Ahmad Hamid PhD PE
e: ahmadahamid16@gmail.com

Michael Schuller PE
e: mschuller@ana-usa.com New York: 917 647 9530
Boulder: 303 444 3620

Assessment and Retrofit of Masonry Structures

Evaluation and Site Investigation

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

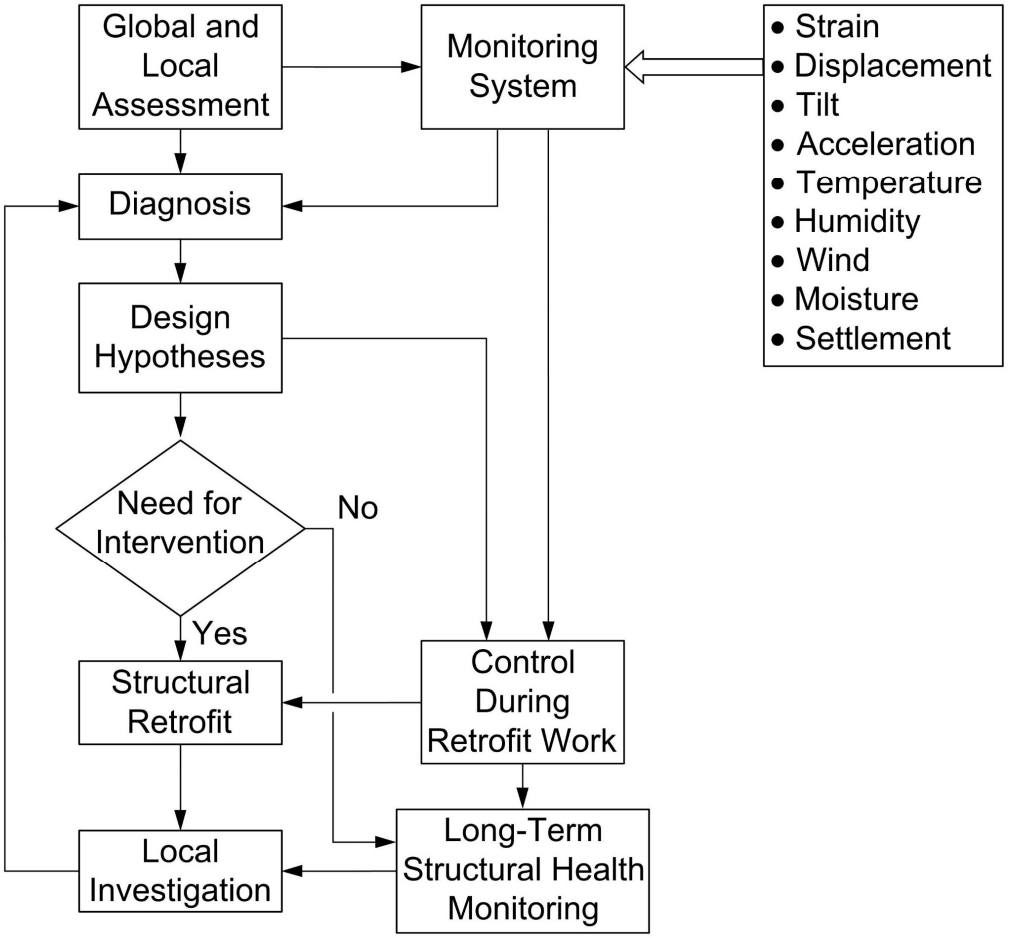
Evaluation and Site Investigation

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

The Process

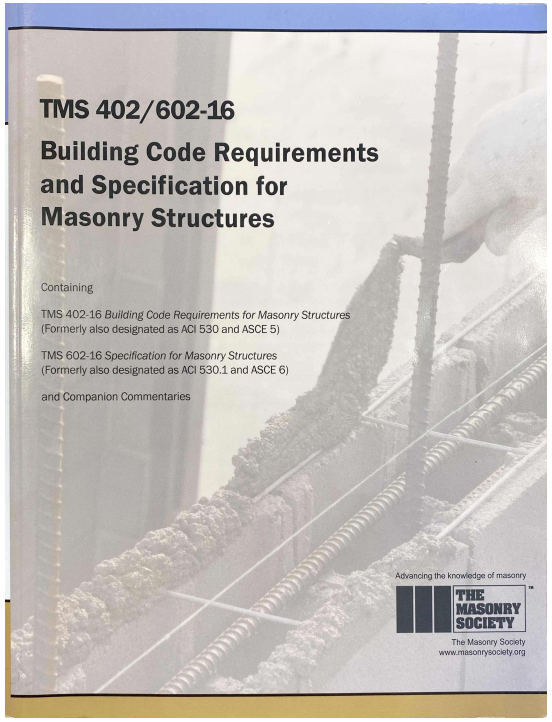
1. Assessment
   a. Information gathering
   b. Observations, investigation, testing
2. Diagnose: analysis, code compliance
3. Prioritize interventions
4. Design and specify
5. Implementation
6. Document completed work

Integrated throughout: monitoring



TMS 402: *Building Code Requirements for Masonry Structures*

- Modern masonry – post 1950
  - Unreinforced masonry
  - Reinforced masonry



TMS 402

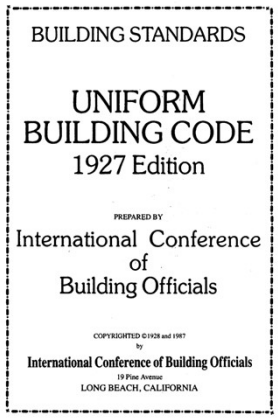
Codes and analysis

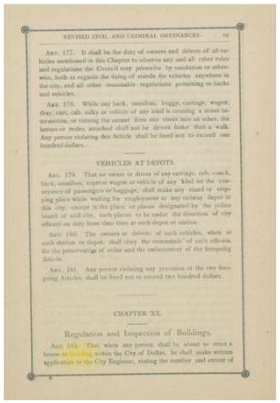
There is no code for historic masonry!

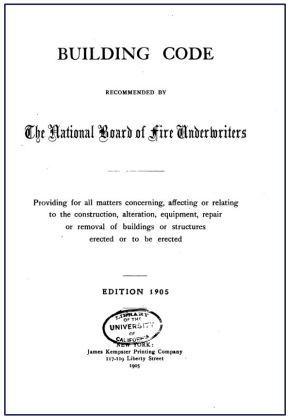
- IPMC: International Property Maintenance Code (2021)

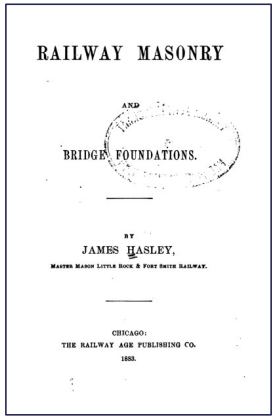
102.6 Structural analysis. CDP

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.





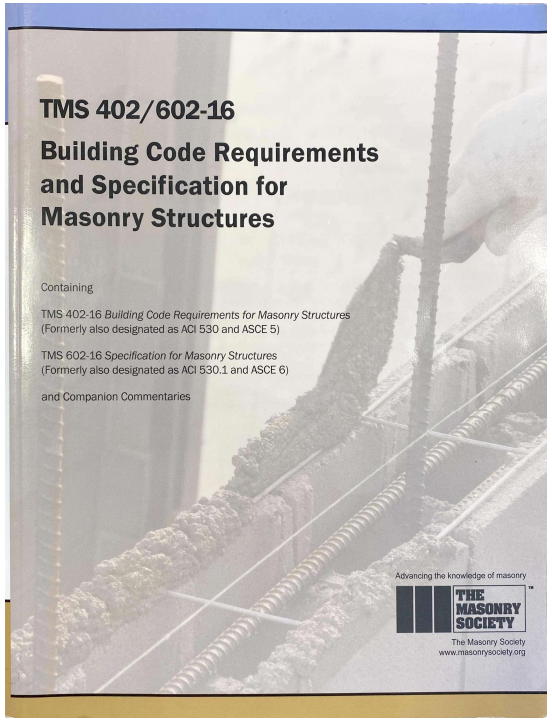




TMS 402: *Building Code Requirements for Masonry Structures*

- 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



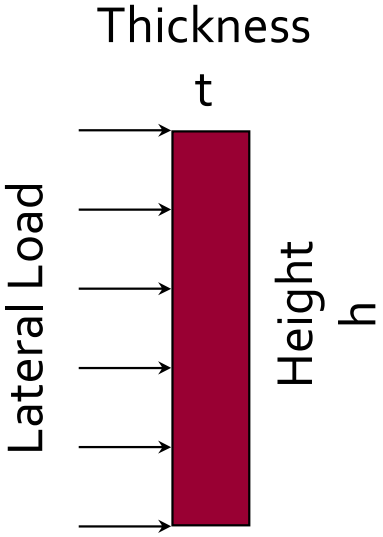
TMS 402

TMS 402: Appendix A – Empirical Design

- Table A.5.1 Wall lateral support requirements

Wall Construction	Max. h/t
Bearing walls	
Solid units or fully grouted	20
Other than solid units or fully grouted	18
Nonbearing walls	
Exterior	18

Parapets: max. h/t = 3



TMS 402: Appendix A – Empirical Design

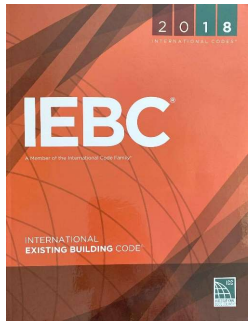
Wall anchorage at floors and roofs

- ½" min. dia., metal strap anchors
- 6'-0" max. spacing

Wood joists parallel to wall

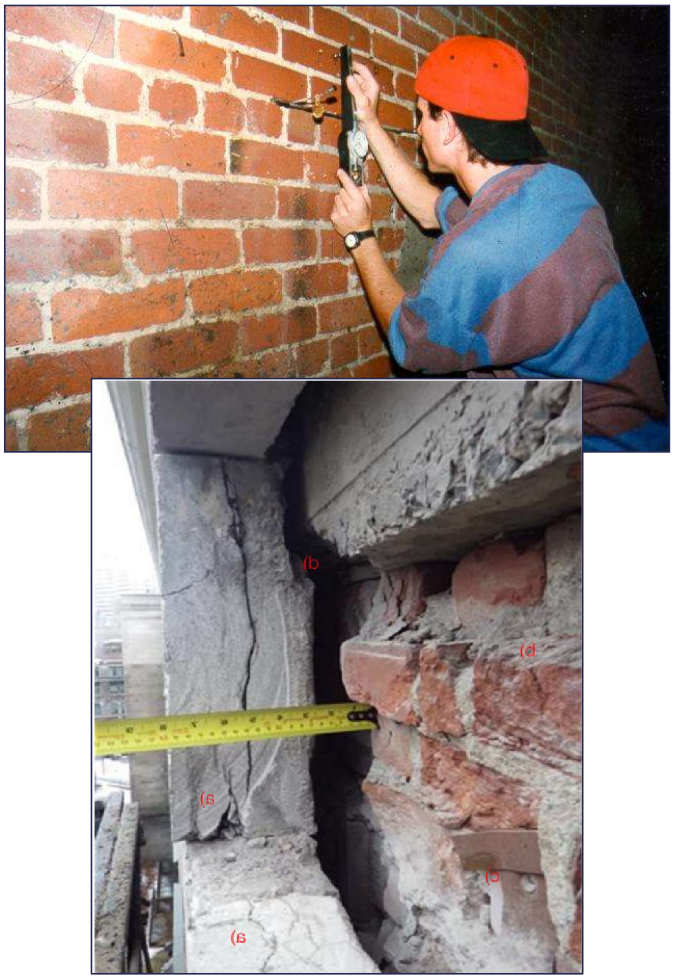
- Secure to 3 joists min.
- Use blocking btwn. joists

International Existing Building Code - IEBC



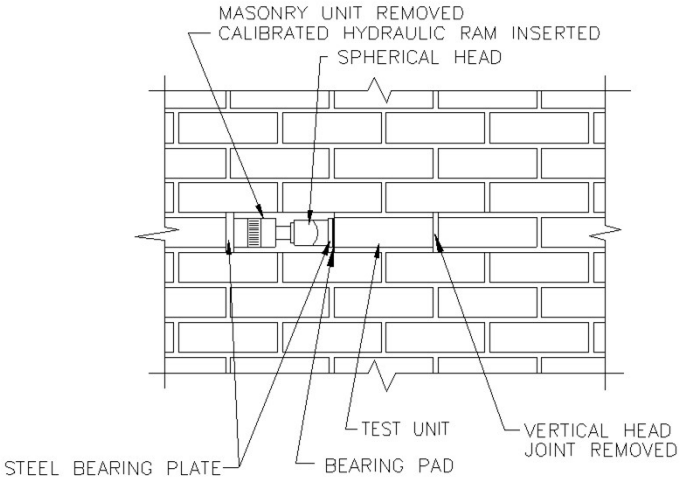
Appendix Chapter A1

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

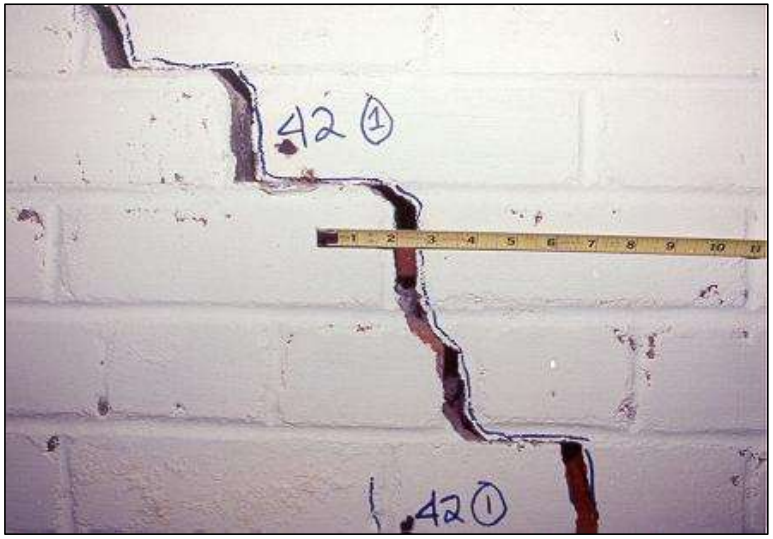


Mortar Bed Joint Shear Resistance

- 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*

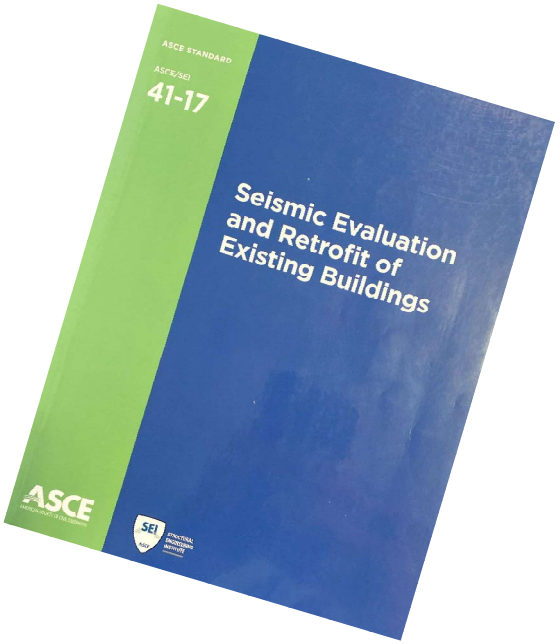
In Place Shear Test

- Bed joint sliding resistance correlated to wall's shear strength
- International Existing Building Code (IEBC)
  - # of tests
  - Results
  - Engineering



ASCE 41-17: *Seismic Evaluation and Retrofit of Existing Buildings*

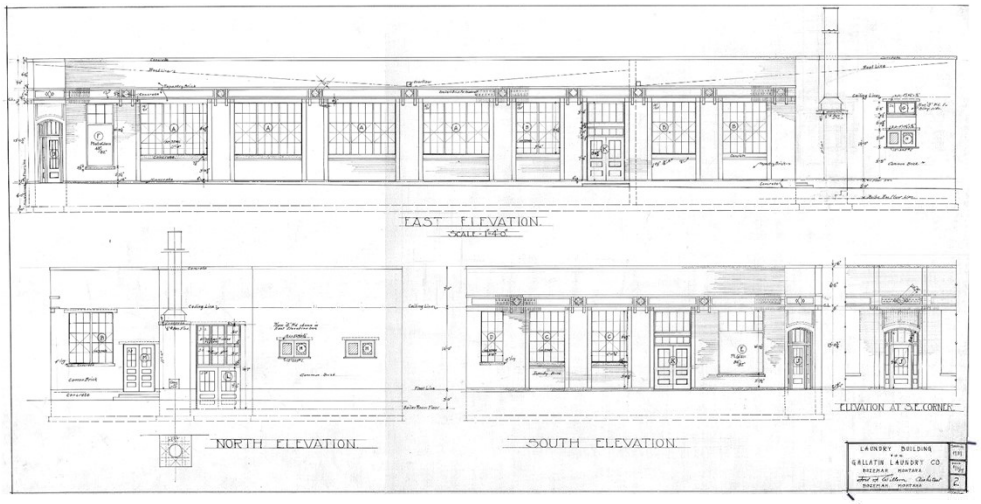
- Seismic evaluation process includes:
  - 1.4.3 As-built information
  - 1.4.4 Evaluation procedures
  - 1.4.5 Evaluation report
- Chapter 11: Masonry
  - Nondestructive evaluation
  - Testing
  - Analysis
  - Retrofit methods



ASCE 41-17: *Seismic Evaluation and Retrofit of Existing Buildings*

- 11.2 As-built information
  - Original drawings
  - Specifications
  - Maintenance records
  - Interviews
- Supplement and verify by onsite investigations
  - Nondestructive evaluation
  - Testing building materials, components

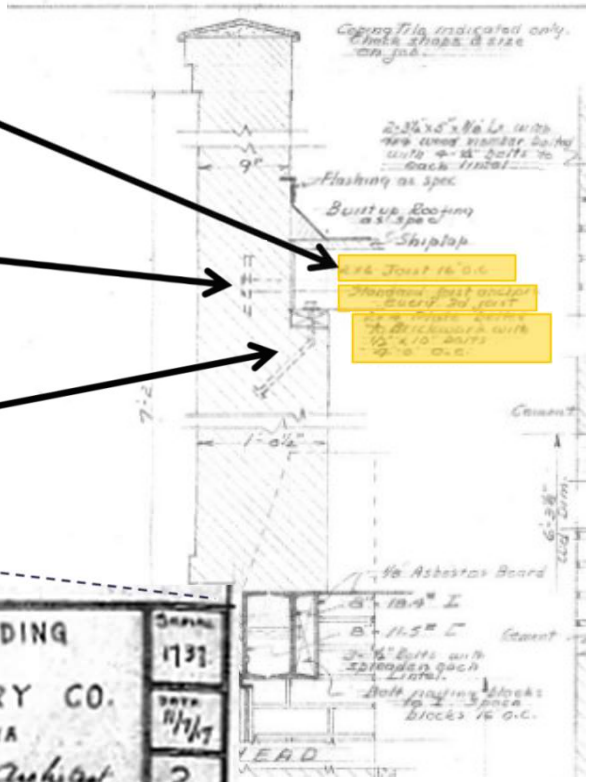
The First Step: Research

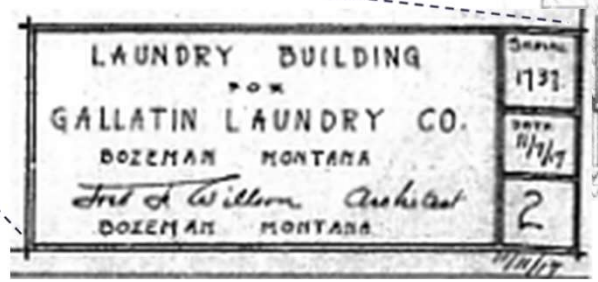


2x6 joist @ 16" o.c.

Standard joist anchor every 3rd joist

2x4 plate bolted to brickwork with ½" x 10" bolts 4'-0" o.c.

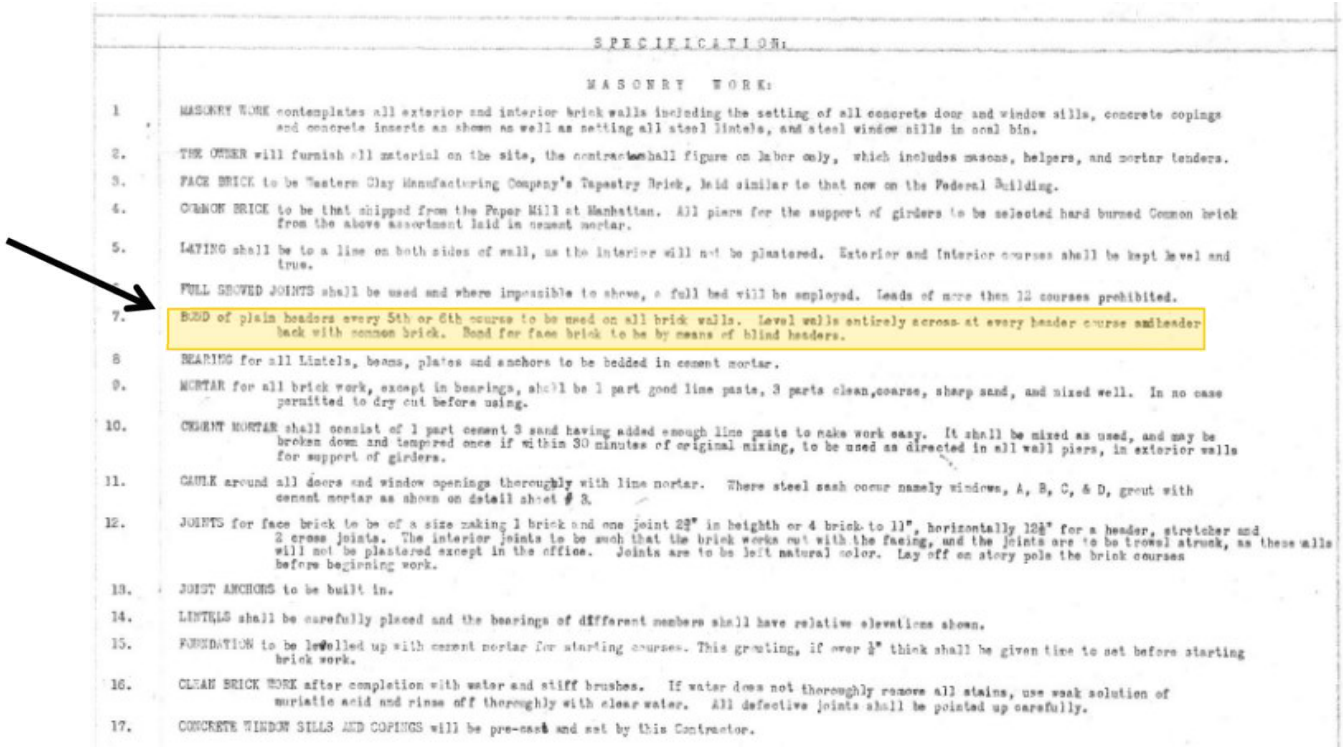





OFFICE
GALLATIN
CLEANERS
LAUNDRY
ONE WAY
STOP
Google
Image capture: Jun 2019 © 2021 Google United States Terms Privacy Report a problem

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.



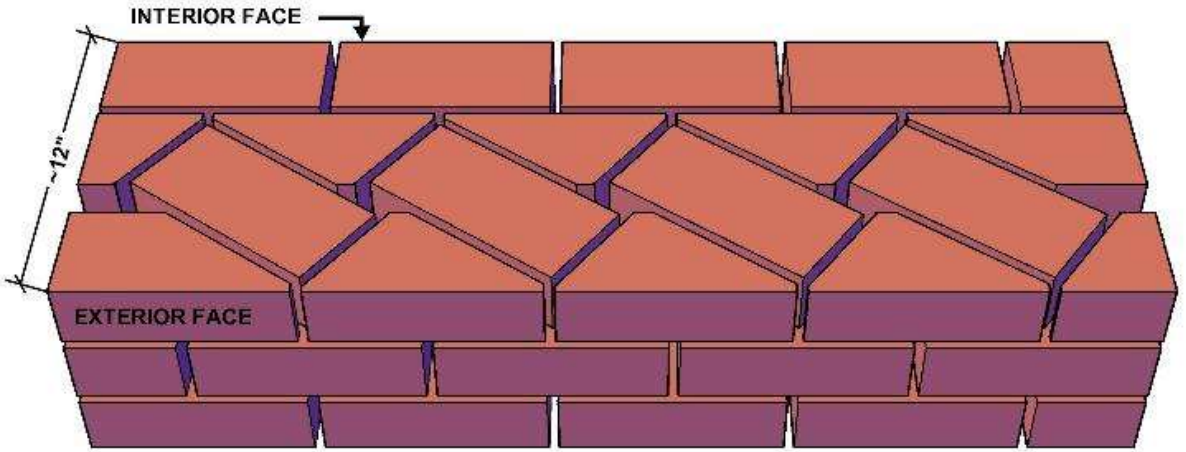
SPECIFICATIONS

MASONRY WORK:

1. MASONRY WORK contemplates all exterior and interior brick walls including the setting of all concrete door and window sills, concrete copings and concrete inserts as shown as well as setting all steel lintels, and steel window sills in coal bin.
2. THE OWNER will furnish all material on the site, the contractor shall figure on labor only, which includes masons, helpers, and mortar tenders.
3. FACE BRICK to be Western Clay Manufactoring Company's Tapestry Brick, laid similar to that now on the Federal Building.
4. COMMON BRICK to be that shipped from the Paper Mill at Manhattan. All piers for the support of girders to be selected hard burned Common brick from the above assortment laid in cement mortar.
5. LAYING shall be to a line on both sides of wall, as the interior will not be plastered. Exterior and interior courses shall be kept level and true.
6. FULL SHOVED JOINTS shall be used and where impossible to shove, a full bed will be employed. Leads of more than 12 courses prohibited.
7. BOND of plain headers every 5th or 6th course to be used on all brick walls. Level walls entirely across at every header course andheader back with common brick. Bond for face brick to be by means of blind headers.
8. BEARING for all Lintels, beams, plates and anchors to be bedded in cement mortar.
9. MORTAR for all brick work, except in bearings, shall be 1 part good lime paste, 3 parts clean,coarse, sharp sand, and mixed well. In no case permitted to dry out before using.
10. CEMENT MORTAR shall consist of 1 part cement 3 sand having added enough lime paste to make work easy. It shall be mixed as used, and may be broken down and tempered once if within 30 minutes of original mixing, to be used as directed in all wall piers, in exterior walls for support of girders.
11. CAULK around all doors and window openings thoroughly with lime mortar. Where steel sash occur namely windows, A, B, C, & D, grout with cement mortar as shown on detail sheet # 3.
12. JOINTS for face brick to be of a size making 1 brick and one joint 2⅔" in heighth or 4 brick to 11", horizontally 12⅛" for a header, stretcher and 2 cross joints. The interior joints to be such that the brick works out with the facing, and the joints are to be trowel struck, as these walls will not be plastered except in the office. Joints are to be left natural color. Lay off on story pole the brick courses before beginning work.
13. JOIST ANCHORS to be built in.
14. LINTELS shall be carefully placed and the bearings of different members shall have relative elevations shown.
15. FOUNDATION to be levelled up with cement mortar for starting courses. This grouting, if over 3" thick shall be given time to set before starting brick work.
16. CLEAN BRICK WORK after completion with water and stiff brushes. If water does not thoroughly remove all stains, use weak solution of muriatic acid and rinse off thoroughly with clear water. All defective joints shall be pointed up carefully.
17. CONCRETE WINDOW SILLS AND COPINGS will be pre-cast and set by this Contractor.

What are “blind headers”?

- Running bond headers, diagonal headers: maintains unform 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

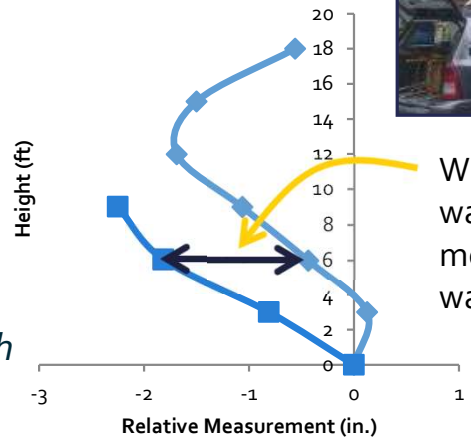
ASCE 41: *"A site visit shall be conducted…"*

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



Why is the outside wall face deflecting more than the inside wall face?

Always measure both sides of the wall!

ASCE 41-17: Table 6-1

	Level of Knowledge					
Data	Minimum		Usual		Comprehensive	
Performance Level	Life Safety (s-3) or lower		Damage Control (S-2) or lower		Immediate Occupancy (S-1) or lower	
Analysis Procedures	LSP, LDP		All		All	
Testing	No tests		Usual testing		Comprehensive testing	
Drawings	Design drawings	Field survey (no design drawings)	Design drawings	Field survey (no design drawings)	Design drawings	Field survey (no design drawings)
Condition Assessment	Visual	Comprehensive	Visual	Comprehensive	Visual	Comprehensive
Material Properties	From construction documents	Default values	From construction documents	Usual tests	From construction documents	Comprehensive tests
Knowledge Factor (κ)	0.9	0.75	1.0	1.0	1.0	1.0

Don't forget the footnotes!!!

ASCE 41: On-site investigations

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

Ultrasonic pulse velocity

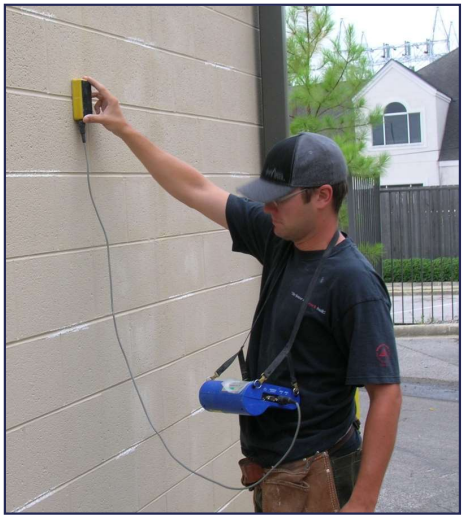
Sonic pulse velocity

Metal detection

Locating metals

- Reinforcement
- Veneer anchors
- Flashing
- Conduit, pipes

"Pachometer"
"Cover meter"
"Rebar locator"

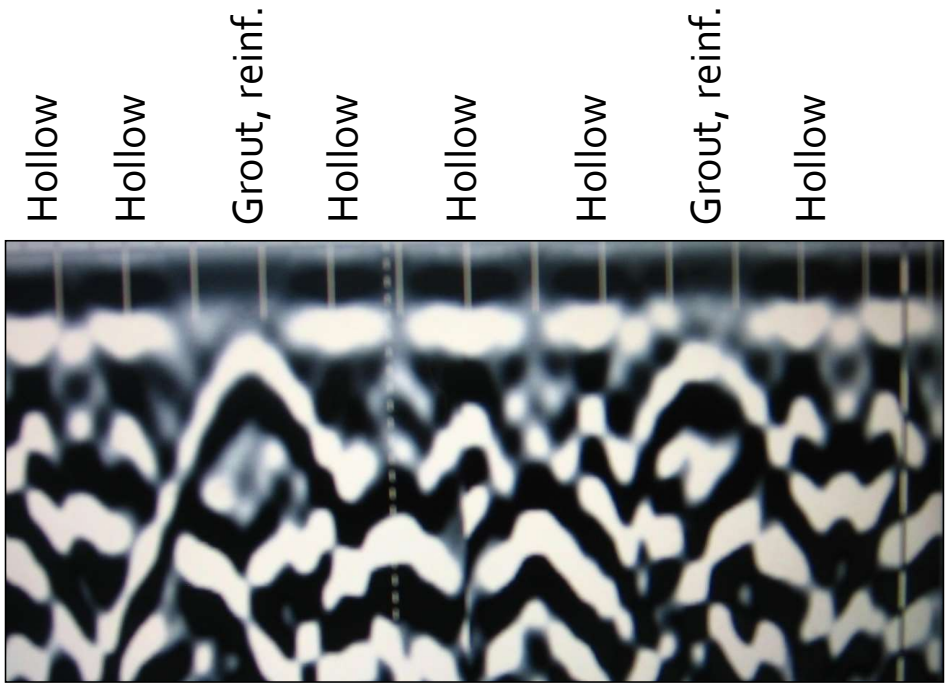


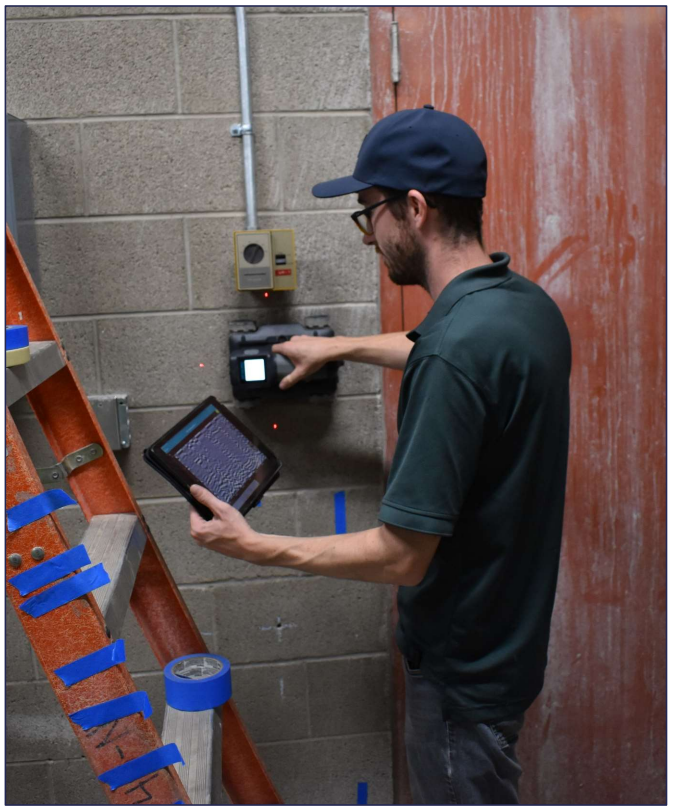
Surface Penetrating Radar (SPR)

- 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

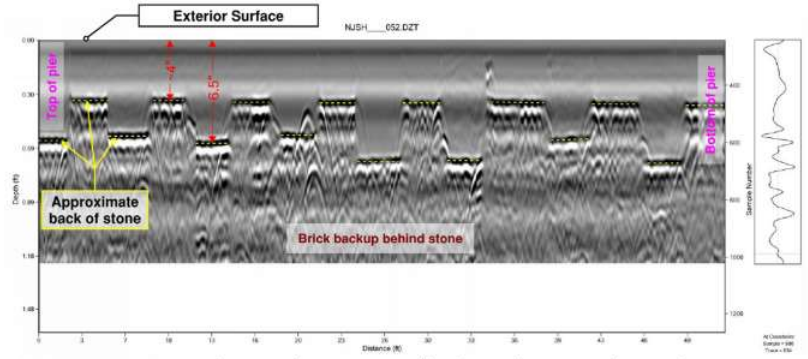
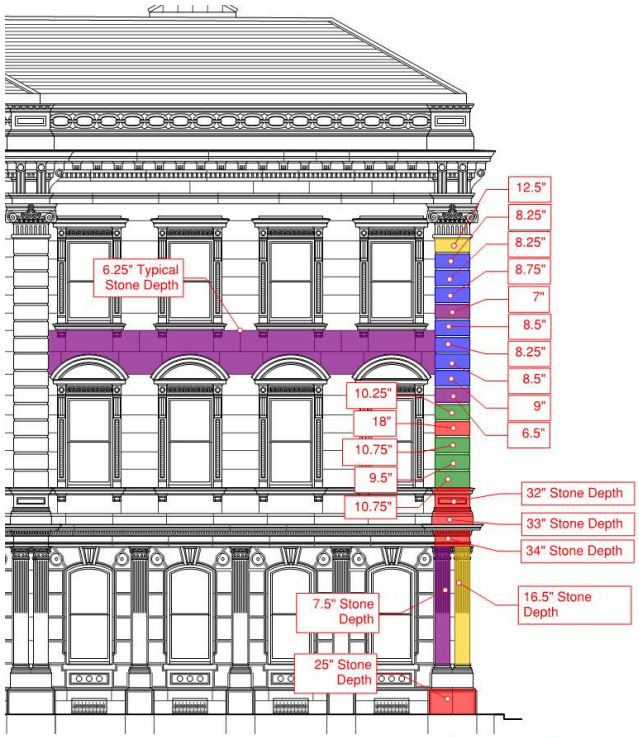
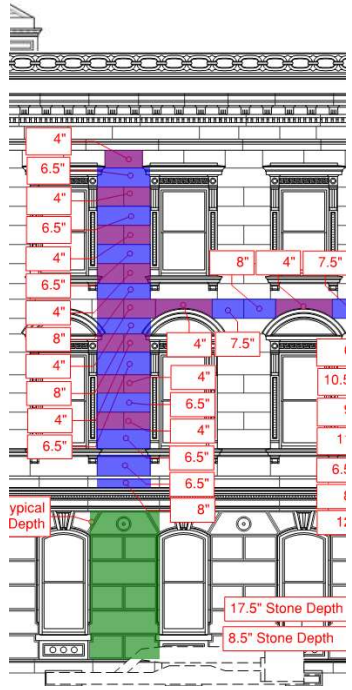


Figure 5.1. Representative vertical SPR scan taken at an exterior wall on the west elevation. Here, the stones alternate in thickness very regularly, which should not be considered the typical condition.

Typical GPR Scan

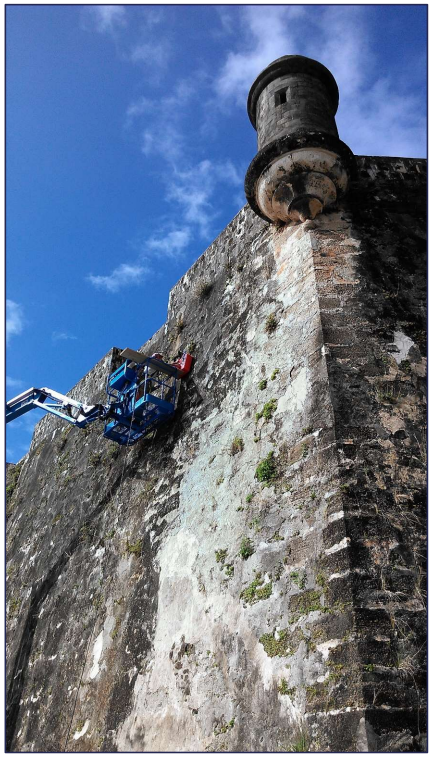


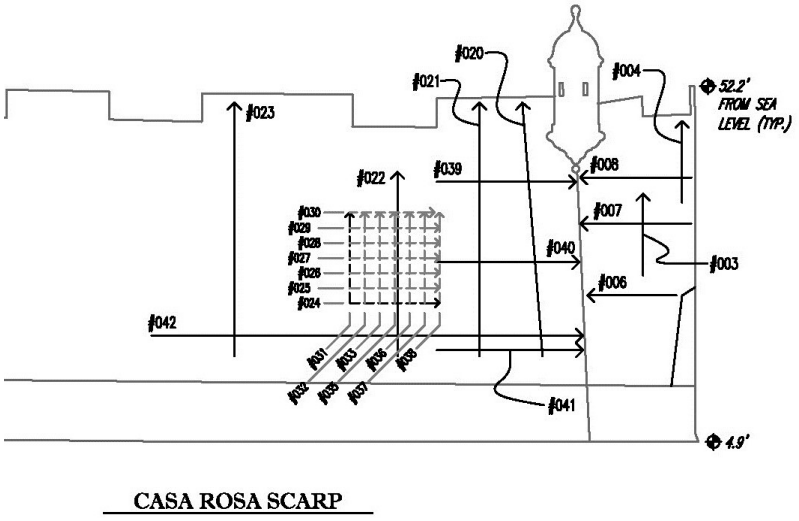


New Jersey Executive State House

Internal Voids

- Defining the extent of repairs

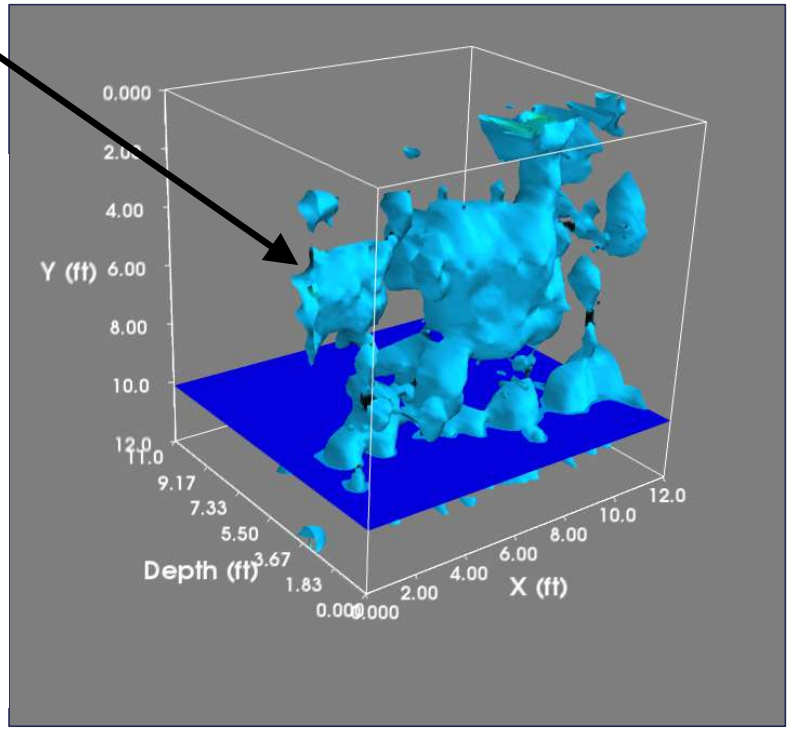




CASA ROSA SCARP

Cliffside erosion behind scarp wall

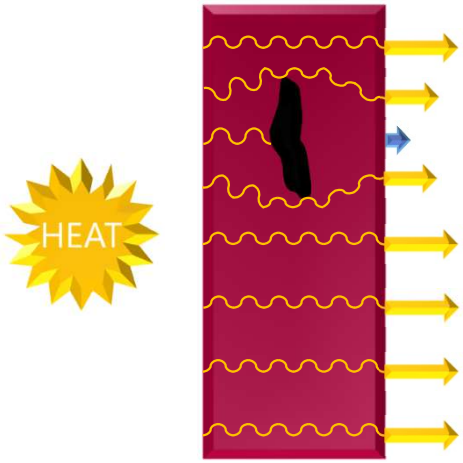
El Morro Fortress, San Juan, Puerto Rico
Surface Penetrating Radar (SPR)

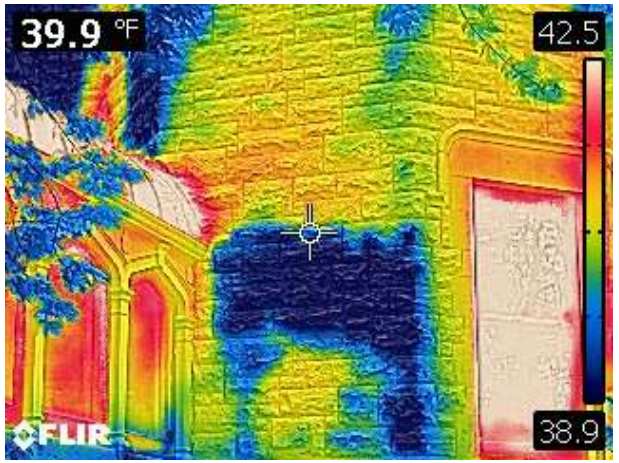


Infrared Thermography: *IRT*

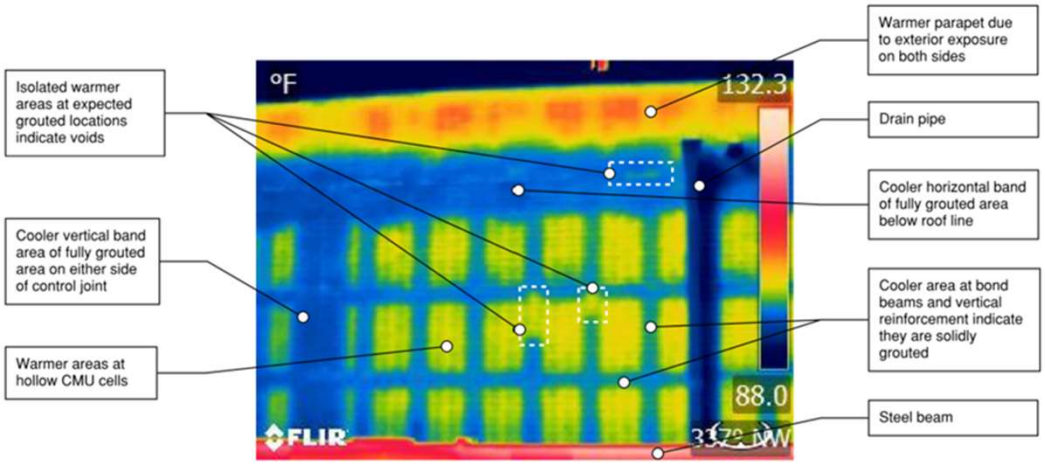
What is it?

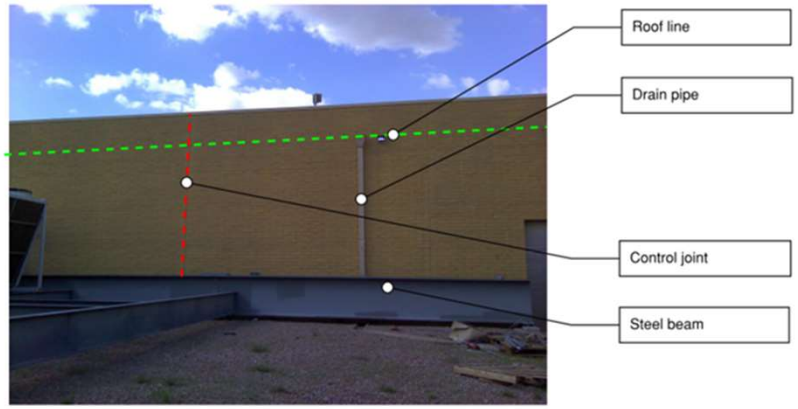
- Measures infrared radiation emission
- Surface temperature: 0.1° C resolution
- Shows variations in material properties and construction





Post-Construction QA

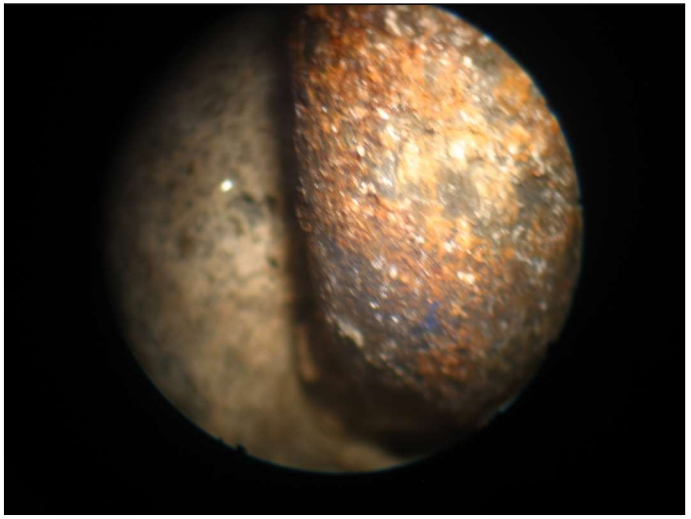




- Infrared thermography
- Videoscope

Borescope, videoscope

Earl Warren Federal Courthouse, San Francisco



Mechanical properties

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 11-2a Type N mortar

Material	Solid Units	Hollow Concrete Units
Compressive strength	600 psi	1,000 psi
Flexural tensile strength	60 psi	38 psi
Shear strength	80% of shear strength determined following TMS 402 Section 9.2.6	

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

Table 11-2c: lime mortar

Material	Solid Units
Compressive strength	285 psi
Flexural tensile strength	5 psi
Shear strength	80% of shear strength determined following TMS 402 Section 9.2.6

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

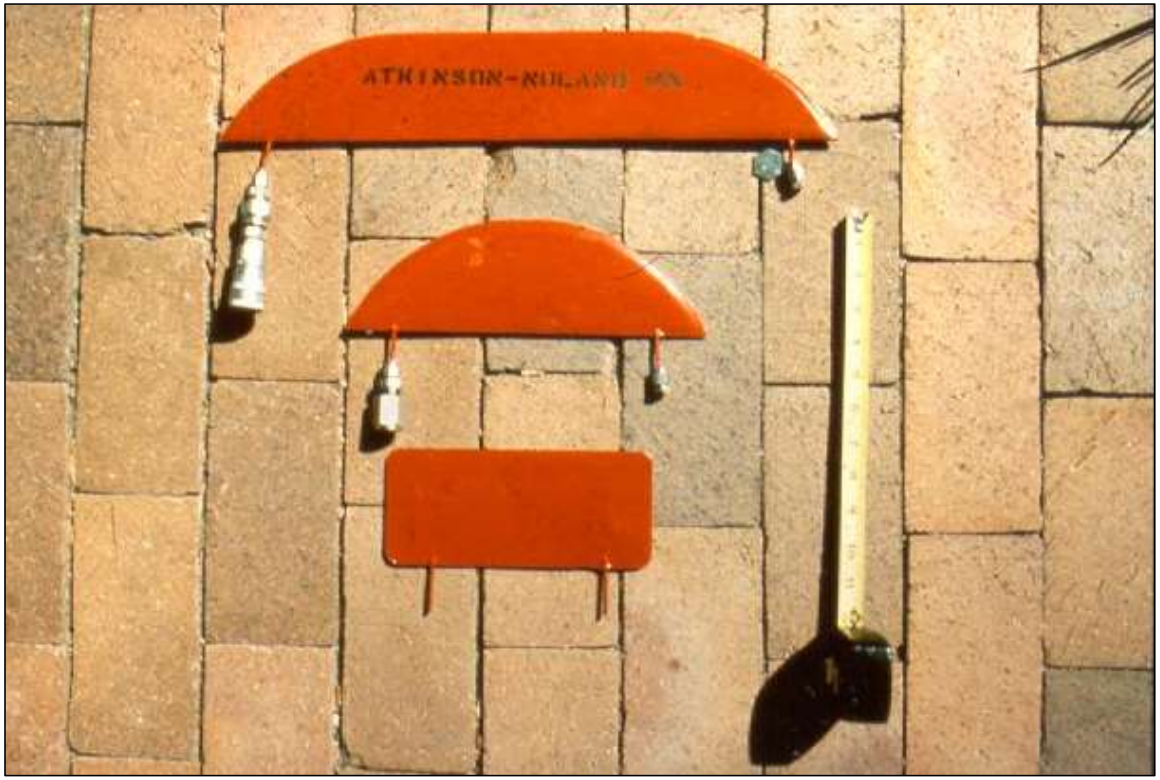
In Situ Tests

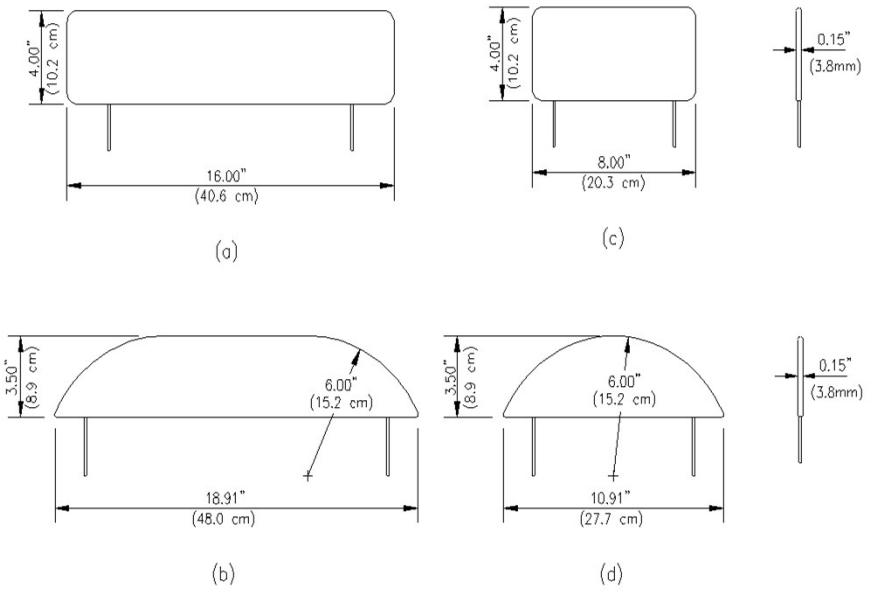
Engineering properties

- Compressive strength: ASTM C1197
- Shear strength: ASTM C1531
- Bond strength: ASTM C1072
- Anchor capacity: ASTM E488
- Core test (diametral tension): ASTM C496

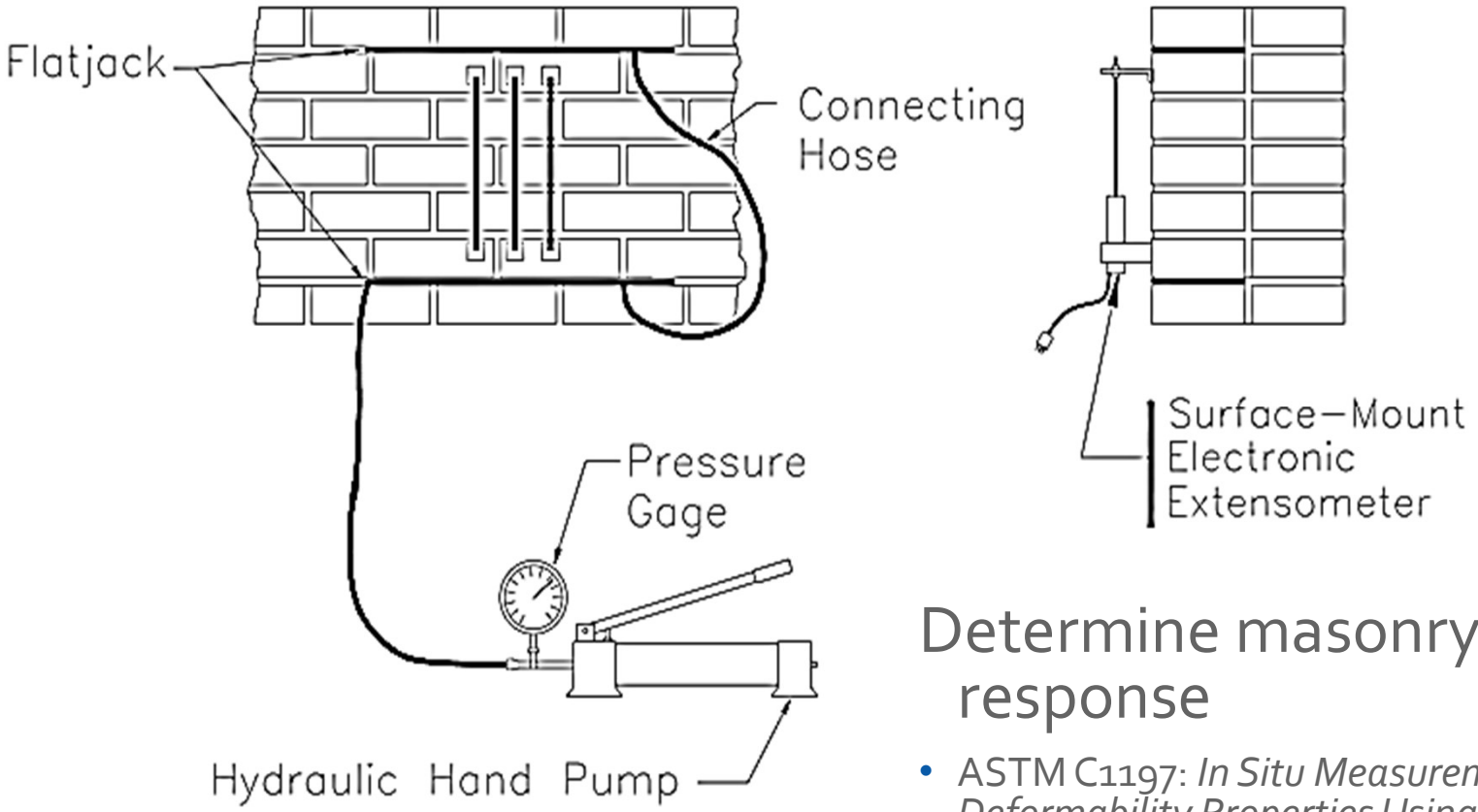



Masonry Flatjacks





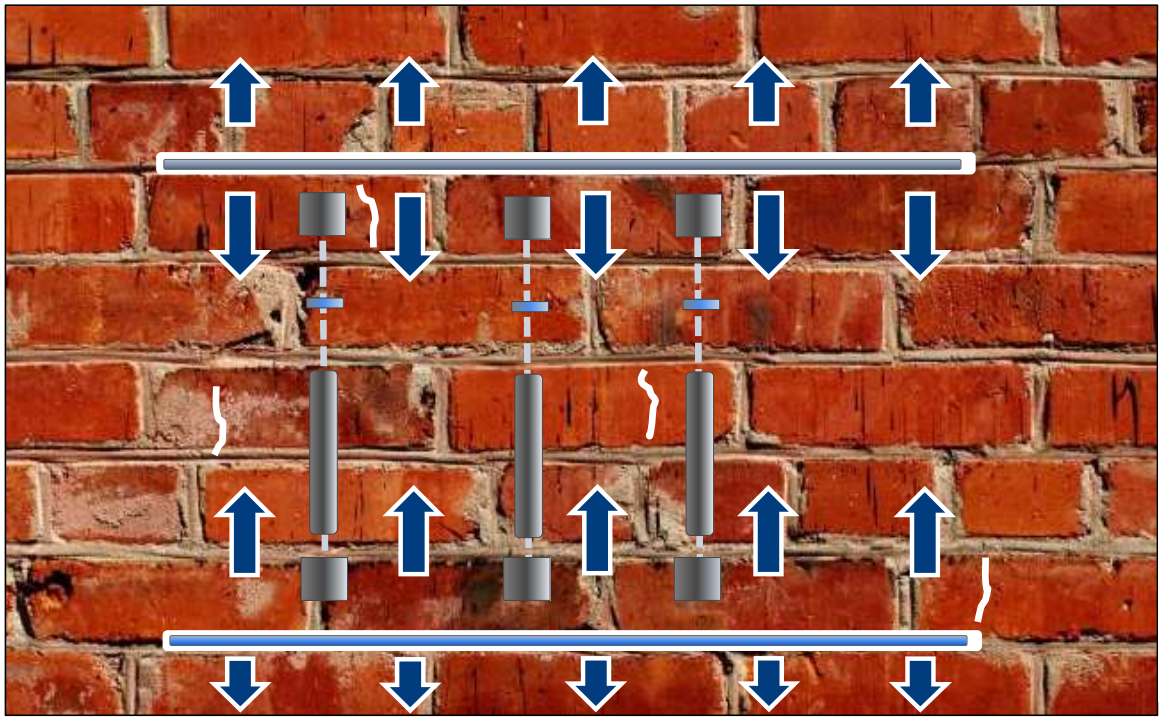
In Situ Deformability Test

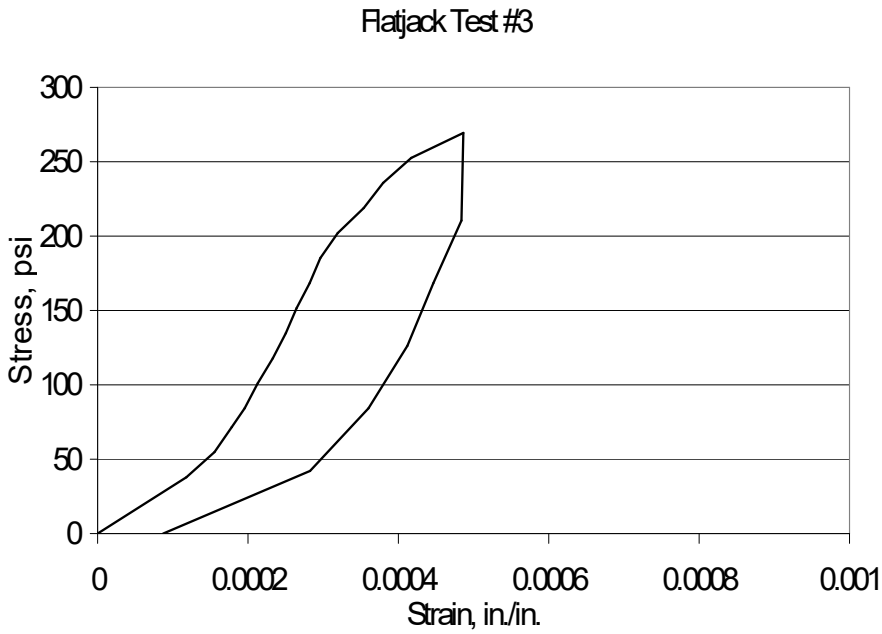


Determine masonry compression response

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

In Situ Deformability Test





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 ft^2 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 ft^2 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