SEISMIC PERFORMANCE OF MASONRY BUILDINGS AND SEISMIC CONSTRUCTION TECHNIQUES

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Session Objective

Participant will able to

– List School Building typology
– Understand typical damage pattern
– Understand theoretical background of damage
– Know Construction ideas to avoid damage
SCHOOL BUILDING TYPOLOGY
Structural Categories And Typology

Structural Categories:
- LOAD BEARING MASONRY (LB)
- RC FRAME WITH INFILL (RC FRAME)
- STEEL FRAME (SF)
- TIMBER (T)

Structural Typology:
- ADOBE (A)
- UNCONFINED MASONRY / UNREINFORCED MASONRY (UCM/URM)
- CONFINED MASONRY
- NON ENGINEERED RC WITH INFILL
- SMRF WITH INFILL
- STEEL FRAME MASONRY INFILL
- TIMBER ROOF, MASONRY
MASONRY WALL TYPE

- Brick in mud
- Brick in cement
- Brick in cement
- Stone in mud mortar with cement pointing
- Rubble masonry wall
- Round Stone cut in half
- Undressed Flat stones used in a dry stone wall
- Dressed Stone masonry wall (Ashlar Masonry)
- Semi Dressed Masonry
DIFFERENT TYPOLOGY

Field Stone in Mud Mortar

Rectangular blocks in mud mortar
Unconfined and Unreinforced masonry (UCM/URM): Rectangular blocks in cement mortar

Fired brick in cement mortar are the most common

Examples of brick in cement mortar buildings
( At Tanahu)
Unconfined and Unreinforced masonry (UCM/URM): Rectangular blocks in mud/cement mortar with seismic

timber tying elements
Cast-in-place concrete lintel bands to provide more overall continuity in the structural system.

Example of traditional building with timber tying elements  Example of RC lintel
Reinforced Concrete frame with masonry infill walls (Non-Engineered), (RC)

Examples of non-engineered RC Frame buildings
Reinforced Concrete frame with and without masonry infill walls (Engineered), (RC-MF)

Lincon School, kathmandu

Designed with following IS 456;2002 and following ductile detailing code IS 13920
Metallic Steel Frame with CGI Roof and masonry walls

Examples of Steel Frame
Masonry Building Timber Post and Rafters
Typology Definitions – Combined Systems (CS)

Define in different pieces and define different structural categories for each floor for mixed systems in elevation. Use different form for each pieces.

Examples of combined (or mixed) typologies

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.

Stone in mud on first floor, brick in mud on second floor [Courtesy of NSET]
DAMAGES IN GORKHA EARTHQUAKE
Overall Percentage Of Different Typology

Proportion of school buildings per structural typology in the eight districts of Phase 1

Reference: SIDA summary report of Phase 1
Damages: Buildings per typology

Reference: SIDA summary report of Phase 1
MASONRY BUILDING
THEORETICAL BACKGROUND OF DAMAGES
Causes of Failure of Masonry Buildings

- Inadequate integrity
- Inadequate out of plane flexure capacity
- Inadequate In-Plane shear resistance
- Irregular configuration
Behavior of Masonry Buildings

Masonry Building Components

Ref: IITK EQ Tips
Behavior of Masonry Buildings

If No proper Connection, Wall B Tends to fail

Advantage of proper Connections

Ref: IITK EQ Tips
Lack of integrity (Corner Separation followed by out of plane failure)

Corner Separation Leads to out of plane failure
Improvement of Connection
Step joint

b) Sloping joints at corners (most satisfactory)
Alternating toothed joint

All dimensions are in mm.

a, b, c Toothed joint in walls A, B and C
Stitch spacing 600 mm
Long Wall and Short wall

Slenderness Ratio = $H/t$
If $H/t > 12$, Wall is slender

Height and length of the wall should be kept in a limit to avoid off plane failure
Buttress for Long Wall
Effect of Openings

Load transfer zone from weak wall to strong wall

Opening Weakens Walls
Single closed band must be provided above openings
Crack Around opening and Wall behavior modified

Cracking of wall without vertical reinforcement

Modified Wall behavior with vertical reinforcements, No Cracking

(Mahankaleshor Lower Secondary School, Saga)
In plane Behavior of Pier (Rocking)

Wall behaves as a discrete units during Earthquake
In-plane behavior of Wall Pier (Shearing)

If vertical reinforcement is absent

X-Cracking of Masonry Piers

Earthquake-induced inertia force

X-Cracking

Sliding above Sill Level
Wall behavior modified (Seismic enhancement)

(b) Rocking of Masonry Piers

Rocking of pier

Uplifting of masonry

Crushing

Vertical steel bars anchored in foundation and roof band

Bending of pier in place of Rocking

No Sliding of masonry

Sliding of masonry
Box Action for Better performance

For Box Action
Lintel band, Sill band, Foundation band
Small openings in wall
Good connection between wall and roof and wall and foundation

Figure 1: Essential requirements to ensure box action in a masonry building.
Possible Shear Cracking Modes

strong mortar
weak units
through masonry units

low vertical compressive stress
sliding along bed joints

weak mortar
strong units
stair step through bed and head joints

Associated NCMA TEK Note
Damage to In-Plane Wall

(Mahankaleshor Lower Secondary School, Saga)
Severity of Crack

Guidance:
After surveying the piece, estimate the percentage of openings that have cracking.

If cracking is observed at openings, record the typical severity of cracking:
- Severe ¼ inch cracks or greater
- Moderate – around 1/8 inch cracks
- Minor or Hairline cracks – around 1/16 inch cracks or cracks in the finish only

Cracking at openings is generally less of a concern for Life Safety but can be uneconomical to repair.
Openings in Walls

\[ b_1 + b_2 + b_3 < 0.5 \, L_1 \] for one storey, \( 0.42 \, L_1 \) for two storeyed, \( 0.33 \, L_1 \) for three storeyed.

\[ b_6 + b_7 < 0.5 \, L_2 \] for one storey, \( 0.42 \, L_2 \) for two storeyed, \( 0.33 \, L_2 \) for three storeyed.

\[ b_4 > 0.5 \, h_2 \] but not less than 600 mm.

\[ b_5 > 0.25 \, h_2 \] but not less than 600 mm.

\[ h_3 > 600 \, mm \] or \( 0.5 \, (b_2 \, or \, b_9 \, whichever 
\, is \, max) \).
# Out of plane failure Mode

<table>
<thead>
<tr>
<th>OP1</th>
<th>OP2</th>
<th>OP3</th>
<th>OP4</th>
</tr>
</thead>
<tbody>
<tr>
<td>free-standing wall plane</td>
<td>with ties at the top</td>
<td>connected to transverse walls</td>
<td>with ringbeam</td>
</tr>
</tbody>
</table>

[Diagram showing different modes of failure]
Off Plane Failure of Wall

Darbaar School, 2015 Nepal Earthquake
Off Plane Failure of Wall
Out of plane damage to Parapets

1994 Northridge Earthquake, Filmore

1996 Urbana Summer
Gable Wall Damage
BANDS AROUND OPENING
Horizontal Bands

(a) Building with Flat Roof

(b) Two-storey Building with Pitched Roof
Off Plane Behavior of Lintel Band

Detailing of Reinforcement in Lintel bands

Correct Practices

Incorrect Practice

Cross-section of Lintel Bands

Small

Large

Direction of earthquake

Lintel Band

Bending of Lintel Band

Pulling of Lintel Band

Direction of Inertia Force

Steel Links

Steel Bars

75 mm

150 mm
Openings
Lintel and Sill Band

Band thickness = height of the brick including mortar, 2-12 mm dia L bar
If window breadth > 4’, Local band depth above opening = 2 Brick height including mortar, 4-12 mm dia L bar
Seismic Resisting Elements
Bond beam and lintel are cast together as one element

Opening
>4’
TIE BEAM
Vertical Reinforcement
Figure 7.2: Strengthening of Masonry Around Openings

- Ø - Diameter,
- W - Window,
- V - Vertical Reinforcement bars,
- t - Thickness of wall (minimum 1 brick length),
- t1 - Minimum thickness 75 mm.,
- L - Length of brick unit.
NBC RECOMMENDATIONS
Construction Materials

- **Concrete**: M15 Grade (1:2:4) {15 Mpa Crushing Strength at 28 days for 150 mm Cube}

- **Cement**:
  - Should be as fresh as possible
  - If stored for 2 months, make lab test
  - Do not use hardened cement
  - Use OPC with NS Mark
Construction Materials

• Coarse Aggregate:
  – Crushed or broken stone
  – Should be hard, strong, dense, durable, clean
  – Proper grading
  – Free from any coating likely to prevent adhesion of mortar
  – Avoid flaky, elongated pieces

• Size of Aggregate:
  – Concrete section thickness > 100 mm: use 20 down
  – Thickness between 40 mm to 100 mm: Use 12 down
Construction Materials: SAND

• Should be free from
  • organic matters, salts
  • dust lumps, mica
  • Soft or flaky particles

• Total undesirable substance< 5%
Construction Materials:

**Brick Masonry**

- Standard rectangular Brick (240 × 115 × 5 mm), burnt red
- 10 mm thick horizontal mortar bed
- Crushing Strength > 3.5 N/mm²
- Thickness of Non load bearing wall
  - Minimum thickness of wall: Half Brick (1:4 Mortar)
  - Maximum Thickness of Wall: one Brick (1:6 Mortar)
- for Better workability: Use fresh lime (25%-50% of Cement)
- For Plaster use 1:6 ratio, cube strength >3Mpa
Reinforcing Bars

• MRT considers Fy = 415 N/mm² Bars for Beam and columns
• MRT prefers fy = 550 N/mm² for slab only
• 7 dia Fe550 = 8 dia Fe 415
• 5 dia Fe 550 =6 dia Fe 250
Categories of Buildings

**Purpose**: achieving seismic resistance at an economical cost,

-three significant parameters:

i) Seismic intensity zone where the building is located,

ii) Importance of the building, and

iii) Stiffness of the foundation soil.
Categories of Buildings Contd..

Seismic Zoning Map For MRT

**Zone A**: Risk of widespread collapse and heavy damage.

**Zone B**: Risk of Moderate damage.

**Zone C**: Risk of Minor damage.
Categories of Buildings Contd..

**Importance of the Building for MRT**

**Important Building:**
- facilities essential before and after a disaster (eg., hospitals, fire and police stations, communication centres, etc.), or
- house large numbers of people at one time (eg., cinema halls, schools, convention centres, etc.), or,
- special national and international importance (eg., palaces, etc.), or
- houses with hazardous facilities (eg., toxic or explosive facilities, etc.).
• **Ordinary Building**: means any building which is not an important building (e.g., residential, general commercial, ordinary offices, etc.).
### Categories of for SEISMIC STRENGTHENING PURPOSES

<table>
<thead>
<tr>
<th>Category</th>
<th>Combination of Condition for the Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Important Building on soft soil in Zone A*</td>
</tr>
<tr>
<td>II</td>
<td>Residential-cum-shop Building on Soft Soil in Zone A*</td>
</tr>
</tbody>
</table>
| III      | Residential-cum-shop Building on Firm Soil in Zone A*  
|          | Residential-cum-shop Building on Soft Soil in Zone B* |
| IV       | Residential-cum-shop Building on Firm Soil in Zone B*  
|          | Residential-cum-shop Building on Firm Soil in Zone C*  
|          | Residential-cum-shop Building on Soft Soil in Zone C*  |

Category I Building shall be designed by Competent professional designer
• Up to three-storeyed
  - load-bearing brick masonry
  - cement mortar construction.

• Up to two-storeyed
  - Stone in cement mortar.
  - Brick in mud mortar construction.
## Bearing Capacity: On the basis of judgment

<table>
<thead>
<tr>
<th>Type of Foundation Materials</th>
<th>Foundation Classification</th>
<th>Presumed Safe Bearing Capacity, kN/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rocks in different state of weathering, boulder bed, gravel, sandy gravel and sand-gravel mixture, dense or loose coarse to medium sand offering high resistance to penetration when excavated by tools, stiff to medium clay which is readily indented with a thumb nail.</td>
<td>Hard</td>
<td>≥ 200</td>
</tr>
<tr>
<td>2. Fine sand and silt (dry lumps easily pulverised by the finger), moist clay and sand-clay mixture which can be indented with strong thumb pressure</td>
<td>Medium</td>
<td>≥ 150 and &lt; 200</td>
</tr>
<tr>
<td>3. Fine sand, loose and dry; soft clay indented with moderate thumb pressure</td>
<td>Soft</td>
<td>≥ 100 and &lt; 150</td>
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<td>4. Very soft clay which can be penetrated several centimetres with the thumb, wet clays</td>
<td>Weak</td>
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Limitation on Size Building Components

<table>
<thead>
<tr>
<th>Floor</th>
<th>Min. Wall Thickness (mm)</th>
<th>Max. Height (m)</th>
<th>Max. Short Span of Floor (m)</th>
<th>Canto-lever (m)</th>
</tr>
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<tr>
<td>Load-Bearing Brick Masonry in Cement Mortar</td>
<td>2nd</td>
<td>230</td>
<td>2.8</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>1st</td>
<td>230</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>Ground</td>
<td>350</td>
<td>3.2</td>
<td>3.5</td>
</tr>
<tr>
<td>Load-Bearing Stone Masonry in Cement Mortar, or</td>
<td>1st</td>
<td>350</td>
<td>3.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Load-Bearing Brick Masonry in Mud Mortar</td>
<td>Ground</td>
<td>350</td>
<td>3.2</td>
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Foundation In sloping ground

X = MINIMUM 2T OR 1.0 m WHICHEVER IS MORE.
H = NOT MORE THAN 300 mm.
Ø = MAXIMUM SLOPE 20°
V = NOT MORE THAN 1.0 m WITHOUT PROVISION OF RETAINING WALL.
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ONE STORY MASONRY
Foundation: One Storied

(a) Brick Masonry, C/S Mortar

(b) Stone Masonry, C/S Mortar

(c) Brick Masonry, C/S Mortar
Walls Thickness

ii) Plinth Level

Brick Masonry,
C/S Mortar(1:6)

Stone Masonry,
C/S Mortar(1:6)

Brick Masonry,
Mud Mortar
TWO STOREYED BUILDING
Foundation and Wall

Stone masonry in 1:6 C/S

Brick masonry in Mud

Up to plinth level
Walls Thickness

From Plinth to F.F.

From F.F. to top Floor
THREE STOREYED BUILDING
Masonry Building in C/S Mortar (1:6)

Foundation

Up to plinth level

Plinth to first floor level

First floor to top floor level
Delamination of Wall
Timber Band

Use of through stone in stone masonry wall
Seismic Enhancement

Example of traditional building with timber tying elements

Example of RC lintel
CONFIGURATION
Redundancy

Redundant building > 2 Nos of wall in any direction
Making Complex Span Simple
Restriction on Plan Projection

\[ K_1, K_2 < \{0.25 A, 0.25 B\} \text{ min} \]
Plan Aspect ratio

$L > 3b$

Long narrow building
CONFINED MASONRY
Key Components of a Confined Masonry Building:

- **Masonry walls** made either of clay brick or concrete block units
- **Tie-columns** = vertical RC confining elements which resemble columns in reinforced concrete frame construction.
- **Tie-beams** = horizontal RC confining elements which resemble beams in reinforced concrete frame construction.
Components of a Confined Masonry Building:
Reinforced Concrete Frame Construction
Confined Masonry Construction
Confined Masonry versus Infilled RC frames:
- construction sequence
- integrity between masonry and frame

**Confined Masonry**
- Walls first
- Concrete later

**Reinforced Concrete Infilled Frame**
- Concrete first
- Walls later

*Source: Tom Schacher*
Confined Masonry vs RC Frames with Infills – Key Differences
Location of Confining Elements is Very Important!

tie-beam in parapets ≥ 500 mm

tie-beam spacing

tie-columns in parapets

slab

confining elements around openings

$H/t \leq 25$

$t \geq 120 \text{ mm}$

Tie-columns at wall intersections

Tie-column spacing:

- 6.0 m (moderate seismicity)
- 4.5 m (high seismicity)
Key Elements – Layout Rules

- tie-column spacing ≤ 4.0m
- thickness ≥ 100mm
- tie-columns at wall ends and intersections
- tie-columns at openings
Confined Masonry Panel Under Lateral Loading: Shear Failure

Shear force

\[ V_m \]

\[ V_m' \]

\[ \sum V_c \]

Displacement
Confined Masonry Construction: Toothing at the Wall-to-Tie-Column Interface

Toothing enhances interaction between masonry walls and RC confining elements
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THANK YOU