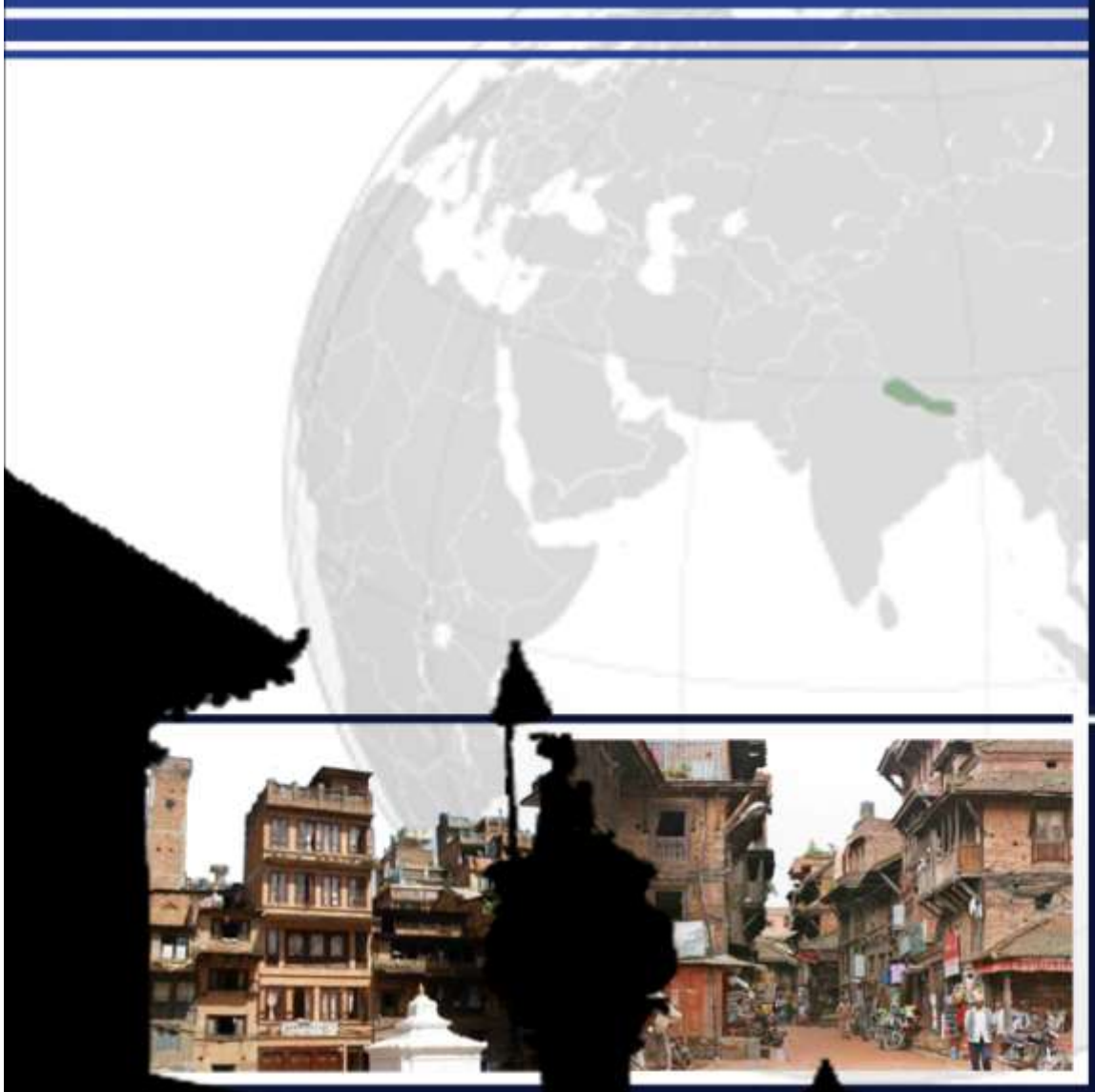
SEISMIC RETROFITTING GUIDELINES OF BUILDINGS IN NEPAL

2013



TRAINING CURRICULUM (Construction)

PART I PARTICIPANTS' WORKBOOK

UNDP

CORD

MRB & Associates

April 2013

S E I S M I C
RETROFITTING
GUIDELINES
of
Buildings in Nepal

TRAINING CURRICULUM
(Construction)

PART I
PARTICIPANT'S WORKBOOK

FOREWORDS

Intentionally Left Blank

ACKNOWLEDGEMENT

Intentionally Left Blank

LIST OF ACRONYMS

Intentionally Left Blank

LIST OF FIGURES

ABSTRACT

Intentionally Left Blank

CONTENTS

1. INTRODUCTION

a) NATURE OF EARTHQUAKE FORCE

Earthquakes originate because of movements of tectonic plates. Indian Plate is moving against Eurasian Plate and Nepal lies in the boundary of these two plates. This movement is the reason for formation of Himalayas and also for the origin of earthquakes in Afghanistan, Pakistan, Nepal, Tibet and India.

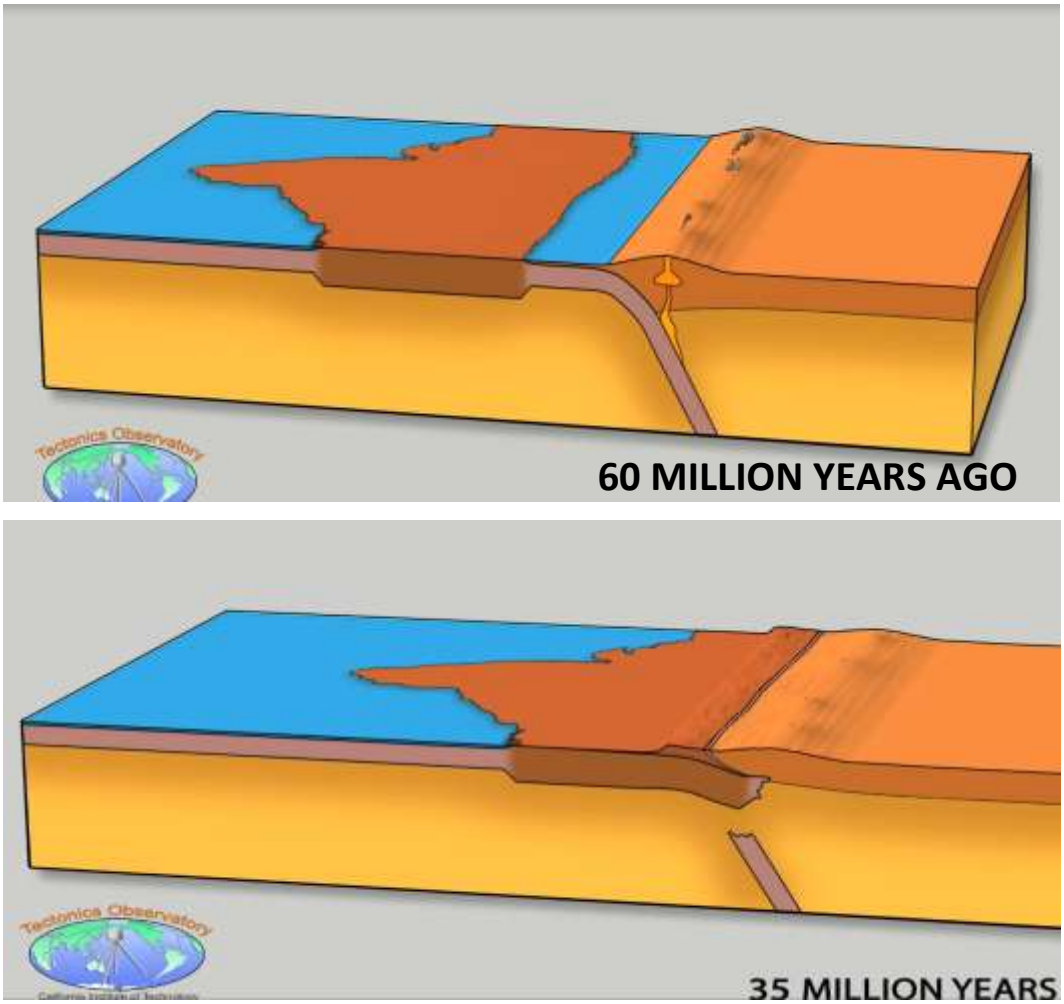
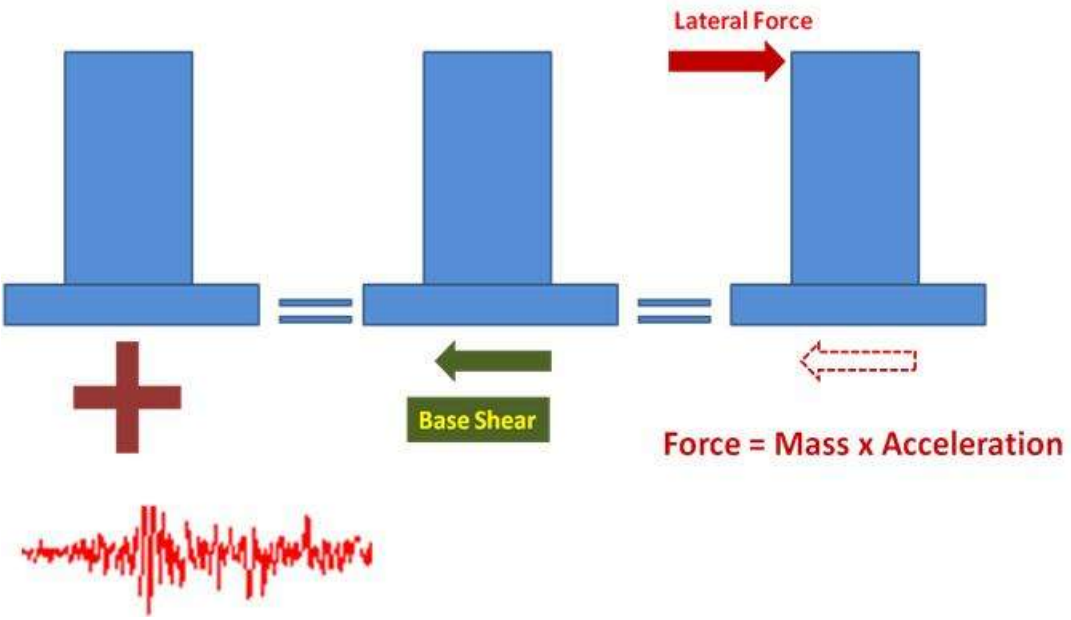


Figure 1-1Tectonic movement of Indian Plate in different period of times

b) EARTHQUAKES AND BUILDINGS

Earthquake generates ground acceleration and inertia force is generated because of mass of the building. The force, in general terms, is equal to multiplication of the mass of the building and acceleration experienced by the building as shown in figure below. Therefore, if all other factors are same, a light structure experiences lesser earthquake force than a heavier structure.



The acceleration is modified, usually amplified, from what is at the rock surface below the building. Amplification takes place due to nature of soil and nature, geometry and physical characteristics of buildings. A structure placed in soft soil experiences more earthquake force compared to a structure placed in hard rock. A shorter building, all other factors remaining same, experiences larger earthquake force than taller structure. However, it should be noted that taller structures have large mass and larger displacement which make them more vulnerable.

c) DAMAGE TO BUILDINGS IN EARTHQUAKES

It is important to understand the relative severities of the various types of damage as they relate to life safety and the protection of historic building fabric. By doing so, priorities for stabilization, repairs, and/or seismic retrofits can be established for each type of damage. If a particular damaged area or component of a building is likely to degrade rapidly if not repaired, then that damaged element assumes a higher priority than others that are not likely to deteriorate. If damage to a major structural element, such as a roof or an entire wall,

increases the susceptibility to collapse, then a high priority is assigned because of the threat to life safety. If damage that could result in the loss of a major feature, such as a wall, compromises the historic integrity of the entire structure, then it is more critical than damage that would result in partial failure, but no loss.

Figure 1-2Failure of buildings in earthquakes. Beautiful buildings do not mean that they are safe (upper figure). A RCC building failed because of improper positioning of hook reinforcement (below two pictures).

Overview of damages to RCC and Masonry Structures is shown in Annex 1.

d) WHAT IS RETROFITTING, REPAIR AND RESTORATION?

Retrofitting is commonly used terminology for strengthening and/or rehabilitation of structures carried out to increase performance of the structure against different hazards. Retrofitting requires unique solution to each individual building and generalization, as in the new construction, has practical limitations. There are specific requirements in each and every step of retrofitting such as vulnerability assessment, design, planning, layout, construction sequence, quality control and safety assurance.

e) IS RETROFITTING SAME AS REPAIR AND RESTORATION?

The concept of retrofitting, covered by this workbook, generally implies that the building is being strengthened for safety against earthquake. The concept for repair, restoration and retrofitting is explained below.

i. REPAIR

Repair to a damaged building is done in order to enable it to resume all its previous functions and to bring back its architectural shape. Repair does not pretend to improve the structural strength of the building and can be very deceptive for meeting the strength requirements of the next earthquake. The actions will include the following:

i. Patching up of defects such as cracks and fall of plaster.
ii. Repairing doors, windows, replacement of glass panes.
iii. Checking and repairing electric wiring
iv. Checking and repairing gas pipes, water pipes and plumbing services.
v. Re-building non-structural walls, smoke chimneys, boundary walls, etc.
vi. Re-plastering of walls as required.
vii. Rearranging disturbed roofing tiles.
viii. Relaying cracked flooring at ground level.
ix. Redecoration, whitewashing, painting, etc.

Repair restores only the architectural damages but do not restore the original structural strength of cracked walls or columns. So a repaired building may be very illusive as it will hide all the weaknesses and the building will suffer even more severe damage if shaken again by an equal shock since the original energy absorbing capacity will not be available.

ii. RESTORATION

It is the restoration of the strength the building had before the damage occurred. Restoration is done whenever there is evidence that the structural damage can be attributed to exceptional phenomena that are not likely to happen again and that the original strength provides an adequate level of safety.

The main purpose is to carry out structural repairs to load bearing elements. It may also involve cutting portions of the elements and rebuilding them or simply adding more structural material so that the original strength is more or less restored. The process may involve inserting temporary supports, underpinning, etc. Some of the approaches are stated below:

(i) Removal of portions of cracked masonry walls and piers and rebuilding them in richer mortar. Use of non shrinking mortar will be preferable.

(ii) Addition of reinforcing mesh on both -faces of the cracked wall, holding it to the wall through spikes or bolts and then covering it suitably. Several alternatives have been used.

(iii) Injecting epoxy like material, which is strong in tension, into the cracks in walls, columns, beams, etc.

Where structural repairs are considered necessary, these should be carried out prior to or simultaneously with the architectural repairs so that total planning of work could be done in a coordinated manner and wastage is avoided.

iii. RETROFITTING (SEISMIC STRENGTHENING)

Retrofitting is an improvement over the original strength when the evaluation of the building indicates that the strength available before the damage was insufficient and restoration alone will not be adequate in future quakes. The original structural inadequacies, material degradation due to time, and alterations carried out during use over the years such as making new openings, addition of new parts inducing dissymmetry in plan and elevation are responsible for affecting the seismic behavior of old existing buildings. But due to historical, artistic, social and economical reasons, generally substituting these weak structures with new earthquake resistant buildings is neglected.

2. CONSTRUCTION PLANNING AND SAFETY

a) PLANNING OF WORKS

Planning is very important aspect of retrofitting as each building requires unique technique and duplicating similar approach may not always be the efficient way. An improper construction process not only damages the structure but also will be unsafe for the workers. An example of bad construction planning is shown in Figure 2-1 which shows that due to improper construction sequence an existing building (which was supposed to be retrofitted) was damaged completely and new building had to be constructed. Figure 2-1 (a) shows an existing structure which was supposed to be retrofitted. As the dismantling process started, the workers dismantled all supporting elements of the structure and whole structure became useless as seen in Figure 2-1(c).

i. SAFETY IS IMPORTANT

While working on an existing building, care should be taken to avoid dangers to the workers and people living inside. Some of the precaution measures are:

1. Know the building before you enter
2. Do not open all the parts at once. Refer the design drawings and consult the site engineer before dismantling any part.
3. Use helmet, boots and other personal safety devices
4. Watch out for any falling hazards
5. Inform the building occupants, if any, for necessary precautions
6. Watch out for persons in the road and inside the building for falling hazards
7. Put proper signs for workers, visitors, occupants and passersby.
8. Try to assemble fitting units outside of the building as far as practicable.

9. Improve visibility inside the building.
10. Follow all safety first rules.

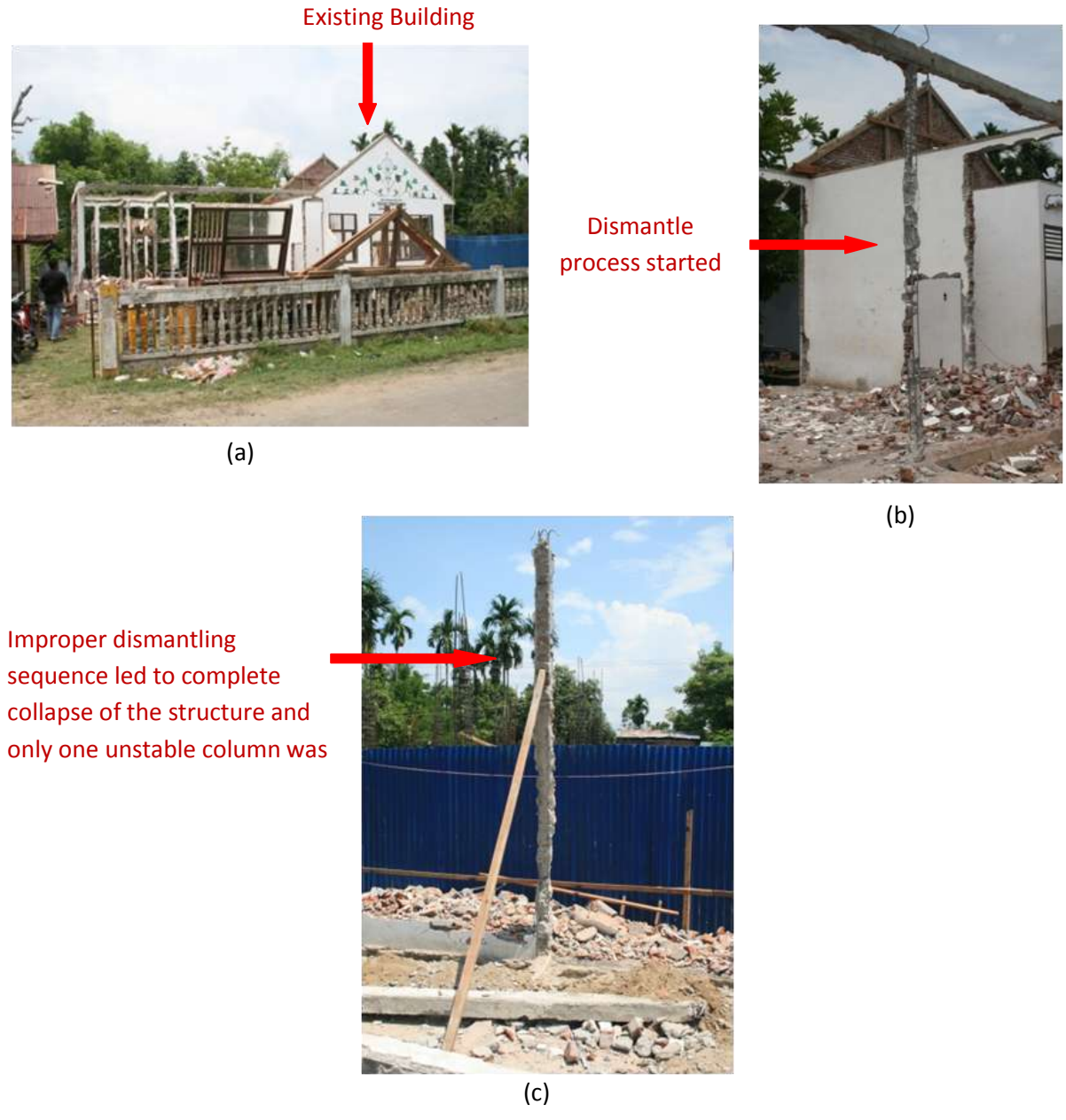


Figure 2-1Improper construction sequence led to complete collapse of the structure during retrofitting

3. RETROFITTING TECHNIQUES

The choice of a retrofitting methodology depends on the type of building, required level of performance, and availability of technology and, overall, financial aspect. Some of the retrofitting techniques used for retrofitting RCC structures are given below:

i. Jacketing – Increasing size of existing members
ii. Shear wall – providing additional shear walls in proper locations
iii. Bracing
iv. Dampers
v. Base Isolation
vi. Addition of frames – Additional steel/concrete frames are added which contribute to the strength of the existing structure
vii. Others – There are many other methodologies, such as use of Fibre Reinforced Polymers (FRP), which can be effectively used for retrofitting of existing RCC structures.

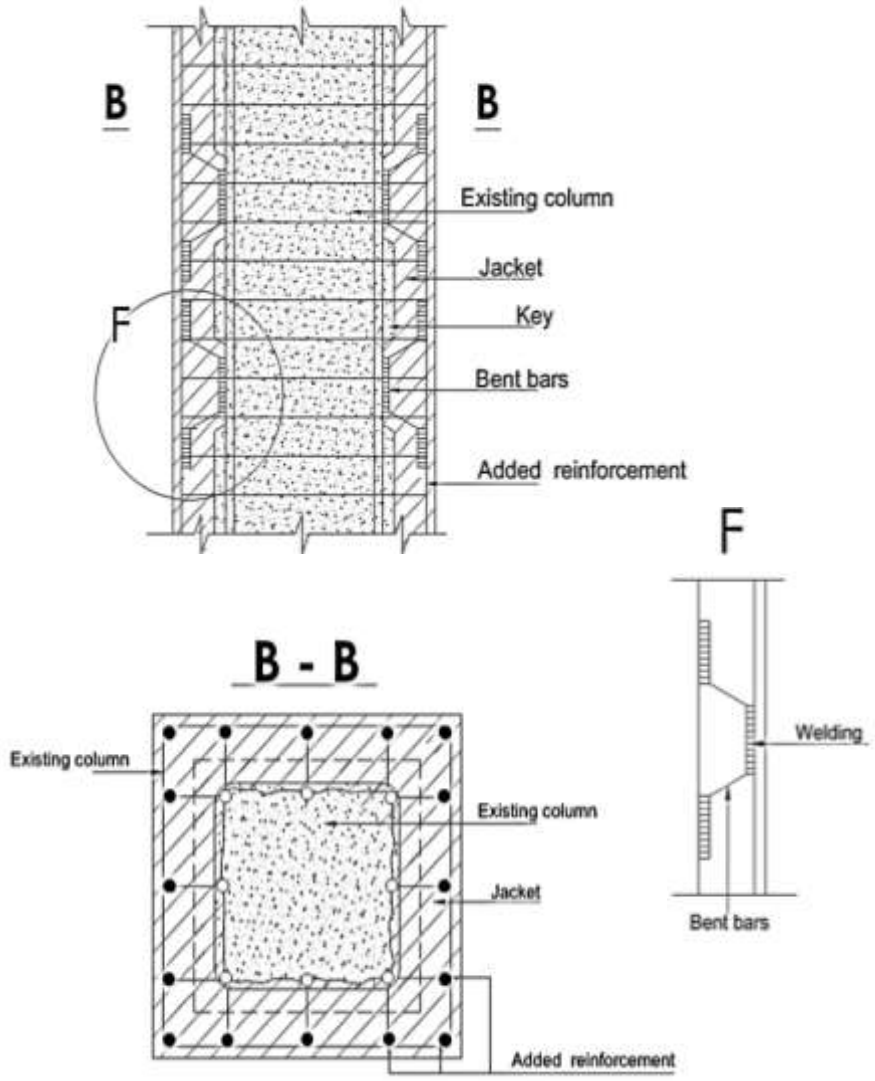
These retrofitting procedures can be adopted in isolation or in combination of one or two methods.

Similarly for masonry and adobe structures, following are some of the common methods:

i. Wall encasing by using wire meshing
ii. Gabion wire
iii. PP band
iv. Introduction of bands and stitches
v. Strengthening/stiffening of roofs/floors
vi. Anchorage of roofs/floors with walls
vii. Strengthening of foundation
viii. Grouting

Additionally, it is always preferable to retrofit a structure at global level to reduce assymmetricity and irregularity. For masonry structures, it's advisable to add cross walls if some of the walls are too long.

Some of the retrofitting techniques are illustrated below.



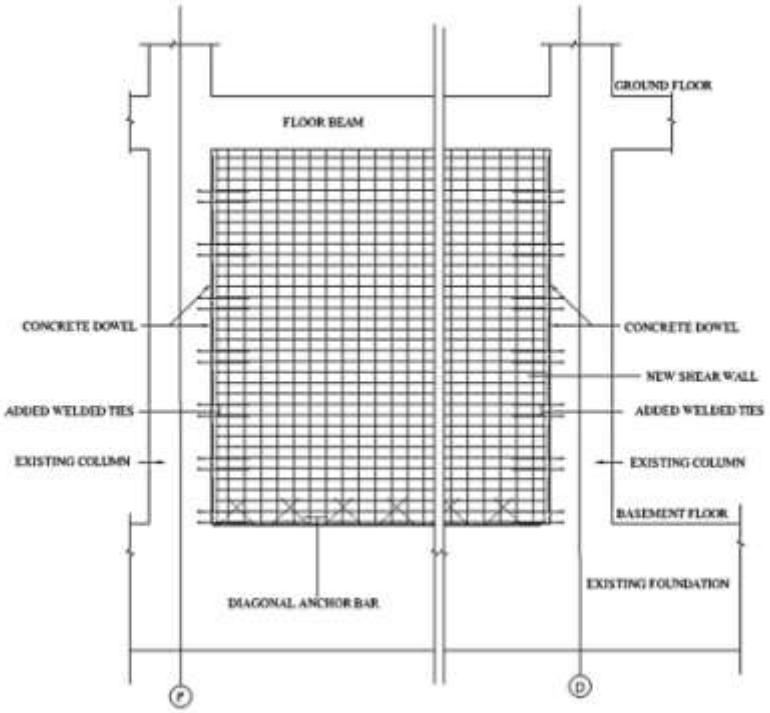


Figure 3-2 Introduction of a new shear wall

Figure 3-3Introduction of a steel frame in existing RCC frame building

Figure 3-4 Introduction of dampers in existing RCC structure

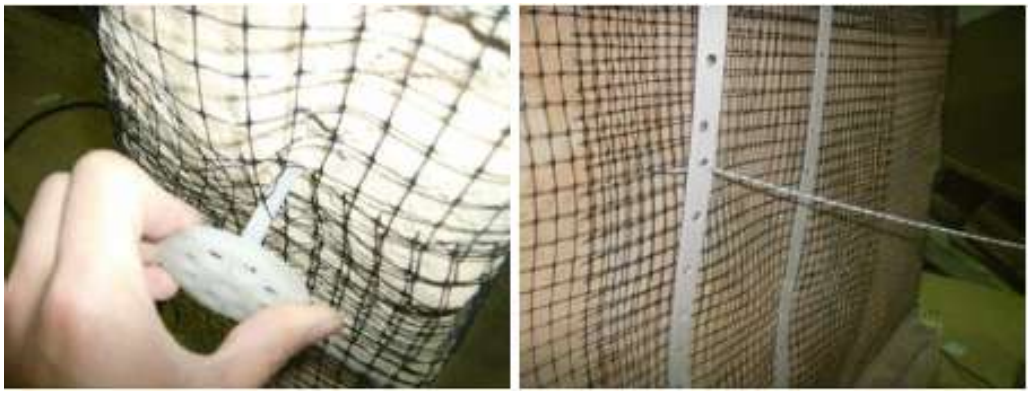


Figure 3-5 Reinforcing masonry/adobe walls with geo-mesh (Source: world housing tutorial)

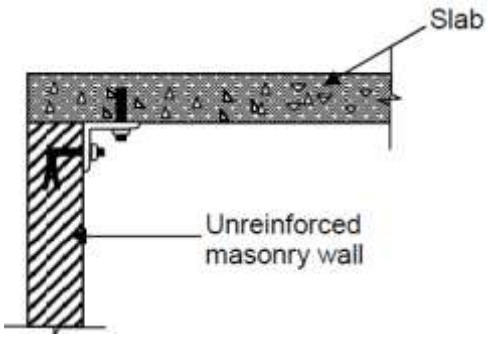


Figure 3-6 Anchorage of slab/floor with masonry wall

After an earthquake in Pakistan, a building can be seen with cracks and major defects at the toe.

Photo: Hari D. Shrestha

4. RETROFITTING OF DIFFERENT ELEMENTS

Retrofitting is commonly used terminology for strengthening and/or rehabilitation of structures carried out to increase performance of the structure against different hazards. Retrofitting requires unique solution to each individual building and generalization, as in the new construction, has practical limitations. There are specific requirements in each and every step of retrofitting such as vulnerability assessment, design, planning, layout, construction sequence, quality control and safety assurance.

Construction is very important aspect of retrofitting as each building requires unique technique and duplicating similar approach may not always be the efficient way.

In order to establish a proper process for construction, the retrofitting design itself should provide detailed process of construction along with drawing as and when required.

Retrofitting approach to be carried out in the field is described in the following section for different elements

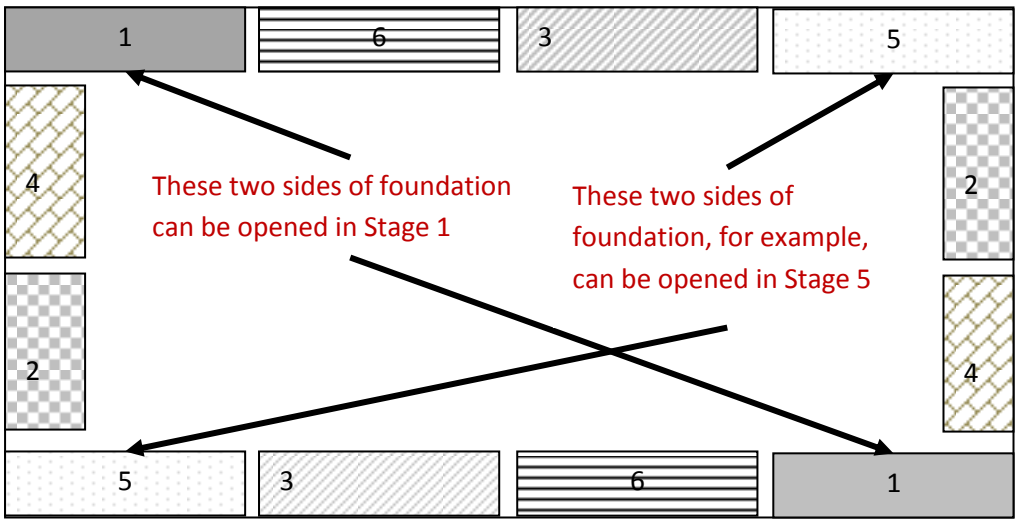


Figure 4-1 Schematic diagram showing stage-wise retrofitting of foundation of load-bearing masonry walls

a) REPAIR OF FOUNDATION

In order to increase size of the footing and also to increase depth of footing, the foundation is opened. The process can be carried along with column jacketing, if necessary

The concrete is laid in the opened foundation. Although reinforcement of the foundation is not shown here, reinforcement required from design is inserted. The reinforcement in the column is observed in the photo.

Completed foundation work for a corner column.

b) REPAIR OF COLUMN

The sides of a column are being opened for jacketing the corner column

The opening should be enough to accommodate reinforcement, additional concrete and workmanship.

Openings in the side of the wall to insert horizontal reinforcement in the walls which will provide support to the walls

Reinforcement placed in a corner column.

The reinforcement fabrication of conventional practice may not be suitable for example the complete circular rings ca not be inserted.

Similar is the case for formwork. A conventional formwork may not be suitable to cast concrete around an existing column and two halves as shown in the photographs may be required.

c) REPAIR OF BEAM

Beams need to properly connected with the columns and the reinforcement of column should continue toward the beam.

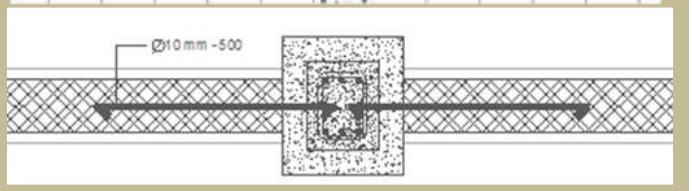
Opening of beam soffit needs special attention as the beam may deflect substantially due to gravity load.

Like in column, complete loop rings are not possible to insert in the beams. U-shaped rings with proper connection may be suitable and engineer should decide on type of bars and rings

d) REPAIR OF WALL

Gable walls are not recommended in earthquake prone areas. They should be removed and replaced with other materials such as CGI sheet. In case gable walls are unavoidable, Gable beam properly connected with the columns shall be placed.

The walls should be properly ties with the columns by providing reinforcement. In case infill walls are not tied, they should be protected by horizontal rings against out of plane failure.



5. QUALITY CONTROL

Quality assurance program must be put in place to assure appropriate approach during evaluation, design and construction of all retrofit projects.

Vulnerability evaluation of each buildings require from preliminary visual assessment to detailed structural analysis. Depending on the scope of the project, size of the structure and location, a detailed geotechnical investigation may be required which should be decided by the engineer and the team.

Retrofit design shall be carried out only after detailed investigation of the existing structural system. The retrofit options depend on building features, scope and objective of the project and cost. The designer shall modify designs and drawings, if necessary, to reflect conditions encountered in the site as the construction progresses.

The designer "shall be responsible for performing periodic structural observation of the rehabilitation work. Structural observation shall be performed at significant stages of construction, and shall include visual observation of the work for substantial conformance with the construction documents and confirmation of conditions assumed during design. Structural observation shall be performed in addition to any special inspection and testing that is otherwise required for the work[1]."

Retrofit design should be peer reviewed by a team of engineers independent from the project.

The designer shall, along with design drawings and specifications, also prepare quality assurance plan with provisions for special inspection and testing reports.

Construction planning and execution is the most critical part of any retrofit project. The importance of construction quality on building performance in general and the likelihood of

[1] FEMA 356

encountering unforeseen conditions in retrofit construction in particular warrant special attention to construction monitoring and quality assurance[2].

Quality control in field is very important to achieve the required performance of a building. Simple and easily available measures such as slump test are very effective in the field.

Continuous monitoring and supervision is required. Quality check of finished product is recommended.

[2] ATC-40