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Diagnostic Procedures for Understanding Existing Construction

Minnesota Structural Engineers Association
2023 Spring Seminar
May 9, 2023

Atkinson-Noland & Associates

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Diagnostic Procedures for Understanding Existing Construction

- Nondestructive evaluation
- In situ tests
  - Methodologies, equipment, pros and cons of each
- Setting up an evaluation program
- Calibration, validation
- Reporting: what to expect

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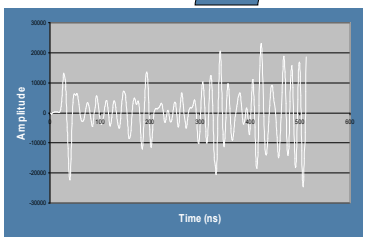
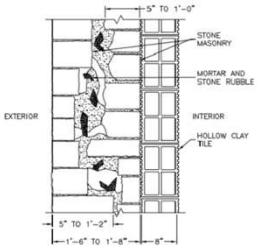
Diagnostics for existing construction

- Nondestructive evaluation
- In situ test methods
- Lab tests

- Planning/specifying an investigation
  - Interpreting and using data
  - Validation and proof testing
  - What to expect in an evaluation report



INTERPRETATION
- Experience
- Software
- Complementary methods
- Calibration
- Probe



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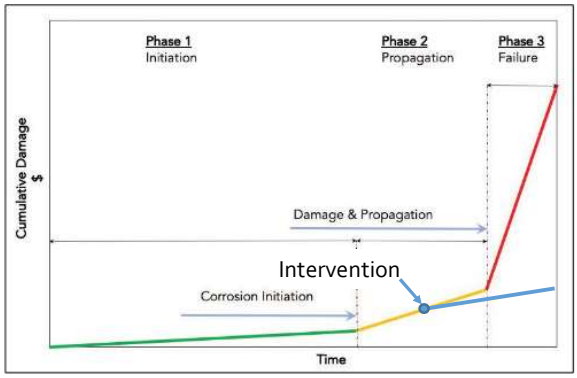
Why carry out an assessment program?

- Address deterioration at an early age



ICRI Concrete Repair Bulletin, Sept/Oct 2021

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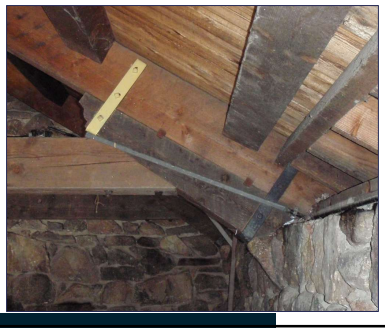
What information do you need?

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



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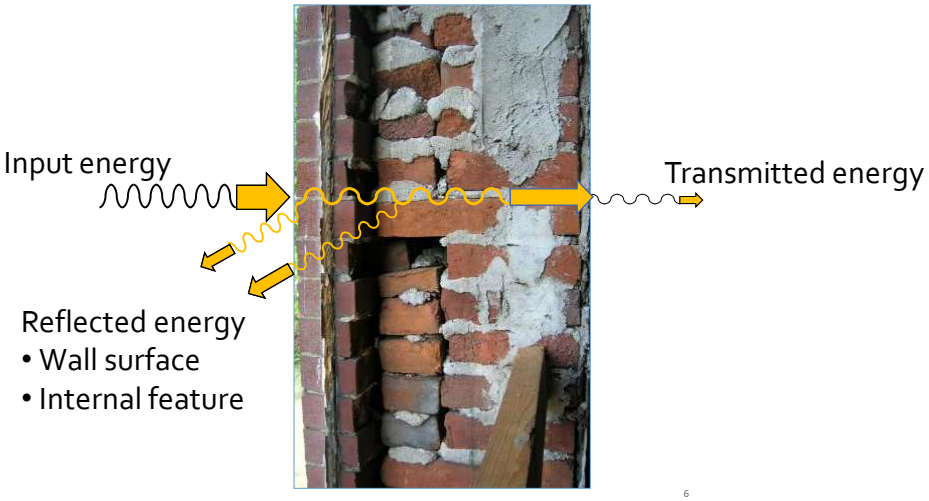
What is nondestructive evaluation?

- Energy "interacting" with the wall section



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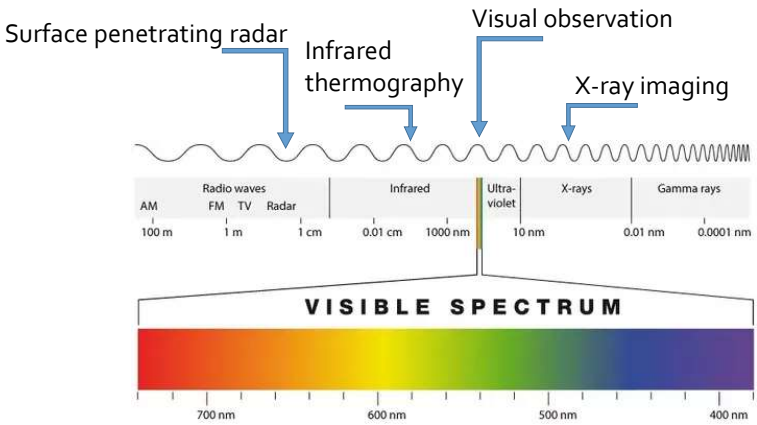
What is nondestructive evaluation?

- Energy
  1. Electromagnetic energy



www.quora.com

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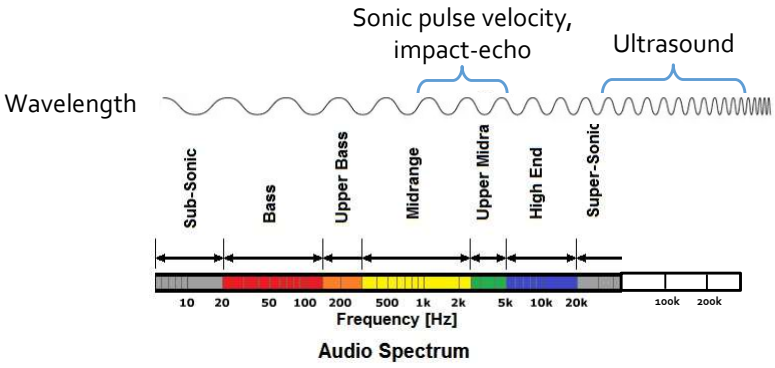
What is nondestructive evaluation?

- Energy
  1. Electromagnetic energy
  2. Stress wave energy



www.audioreputation.com

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Nondestructive Evaluation (NDE)

- Visual
- Moisture meter
- Rebound hardness
- **Drilling resistograph**
- Metal location
- **Pulse velocity**
- Impact-echo
- Sounding
- **Microwave radar**
- **Infrared thermography**
- **Borescope**

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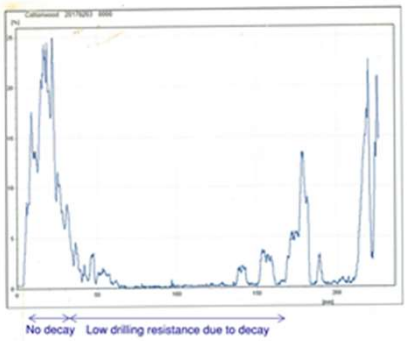
Resistance Drilling

- Wood "hardness" - Measures *resistance*
- Can locate decay not visible on the member surface



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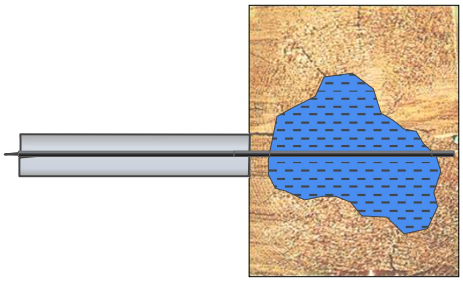
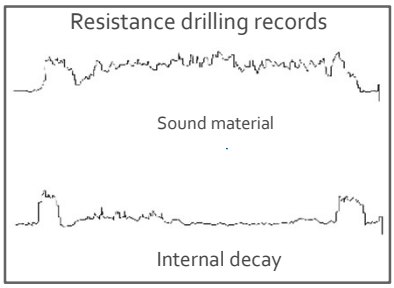
Resistance Drilling - Applications

Area of member suspected to have decay:

- Where?
- Size?
- Extent of degradation?

- Resistance is *consistent* through sound material
- Resistance *changes* where areas of decay exist
- Strong indicator of *relative quality*, but not necessarily *strength*





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Pulse Velocity Testing

- Wood, concrete, masonry, steel
  - Ultrasonic
  - Sonic (mechanical pulse)
- Parameters of interest
  - Arrival time: velocity
  - Amplitude: attenuation
  - Frequency: attenuation, reflections from subsurface anomalies

Steel: ultrasonic thickness meter

ASTM C597: *Test Method for Pulse Velocity Through Concrete*

Sylva Test - wood density: quality, strength?

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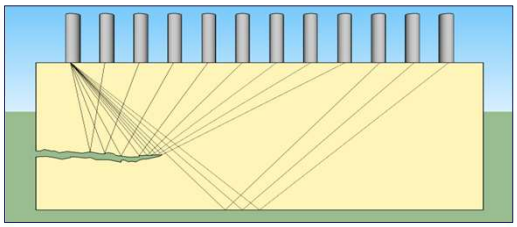
What's new?

- Ultrasonic Array "B-Scan"



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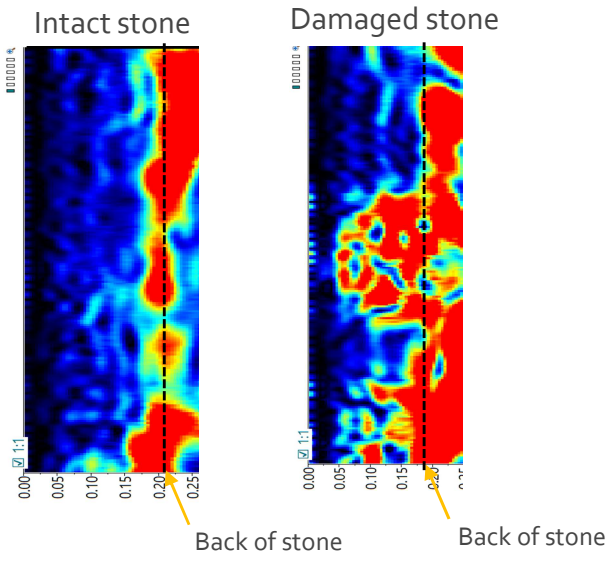
Ultrasonic B-scan



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Sounding

- Hollow vs. solid
- Near-surface delaminations
  - Plaster delaminations
  - Spalls, separations
- ASTM C4580
  Chain-drag method – bridge deck delaminations

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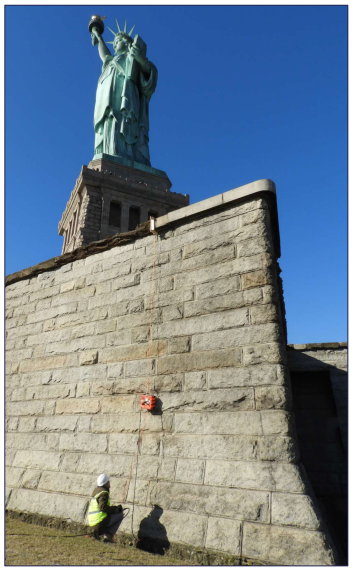
Surface Penetrating Radar (SPR)
a.k.a Ground Penetrating Radar (GPR)

- Thickness
  - Slab
  - Walls
  - Stones
- Metals
  - Structural steel
  - Reinforcement
  - Anchors
- "Anomalies"
  - Voids
  - Changes
  - Moisture, salts
- ASTM D6432



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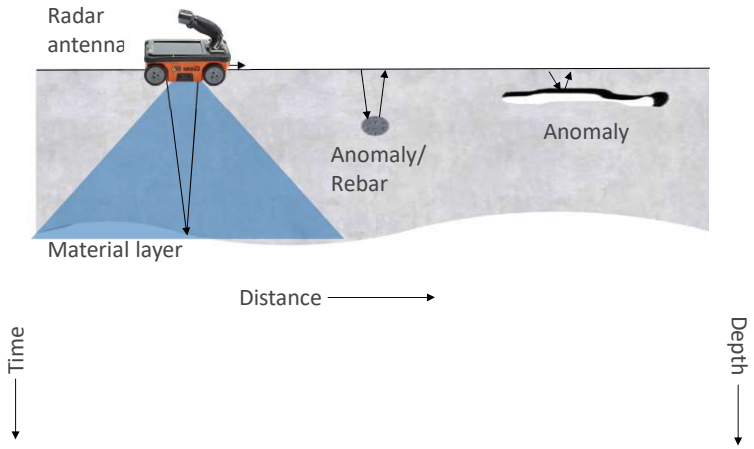
Acquiring a radar trace (SPR)



GSSI Mini XT Image Source: Line Surveying

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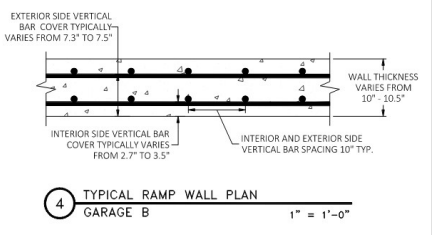
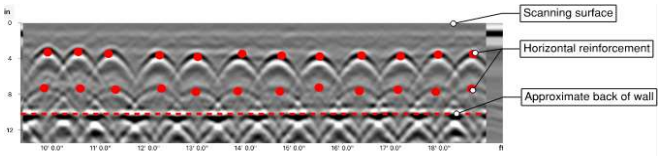
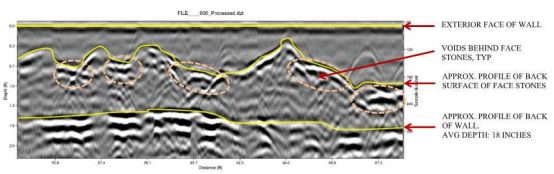
Surface Penetrating Radar



Existing Condition





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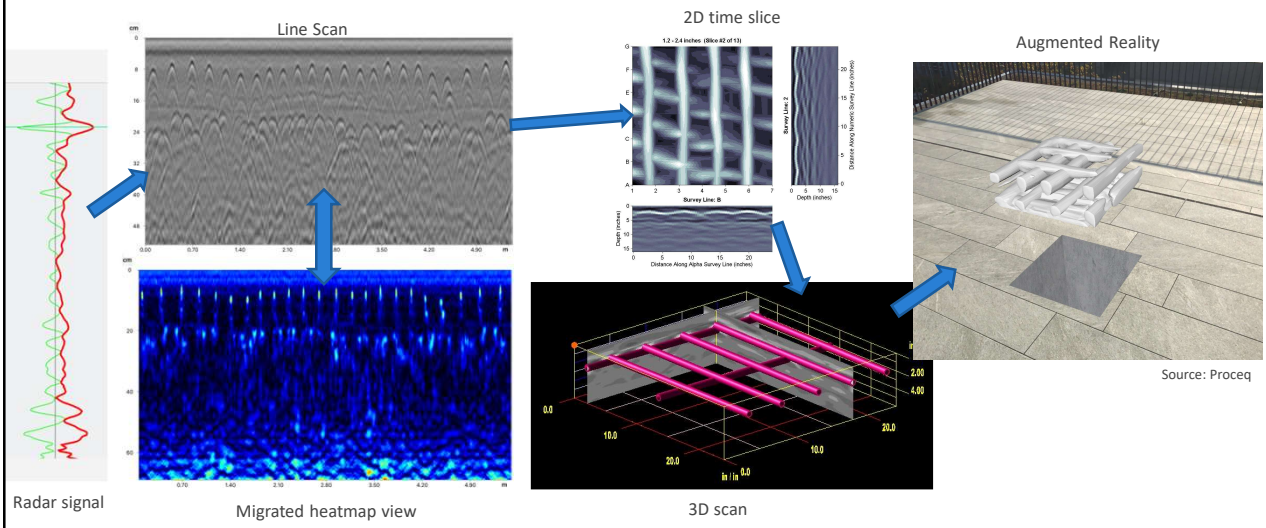
From Line Scans to Augmented Reality



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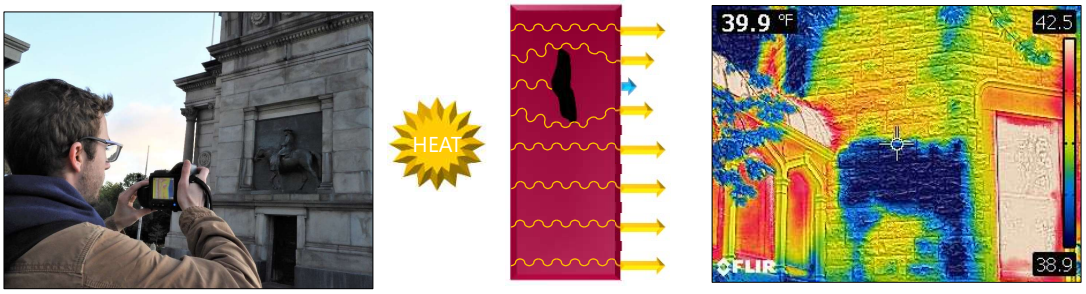
Infrared Thermography: *IRT*

What is it?

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



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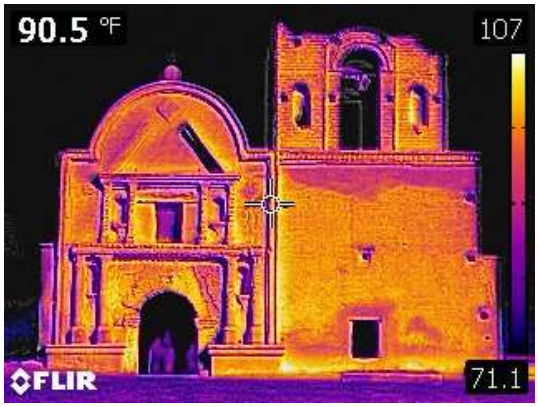
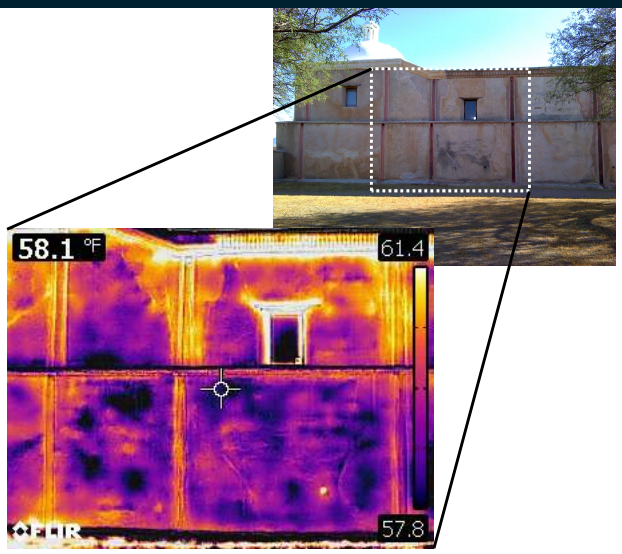
Infrared Thermography: *IRT*



Tumacacori National Historical Park, Arizona



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- Nondestructive methods
  - No effect on materials
  - Rapid
  - Correlation with material properties?
  - Inexpensive?
- In situ testing
  - Direct measure of material response
  - "Moderately" destructive

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Evaluating Wood In Situ

- Condition
  - Moisture
  - Decay
  - Insect damage
- Species
  - Sample removal: hand saw, hole plug
  - ½" x ½" x thin
  - USDA Forest Products Laboratory https://www.fpl.fs.usda.gov/
  - Grade

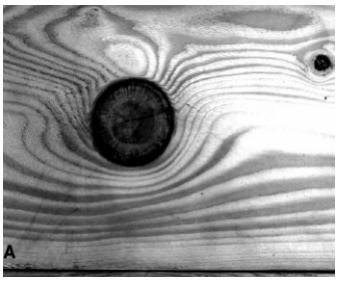

Photo: Anthony & Associates

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Why grade your timber?

- Engineers are conservative
- Most older wood – very high quality
- Capacity limited by flexure?
  - "Getting a good grade" will help!

Species/Grade	Size Classification	Max Fiberstress	Modulus of Elasticity	Max Shear
Douglas Fir-Larch				
Dense Select Structural	**Beams and Stringers**	1850 PSI	1.7 Million PSI	170 PSI
Select Structural		1600 PSI	1.6 Million PSI	170 PSI
Dense No.1		1550 PSI	1.7 Million PSI	170 PSI
No.1		1350 PSI	1.6 Million PSI	170 PSI
Dense No.2		1000 PSI	1.4 Million PSI	170 PSI
No.2		875 PSI	1.3 Million PSI	170 PSI
Dense Select Structural	**Posts and Timbers**	1750 PSI	1.7 Million PSI	170 PSI
Select Structural		1500 PSI	1.6 Million PSI	170 PSI
Dense No.1		1400 PSI	1.7 Million PSI	170 PSI
No.1		1200 PSI	1.6 Million PSI	170 PSI
Dense No.2		800 PSI	1.4 Million PSI	170 PSI
No.2		700 PSI	1.3 Million PSI	180 PSI

Allowable design stress: Douglas fir/larch

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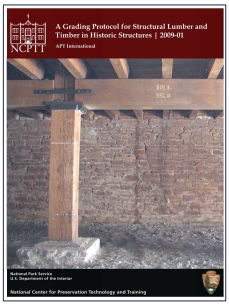
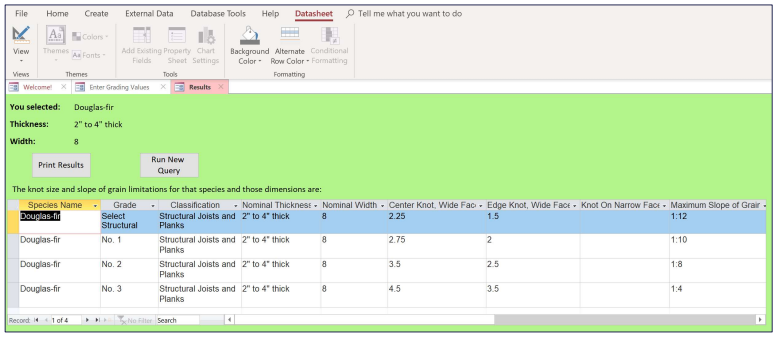
Timber Grading Protocol



https://ncptt.nps.gov



"Manual" for timber grading

- History of timber grading
- Grading procedures
- Timber grading database

Grade:

- Measure grade-limiting characteristics
- Knots
- Defects
- Slope of grain

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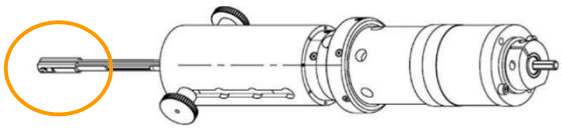
Wood load-jacking

- Emerging method for performing compression stress-deformation measurements directly on a wood member in situ



Surface area of jack

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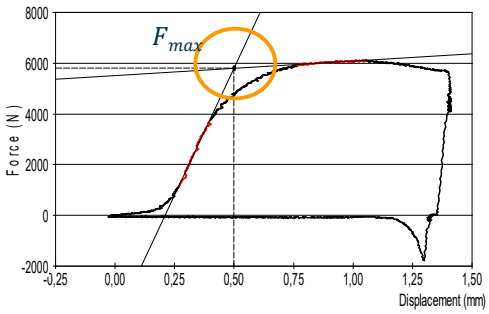
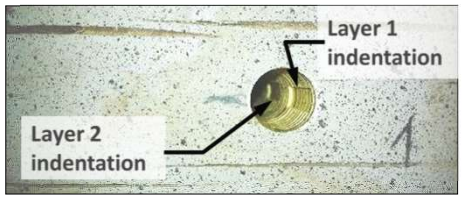
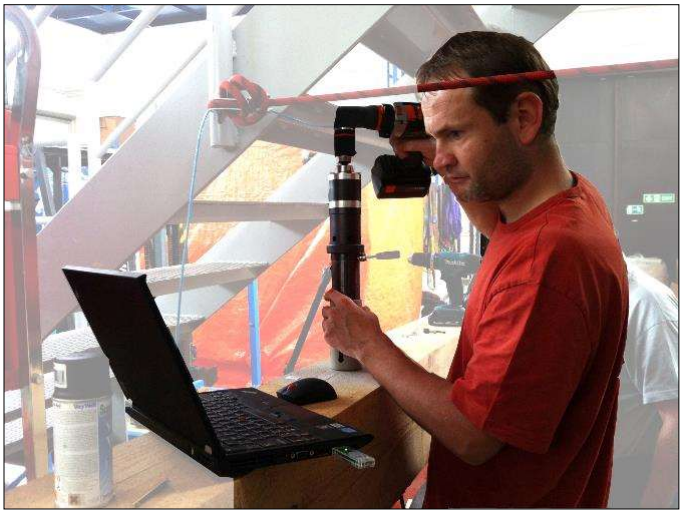
Wood load-jacking



Yield Point = 57,990 N/mm Module = 20023,985 N/mm





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Borehole dilatometer

- In situ deformability: compression modulus

Roctest.com

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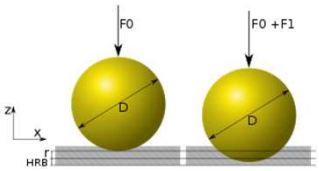
Metal Hardness

- Rockwell Hardness
- Brinell Hardness

Imprint Diameter (Inches)	BHN	Strength (PSI)	Working Pressure (PSI) *
0.038	36.6	52,045	46,900
0.039	34.8	49,486	44,489
0.040	33.0	46,926	42,256
0.041	31.4	44,651	40,185
0.042	29.9	42,518	38,260
0.043	28.5	40,527	36,461
0.044	27.2	38,678	34,796
0.045	26.0	36,972	33,234
0.046	24.8	35,266	31,713
0.047	23.8	33,844	30,405
0.048	22.7	32,279	29,120
0.049	21.8	31,000	27,914
0.050	20.9	29,720	26,719
0.051	20.1	28,582	25,710
0.052	19.3	27,445	24,703
0.053	18.6	26,449	23,751
0.054	17.9	25,454	22,852
0.055	17.2	24,458	22,002
0.056	16.6	23,605	21,196
0.057	16.0	22,752	20,433
0.058	15.4	21,899	19,109



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In situ tests

Engineering properties - masonry

- Existing stress: ASTM C1196
- Compressive strength: ASTM C1197
- Shear strength: ASTM C1531
- Bond strength: ASTM C1072
- Anchor capacity: ASTM E488

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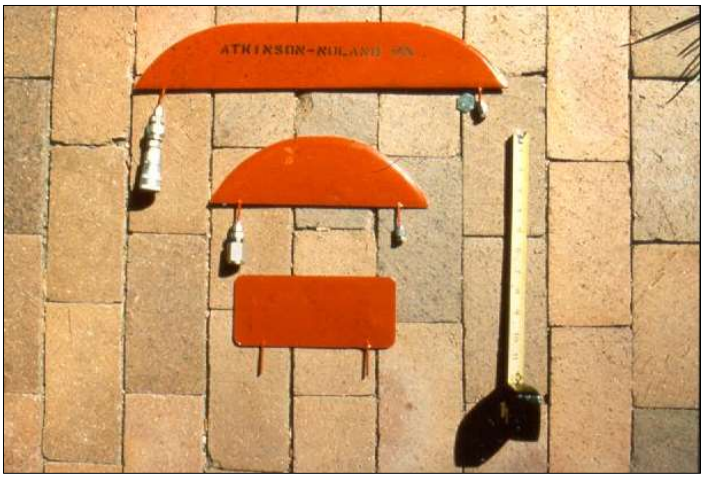
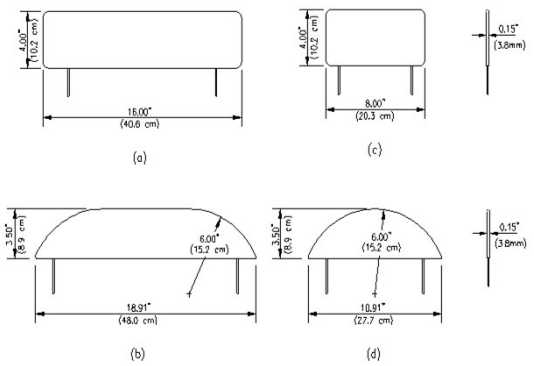
Masonry Flatjacks





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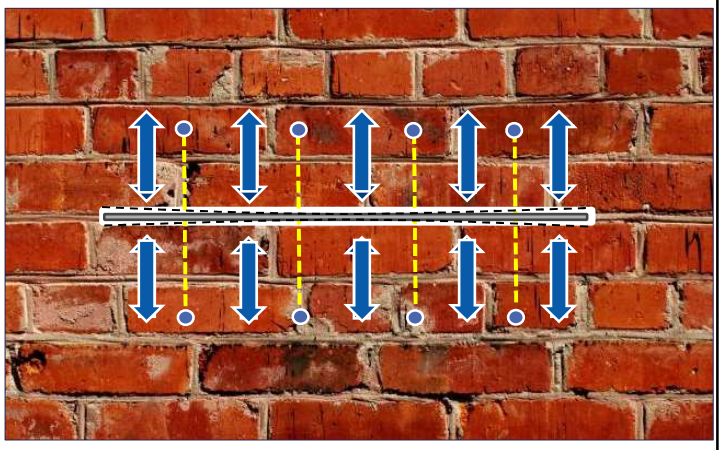
In Situ Stress Test

- Direct measure of compression stress in the wall
  - Measure dead load stresses
  - Stress distribution in arch, vault
  - Stress gradient across wall: bending moment/flexure
  - Long term monitoring



ASTM C1196, *In Situ Compressive Stress Within Solid Unit Masonry Estimated Using Flatjack Measurements*

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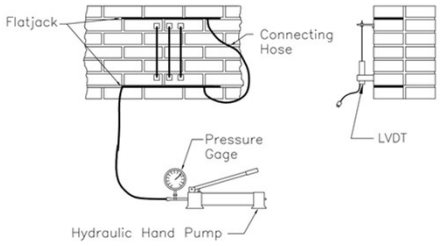
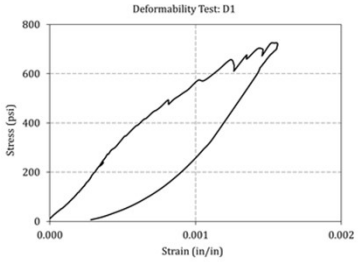
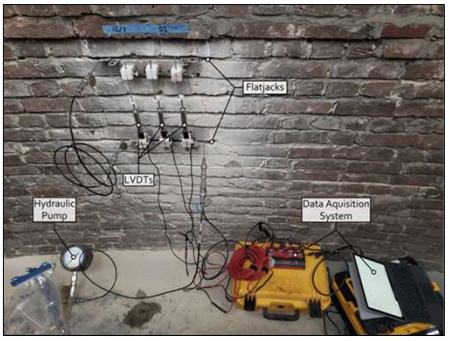
Deformability Test - Compression Behavior







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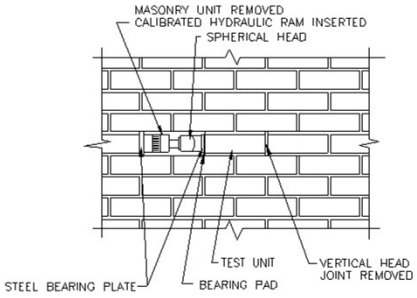
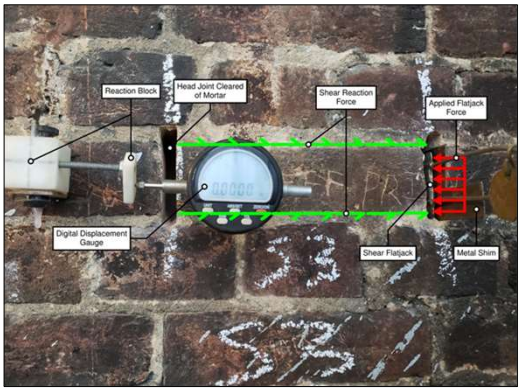
Shear Test - Bed Joint Shear Strength

Very difficult to remove specimens for lab testing without damage…

ESPECIALLY IN HISTORIC MASONRY!





ASTM C1531, *Standard Test Methods for Determination of Masonry Mortar Joint Shear Strength Index*

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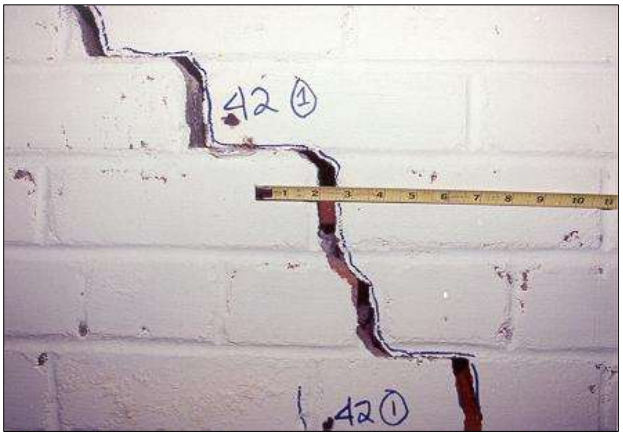
In Place Shear Test

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



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Planning an Investigation

How best to employ NDE and NDT

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Planning an Investigation
What information do you need?

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

- Assemble *a priori* information
  - Original drawings
  - Photographs
  - Prior reports
  - Repair drawings
  - Maintenance records

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Planning an investigation

- Confidence limits, expected accuracy
- How many tests?
  - New construction: 3 specimens = 1 test
  - How variable is the construction/condition?
  - Different construction eras
  - Different materials
  - Deterioration/damage

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Planning an investigation

- Confidence limits, expected accuracy
- How many tests?
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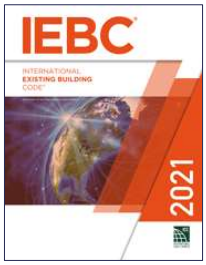

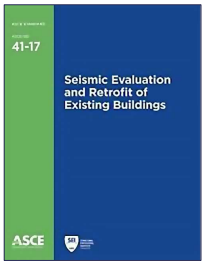

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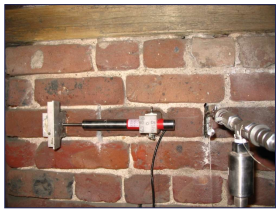
International Existing Building Code (IEBC)

Appendix Chapter A1
Guidelines for the Seismic Retrofit of Existing Buildings

- Testing
  - Masonry shear strength: locations, number of tests
  - Anchors: test new and existing anchors



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Industry Best Practices:

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

- As-built information
  - Original drawings, specifications
  - Building codes of the construction period
  - Maintenance records
  - Interviews
- Supplement and verify by onsite investigations
  - Nondestructive evaluation
  - Testing building materials, components

At least one site visit required to verify information represents existing conditions

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Industry Best Practices:
ASCE 41: *Seismic Evaluation and Retrofit of Existing Buildings*

Steel, concrete, masonry, wood

- Types of tests
- How many tests?
- Default material properties

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Industry Best Practices

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

"Usual" Testing

Number of tests required:

- If specified f'_m is known: 3 min. per building
- Otherwise: 6 min. per building

f'_m: *specified masonry compressive strength*

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Industry Best Practices

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

"Comprehensive" Testing

Masonry in **fair** or **good** condition

Number of tests required:

- 3 tests for each masonry type
- For each 3 floors or 3000 ft² wall area:
  - With original const. records: 3 tests
  - Without records: 6 tests
- 2 tests per each line of shear wall elements
- Minimum 8 tests per building

Masonry in **poor** condition

Number of tests required:

- Conduct additional tests to estimate strength at areas with varying condition

  OR

- Use nondestructive tests to quantify variations in material strength

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Diagnostics should be driven by ANSWERS not TOYS!

"I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail."

- **Abraham Maslow,** The Psychology of Science, 1966

- In the world of NDE, it has become increasingly common to sell services rather than solutions.
- Beware of the "single method" sell

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Radar Evaluation

Beware of:

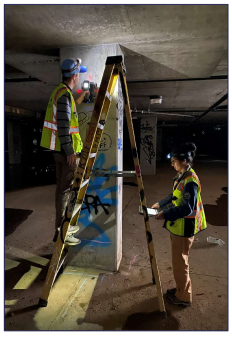
- Large metal inclusions
- Moisture and salt variations

Use complementary methods:

- Impact echo
- Metal detectors
- Moisture meters
- Borescope examination
- Infrared thermography

Resistance-based

Electromagnetic-based



Metals: pachometer

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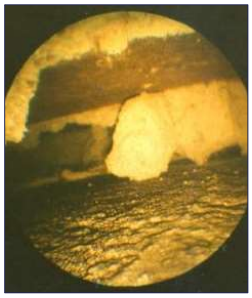
Planning an Investigation

How best to employ NDE:

- Be prepared for *validation/proofing*
  - Complementary methods
  - Laboratory mockups
  - Borescope
  - Probes
- Expensive repairs?
  - *Verify*



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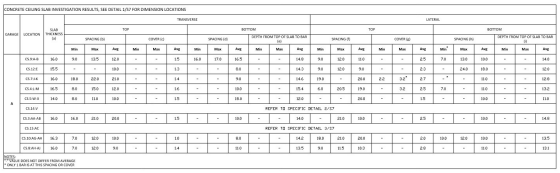
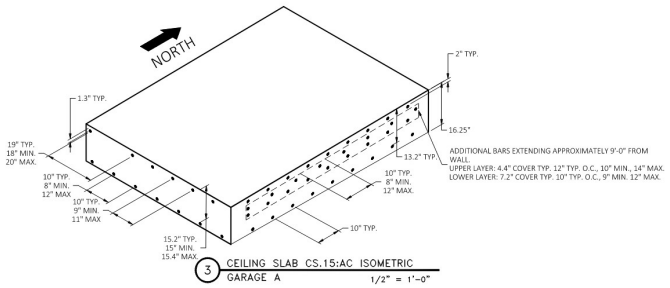
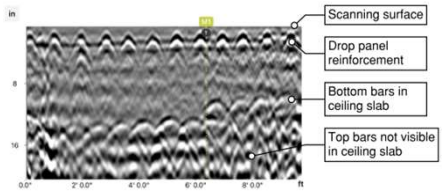
The Building Diagnostics Report

- Moving away from data-driven reporting
  - ➔Graphical representation of results
  - ➔Random sample areas
  - ➔Statistical evaluation







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Stone thickness, internal construction

Existing Condition

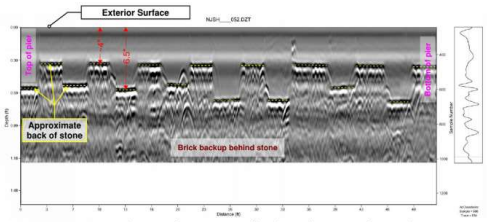
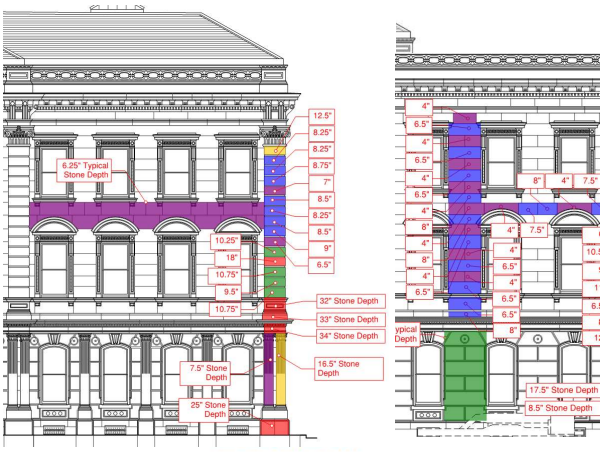


Figure 5.1. Representative vertical SPR scan taken at an exterior wall on the west elevation. Here, the stones alternate in thickness very regularly, which should not be considered the typical condition.

Typical GPR Scan



New Jersey Executive State House

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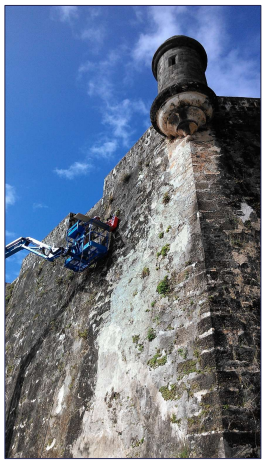
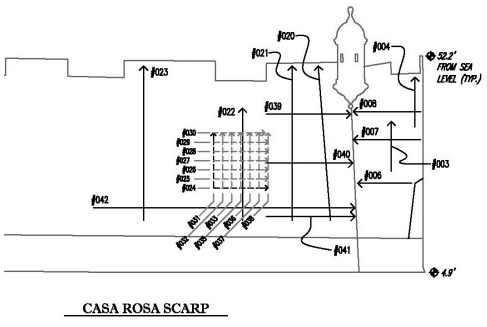
Internal Voids

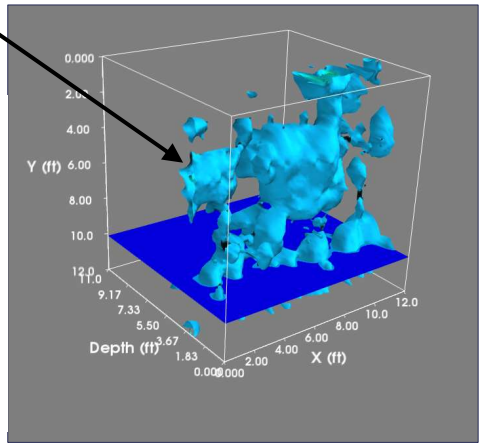
- Defining the extent of repairs





Cliffside erosion behind scarp wall

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



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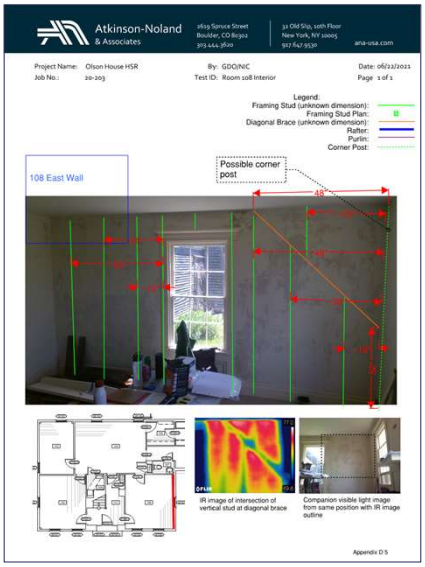

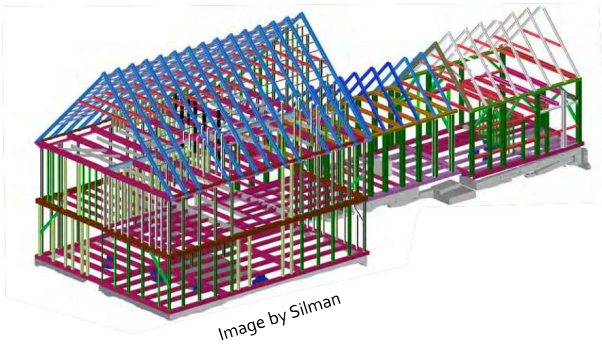

Image by Silman

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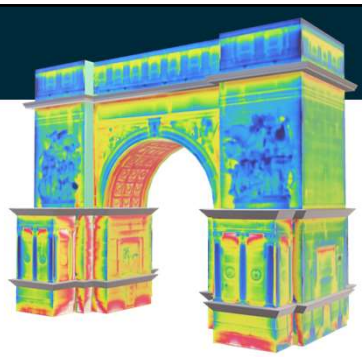
Infragrammetry

Photogrammetry concepts…

- IR images are low resolution:
  - 76,800 pixels per image
- Rectify images individually
- Stitch
- Overlay onto 3D model



Soldiers' and Sailors' Memorial Arch, Brooklyn

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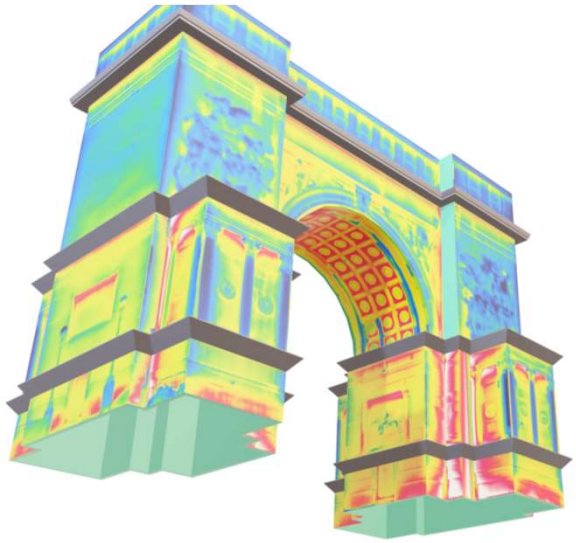
Infragammetry

Reporting: what would you rather have?

- 140 images in an Appendix?
- Interactive 3D model



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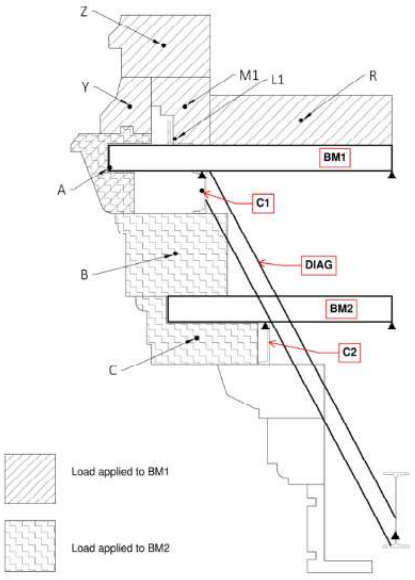
Ultrasonic Thickness

- Member thickness
- Section loss (corrosion)



Steel framing, terra cotta cornice

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Ultrasonic thickness

- Steel framing, terra cotta cornice
  - 541 measurements
  - Many elements – no strengthening required
  - Top beam and channel – moderate to severe section loss

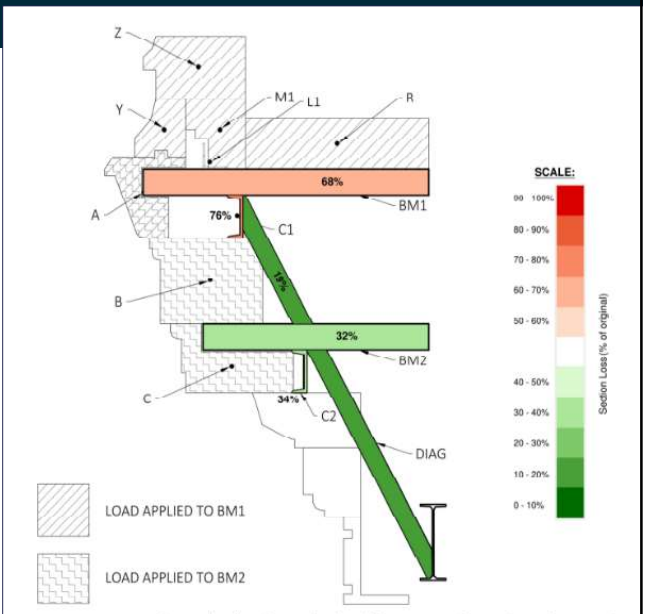

Figure 12. Section view of a typical steel test frame with colored fill annotations indicating the **maximum** tested section loss for each of the five distinct steel elements. These are global maximums and not necessarily recorded at the same test frame.

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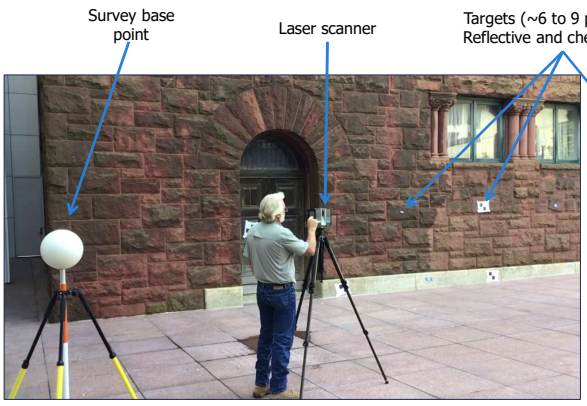
NDE Implementation into BIM Models

Data Collection: Stone Walls



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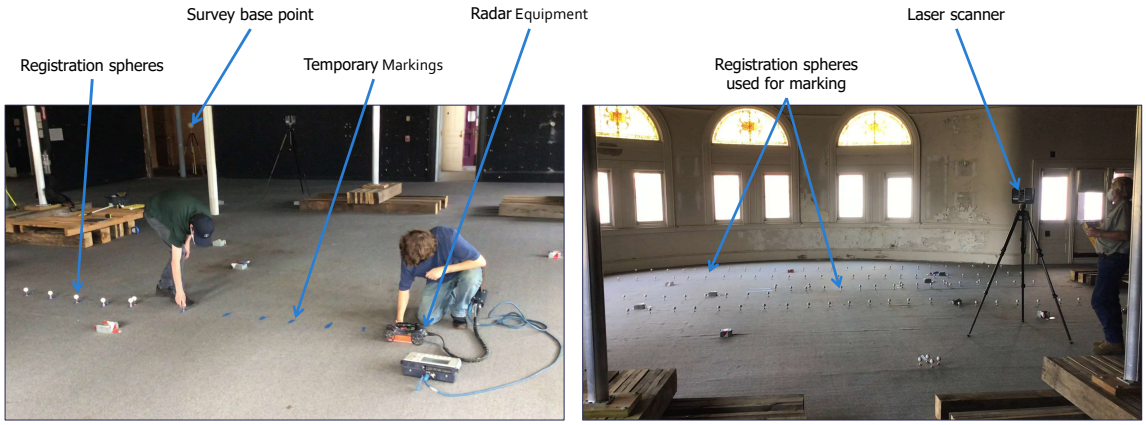
NDE Implementation into BIM Models

Data Collection: Floor Framing



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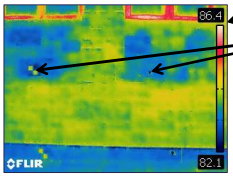
NDE Implementation into BIM Models

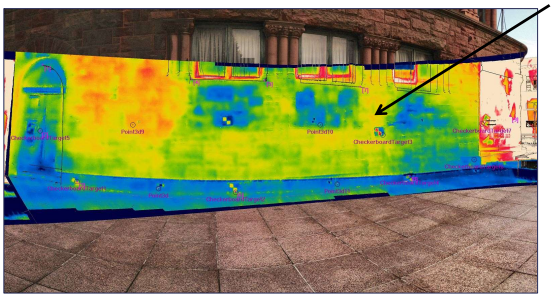
Post Processing: Infrared Thermography



Maintain consistent temperature range

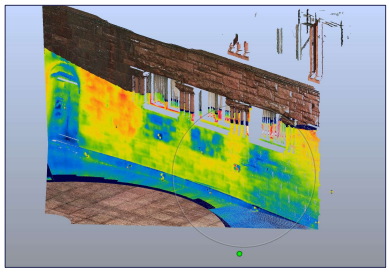
Two types of targets

1. Individual IR Images



Targets in images matched with targets processed in point cloud

2. Match survey targets visible in IR images to reference points in the point cloud



3. Matched points are used to colorize point cloud from IR images

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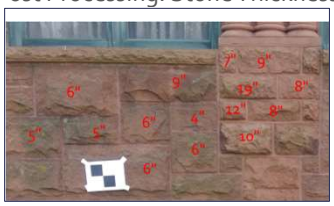
NDE Implementation into BIM Models

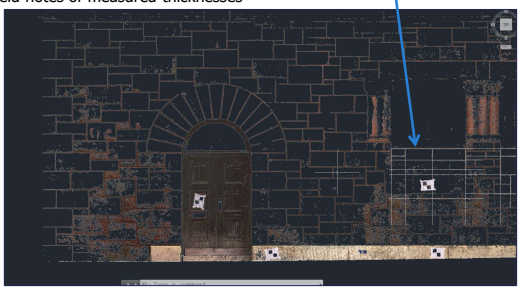
Post Processing: Stone Thickness



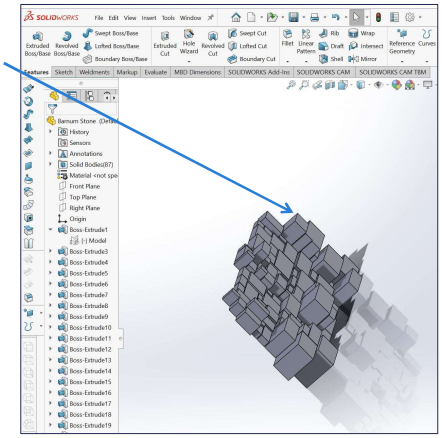
1. Field notes of measured thicknesses

Stone outlines extruded to match dimensions identified in with NDE

Stone mortar joints exported and traced in drafting software



2. Intensity filter to highlight and trace mortar joints



3. Extrude outlined stones to generate 3D profile

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NDE Implementation into BIM Models

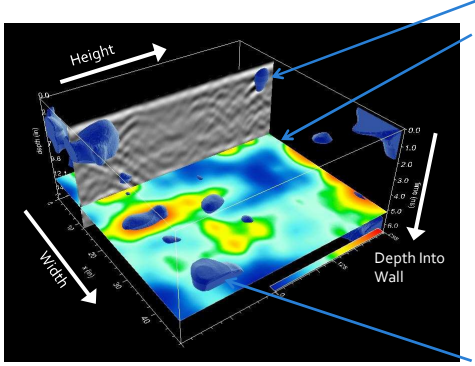
Post Processing: 3D Radar

Individual radar trace

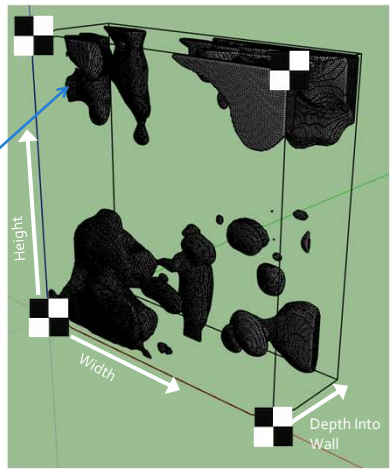
2D contour slice

3D representation of approximate internal void volume

3D contour surface. Calibrate size of iso surface to match internal voiding



1. Align and merge individual traces in processing software to generate 3D surface



2. Export 3D surface into compatible format for final documentation

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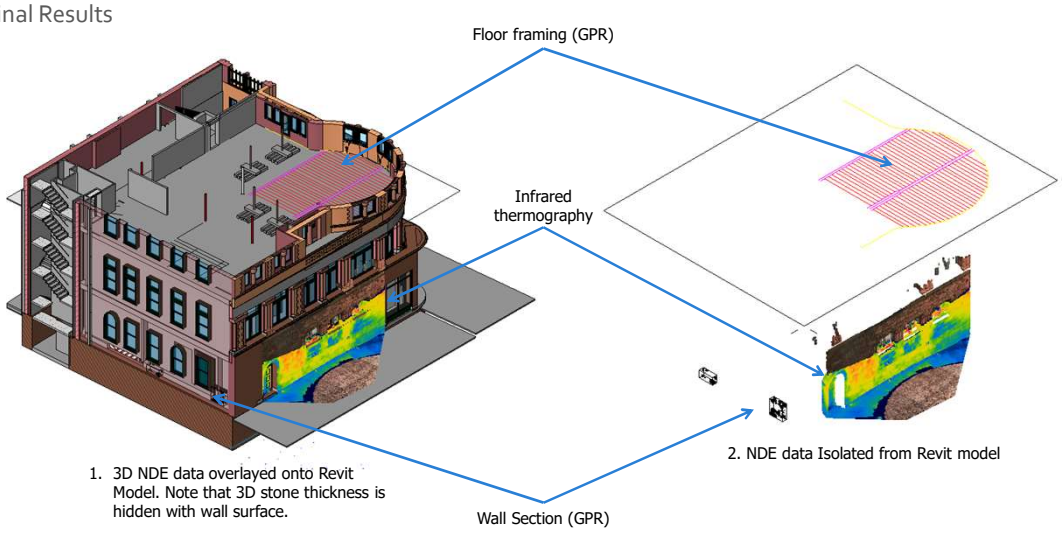
NDE Implementation into BIM Models

Final Results



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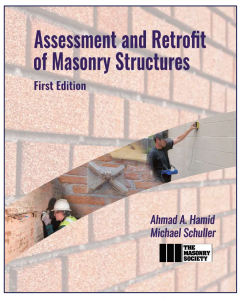
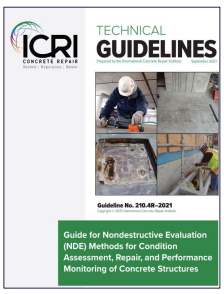
More Information



www.masonrysociety.org



www.icri.org

- APT: Association for Preservation Technology
  - Preservation Engineering Technical Committee
  - Documentation Technical Committee
- TMS: The Masonry Society
  - Existing Masonry Committee
- ACI: American Concrete Institute
  - Committee 228: NDE
- ASCE: American Society of Civil Engineers
  - ASCE 11: Guide for Structural Condition Assessment
- International Concrete Repair Institute
  - Guide: NDE for Concrete

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Diagnostic Procedures for Understanding Existing Construction

Minnesota Structural Engineers Association
2023 Spring Seminar
May 9, 2023

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