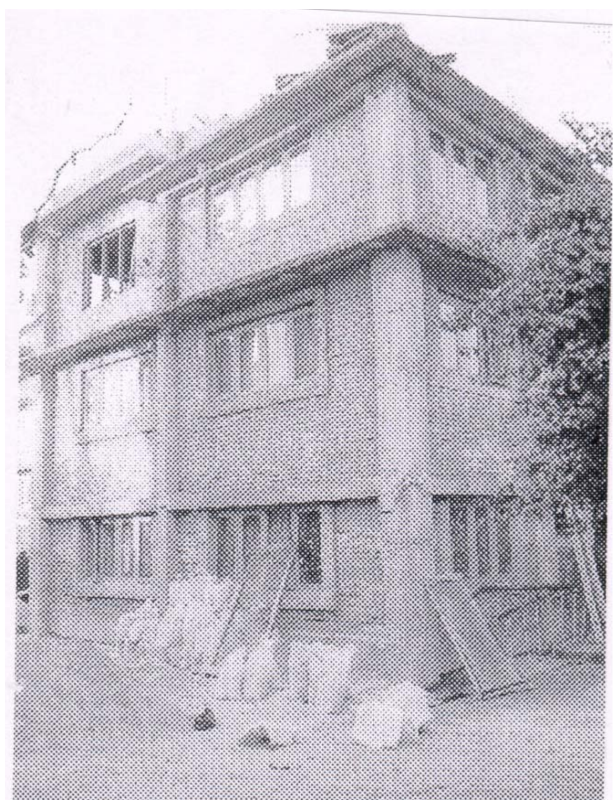
Photograph 4.16: No mortar between walling units. [Courtesy: Jitendra K. Bothara]

Photograph 4.17: Delamination of structural walls due to absence of 'through' stone. [NSET-Nepal's Archive]

Photograph 4.18: Lack of maintenance leading school building to severe deterioration. [NSET-Nepal's Archive]

Photograph 5.1: Improving the roof integrity by nailing and strapping. [NSET-Nepal's Archive]

Photograph 5.2: **Splint and bandage technique for retrofitting masonry building. [NSET-Nepal's Archive]**



Photograph 5.3: **RC column-Beam technique for retrofitting masonry building. [Courtesy: Jitendra K. Bothara]**

Appendix-10: Figures

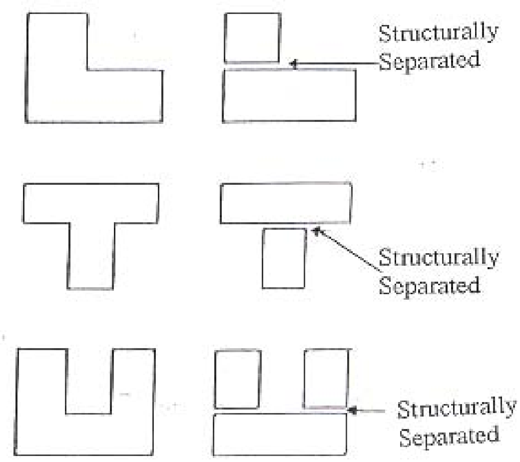


Figure 5.1: Simplification of plan shape by separation [

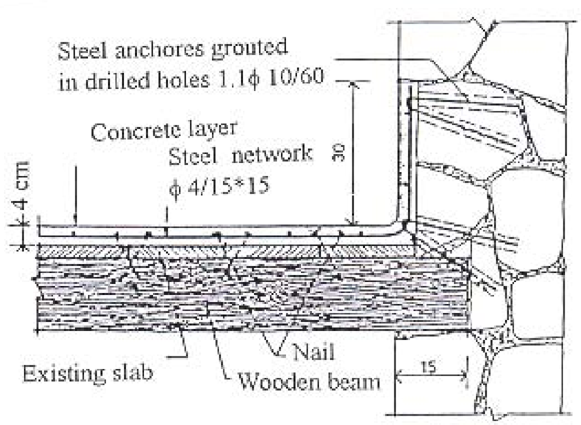


Figure 5.2: Floor stiffening by RC topping [9]**.**

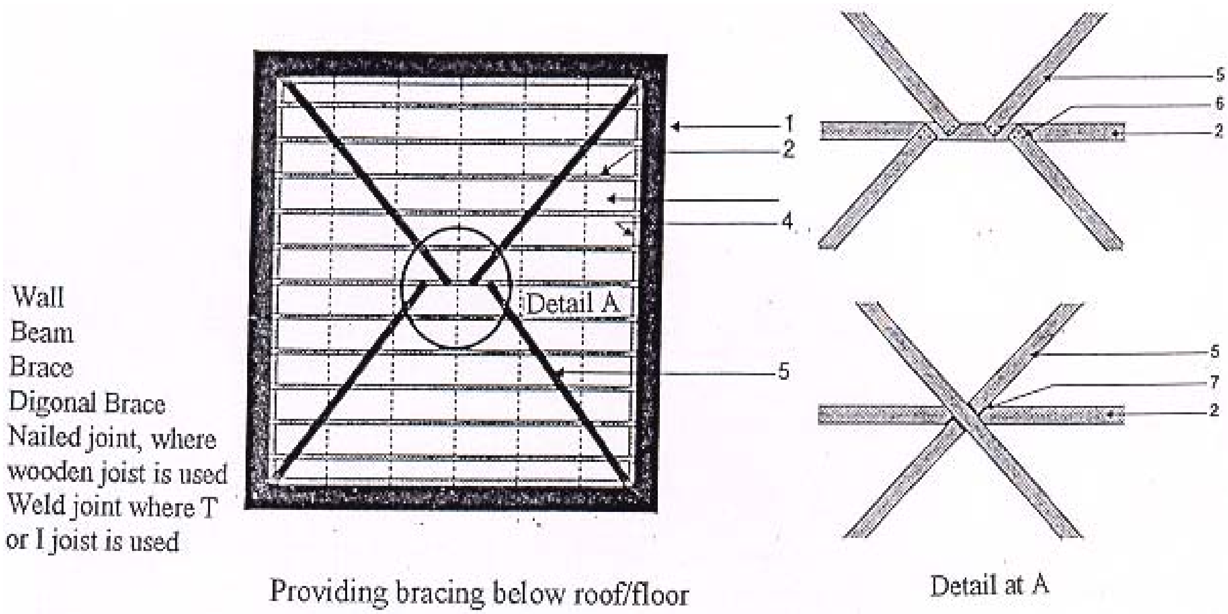


Figure 5.3: Stiffening flexible floor by bracing [1].

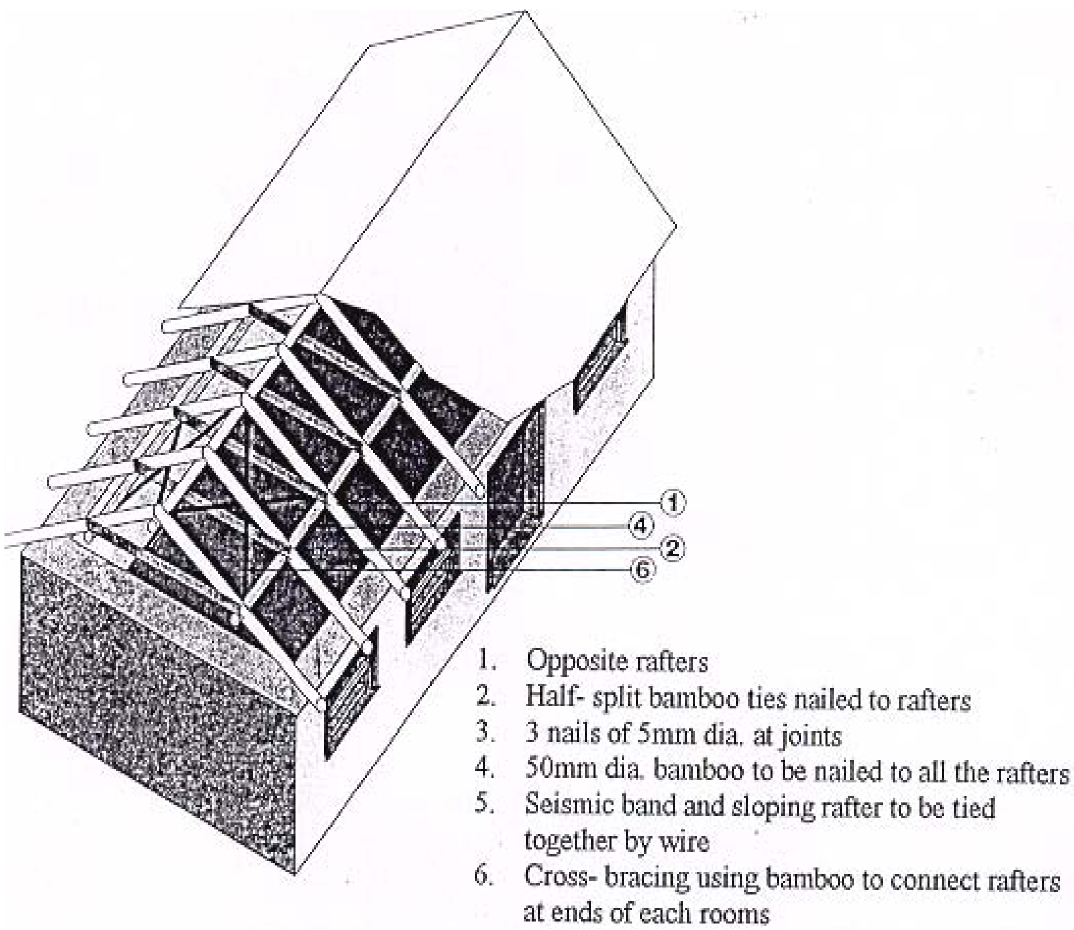


Figure 5.4: Roof bracing [1]**.**

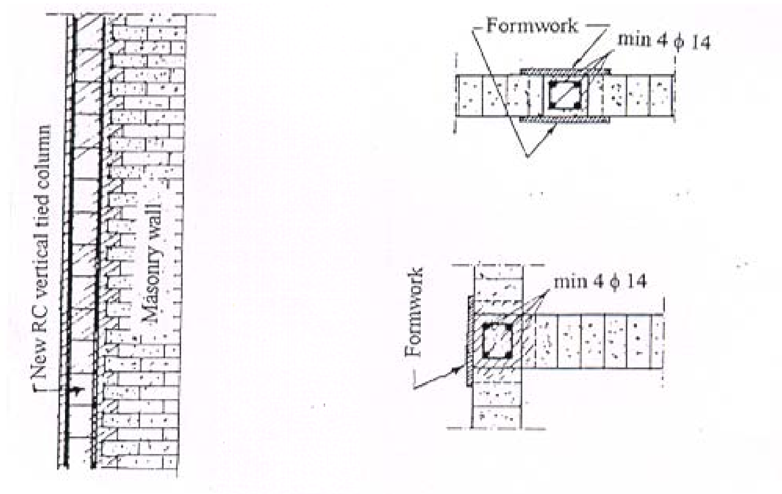


Figure 5.5: Masonry strengthened by introduction of column [9]**.**

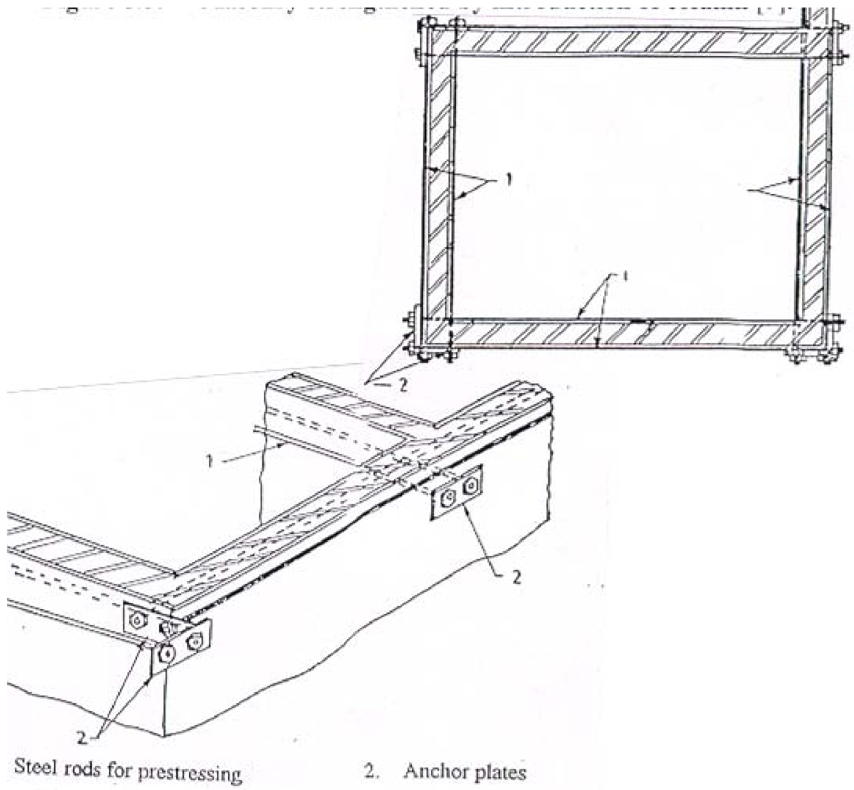


Figure 5.6: Retrofitting masonry building by prestressing [9]**.**

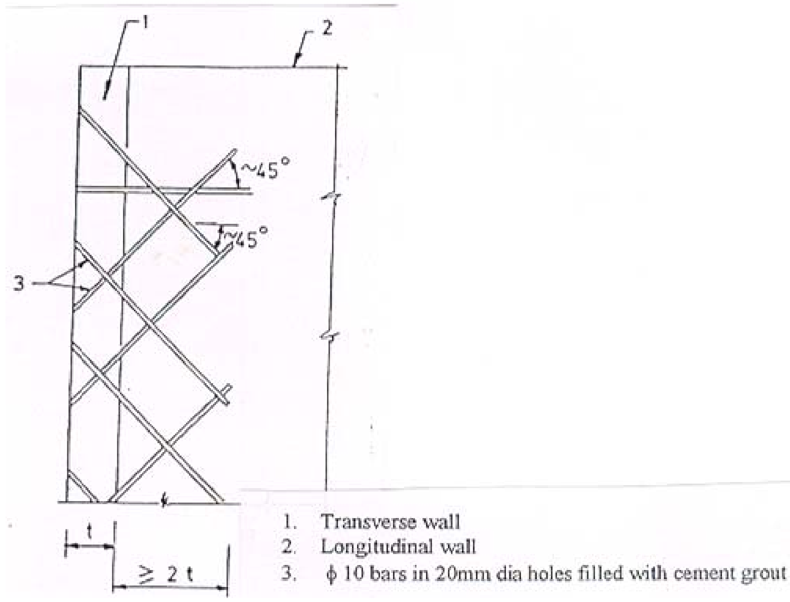


Figure 5.7: Stitching of transverse walls with inclined bars [3]**.**

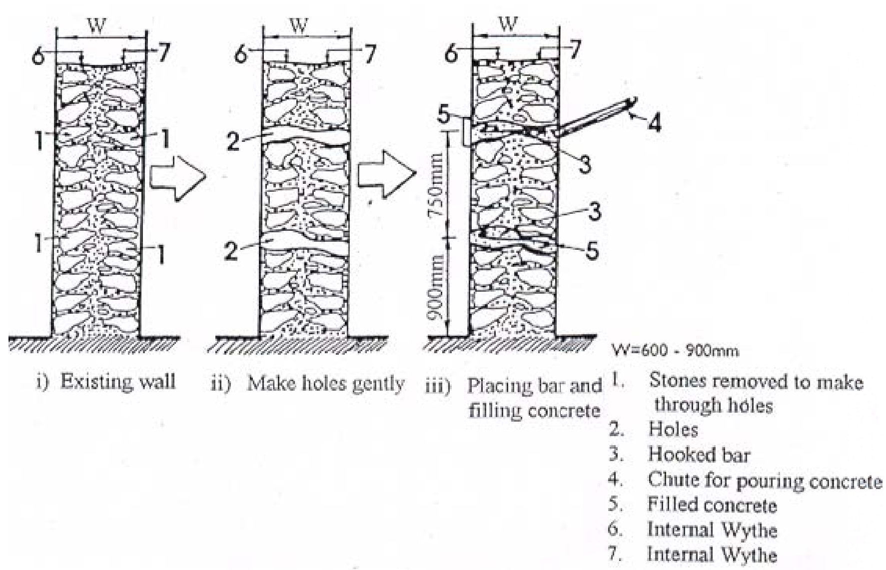


Figure 5.8: Providing RC 'through' elements for 'stitching ' stone wythes [2]**.**

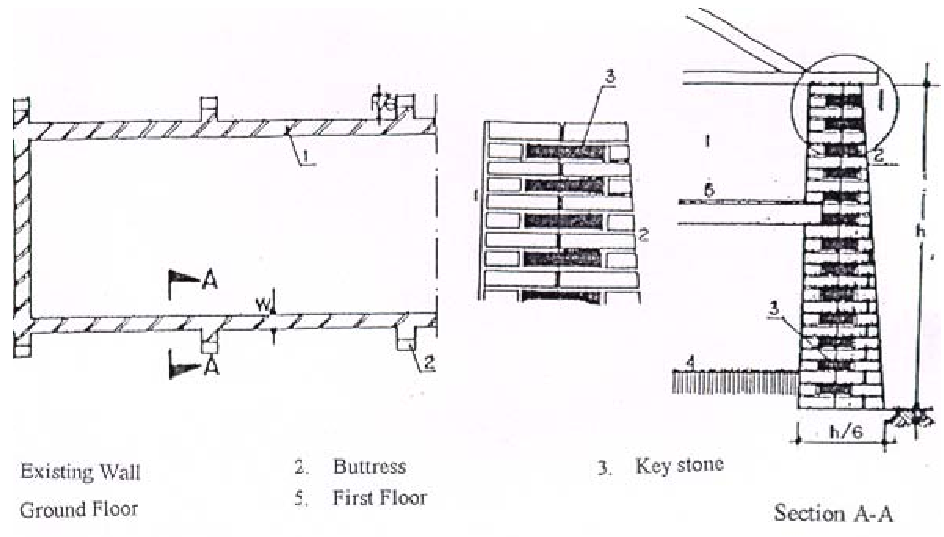


Figure 5.9: Long masonry walls stiffening by introduction of buttress [18]**.**

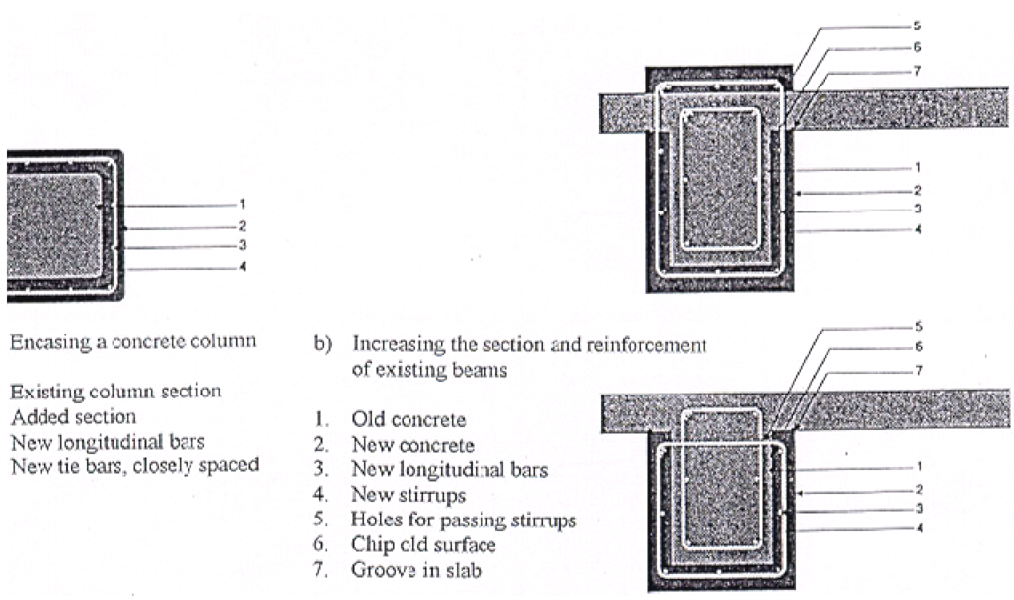


Figure 5.10: RC jacketing of RC beam and column [1]**.**

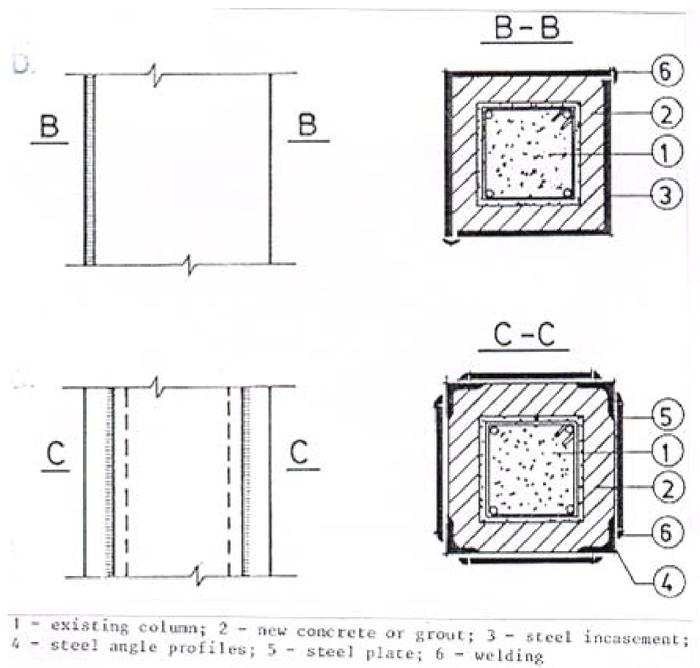


Figure 5.11: jacketing of columns with steel columns [9]**.**

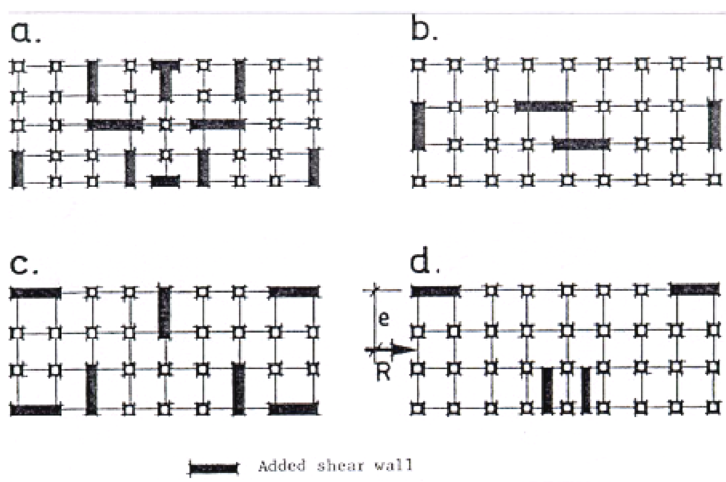


Fig 5.12: RC building retrofitted by introduction of sh ear walls [9]**.**