Assessment and Retrofit of Masonry Structures

Case Studies

College of Continuing and Professional Studies
Structural Engineering Webinar
March 7, 2023
Case Studies

- The process
  - Evaluation/diagnostics
  - Design
  - Implementation
  - Quality assurance

- Lessons learned
  - 1963 - New Jersey coast
    “Architectural” maintenance
  - 1889 - New Orleans
    Structural strengthening
Brick veneer cavity wall

- 7-story apartment building
- 1960’s construction
  - 4” brick veneer
  - 4” CMU backup
  - 1” drainage cavity
- Reinforced concrete frame
  - Steel shelf angles each floor
- Masonry – 50 years old, in great shape!
- Mortar – mostly OK
- Sealant failure
- Localized cracks at building corners
- Ongoing maintenance
  - 1990’s: window, sealant replacement
  - Crack repair
  - Stains - cleaning

Bricks replaced – cracked again!
Existing conditions

- No movement joints
Rust-jacking

- Steel shelf angles at each floor line
- Steel corrosion
  - Oxidation byproducts occupy a larger volume than original metal
  - Expansion: up to 7x
Displacement: parapet movement

- 2014: superstorm Sandy
  - Parapet rocking back and forth
  - Permanent displacement
Investigation

- Document review, interviews
  - Prior reports, repairs

- NDE: anchor location, videoscope
Diagnostics: flashing and shelf angles

- Probe openings

- Flashing
  - PVC type
  - Still flexible!

- Shelf angle corrosion
  - Minor: visible surface oxidation
  - Moderate: surface pitting
  - Severe: flaking, section loss
Visual Condition Survey

- Severity
- Prioritize repairs
  - Emergency

APPENDIX A
Exterior Condition Survey

Key:
- Red: Severe shelf angle/lintel corrosion
- Yellow: Moderate shelf angle/lintel corrosion
- Green: Minor shelf angle/lintel corrosion
- Black: Crack
- Gray: Displacement
Prioritizing repairs

Corrosion, cracks, sealants, staining

- **High priority: life safety implications**
  - Shelf angle repairs: severe corrosion, displaced brick
  - Veneer movement at parapet

- **Medium priority repairs: moderate distress**
  - Shelf angle repairs: moderate corrosion
  - Cracks and displacement
  - Veneer expansion joints
  - Parapet displacement

- **Maintenance-level repairs**
  - Flexible sealant replacement
  - Cleaning: stains
Solutions

- Shelf angle replacement

1. **Masonry Demolition at Shelf Angle**
   - Wall Section
   - 3” = 1'-0"

2. **Shelf Angle Repair**
   - Wall Section
   - 3” = 1'-0"
Brick shoring

Wood blocking

Shear pins
Brick bracing

Brickbrace.com
Corrosion – the actual conditions

- Veneer anchors
  - Minor – moderate corrosion
  ![Veneer anchor corrosion example]

- Shelf angles
  - Much worse than expected!
  ![Shelf angle corrosion example]
Solutions

- Expansion joints needed
  - Vertical
  - At building corners
  - Horizontal
  - Beneath shelf angles
Parapet repair

- Strengthening or rebuild?
Lessons learned

- Good maintenance records
  - Nice to have
  - Saved $10,000 in diagnostics?

- Masonry construction needs movement joints

- What’s cheaper?
  - Localized repairs or re-cladding building

- Repairs are expensive and materials are a small part of the total cost
  - Long-lasting sealants
  - Corrosion protection
    - Hot-dipped galvanizing
    - Epoxy coating
    - Stainless steel

- You can find a replacement brick...
Veneer Maintenance and Repair

- Lessons learned
  - It’s hard to find a good brick match
Case Study: Strengthening Historic Masonry

- Diagnostics
  - NDE, in situ tests
  - Laboratory

- Stabilization
  - Helical anchors
  - Injection

- Strengthening
  - Vertical reinf.
  - Horizontal reinf.
New Orleans Topography

City of New Orleans Ground Elevations

From Canal St. at Mississippi River to the Lakefront at U.N.O.

Floodwall Along Mississippi River

London Avenue Canal Floodwall

Elevations in Feet NGVD

-20 -10 0 10 20 30
August 29, 2005:
Hurricane Katrina
Retrofit Design Requirements

- **USACE Design Requirements**
  - Full-strength category 4 hurricane
  - Wind 156 mph (251 km/h)
  - Flood loading to 5 ft. (1.5 m)
  - Risk Category IV (Additional 15%)
  - Large out-of-plane loads

⇒ **Strengthening required**
Operational Challenges

- Stations house large, tightly spaced pumps
- Many pipes and utilities directly adjacent to wall interior

*MUST REMAIN IN OPERATION THROUGHOUT CONSTRUCTION*

> *Internal strengthening methods*
The first step:  
Condition and material evaluation

- ASCE 41: Seismic Evaluation and Retrofit of Existing Buildings
- International Existing Building Code (IEBC)
  - Evaluation methodology
  - Number of tests, where
  - Interpretation and use
Evaluation and Testing

- **Condition survey**
  - Cracks, deterioration
  - Microwave radar: interior voids, metals
  - Borescope: interior voids
  - Pachometer: metals
  - Typical wall sections
  - Typical conditions: roof anchors, steel lintels

![Internal voids and Back of wall images](image-url)
Evaluation and testing

- In situ tests
  - Exterior face wythe
  - Interior common brick wythes
  - Flatjack (compression): ASTM C1197
  - Shear: ASTM C1531
  - Flexural bond: ASTM C1072
  - Anchor tension: ASTM E488
  - Anchor shear: ASTM E488
# Engineering recommendations

- Diagnostic information used to design strengthening

## Table 9. Engineering Design Values: Construction Typology 1, Multi-Wythe Brick Masonry, No Visible Header Courses, Construction Era 1898 – 1930’s

<table>
<thead>
<tr>
<th>Property</th>
<th>Average Load/Strength</th>
<th>Conservative Design Load/Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Common Wythe</td>
<td>Face Wythe</td>
</tr>
<tr>
<td>Masonry compressive strength $f'_m$ (psi)</td>
<td>260</td>
<td>390</td>
</tr>
<tr>
<td>Masonry compression modulus $E_m$ (psi)</td>
<td>86,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Masonry flexural tensile strength, normal to bed joints (psi)</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Masonry shear strength (psi)</td>
<td>25</td>
<td>64</td>
</tr>
<tr>
<td>Anchor tensile strength (lb)</td>
<td>3,340</td>
<td></td>
</tr>
<tr>
<td>Anchor shear strength (lb)</td>
<td>2,140</td>
<td></td>
</tr>
</tbody>
</table>

¹Factor of safety of 4 applied to average ultimate load values.
Retrofit Methodology

- Components
  - Compatible Injected Fill: CIF grout injection
  - Helical wall ties
  - Enhancement rods – hollow stainless steel reinforcing
    - Placed in holes, cored vertically and horizontally
    - Tapered anchor conditions at wall base
Dry-fix helical anchors

- Easy
- Adequate capacity
- Cheap?

Dry-fix spiral wall tie.
Horiz. spacing: 24 in. (610 mm)
Vert. spacing: 16 in. (410 mm)
Install within 4 in. (100 mm)
of wall openings and edges.

0.04 in. (1 mm) gauge, 0.3 in.
(7.8 mm) Ø spiral wall tie, Type 304 SS.
Install and countersink in 1/2 in. (6 mm) hole.
Masonry Stabilization

- Injection procedures
  - Compatible Injected Fill: CIF
  - Low pressure injection
  - Small-diameter holes
Internal reinforcement scheme

EXISTING MASONRY WALL TO BE INJECTED AND GROUTED SOLDER WITH AN ENGINEERED MATERIAL THAT IS COMPATIBLE WITH THE EXISTING WALL CONSTRUCTION. REFER TO SPECIFICATIONS FOR CRITERIA, SUBMITTALS AND APPROVAL. PRIOR TO GROUTING, THE WALLS ARE TO HAVE STAINLESS STEEL HELICAL TIES DRILLED, INSTALLED AND INJECTED INTO THE EXISTING WALL STRUCTURE IN A GRID PATTERN OF 8" HORIZONTALLY AND 16" VERTICALLY (IN ADDITION TO HORIZONTAL AND VERTICAL REINFORCEMENTS, TYP.). SEE DETAIL.

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NORTH WALL ELEVATION-POWER HOUSE

STEEL WALL WELDED T
BRICK TO INSTALL SOLID, APARTMENT STONE, APARTMENT
Enhancement rods

- Cold rolled stainless steel
- Hollow
- Socked
Coring through fragile historic fabric

Dry coring – no water involved
Typical pilaster details

**Typ. Pilaster Detail**

**Power House**

**Wall Reinforcement**

Scale: 1/8" = 1'-0"

- 4-GS32 bars vert. to top of crane rail
- 2-GS32 bars vert. full height
- 4-GS32 bars hollow Injectable enhancement bars SA. Face (or approved equivalent). Drill 2" hole full height of wall into conc. foundation. Anchor in concrete foundation to develop bar. (Typ. 4 places)

**Back of Exst. Coll.**

- Outside face of masonry
- Horiz. GS25 bars; exterior bar not to penetrate column flange
Project summary

- Over 85,000 sq. ft. (1050 m²) of wall area
- Over 1200 US tons CIF grout injected
- Approx. 8% of wall volume was void
- Over 30,000 linear ft. (9,200 m) of stainless steel reinforcing bars
- No visible change to structure
- No service interruption
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