SEISMIC RETROFITTING OF EXISTING BUILDINGS

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OBJECTIVE

• KNOW RETROFITTING OVERVIEW
• LIST DIFFERENT RETROFITTING TECHNIQUES
• GLOBAL AND LOCAL RETROFITTING
Introduction

• Improving Strength
• Improving Ductility
• Improving configurations
• For both damaged and vulnerable structure.
NEED OF RETROFITTING

• Due to Revision of Code
• Well designed but poor construction
• Improving performance of building for higher earthquakes
• If occupancy need to change (from ordinary structure to important structure)
Retrofitting of school buildings

**RETROFITTING:** actions taken to upgrade the seismic resistance of an existing building to make it safer under future earthquakes.

- providing seismic bands
- eliminating sources of weakness or concentrations of large mass and openings in walls
- adding shear walls or strong column points in walls, bracing roofs and floors to be able to act as horizontal diaphragms,
- adequately connecting roofs to walls and columns
- connecting walls and foundations.
Design philosophy for strengthening

Change in the displacement demand and capacity of the structure after strengthening
Retrofitting Process

- Structural Assessment: Visual investigation, structural investigations and testing
- Analysis: Detailed Analysis
- Retrofitting technique
- Construction
Improving the Configuration

Building blocks can be separated by seismic gaps. The individual blocks are now vibrate in plan separately. The stress concentration in block joints can be avoided.

During earthquake three blocks undergo twist in three different orientations.
IMPROVING LOAD PATH

Relocate Structural system (walls) and adjust opening percentage
Masonry Building

SPLINT AND BANDAGE

BOTH SIDE JACKETING

OUTER JACKETING AND INSIDE SPLINT AND BAND
Summary: Failure Mechanism

(a) Out-of-plane bending
(b) Direction of seismic action
(c) Shear

AS Arya

M Tomazevic
Retrofitting of Masonry Structures

Principle of Seismic Safety of Masonry Buildings

• Integral box action

• Integrity of various components
  • Roof to wall
  • Wall to wall at corners
  • Wall to foundation

• Limit on openings
MASONRY BUILDING: ADDING A BANDS
Interface Bond between wall and band

Interface bonding force = \( T=C = A_{st} \times 0.56 \times f_y \)

Bond stress = \( \frac{T}{\text{Wall length} \times \text{Band depth}} \)
**Vertical Bending of Wall**

![Diagram of a wall showing vertical bending](image)

**Unit Vertical Strip**

**Inertia force carried vertical strip,**

\[ q = C \gamma t h l \]

\[ = 0.43 \times 19 \times 0.35 \times 1 \times 1 \]

\[ = 2.86 \text{ kN/m} \]
Forces in Wall

**Axial Compression**

- Vertical load = \( P \)
- Area = \( A = 1 \text{m} \times \text{thickness} \)
- Direct stress = \( \frac{P}{A} \)

Lateral Inertia force

Out of plane bending due to inertia

Moment of Inertia = \( I = \frac{(1000 \times t^3)}{12} \)

Bending stress = \( \left(\frac{M}{I}\right)^* \times \frac{t}{2} \)
CORNER STICH

Tributary Volume for the junction = \( \frac{1}{2} h \times (\frac{h}{2}) \times t \times \gamma \)
Repair of Cracks

- Stitching of cracks
- Grouting with cement or epoxy
- Use of CFRP (carbon fiber reinforced polymer) strips
Splint - bandage on both outer and inner wall

Outer wall

Inner wall
Concrete Jacket on both outer and inner wall

Outer wall

Inner wall
Retrofitting Techniques

Retrofitting process using steel wire mesh
Wall junction Stitch
Stitch Detail

For 1 and half brick thick wall

For 1 brick thick wall
Preparing for splint & Bandage

First coat micro-concrete

Cleaning the wall
Splint and bandage inside room
(sub-diving the wall)
Retrofitting Techniques

**Splint and Bandage**

- At corners
- At sill and lintel level
Concrete Jacket

Concrete jacket on outer wall and splint-bandage on inner wall

Concrete jacket on both outer wall inner wall

Foundation works

Reinforcement arrangements on wall and openings
Reinforcement Detail in Splints (Vertical bandage)

- 2 nos. 8 mm dia. Toresteel
- 4.75 mm Torkari @ 150 mm c/c
- 4" Nail @ 400 mm c/c (Staggered)
- 2 nos. 8 mm dia. Toresteel

5 nos. 8 mm dia. Toresteel
- GI Wire mesh jacketing
- Tor Steel Mesh jacketing
Add Buttress for Long Wall
Repair & Strengthening

FOUNDATIONS

1 cause of deterioration of the walls is their direct contact with the ground humid thus making them vulnerable during earthquake.
Repair & Strengthening

REPAIR & STRENGTHENING OF FOUNDATIONS

Cleaning & Drainage

Demolition & Reconstruction
OUT OF PLUMB WALL

WALL

- Wall out of plumb by more than 2% per m need to be dismantled or completely demolished, after having checked the stability of the roof.
- Wall out of plumb is less than 1% & without any signs of damage or diagonal cracks, affected parts can be repaired.
Repair & Strengthening

- Making gable wall lighter using wattle & daub technique
- Crack in a gable wall
Repair & Strengthening

WALL CORNER

REINFORCEMENT WITH KEYS

• Corner joints are weak areas during earthquake, especially when they do not have correct bonding.

• If the cracks are not serious and there is no loosening, then they can be repaired by fitting keys.

• Fit them at 5 row intervals with the help of the mortar joints.
Repair & Strengthening

WALL CORNER

REINFORCEMENT WITH KEYS

Corner strengthening with key

Construction iron Ø 8mm

Wood 7x5x80 cm

connection
Repair & Strengthening

WALL CORNER

DISMANTLING & RECONSTRUCTION

• Greater damage (e.g. collapsed sections) needs more delicate operation.
  – Dismantling & rebuild & fit supports at 4 row intervals (keys)
  – Rebuild with buttresses
Repair & Strengthening

ROOF

• Missing of ring beam which distributes the load horizontally can result cracks. Such cracked portion of wall can be replaced.

• First, the roof structure above needs to be supported at the place of the replacement, then the damaged adobes are eliminated and replaced.

• The topmost layer of the wall is removed and replaced with a ring beam or a wall plate (made from wood, cement, bamboo or a similar material).

Cracks at the bottom of roof support
Repair & Strengthening

ROOF

Two ways of fitting a ring beam:

• Build a ring beam around the wall's entire perimeter if the wall is not gabled.

• Or only on the parts which receive the roof, finishing at the ends with a key embedded in the gabled wall.
Repair & Strengthening

FLOOR BRACING

- In case of wooden or flexible floor, the rigidity of the floor should be increased.
- The rigidity of the floor can be increased by providing diagonal bracings.
Retrofitting Techniques

Adding Steel Bracings

- Effective solution when large openings are required

- **Potential Advantages:**
  - Higher strength & stiffness
  - Opening for natural light
  - Amount of work is less since foundation cost may be minimized
  - Adds only less weight to the existing structure

**Diagonal Bracing**

**Vertical Bracing**
Retrofitting Techniques

Jacketing

- Most popular method for strengthening of building columns

- Types:
  1. Steel jacket,
  2. Reinforced Concrete jacket,
  3. Fibre Reinforced Polymer Composite (FRPC) jacket
Retrofitting Techniques

Jacketing

• Purpose for jacketing:
  • To increase concrete confinement
  • To increase shear strength
  • To increase flexural strength

Column Jacketing

Beam Jacketing
Retrofitting Techniques

Floor ties and plywood diaphragm are techniques used to improve floor stiffness and their integrity with vertical lateral load resisting structure.

*Floor Ties*
PARAPET WALL

Strengthening of parapet wall using bracing. Parapet walls are among the first to collapse in earthquake.
Strengthening parapet walls
RC BUILDINGS
Retrofit Design (RC Moment Frame)

- **RC Jacketing of Column**
  - It Increases flexural strength, Shear Strength and ductility
Steel Column jacketing

- New concrete/non-shrink grout
- Welding
- Existing column
- Steel plate
- Shear lugs
- Steel angle

STEEL JACKETING
TYPICAL JACKETING SCHEME OF COLUMN

WHEN BEAM & BEAM COLUMN STRENGTHENING IS NECESSARY

1 - Existing reinforcement
2 - Added longitudinal reinforcement
3 - Added stirrups
4 - Welded connecting bar
5 - Concrete jacket
6 - Welding
WHEN BEAM & BEAM COLUMN JOINT NEED NOT BE STRENGTHENED
Beam Retrofitting, RC Jacketing

**ORIGINAL SECTION**
- Increased section with micro concrete: Shortcrete self compaction concrete
- Fixing of stirrup with epoxy and quartz sand mortar as specified

**BEAM SECTION ENLARGEMENT**

**COMBINATION SLAB AND BEAM OVERLAY WITH BEAM ENLARGEMENT**
Bonded Steel plate

Steel Plate

Existing concrete beam

Epoxy adhesive

Bonded steel plate

Anchors
RC jackets

• One of the most frequently used methods for strengthening of the reinforced concrete elements.

• Jacketing can be defined as the confinement of the element with new and higher quality reinforced concrete elements may be implemented for various purposes based on the type of deficiencies that the structural member has.
Steel jackets

- Jacketing with steel elements is a practical method used frequently for various applications.
- Steel jacketing can readily be used to especially enhance the shear strength of reinforced concrete elements.
TYPICAL CONNECTION DETAIL OF NEW SHEAR WALL WITH EXISTING STRUCTURAL ELEMENTS

(a) Connection with existing slab, column / beam

Legend for (a)
1 - Shear wall
2 - Reinforcement
3 - Dowel bars
4 - Connection reinforcement
5 - Existing column
6 - Dowel opening
7 - Welding with column bar

(b) Connection with existing foundation

Legend for (b)
1 - Existing columns
2 - Existing column base
3 - New shear wall
4 - New shear wall base
5 - Anchorage bars
ADDING SHEAR WALL

Adding new Shear Walls

• New elements preferably be placed at the exterior of the building.
STIFFENING / STRENGTHENING BY BRACING MEMBERS

1 - New bracing members
2 - Existing concrete structural elements
3 - Joints of bracing members and existing RC elements

(a) Arrangement of bracing members

1 - Existing beam
2 - Existing column
3 - Structural steel angle cleat
4 - Structural steel gusset plate
5 - Bolt
6 - Grout to be injected in the gap between concrete surface and steel surface
7 - Bracing members
8 - Gap in the hole for bolt to be filled by grout

(b) Typical connection details of existing concrete elements and structural steel bracing members
TYPICAL DETAIL OF STRENGTHENING OF FOUNDATION

1 - Existing foundation
2 - Existing column
3 - Reinforced jacket
4 - Added concrete
5 - Added reinforcement
System based strengthening techniques

Infill shear walls

Infill wall application in an RC building

Formation of the end zones in full or partial shear walls
External shear walls

shear wall layout example

An external shear wall strengthened building
Carbon fiber/ Glass Fiber
Carbon fiber/ Glass Fiber
Carbon fiber/ Glass Fiber

Figure 10 – Inner portion of joint of column C6
Fiber reinforced polymers

- Fiber Reinforced Polymer has considerably become widespread in strengthening applications.
- Strengthen without increasing volume of member.
- May practically be used for numerous purposes such as enhancement of the flexural capacity of floor slabs and improvement of shear capacity of beams, columns or shear walls.

FRP confinement of a beam
Liquefaction: Gravel Columns

LOCATION FOR GRAVEL COLUMNS TO CHECK LIQUIFACTION

GROUND FLR. LVL.± 0.00
Gravel Column of dia 200 mm and depth 15 m

15000
200
OBSERVATION OF RETROFITTED BUILDING AFTER GORKHA EARTHQUAKE
Observations after Gorkha Earthquake 2015

- Overall 36 schools at different locations in Kathmandu valley were visited.
- 29 were retrofitted blocks and 18 were non-retrofitted blocks.
- 26 blocks were retrofitted load bearing buildings and 11 blocks were non-retrofitted load bearing blocks.
- 3 blocks were retrofitted framed and 7 blocks were non-retrofitted framed.
SCHOOLS LOCATION

RETROFITTED AND NON RETROFITTED SCHOOLS

Legend
- Green dot: School
- Blue area: Kathmandu Valley

Legend
- Red dot: Non-Retrofitted School
- Blue dot: Retrofitted School
- Yellow area: Kathmandu Valley
BUILDING TYPE

WALL TYPE

Legend
- △ Retrofitted (Framed)
- ● Retrofitted (Load Bearing)
- ■ Non-Retrofitted (Framed)
- ▼ Non-Retrofitted (Load Bearing)

Kathmandu Valley

Legend
- △ Retrofitted (Cement and Mud Mortar)
- ■ Retrofitted (Brick with Mud Mortar)
- ● Retrofitted (Brick with Cement Mortar)
- ▼ Non_Retrofitted (Brick with Mud Mortar)
- ▼ Non-Retrofitted (Brick with Cement Mortar)

Kathmandu Valley
## Summary of surveyed school blocks

### Impact on already retrofitted school blocks

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<th>Minor repair</th>
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### Impact on non-retrofitted school blocks

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<tr>
<td>Total</td>
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Retrofitted School Building

2-storey load bearing school building with brick + mud mortar.
Retrofitted with splint bandage on inner and outer wall.

3-storey load bearing school building with brick + cement mortar.
Retrofitted with concrete jacket on outer and splint-bandage on inner wall.

No minor damage in the earthquake.
Damage seen in nearby buildings

Significant damage in a residential building.

Significant damage in RCC building.

Cracking of brick wall of under construction building.

Cracks in infill

Substantial damages in column and infill walls

Owner showing cracks in building
Damage seen in nearby buildings

- Corner separation of brick + mud mortar building.
- Cracking in brick + mud mortar building.
- Collapse of brick rubble masonry building.
- Collapse of brick rubble masonry building.
Retrofitted school building

3-storey load bearing building with brick + mud mortar in ground floor and brick + cement mortar in 1st and 2nd floor.

Retrofitted with splint bandage on inner and outer wall

No minor damage in the earthquake

No damage seen in the retrofitted walls
Non-retrofitted building

5-storey RCC building

Substantial cracking of infill walls and separation from column.

Cracking in the column.

Cracking in infill walls.
Non-retrofitted buildings

3-storey RCC building

Minor cracking in wall and frame interface.

Hairline cracks through openings.
Damage seen in nearby buildings.

Complete collapse of a building with brick + mud mortar.

No damage seen in low rise RCC buildings.

Damage of a residential building with brick + mud mortar.
Retrofitted building

2-storey load bearing building with brick + mud mortar in ground floor and brick + cement mortar in 1st floor.

Retrofitted with concrete jacket on outer wall and splint-bandage on inner wall.

No minor damage in the retrofitted walls
Non-retrofitted buildings

Significant damage of a 2-storey school building with brick + mud mortar.

Cracking through opening.

Corner separation in cross walls.
Non-retrofitted building

Significant damage of a 3-storey school building with brick + mud mortar.

Diagonal cracking in wall

X-cracking in wall

Failure of parapet wall
Damage seen in nearby buildings

Damage of a residential building with brick + mud mortar.

Out-of-plane collapse of masonry wall
Summary on visual inspection

Retrofitted buildings

• All the surveyed buildings perform well in the earthquake without minor damage.
• Retrofitting successfully helps to maintain the integrity of low strength and brittle vulnerable masonry school buildings.

Non-retrofitted buildings

• Post-earthquake survey after the recent earthquake have shown poor performance of non-retrofitted school buildings that are often vulnerable
• Poor construction practice, deterioration of materials, lack of seismic resistant design and some localized effects cause more damage.
THANK YOU