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

Monitoring and Maintenance

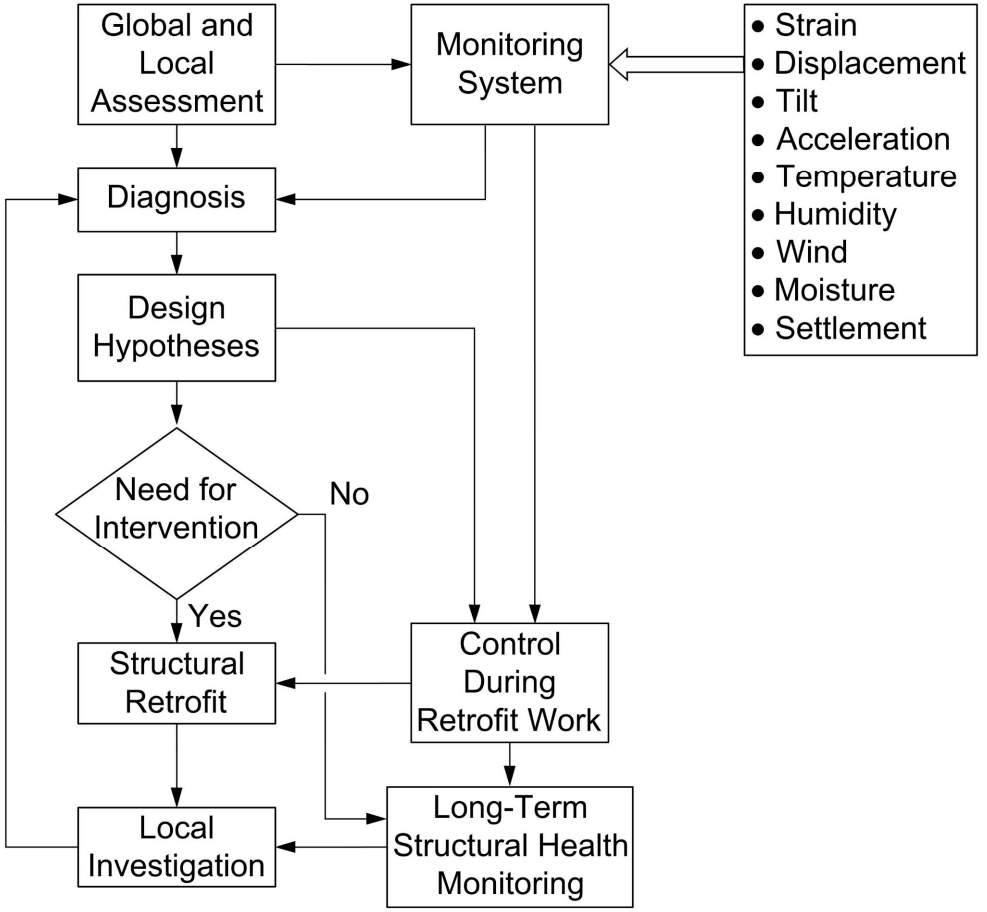
College of Continuing and Professional Studies
Structural Engineering Webinar
March 7, 2023

Monitoring

Important diagnostic component

- Causes of distress
- Plan future interventions
- Verify retrofit performance
- Movement joint design

- Sensors for many physical properties



Hamid and Schuller, Assessment and Retrofit of Masonry Structures (2019), Chapter 6, Monitoring

Motivation

Q. Why Monitor?

A. To get answers to questions and make informed decisions.

A. Increase *confidence* that we are doing the right thing.

Monitoring Considerations

- Total cost
  - Equipment, installation, data acquisition, data reduction/interpretation, reporting, removal
- Manual vs automated data acquisition
  - Manual data recording
  - Periodic manual download from data acquisition system
  - Download to computer via modem
  - Automated data feed to website

Monitoring Considerations

- Duration
  - Long enough to eliminate external variations as the source of changes
  - At least one "cycle"
- Precision
  - As appropriate - don't get too carried away
- Sampling frequency
  - Again, as appropriate

1 sample every 10 minutes
adds up to ~4,400 samples
per month

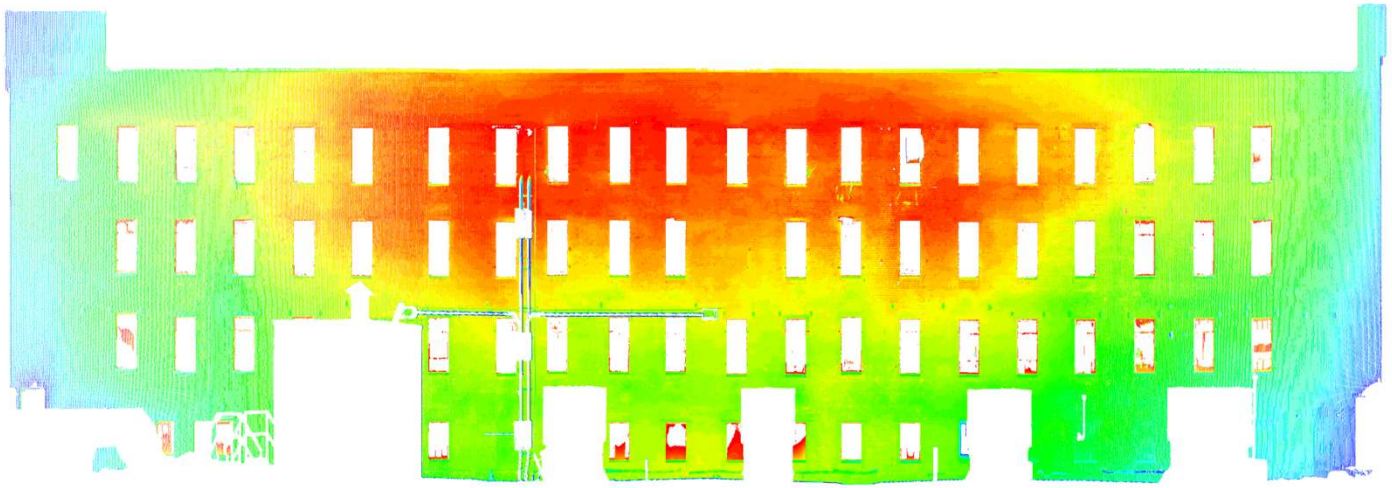
Monitoring approach

- Periodic measurements
  - Visual
  - Photographs
  - NDE
  - LiDAR

Wright Brothers Memorial
Cape Hatteras National Seashore
North Carolina

Deviation Survey: mapping a bulging wall

- LiDAR: Light Detection and Ranging
- 3D point cloud



EAST ELEVATION TOP DEVIATION SURVEY: 37 feet 7 inch to 38 feet 7 inch quarter inch interval (by Berkshire Dimensions)

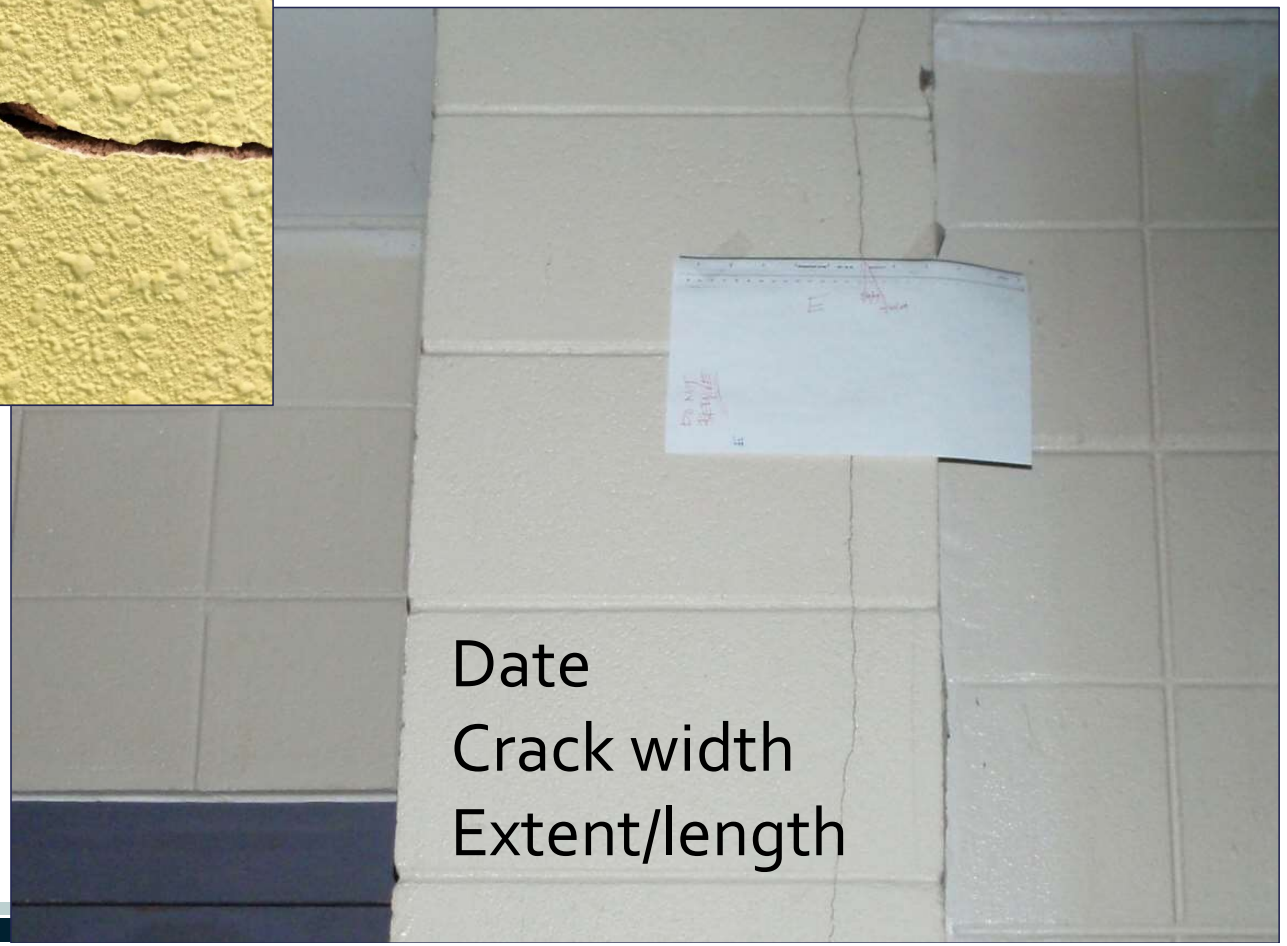
Crack Evaluation

Tell-Tale

Crack Comparator

Removable Extensometer

- Date
- Crack width
- Extent/length



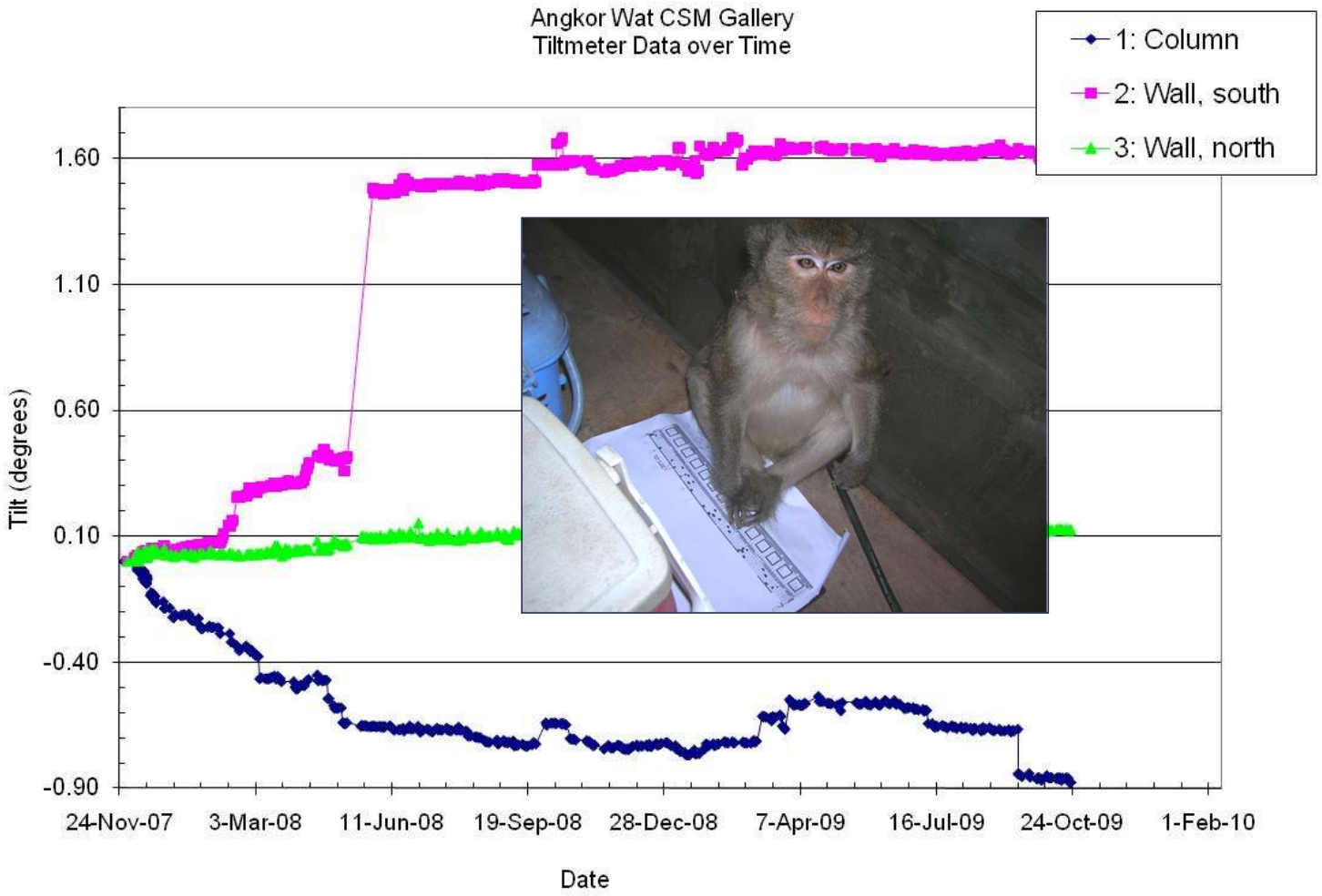
Date
Crack width
Extent/length

Periodic Electronic Measurements

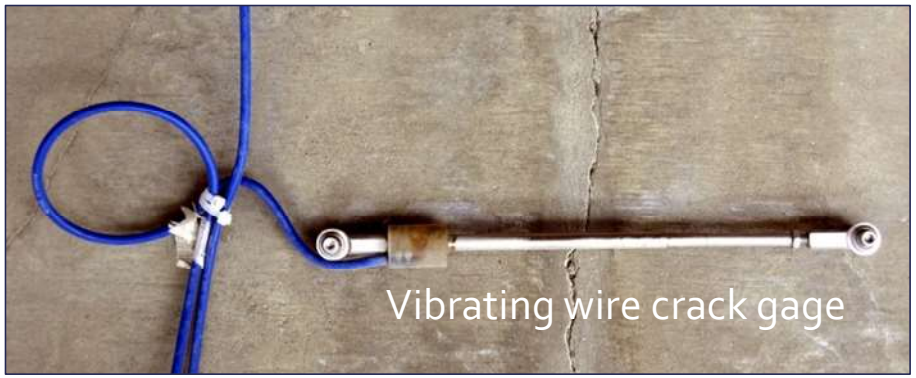
Angkor Wat, Cambodia

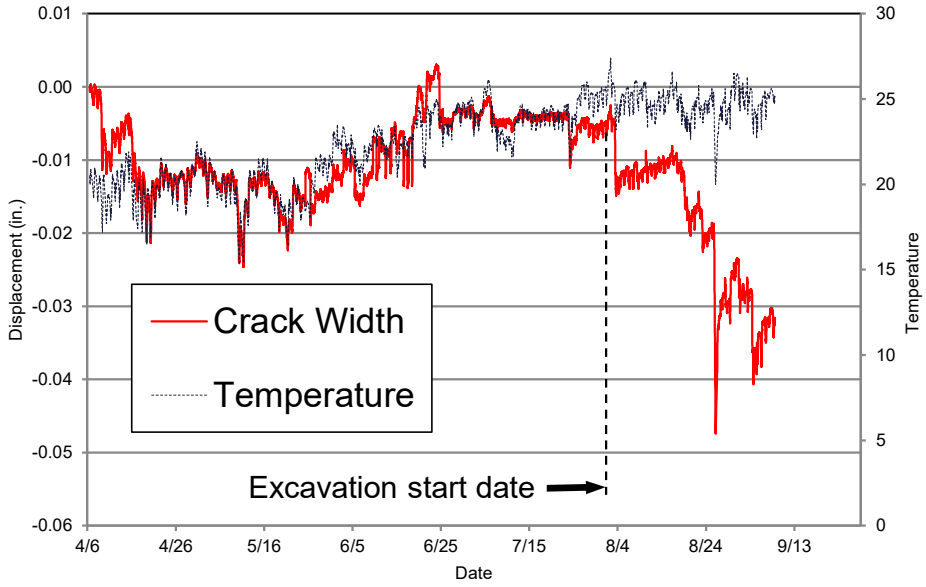
Tiltmeter

Tiltmeter with portable readout box


Angkor Wat CSM Gallery
Tiltmeter Data over Time
1: Column
2: Wall, south
3: Wall, north
1.60
1.10
0.60
0.10
-0.40
-0.90
Tilt (degrees)
24-Nov-07
3-Mar-08
11-Jun-08
19-Sep-08
28-Dec-08
7-Apr-09
16-Jul-09
24-Oct-09
1-Feb-10
Date

Automated Monitoring



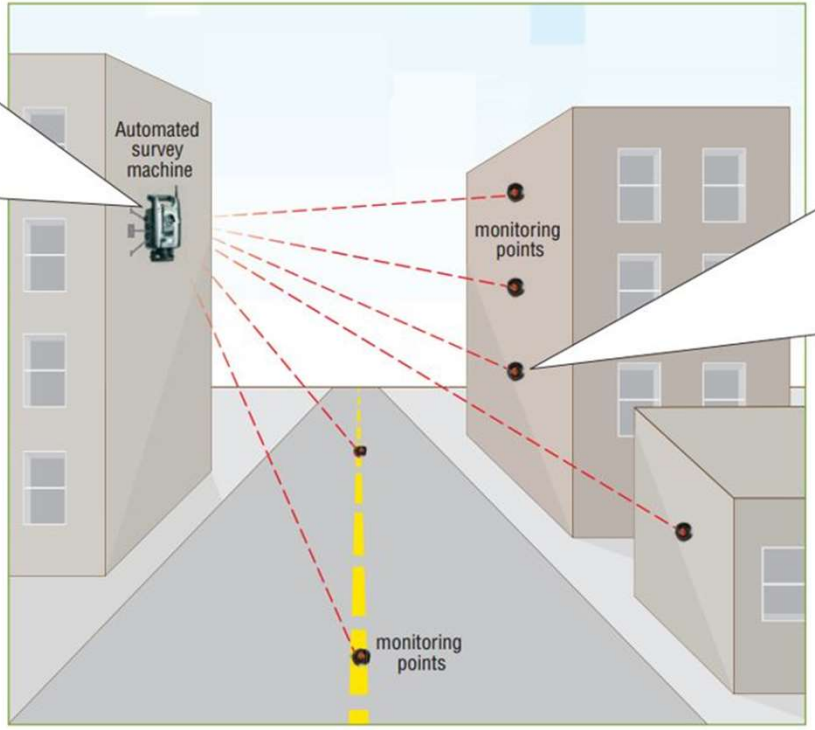


Dedicated Data Logger

Automated Geodetic Measurements

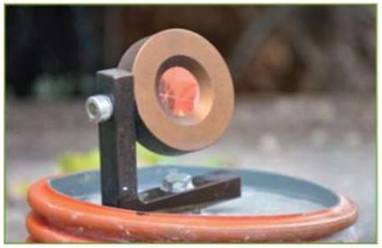
Automated Survey Machines

An automated survey machine is a 12 in. (305 mm) by 6 in. (152 mm) machine placed on a wall or rooftop.



Automated survey machines monitor building movement by continuously scanning predetermined points on adjacent buildings and in the street.

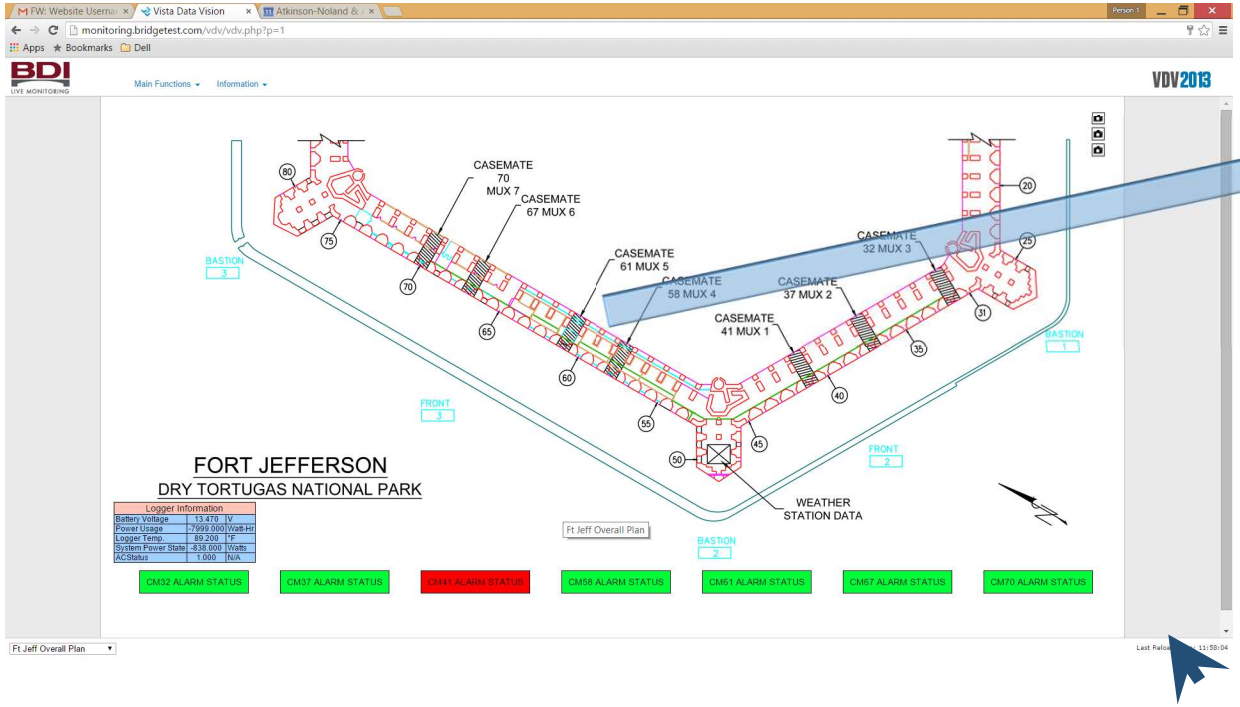
Monitoring Points

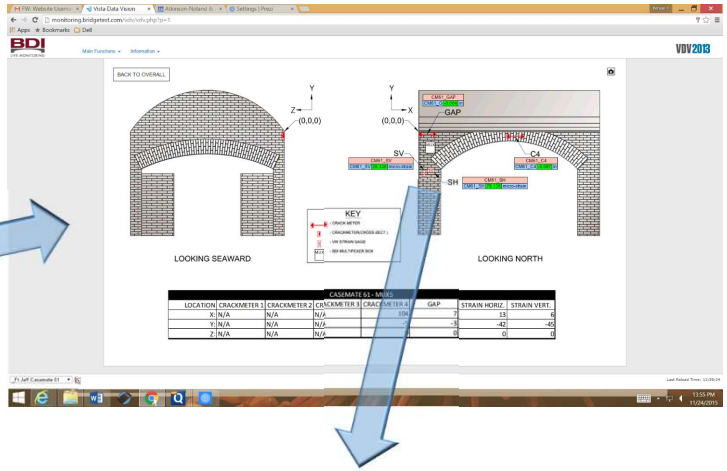


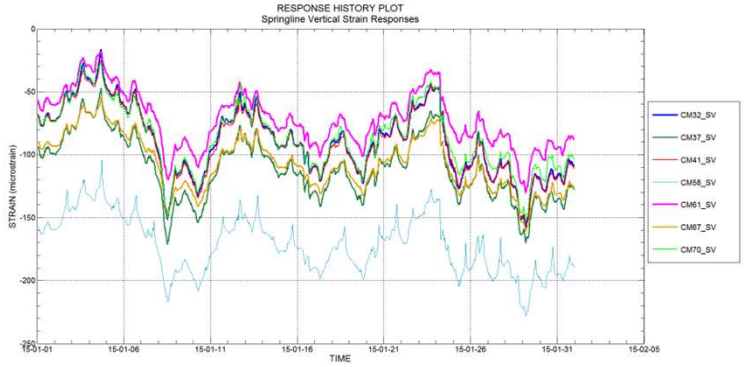
Monitoring points are typically 6 in. (152 mm) by 6 in. (152 mm) prisms mounted on buildings with a 2 in. (51 mm) long by 0.5 in. (13 mm) diameter screw.

Monitoring points can also be as small as the head of a nail.

Web-Based Interface







Vibration Monitoring

Effects of

- Traffic
- Adjacent construction
- Blasting, mining

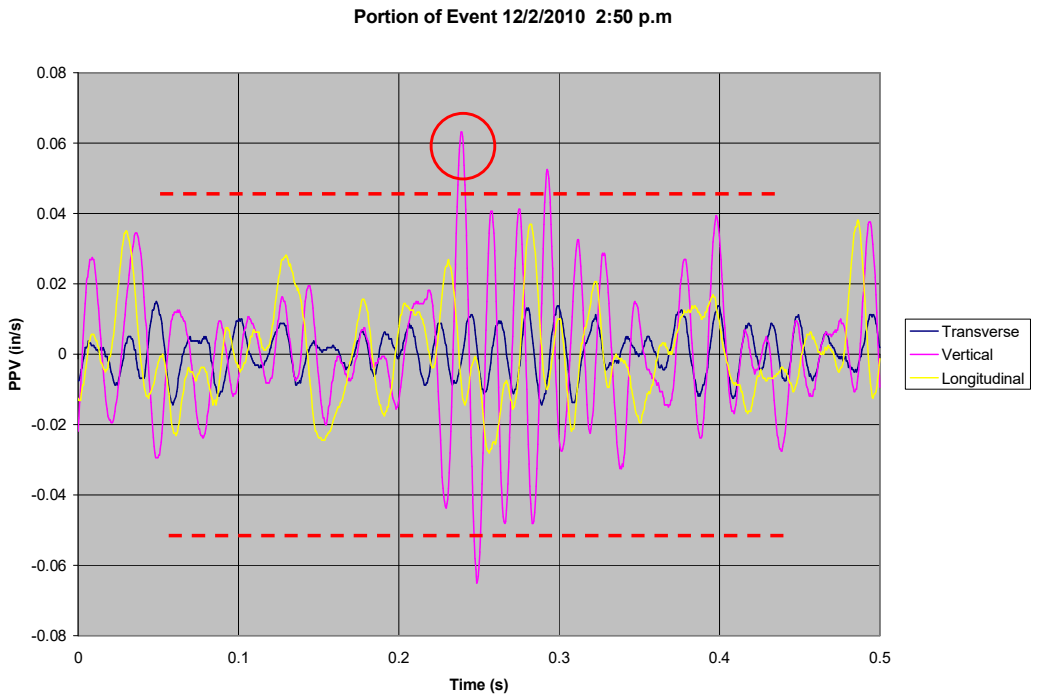
- Required during construction?
  - City of New York TPPN No. 10/88 Historic buildings within 90 ft

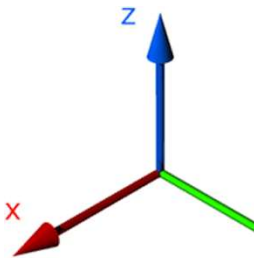
Vibration Amplitude (Peak Particle Velocity) at 50 ft from source		Typical Sources	Effects on Humans	Effects on Buildings
in./sec	mm/sec			
< 0.005	< 0.13	Typical background vibration	Imperceptible	No effect on buildings
0.005 to 0.019	0.13 to 0.5	Bus or truck, typical	Perception threshold	No effect on buildings
0.02 to 0.05	0.5 to 1.3	Bus or truck over bump, commuter rail	Continuous vibrations begin to annoy people	No effect on normal buildings
0.1 to 0.5	2.5 to 13	Commuter rail, upper range, rapid transit	Considered unacceptable when exposed to continuous or long-term vibrations	Minimal potential for damage to weak or sensitive structures. Some risk to ancient monuments and ruins.
0.5 to 1.0	13 to 25	Bulldozers or other heavy tracked construction equipment	Bothersome by most people, may be tolerable if short-term	Risk of architectural damaged to plastered ceilings and walls.
1.0 to 2.0	25 to 50	Blasting from construction projects	Considered unpleasant by most people	Blasting vibrations in this range will not harm most buildings. Many construction vibration limits are in this range.
> 3.0	> 76		Unpleasant	Potential for architectural damage and minor structural damage.

Table 6.1 Vibration effects (from Ref. 6.6 and 6.7)

Vibration Monitoring

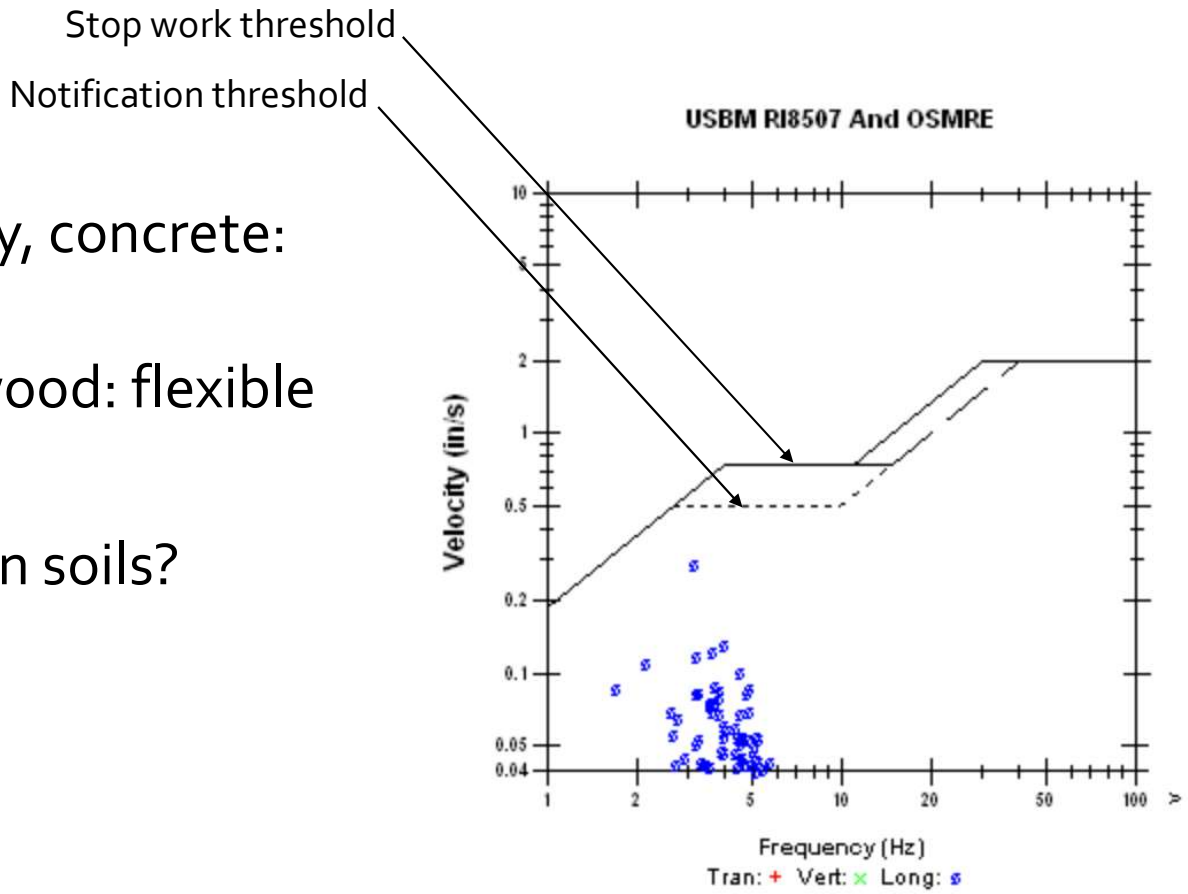
- Samples at higher speeds (~ 1000 samples/second)
- Specialized equipment
- Data storage?
- Monitor only mode
- Recording triggered when threshold level is exceeded
- Alarms – email, phone, text





Vibration Thresholds and Alerts

- Masonry, concrete: brittle
- Steel, wood: flexible
- Effect on soils?



Monitoring

- What is important?
- Wide range of equipment, cost
- Be sensible about accuracy requirements and sampling rates
- Monitor for an appropriate length of time
- Use an appropriate number of sensors – but just

Maintenance

Masonry is durable!
Why do anything at all?

International Property Maintenance Code (IPMC, 2021)

- *The exterior of a structure shall be maintained in good repair, structurally sound, and sanitary so as to not pose a threat to public health, safety, or welfare.*
- Dangerous: insufficient strength, stability, or anchorage to resist loads of 1.5 times the original design value

Maintenance

2021 IPMC Unsafe Conditions:

- Nominal loads that exceed nominal capacity - any structural member
- Floor anchorage incapable of resisting nominal loads
- Structures or components that have reached their serviceability or ultimate limit state
- Masonry joints that are not maintained to be weather resistant
- Open cracks, breaks, leaning, of exterior walls and foundation systems.
- Inadequately anchored veneer, cornices, belt courses, corbels, trim, and other decorative features
- Unsound or improperly anchored chimneys, smokestacks, and other similar construction

Maintenance

Masonry

- Repointing mortar joints
- Brick replacement
- Moisture intrusion
- Stains, efflorescence
- Inappropriate prior interventions

Non-masonry

- Joint sealants
- Mold
- Vegetation removal
- Corrosion
- Drainage

Concentrate on high exposure areas, frequently wet: parapets, chimneys, base of building

Maintenance Process

1. Observe, inspect, document
2. Analyze, diagnose
3. Prioritize
4. Design and specify: address the cause first!
5. Implementation
6. Document completed work

Maintenance Process

- Conditions-based
- Fixed time (periodic)
- Preventive
- Corrective
- Event-triggered

Inspection Intervals

- Related to material service life
  - Service life: performance period, *before requiring significant maintenance*

Material	Service Life (years)
Brick walls	100 to 150
Concrete masonry walls	More than 100
Mortar	50 to 100
Flexible joint sealant	5 to 20
Plastic flashing	5 to 25
Metal flashing	20 to 75
Water repellent coating	5 to 10
Metal anchors and ties	More than 15
Paint finishes	5 to 10
Cleaning	15

Table 7.1 Service life of materials related to masonry construction.

Appendix D

Masonry Maintenance Checklist

Item	Conditions	Evaluation cycle
Roof, balcony, porch drainage		
Flashing	Open joints, failed attachment, missing, corrosion, deterioration, wind damage	Yearly
Scuppers	Blockage, leaks at perimeter, proper drainage	6 months
Gutters and downspouts	Blockage, leaks, open joints and seams, attachment to building	6 months
Ponding	Water retention, freezing	Yearly
Roofing	Cracked, missing, displaced shingles; slope, ponding, blisters, mechanical damage, tears and other locations for moisture infiltration, membranes	Yearly
Site drainage	Slope away from building, ponding; check sidewalks, slabs, nearby pavements	2 to 4 years

Appendix D, Assessment and Retrofit of Masonry Structures, masonrysociety.org

Appendix D

Masonry Maintenance Checklist

Item	Conditions	Evaluation cycle
Coping	Water infiltration at head joints, failed sealant, cracked mortar, stains, unit deterioration.	Yearly
Chimneys	Leaning, cracks, stains, displacement, flashing at sidewalls, coping	2 years
Parapets	Leaning, cracks, stains, displacement, coping, roof counterflashing	2 years
Windows and doors	Check for frame movement and proper operation, leaks, material conditions. Check condition of glazing, seals, weeps, and finishes. Check sills, cover plates, and door thresholds for signs of moisture intrusion and material deterioration.	Wood, polymer: every 2 to 4 years Metal: 4 years
Flashing	Cracks, separations, deterioration, leaks, stains	4 years
Weeps and vents	Missing, or blocked by insects, plant growth, or sealant	2 years

Appendix D, Assessment and Retrofit of Masonry Structures, masonrysociety.org

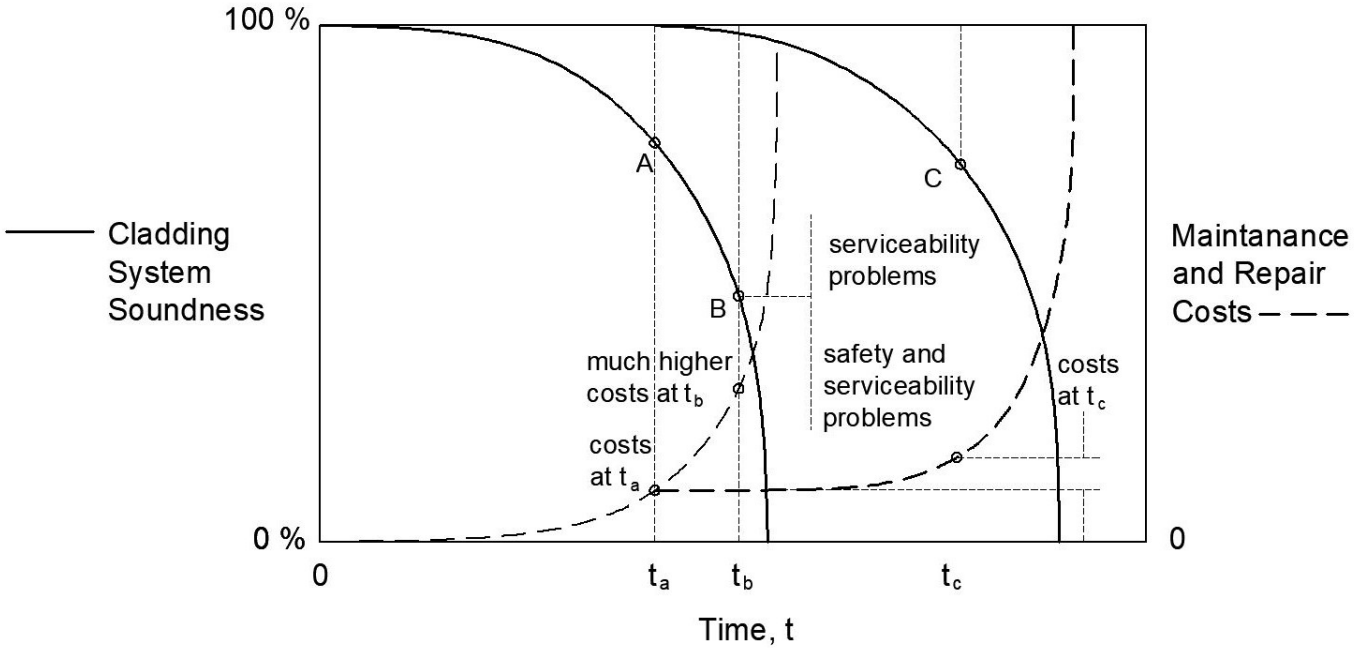
Appendix D

Masonry Maintenance Checklist

Item	Conditions	Evaluation cycle
Masonry Units		
Natural stone	Cracking, moisture, staining, efflorescence	4 years
Terra cotta, faience	Unit cracking, glaze cracking or separation, spalls, moisture infiltration, stains	4 years
Cast stone	Moisture infiltration, movement, spalls, cracking, crazing, corrosion of embedded metals, stains, efflorescence, calcite deposits	4 years
Brick	Dampness, moisture infiltration, movement, spalls, cracks, spalls, efflorescence, stains	4 years
Concrete block	Cracks, spalls, moisture infiltration, displacement, efflorescence, stains, calcite deposits	4 years
Masonry Walls	Cracks, displacement, leaning, bowing, and bulging, moisture infiltration, stains, efflorescence, calcite deposits, graffiti, plant growth, mortar deterioration, poor drainage	2 years
Flexible joint sealant	Cracking and separation, moisture infiltration, UV damage, chemical reversion, internal cracking	Yearly

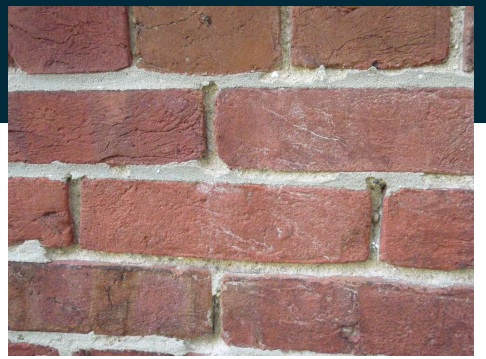
Maintenance Costs

- Regular maintenance will save costs over time!



Adapted from Johnson, B. (1985). Towards a Decision-Making Strategy for Masonry Cleaning. (J. G. Conway, Ed.) ASTM STP 871.

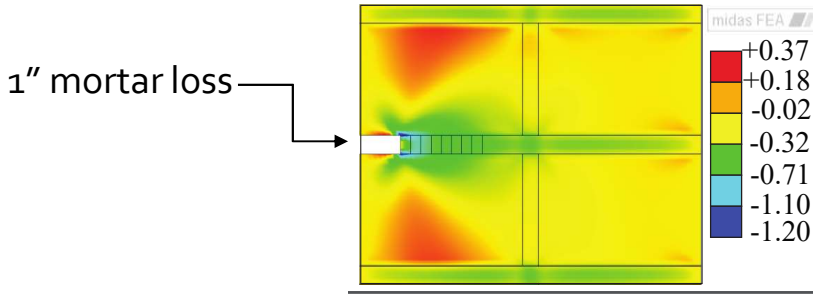
Maintenance Activities



Mortar repointing

- How much mortar loss is significant?
  - Depends on applied stress
  - Stress concentration increases average stress by 2.5 times for 1 ¼" mortar loss
  - 2 ½" mortar loss: stress increase could fail unit

Wall Section



Maintenance Activities

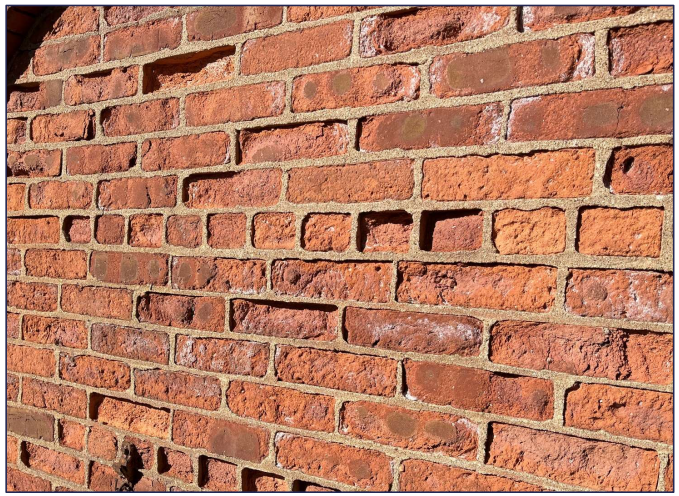
Mortar repointing

- Things to get right
  - Use compatible mortar
  - Remove mortar to 2x joint width
  - Pack mortar into slot in lifts
  - Don’t bring mortar out to the wall face

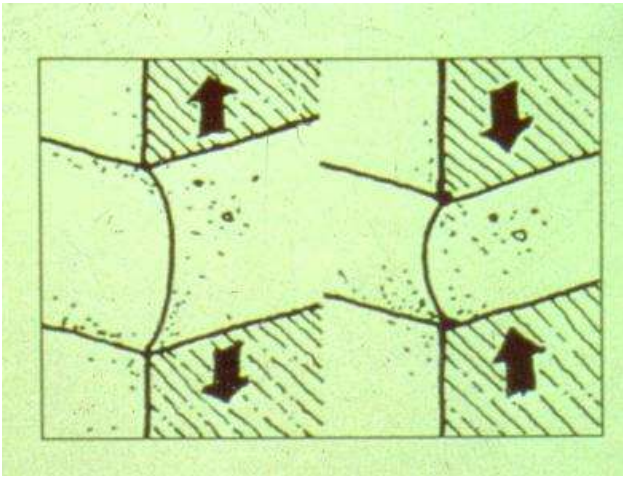
Crack Repair: Repointing

Mortar type?

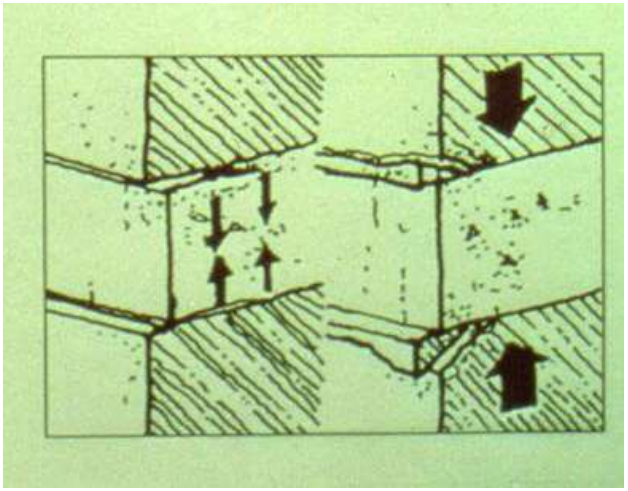
- Durability
- Compatibility
  - Strength
  - Vapor permeability



Preferred:
Elastic, softer mortar

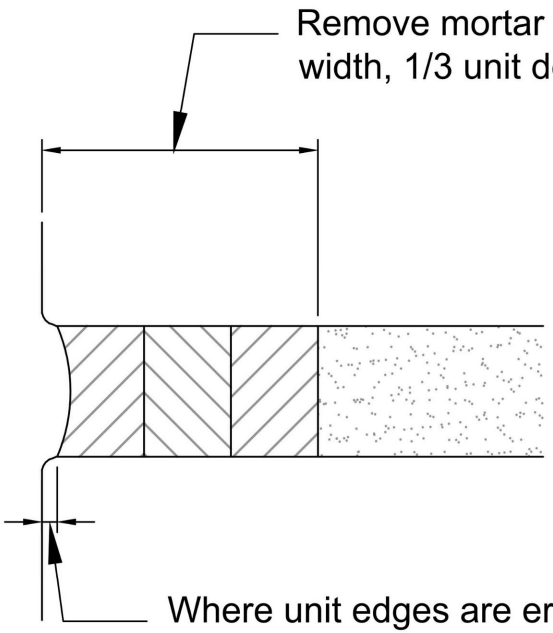


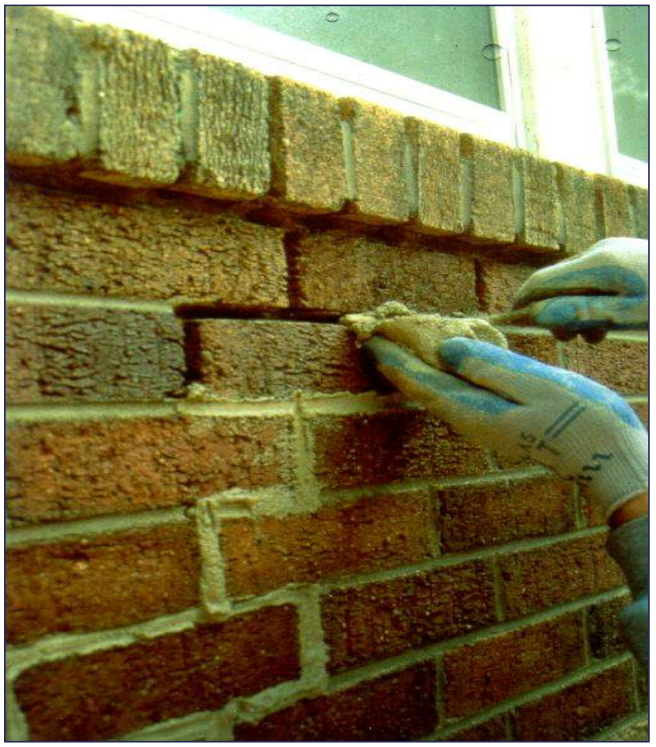
High strength, high stiffness mortar can be problematic!



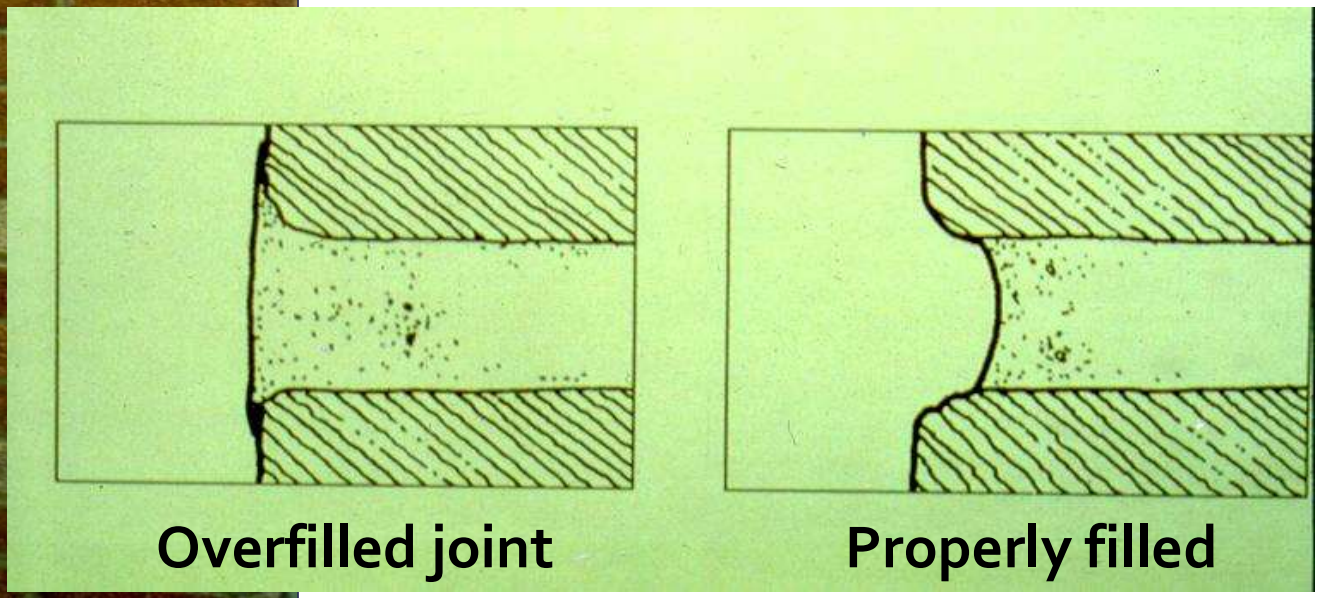
Repointing Mortar Joints

Repoint by packing mortar into slot in 3 lifts. Tool joint profile concave to match existing.





Note: maintain original joint width. Do not overfill mortar joint.


Overfilled joint
Properly filled

Mortar Repointing

2 Preservation Briefs

Technical Preservation Services
National Park Service
U.S. Department of the Interior

Repointing Mortar Joints in Historic Masonry Buildings

Robert C. Mack, FAIA, and John P. Speweik

Free download from the National Park Service!

http://www.nps.gov/history/hps/tps/briefs/brief02.htm

See also: ASTM C270, *Appendix X3, Tuck Pointing Mortar*

Replacing Units

Replacement units must have similar

- Strength
- Stiffness
- Water vapor transmission
- Thermal expansion
- Dimensions
- Appearance

New units?

For large areas, >100 ft^2

- Condition before putting in the wall
  - Pre-wet clay units (weeks, months?)
  - Cure concrete units (6-8 weeks)

  or
  - Install movement joints

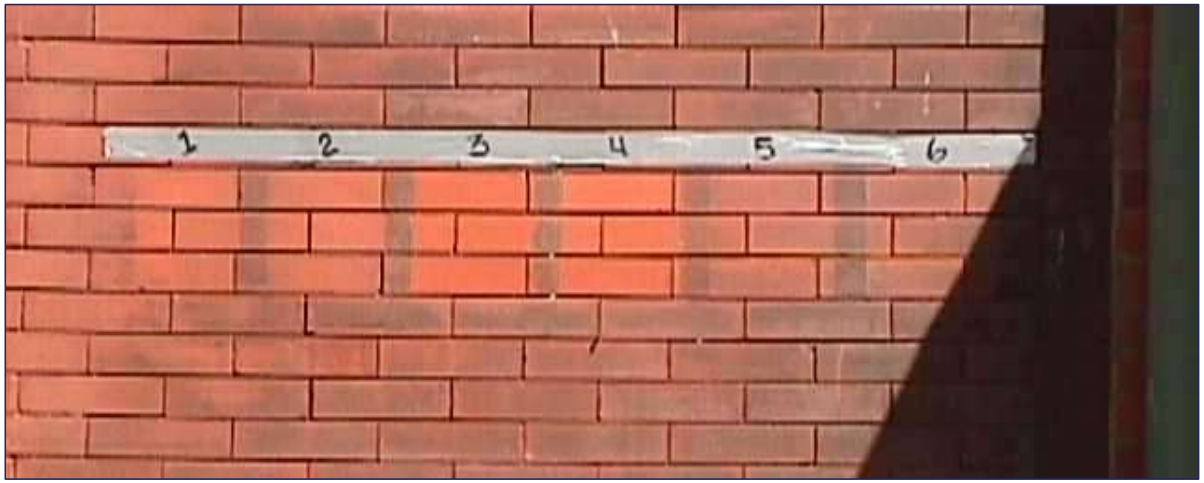
2018 IBC 2103.1.1: Second-hand units must conform to requirements of new units.

Replacing Units

- Remove, flip, replace
- On-site "mining"
- CMU: remove face and replace with 2-in. "soap" unit
- Cast stone, GFRC facsimile
- Cover

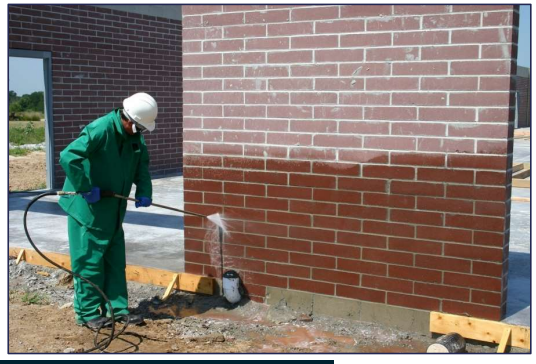
Cleaning Masonry

- Why do you want to clean your wall?
- What are you trying to clean off what substrate?
- How clean is clean?



Cleaning Methods

- Guiding Principles
  - Start with gentlest method possible
  - Test methods for each masonry type and condition
  - Test appropriately sized area
  - Allow for period of weathering after testing
  - Be aware of personal & environmental safety



Cleaning Masonry Guiding Principles

- Use the gentlest method that produces the desired result

<u>Abrasive</u>

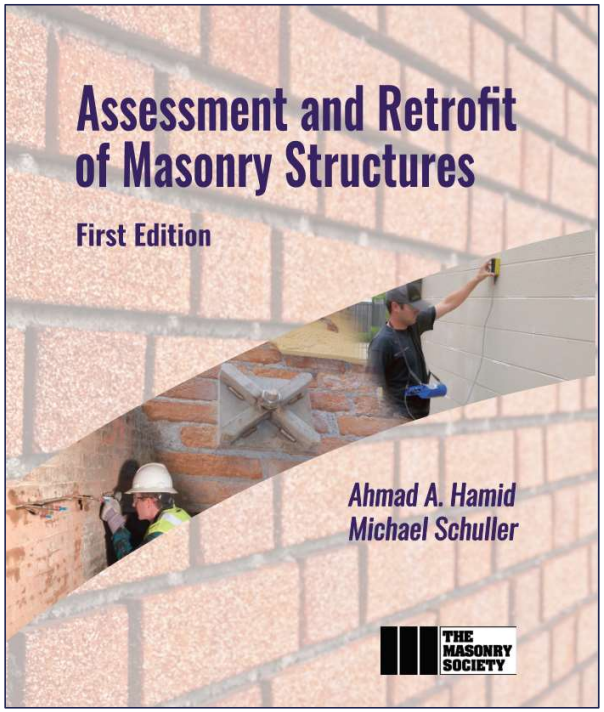
Dry brushing
Low pressure water
Bucket and brush
Pressure washing
Blasting

<u>Chemical (acidic)</u>

Hot water
Water plus non-ionic detergents
Citric acid
Oxalic acid
    Removes iron stains
Muriatic - impure hydrochloric
Hydrochloric acid
Hydrofluoric acid

Masonry Industry Resources

- The Masonry Society
  - www.masonrysociety.org
- Brick Industry Association
  - www.gobrick.com
- National Concrete Masonry Association
  - www.ncma.org
- International Masonry Institute
  - www.imiweb.org



www.masonrysociety.org