Assessment and Retrofit of Masonry Structures

Evaluation and Site Investigation

College of Continuing and Professional Studies
Structural Engineering Webinar
March 7, 2023
Evaluation and Site Investigation

- The process
- Codes and guidelines
- Diagnostics
  - Nondestructive evaluation
  - In situ testing
  - Laboratory testing
The Process

1. Assessment
   a. Information gathering
   b. Observations, investigation, testing
2. Diagnose: analysis, code compliance
3. Prioritize interventions
4. Design and specify
5. Implementation
6. Document completed work

Integrated throughout: monitoring
Modern masonry – post 1950
  - Unreinforced masonry
  - Reinforced masonry
There is no code for historic masonry!


102.6 Structural analysis.

Where structural analysis is used to determine if an unsafe structural condition exists, the analysis shall be permitted to use nominal strengths, nominal loads, load effects, required strengths and limit states in accordance with the requirements under which the structure was constructed or in accordance with any subsequent requirement.
Appendix A: Empirical Design of Masonry
- Seismic Design Category A, B, C only
- Building height < 35 feet
- Basic wind speed <110 mph

Simple rules of thumb to check
- Lateral stability
- Compressive strength
- Wall thickness
- Wall connections
Table A.5.1 Wall lateral support requirements

<table>
<thead>
<tr>
<th>Wall Construction</th>
<th>Max. h/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing walls</td>
<td></td>
</tr>
<tr>
<td>Solid units or fully grouted</td>
<td>20</td>
</tr>
<tr>
<td>Other than solid units or fully grouted</td>
<td>18</td>
</tr>
<tr>
<td>Nonbearing walls</td>
<td></td>
</tr>
<tr>
<td>Exterior</td>
<td>18</td>
</tr>
</tbody>
</table>

Parapets: max. h/t = 3
Wall anchorage at floors and roofs
- ½" min. dia., metal strap anchors
- 6’-0” max. spacing

Wood joists parallel to wall
- Secure to 3 joists min.
- Use blocking between joists
Appendix Chapter A1

Seismic Strengthening Provisions for Unreinforced Masonry Bearing Wall Buildings

- **Condition**
  - Not in “good condition”? *Repairs/retrofit required*
  - Report percent mortar fill in collar joint
  - Evaluate wood diaphragms, wood shear walls

- **Testing**
  - Masonry shear strength
  - Anchors: test new and existing anchors
In Situ Shear Test

Mortar Bed Joint Shear Resistance

• International Existing Building Code, UBC 21-6, *In Place Masonry Shear Tests*
• ASTM C1531, *Standard Test Methods for Determination of Masonry Mortar Joint Shear Strength Index*
In Place Shear Test

- Bed joint sliding resistance correlated to wall’s shear strength
- International Existing Building Code (IEBC)
  - # of tests
  - Results
  - Engineering
Seismic evaluation process includes:
- 1.4.3 As-built information
- 1.4.4 Evaluation procedures
- 1.4.5 Evaluation report

Chapter 11: Masonry
- Nondestructive evaluation
- Testing
- Analysis
- Retrofit methods
11.2 As-built information
- Original drawings
- Specifications
- Maintenance records
- Interviews

Supplement and verify by onsite investigations
- Nondestructive evaluation
- Testing building materials, components
The First Step: Research

2x6 joist @ 16” o.c.
Standard joist anchor every 3rd joist
2x4 plate bolted to brickwork with ½” x 10” bolts 4'-0” o.c.
Mercantile Buildings – How is historic masonry built?

Bond: plain headers every 5th or 6th course. Bond for face brick to be by means of blind headers.
What are “blind headers”? 

- Running bond headers, diagonal headers: maintains uniform appearance at outside face 
- Expensive – lots of cuts
Condition assessment

What information do you need?

- As-built conditions
  - Geometry
  - Connections
- Current condition
  - Deterioration, corrosion
  - Distress, cracking, delamination
- Engineering properties
  - Strength
  - Stiffness

ASCE 41: “A site visit shall be conducted…”
Visual Condition Assessment

As-built information
- Building configuration
- Component properties
- Site and foundation information
- Adjacent buildings
- Primary and secondary components

“Reward” for more diagnostic efforts

Always measure both sides of the wall!

Why is the outside wall face deflecting more than the inside wall face?
<table>
<thead>
<tr>
<th>Data</th>
<th>Level of Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>Performance Level</td>
<td>Life Safety (s-3) or lower</td>
</tr>
<tr>
<td>Analysis Procedures</td>
<td>LSP, LDP</td>
</tr>
<tr>
<td>Testing</td>
<td>No tests</td>
</tr>
<tr>
<td>Drawings</td>
<td>Design drawings</td>
</tr>
<tr>
<td></td>
<td>Field survey (no design drawings)</td>
</tr>
<tr>
<td>Condition Assessment</td>
<td>Visual</td>
</tr>
<tr>
<td></td>
<td>Comprehensive</td>
</tr>
<tr>
<td>Material Properties</td>
<td>From construction documents</td>
</tr>
<tr>
<td></td>
<td>From construction documents</td>
</tr>
<tr>
<td>Knowledge Factor ($\kappa$)</td>
<td>0.9</td>
</tr>
</tbody>
</table>
11.2.2 Condition assessment required

Classify masonry condition as:

- **Good**
  - Intact mortar, intact units
  - No visible cracking, deterioration, or damage

- **Fair**
  - Intact mortar, intact units
  - Minor cracking

- **Poor**
  - Degraded mortar
  - Degraded units
  - Significant cracking

What’s “minor”? Commentary: cracks < 1/16”
On site investigations

- ASCE 41: 11.2.2.2 Comprehensive condition assessment
- Nondestructive evaluation (NDE): conditions, planning material tests
  - Pulse velocity: ultrasonic, sonic
    - Density variations, cracks, discontinuities
  - Impact echo
    - Grouted cells in reinforced masonry
  - X-Radiography
    - Masonry reinforcement
Metal detection

Locating metals
- Reinforcement
- Veneer anchors
- Flashing
- Conduit, pipes

“Pachometer”
“Cover meter”
“Rebar locator”
Surface Penetrating Radar (SPR)

- Microwave energy reflected at internal discontinuities
Reinforced concrete masonry

- Surface penetrating radar
  - Locate internal voids, steel
  - Concrete masonry grout quality
Surface Penetrating Radar

Existing Condition

Figure 5.1 Representative vertical GPR scan taken at an exterior wall on the west elevation. Here, the stones alternate in thickness very regularly, which should not be considered the typical condition.

Typical GPR Scan

New Jersey Executive State House
Internal Voids

- Defining the extent of repairs

Cliffside erosion behind scarp wall

El Morro Fortress, San Juan, Puerto Rico
Surface Penetrating Radar (SPR)
Infrared Thermography: *IRT*

What is it?

- Measures infrared radiation emission
- Surface temperature: 0.1° C resolution
- Shows variations in material properties and construction
Post-Construction QA

- Infrared thermography
- Videoscope
Borescope, videoscope

Earl Warren Federal Courthouse, San Francisco
11.2.3 Properties of in-place materials

Compressive strength

- Modern masonry: use TMS 602 unit strength tables
- Older masonry (pre-1950s)
  - Test prisms – extracted from wall
  - Fabricate prisms using like materials
# ASCE 41: Default Lower-Bound URM Strength

<table>
<thead>
<tr>
<th>Material</th>
<th>Solid Units</th>
<th>Hollow Concrete Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>600 psi</td>
<td>1,000 psi</td>
</tr>
<tr>
<td>Flexural tensile strength</td>
<td>60 psi</td>
<td>38 psi</td>
</tr>
<tr>
<td>Shear strength</td>
<td>80% of shear strength determined following TMS 402 Section 9.2.6</td>
<td></td>
</tr>
</tbody>
</table>

Good or fair condition only
Portland cement/lime or mortar cement

<table>
<thead>
<tr>
<th>Material</th>
<th>Solid Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>285 psi</td>
</tr>
<tr>
<td>Flexural tensile strength</td>
<td>5 psi</td>
</tr>
<tr>
<td>Shear strength</td>
<td>80% of shear strength determined following TMS 402 Section 9.2.6</td>
</tr>
</tbody>
</table>

Lime mortar? *Can be easily scraped away from the joints by hand with a metal tool*

Expected values? Multiply lower-bound strengths by 1.3
In Situ Tests

Engineering properties

- Compressive strength: ASTM C1197
- Shear strength: ASTM C1531
- Bond strength: ASTM C1072
- Anchor capacity: ASTM E488
- Core test (diametral tension): ASTM C496
Masonry Flatjacks
In Situ Deformability Test

Determine masonry compression response

- ASTM C1197: In Situ Measurement of Masonry Deformability Properties Using the Flatjack Method
In Situ Deformability Test

Flatjack Test #3

Stress, psi

Strain, in./in.
Mechanical properties

ASCE 41: 11.2.3.9 Minimum testing requirements – number of tests

“Usual” Testing

Number of tests required *per wall or line of wall elements*:

- Top and bottom stories: 2 tests
- All other stories: 1 test per wall
- No fewer than 1 test per 1,500 ft² of wall surface
- No fewer than 8 tests total
Mechanical properties

ASCE 41: 11.2.3.9 Minimum testing requirements – number of tests

“Comprehensive” Testing

- At least 3 tests per URM “class”
- For each 3 floors or 3000 ft² wall area:
  - With original const. records: 3 tests
  - Without records: 6 tests
- At least 2 tests per wall or line of wall elements
- Minimum 8 tests per building

Where material properties differ:

- Conduct additional tests to estimate strength at areas with varying condition
  OR
- Use nondestructive tests to quantify variations in material strength

- Coefficient of variation exceeds 25%?
  - Double the number of tests
Evaluation and Site Investigation

- The evaluation process
- IPMC, TMS 402, IEBC, ASCE 41
- Nondestructive investigations
- In situ tests