Workshop on

Performance Evaluation of Housing Units

Testing Protocols for Performance Evaluation of Masonry Panels

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Performance Evaluation of Masonry

- Material Characterization
  - Laboratory Tests
  - Field Tests

- Masonry Wall
  - Laboratory Tests
    - Testing Protocols
Characterization of Brick Units

- Material Properties
  - Field Tests
  - Water Absorption (WA)
  - Initial Rate of Absorption (IRA)
    - Mortar bond strength
    - Important to assist in mortar selection and material handling
  - Compressive strength \( (f_b) \)
  - Tensile strength
    - Flat Position
    - On edge
Characterization of Brick Units…

- Water Absorption and Initial Rate of Absorption
  - Gives information about quality of bricks

**IRA:** Suction of water from mortar due to capillary action in bricks (per minute, per unit area, brick immersed in about 3 mm deep water) – ASTM C67

IRA test is not mandatory as per IS:3495 (1992)!!!
Characterization of Brick Units…

- **Compressive Strength**
  - **IS 3495 – Part 1**: Solid, Perforated Clay Bricks, Fly-ash Bricks
  - **IS 2185 – Part 1**: Hollow and Solid Concrete Blocks
  - **IS 6441 – Part 5**: Autoclaved Cellular Concrete Products
  - **ASTM C67-13**: Testing Brick and Structural Clay Tile

*Source: Basha and Kaushik (2015)*
Characterization of Brick Units...

- Tensile Strength

Designation: C 1006 – 07

Standard Test Method for Splitting Tensile Strength of Masonry Units

Source: Singhal and Rai (2014)
Characterization of Masonry

- In any masonry structure, during a seismic event its various elements/components are under the influence of a variety of actions.
- For instance, a masonry wall could at any point be under a vertical compressive load, in-plane and/or out-of-plane lateral loads, etc.
- Important to characterize the fundamental behaviour
  - Compression
  - Tension
  - Flexure
  - Shear
Characterization of Masonry in Compression

- **IS 1905** – recommend to determine compressive strength of masonry by prism test.
- Masonry prisms should be at least 40 cm high and shall have a height to thickness ratio \((h/t)\) of at least 2 and not more than 5.
- Prisms shall be tested after 28 days
Characterization of Masonry in Compression

- ASTM C1314
- Used for determining the compressive strength of prisms obtained from field-removed masonry specimens.

Construction of different types of masonry prisms:

- Solid unit prism
- Hollow unit prism
- Grouted hollow prism
- Hollow unit
- Grouted hollow unit
- Grouted multi-wythe prism
Characterization of Masonry in Tension

- **Tension Bond Strength**: required for masonry walls subjected to wind, eccentric gravity loads, and so on.

- Indian code remains silent.

- Tests include the **bond wrench test**, **direct tension test**, and **crossed couplet test**, and all the test procedures has their own drawbacks and problems (Khalaf 2005).

- A new **Z-shaped specimen** proposed by Khalaf (2005).

Source: Singhal and Rai (2014)
Characterization of Masonry in Flexure

Flexure Bond Strength

- Flexural bond strength is crucial in normal as well as parallel directions to the bed-joint.
- Current masonry design codes [MSJC (2011)] duly consider the flexural tensile strength in the design of masonry in both directions.
- BS EN 1052-2 describes the test method.

Source: Singhal and Rai (2014)
Contd.-Flexure test

Plane of failure parallel to bed joints

Plane of failure perpendicular to bed joints
Characterization of Masonry in Shear

- BS EN 1052-2 describes the test method
- Shear Strength and Friction Factor
- Without pre-compression – initial shear strength
- With pre-compression at 0.2, 0.4, 0.6 and 0.8 MPa – friction factor
In-Situ Strength Measurement

- To determine the level of stresses in the masonry
- Various mechanical parameter
  - Elastic Modulus
  - Compressive Strength
  - Joint Shear Strength
Flat-Jack Test

- ASTM C 1197
- Deformability properties in compression and compressive strength (double flat-jack test)
- Shear strength parameters (shear flat jack test)

Source: NCREP
Flat-Jack Test

- ASTM C 1197
- Deformability properties in compression and compressive strength (double flat-jack test)
Flat-Jack Test

- ASTM C 1197
- Shear strength parameters (shear flat jack test)

Source: Simoes et al. (2012)
Shove Test

- **ASTM C1531**
- Used to determine the in-situ the shear strength of the masonry.

*Source: giancarlomaselli.it*
Shove Test

ASTM C1531

- Method A: with Flat jacks Controlling Normal Compressive Stress
- Method B: without Flat jacks Controlling Normal Compressive Stress
Test on Masonry Wall Panels

- **Diagonal Compression Test**

- **ASTM E519/E519M**
  - Determine the shear strength of masonry panel by loading them in compression along one diagonal

- Size of panel > 1.2 m by 1.2 m [4 by 4 ft.]
Test on Masonry Wall Panels...

- ASTM C1717

- Determine the strength and load-deflection characteristics of masonry wall elements.

- Simplest loading protocol is monotonic loading to failure.

- Complex loading protocol is cycles of loading (possibly reversed) to monotonically increasing maximum amplitudes.
Axial Compression Test

Test Setup for Axial Compressive Loading

- User can measure axial load, axial deformation, out-of-plane deflection using a reference line or a fixed line.
Apparatus for Uniformly Distributed Transverse Load (Bag Method)

- Apply transverse load to the specimen by increasing the air pressure in the bag.
- Measure the pressure by means of a manometer.
Out-of-plane Load Test…

Source: Myers (2008)
Apparatus

- Steel Channel with Roller Supports
- Loading Assembly
- Hydraulic Ram.
- Load-measurement Devices.
- Out-of-plane Deflection Gauges
- Axes of the rollers shall be parallel to the faces of the specimen.
- Apply the loads horizontally by a hydraulic ram
- Measure load using a load cell between the hydraulic ram and the specimen, or using two load cells, one between the specimen and each end of the loading beam.
Concentrated Load Test

Test Setup for Concentrated Load Test
Contd.-Tests of Masonry Wall Panels

- **In-Plane Shear Load**

- **Apparatus**
  - Base
  - Loading Beam
  - Hydraulic Rams
  - Load-measurement Devices
  - Out-of-plane Restraint
  - In-plane Deflection Gauges

- Subject the specimen to the desired protocol of shear and axial loading.
**In-plane Load Test**

- **Setup**
  - Base
  - Loading Beam
  - Hydraulic Rams
  - Load-measurement Devices
  - Out-of-plane Restraint
  - In-plane Deflection Gauges

*Test Setup for In-plane Load*
In-plane Load Test…

Source: Billington et al. (2009)
Cyclic Load Test

- ASTM E2126
  - Stiffness and strength parameters
  - Deformation/Ductility capacity
  - Hysteretic response
  - Energy Dissipation capacity
  - Degradation and Recovery parameter
Elastic shear stiffness, shear strength and ductility of specimens are determined by subjecting a specimen to full reversal cyclic racking shear loads.
Cyclic Load Test…

Test Setup for Shear Wall Specimen
Contd.- Cyclic Load Test for Masonry Wall

- Racking load is applied horizontally along the plane of the specimen using a double-acting hydraulic actuator.
- A minimum of two specimens is required for the testing.
  - Method A (Sequential-Phased Displacement Procedure)
  - Method B (ISO 16670 Protocol)
  - Method C (CUREE Basic Loading Protocol)
Method A: Sequential Phased Displacement (SPD) Loading Protocol

- Displacement-controlled loading procedure that involves displacement cycles grouped in phases at incrementally increasing displacement levels.
- The cycles shall form either a sinusoidal wave or a triangular wave.
Contd.- Method A

- SPD loading consists of two displacement patterns
- First pattern consists of three phases, each containing three fully-reversing cycles of equal amplitude, at displacements representing 25 %, 50 %, and 75 % of anticipated FME.
- In second pattern, each phase is associated with a respective displacement level and contains one initial cycle, three decay cycles, and a number of stabilization cycles.

![Performance Parameters of Specimen](image-url)
Test Method B (ISO 16670 Protocol):

- Procedure involves displacement cycles grouped in phases at incrementally increasing displacement levels.
- Consists of two displacement patterns
- First pattern consists of five single fully reversed cycles at displacements of 1.25 %, 2.5 %, 5 %, 7.5 %, and 10 % of the ultimate displacement $\Delta_m$.
- Second pattern consists of three fully reversed cycles of equal amplitude, at displacements of 20%, 40, 60%, 80%, 100%, and 120% of the ultimate displacement $\Delta_m$. 
Test Method C (CUREE Basic Loading Protocol):

- Procedure involves displacement cycles grouped in phases at incrementally increasing displacement levels.
- The value of $\Delta$ shall not exceed 0.025 times the wall height.

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Step</th>
<th>Minimum Number of Cycles</th>
<th>Amplitude of Primary Cycle, % $\Delta$</th>
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<tr>
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<td>9</td>
<td>3</td>
<td>$100 + 100\alpha^A$</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>3</td>
<td>Additional increments of $100\alpha$ (until specimen failure)</td>
</tr>
</tbody>
</table>

$^A \alpha \leq 0.5.$

Cyclic Displacement Pattern (Test Method C)

Amplitude of Primary Cycles
Loading Protocol for Biaxial Loading

- Choice of a testing program and associated loading history depends on
  - purpose of the experiment,
  - type of test specimen and
  - type of anticipated failure mode

- Masonry walls tested independently in **in-plane** and **out-of-plane** direction using the various standard loading protocol developed for planar structures and sub-assemblages:
  - ATC-24, SPD-TCCMAR, CUREE, ACI 374 and FEMA 461 protocols
Masonry walls were tested via several loading protocols to assess the interaction of in-plane damage over the out-of-plane behavior and vice-versa.

- Each have certain merits
- Difficult to isolate reqd. information to describe the interaction behavior

Various Loading Protocols:

- Sequential Loading
  - IP followed by OOP
  - OOP followed by IP

- Simultaneous Loading
  - Static
  - Dynamic
Simultaneous loading

- Masonry panel is subjected **simultaneously to bidirectional loading** either statically or dynamically.

- Simultaneous dynamic loading using biaxial shake table (Gülkan et al., 1990; Žarnić et al., 2001)

- Simultaneously varying static loading is relatively difficult.
  - Simultaneous static loading by holding the in-plane deformation and applying the out-of-plane pressure using air bag (Angel et al., 1994; Flanagan and Bennett, 1999)

![Diagram of Simultaneous Loading](image)
Sequential loading…

- **In-plane Damage followed by Out-of-plane Load**
  - Significant reduction in out-of-plane capacity with in-plane damage (Angel et al. 1994, Komaraneni et al. 2011)

Several experimental studies were conducted to study such interaction:

- apply known in-plane damage to wall specimens before exposing it to out-of-plane loading

- **Interpretation on Interaction curve:** Test results of Angel et al. 1994; Calvi and Bolognini 2001

**Significant effect of prior in-plane damage on out-of-plane capacity**
Unique loading protocol

- involves successive applications of dynamic out-of-plane and static cyclic in-plane loads
Thank You!

Questions and Suggestions...