Post-earthquake School Reconstruction Project

Workshop on Earthquake Resilient Design for School Buildings

Day-2 Session 4

Strengthening or Retrofitting

Chandani Chandra Neupane
Various Terms used with similar meaning

- **Refurbishment**: Is a process carried out to improve the existing structure or its facilities by altering internal areas, provision of decorating components and materials and new facilities and equipment etc.

- **Repair**: Is the process of restoring the performance of a damaged building component to its original condition by fixing it.

- **Renovation**: Renovation refers to the process carried out to upgrade an existing structure to improve performance by either altering the scope of structure, providing additional facilities or improving existing facilities.

- **Restoration**: Refers to process carried out to bring a deteriorating structure or its component back to its original design plan. Usually, this is required for old existing structures of any historical importance.

- **Retrofitting**: Refers to measures or process carried out to restore or enhance the load-carrying capacity and/or performance of a structure or its components. These measures may vary depending upon intended purpose, type of structural component and extent of damage, and are not conceived or foreseen in the original design of structure.

- **Rebuilding**: Refers to demolishing and reconstruction of a structure or its components and is usually considered if retrofitting is not an adequate option due to economic or other reasons.

- **Strengthening**: Refers to measures or process carried out to increase the strength of a structural component. It is considered in cases where expected loading may exceed the capacity of member.

- **Rehabilitation**: This refers to process carried out to extend the life of a structure and may include options from strengthening and retrofitting. The purpose of rehabilitation is to restore the intended function of a building or structure which is rendered uninhabitable due to some man-made or natural disaster.

- **Conservation**: It refers to measures taken to reduce structural deterioration due to environmental conditions and is usually associated with historical structures and monuments.
Overview
Why Retrofit is Needed

• Any deficiencies in design are found
• Any indications of deficiencies in construction process
• Structure is deteriorated, damaged
• Structure is required to serve a new function
• Required to support new loads
• Structure or a portion does not comply with the critical requirements of code
Key Retrofit Objectives

• New performance needs imposed on the members are satisfied

• New loads are transferred to the new system and/or existing members are relieved from existing loads, as the case may be

• The old and new system act together or the old and new systems do not act together, as intended by the designer
Outcome of Retrofit

• Measures resulting in overall strengthening of system

• Actions for enhancing the stiffness of system

• Enhancing deformational capacity of load-resisting system

• Enhancing energy-dissipation capacity of structure

• Measures resulting in reduced demand on structure
Key philosophy for strengthening

Change in the displacement demand and capacity of the structure after strengthening
What Retrofit should focus on

• Provision of an Efficient and Integrated Load Path
• Strengthening and Stiffening of Structures
• Identification of Possible Failure Modes
• Increase in Deformational Capacity of Sections and Members
• Reducing Force Demands on Sections and Members
• Aesthetic Considerations
• Practicality of Construction
• Cost considerations

• Final Selection of Retrofit Scheme consider all factors
Retrofit Process
Overall Retrofitting Process

1. Structural Assessment
2. Analysis to Determine Retrofit Needs
3. Design of retrofitting Systems
4. Verification of the Retrofitting
5. Construction
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<th>Year</th>
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<td>Pre-standard and Commentary for the Seismic Rehabilitation of Buildings</td>
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<td>ASCE/SEI 31-03 American Society of Civil Engineers (ASCE)</td>
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<td>Seismic Evaluation of Existing Buildings</td>
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<td>2007</td>
<td>Supplement No. 1, Seismic Rehabilitation of Existing Buildings</td>
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Overall Retrofit Strategy

• Global

• Local

• Combined
System and Element Strengthening

• System strengthening does not only prevent collapsing but also delays structural damages.

• The element strengthening is a method based on the reinforcement of inadequate elements triggering the loss of stability due to the sustained damages without undertaking major changes in the load-bearing system of the building.

• Negligible changes take place in the characteristics of a building such as stiffness and mass.
Retrofitting Techniques

Global

- Adding shear wall
- Adding infill wall
- Adding bracing
- Adding external frames
- Mass reduction
- Supplemental damping and base isolation

Local

- Jacketing or encasing /stressing of beams
- Jacketing or encasing of columns
- Strengthening of slab
- Jacketing of beam column joints
- Wall thickening
- Strengthening individual footings
Effectiveness of various Retrofit Techniques for RC Frames

Force-Displacement response of a portal frame with different retrofitting techniques (Source: Sugano, 1989; CEB 1997)
Common Retrofit Techniques

• Surface Treatment, Plastering and Pointing
  • Ferro cement / reinforced plaster

• Jacketing and Encasement
  • Concrete Jacketing or Encasing
  • Steel Jacketing
  • FRP Jacketing
Innovative Thinking

• Rather than strengthening a weak member which may be difficult due to construction, operational constraints, alternate load paths may be provided to reduce the action on the members, or strengthen/stiffening nearby members to redistribute the loads.

• Avoid strengthening methods that increase dead load. For example, if a flat slab is weak in punching shear, consider adding column capitals rather than an attempt to increase thickness.

• For continuous and indeterminate members, strengthen location that are easily accessible even if it is not at weak location as the new loads will be redistributed to section of higher stiffness and old loads can be resisted with the help of plastic deformations.

• If many members in a structure are found to be defective or need strengthening, consider modifying the basic structural system. For example, a moment resisting frame may be converted to braced frame by adding external/internal bracing/walls.

• Utilize non-structural components as structural components. For example, the partition walls, door and window frames, floor finishes etc., can be modified to assist in carrying loads.

• In case of foundation strengthening, consider re-evaluating or investigating the soil properties by re-testing. Often modifying the factor of safety from 3 to 2.5 or by computing the allowable bearing capacity for each footing individually can eliminate or reduce the need to strengthen the footing.
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
Infill shear walls

• Existing partition walls in the building are removed and high strength reinforced concrete shear walls are built instead.

• Such a strengthening application, the shear walls bear majority of the earthquake loads and limits the displacement behavior of the building while the frame system resists very low amounts of the earthquake loads.

• Reinforced concrete infill walls can also be used as partial walls and wing walls.
External shear walls

shear wall layout example

An external shear wall strengthened building
Steel bracing

- Steel bracing for RC frames has also been used to reduce drift demands.
- Bracing can either be implemented inside the frame or applied from outside of the system like RC walls.
- Post-tensioning can also be applied to bracing elements

Buttress type external steel shear wall
Infill strengthening

- Those walls of which effects on the behavior are not considered during structural design can generally produce a certain bracing effect and make a positive contribution to the behavior.

- Some of them include strengthening with mesh reinforcement, strengthening with precast panel and strengthening with FRP materials.
Local Element-based strengthening

- Element-based strengthening approach is the modification of deficient elements to increase ductility so that the deficient elements will reach their limit states in a ductile manner.

- Effective results can be obtained by using such methods in buildings with a limited number of deficient elements.
Jacketing and Encasement

a) Jacketing of existing members

b) Encasing of existing members using concrete
• 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.
RC Jackets for Columns
Steel Jackets for RC Columns

• 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.
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.
System or element strengthening?

- Element based techniques are more economical solutions when local problems are the main reason of the strengthening decision.

- If the problems related with the global ductility, stiffness or strength of the structure are the main concern, global strengthening techniques are more advantageous.

- Both approaches can also be utilized if needed.

- Also, Performance of the elements connecting the old and new members mostly has a vital effect on the performance of the strengthened system.
Retrofitting of Schools in Nepal
School buildings in Nepal

• 8.5 million students attend pre-school.
• 82000 school buildings, 35000 school campuses.
• 89 % load bearing school buildings.
• 49000 schools needed to be retrofit and 12000 to be demolished.
  (As of vulnerability school assessment 2011)

• Loss (Gorkha Earthquake 2015)
  ➢ 27000 class room totally destroyed
  ➢ 26000 partially destroyed
Typical school buildings in Nepal

One story unreinforced brick masonry building

Two story unreinforced brick masonry building

Three story unreinforced brick masonry building

Four story RCC building
Common retrofitting techniques used for masonry

Concrete Jacketing
- Concrete jacket on both inner and outer wall.
- Concrete jacket on outer wall and splint-bandage in inner wall.

Splint and bandage
- Splint and bandage on both inner and outer wall.

Reference: NSET, Kathmandu
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

Reference: NSET, Kathmandu
Concrete Jacket on both outer and inner wall

Outer wall
Inner wall
Concrete jacket on outer wall & Splint-bandage on inner wall

Reference: NSET, Kathmandu
Splint and bandage arrangements

Surface preparation

At corners

Splints and bandage at sill and lintel level
Splint-bandage on both outer and inner wall

Outer wall

Inner wall
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.
Summary of surveyed school

Impact on already retrofitted school blocks

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Impact on non-retrofitted school blocks

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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.

Owner showing cracks in building

Cracking of brick wall of under construction building.

Substantial damages in column and infill walls

Cracks in infill

Cracks in infill
Damage seen in nearby buildings

- Corner separation of brick + mud mortar building.
- Cracking in brick + mud mortar 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

- No damage seen in low rise RCC buildings.
- Complete collapse of a building with brick + mud mortar.
- 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 performs 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.
Pushover analysis

Pushover curve along X-direction

Pushover curve along Y-direction

Base shear (KN) vs. Roof displacement (m)

- Non-retrofitted building
- Retrofitted building

Base shear (KN) vs. Roof displacement (m)

- Original building
- Retrofitted building
Summary of research

- Despite being made of a weaker building material (low strength brittle structures), the retrofit proved to be successful.

- Retrofitting can be the better solution to make existing masonry school buildings earthquake resistant, rather demolishing them.

- The actual behavior of the buildings in recent earthquake were obtained through visual inspection.

- Global performance comparison of non-retrofitted and retrofitted school building was obtained by simplified numerical analysis. Comparison between the non-retrofitted and retrofitted building shows retrofitting strategy increase effective lateral stiffness, slight ductility and significant load carrying capacity of the building.
Tags from Government

NON- RETROFITTED SCHOOL BUILDING

UNSAFE

RETROFITTED SCHOOL BUILDING

SAFE
References


Thank You