

The Role of Non-Destructive Evaluation in the Engineering and Preservation of Concrete Structures

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CONCRETO
ACADEMY



Latourell Creek Bridge. Source: <https://www.hoodriverhistorymuseum.org>

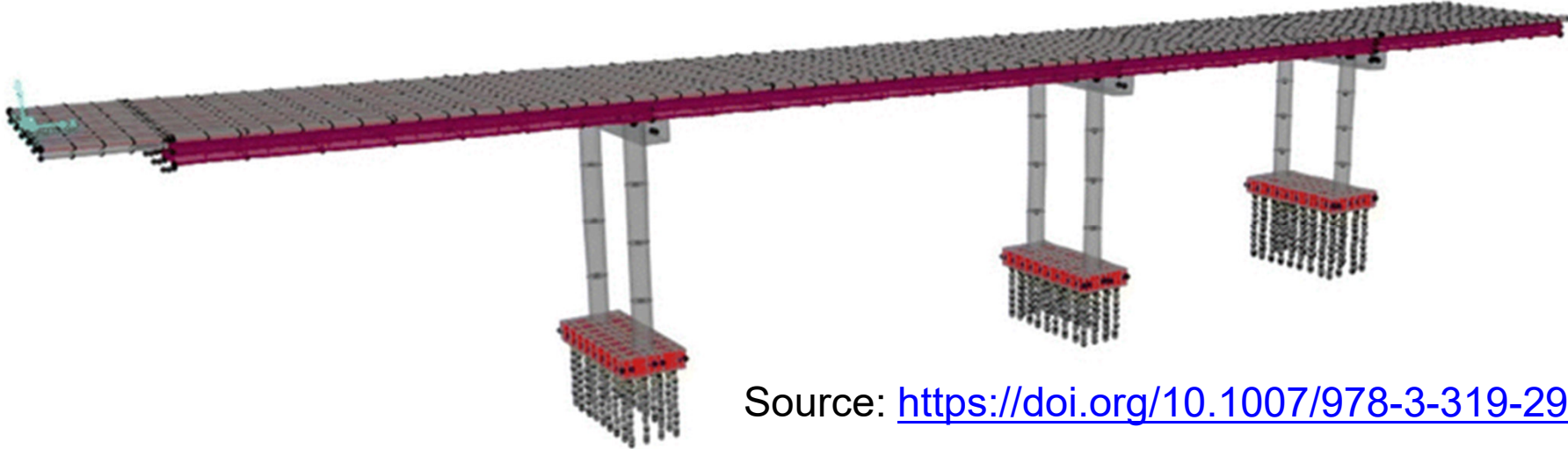
Outline

- **Introduction to non-destructive evaluation (NDE)**
- **Two NDT case studies**
 - *NDT-supported load rating of a prestressed concrete bridge without plans*
 - *Image fusion to confirm a hidden corridor in the Great Pyramid*
- **Two SHM case studies**
 - *Ultrasonic monitoring of a full-scale RC bridge under lateral loading*
 - *Acoustic emission monitoring of an in-service bridge for prestress wire breaks*
- **Conclusions and outlook**
- **New M.S. focus area at PSU**



How can NDE help preserve existing structures?

- **Structural condition assessment** ⇒ Input for models, decision making
- **Monitoring after damage is detected** ⇒ Ensure safety until repair done
- **Monitoring after repair** ⇒ Ensure repair works



Source: https://doi.org/10.1007/978-3-319-29751-4_19

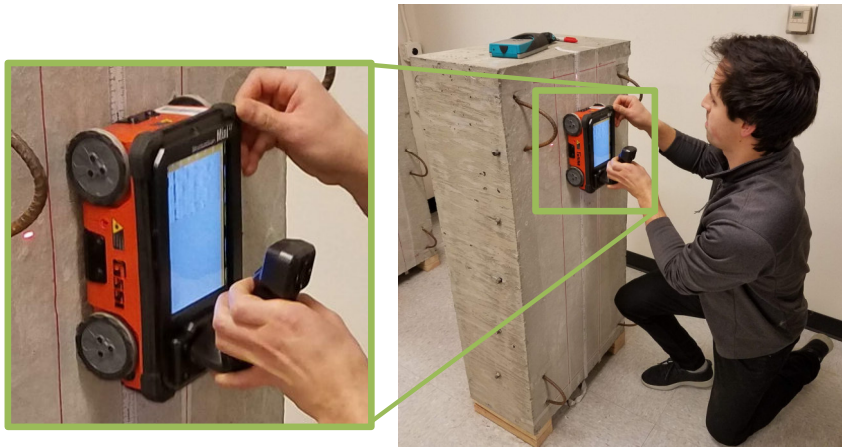
- **Asset management** ⇒ Inform objective decision making
- **Sustainability** ⇒ Extend service-life, avoid unnecessary replacement
- **Digitalization** ⇒ Create digital models, support digital twins



Non-destructive evaluation (NDE)

Non-destructive testing (NDT)

- Intermittent - few measurements
- Active - stimuli known/controlled
- Absolute - to determine as-is



GPR scanning of RC specimen during graduate course.

Structural health monitoring (SHM)

- Continuous - short or long-term
- Passive - stimuli unknown
- Relative - to capture change



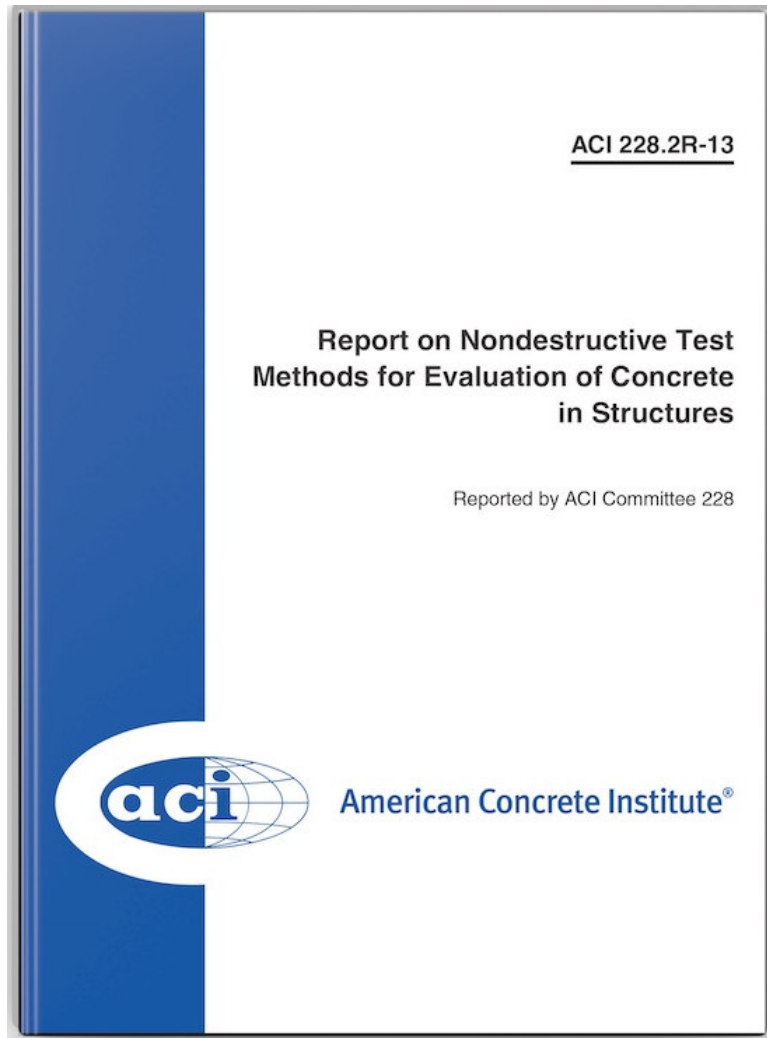
Long-term SHM of Indian River Inlet Bridge. Source: Skanska USA.

Measurement – Signal processing – Analysis – Visualization – Evaluation

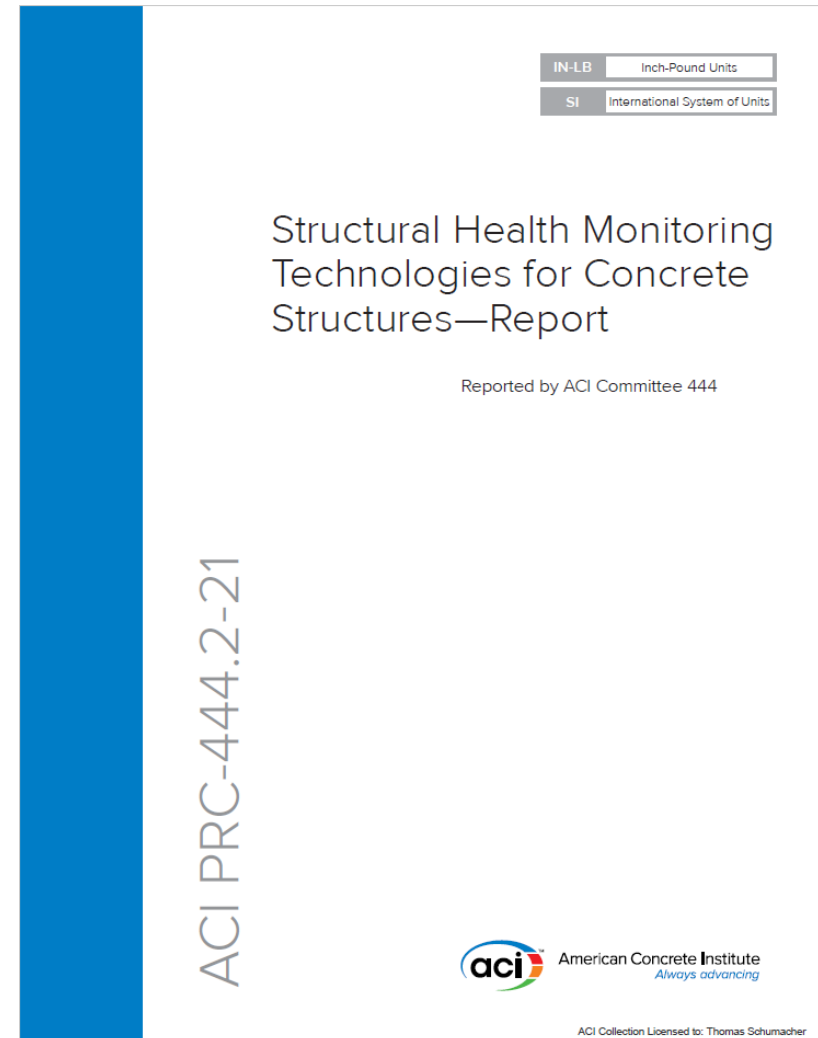


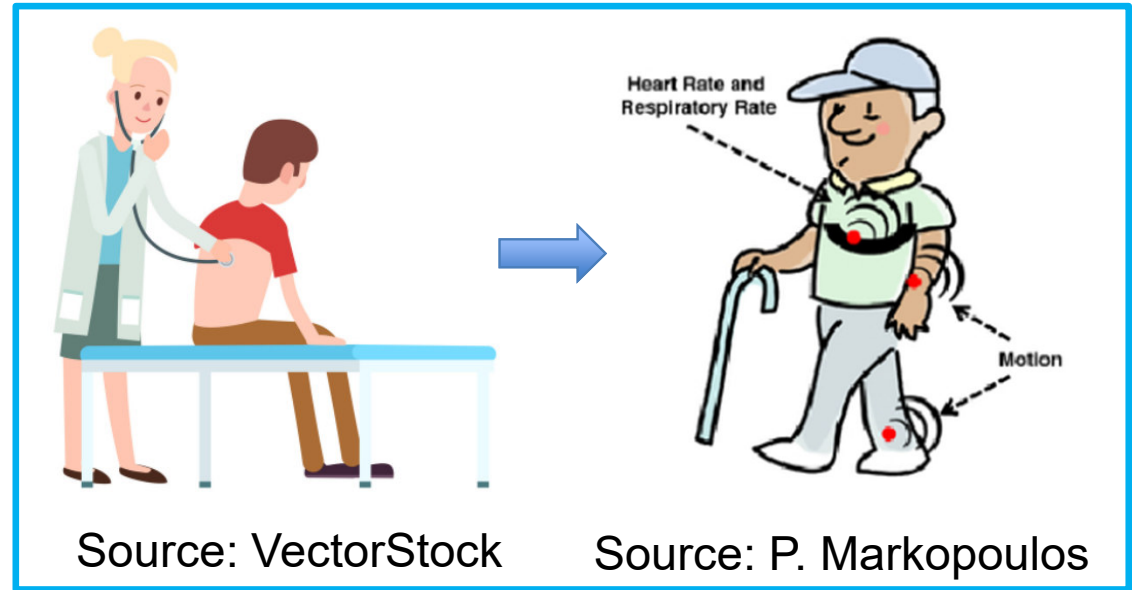
Non-destructive evaluation (NDE)

Non-destructive testing (NDT)



Structural health monitoring (SHM)



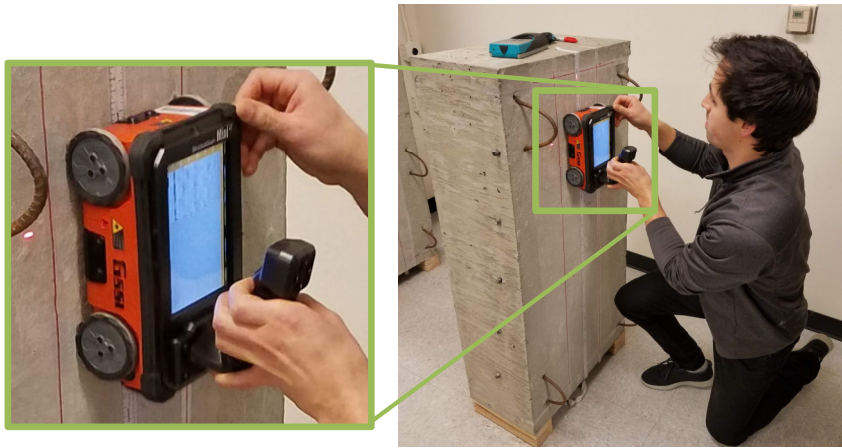




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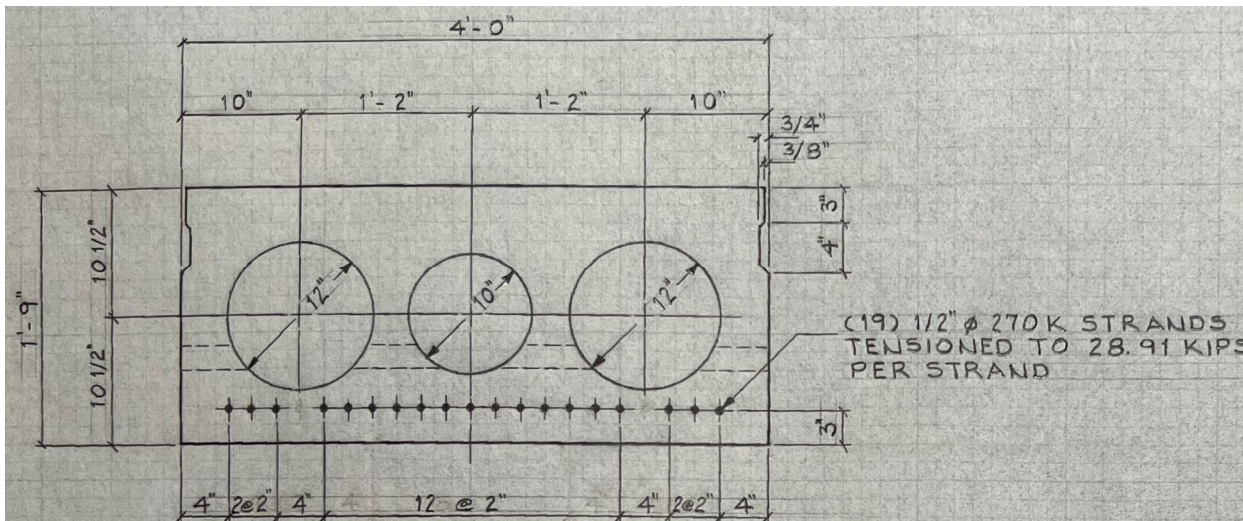
Case study 1: Background



Task: Bridge load rating

Problem: No as-built plans exist!

- Simply-supported, span ~ 14.6 m
- Three side-by-side prestressed concrete voided (?) slabs ($b \times h \times L = 1.22$ m \times 0.53 m \times 15.2 m)
- Transverse post-tensioning
- How many strands? Concrete cover?
- How many voids? Size? Location?



Best guess based on age
(1960s)

Case study 1: Initial site visit



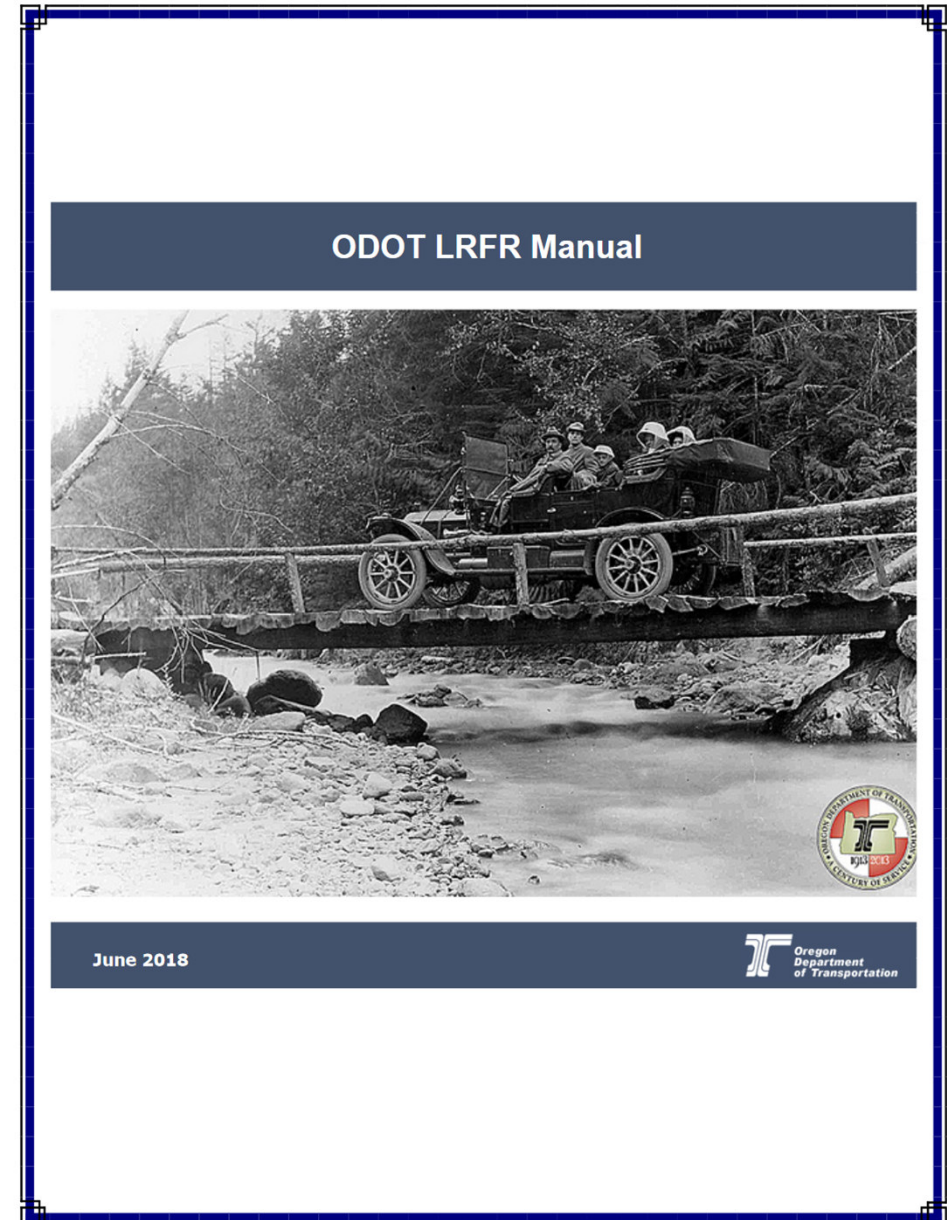


Case study 1: Load rating without existing plans

⇒ 2018 ODOT LRFR Manual, Sec. 15

	No plans method
Truck	Rating factor
AASHTO1 (Type 3)	1.00
AASHTO2 (Type 3S2)	1.00
AASHTO3 (Type 3-3)	1.00
Special Haul Veh's	
Single Unit 4-axles	1.00
Single Unit 5-axles	0.95
Single Unit 6-axles	0.89
Single Unit 7-axles	0.85
Emerg. Veh.2	1.00
Emerg. Veh 3	0.69
Cont. Trip Permit-3	0.95
Single Trip Permit-4A	0.90
HL-93 (Operating)	

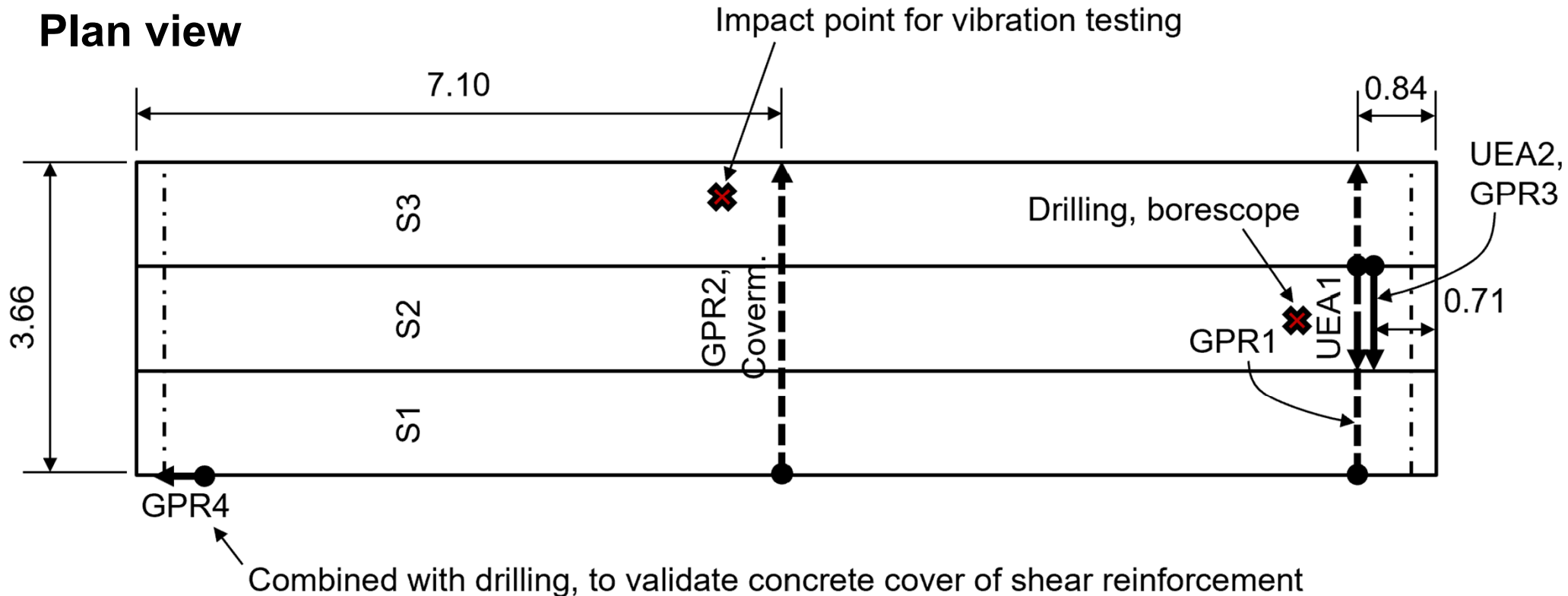
Using this simplistic procedure, bridge does not pass load rating for six vehicles!





Case study 1: Overview of NDT measurements

Plan view



Additional measurements for confirmation

- Vibration testing \Rightarrow Structural parameters (span length, mass, stiffness)
- Covermeter \Rightarrow Concrete cover depth of prestressing strands
- Rebound hammer \Rightarrow Quality of concrete, surface hardness
- Drilling holes \Rightarrow Depth of shear rebars, location and content of void



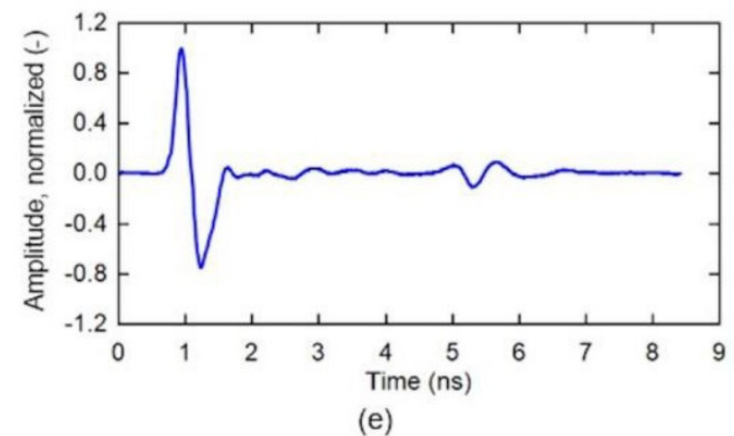
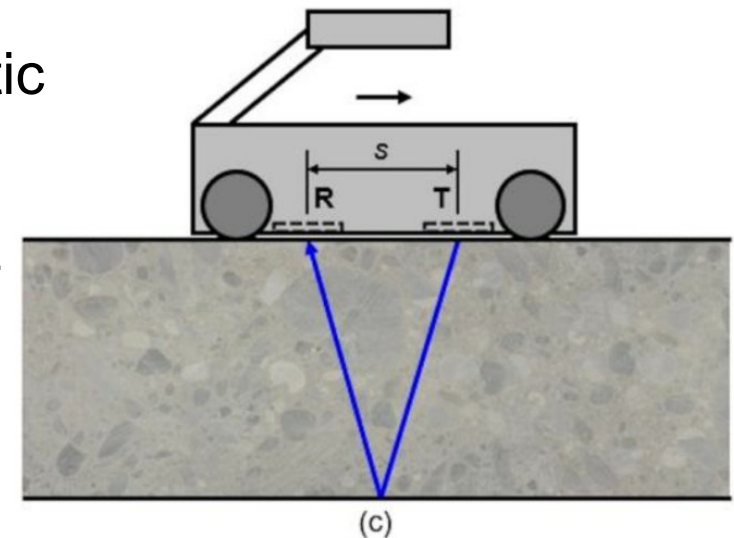
Case study 1: Imaging and image fusion

Ground penetrating radar (GPR)

Source: Schumacher, 2024

Instrument: GSSI StructureScan Mini XT

Wave type:	Electromagnetic
Central pulse frequency:	2.7 GHz
Sampling frequency:	32 to 270 MHz
Spatial resolution:	2.5 mm
Number of transducers/rows:	2/1
Transducer spacing:	60 mm



⇒ Electromagnetic waves ideal for detecting **metallic objects**.



Case study 1: Imaging and image fusion (cont.)

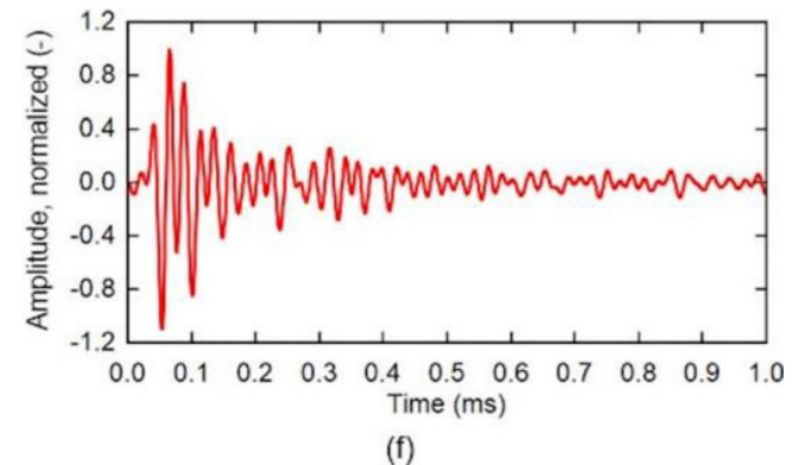
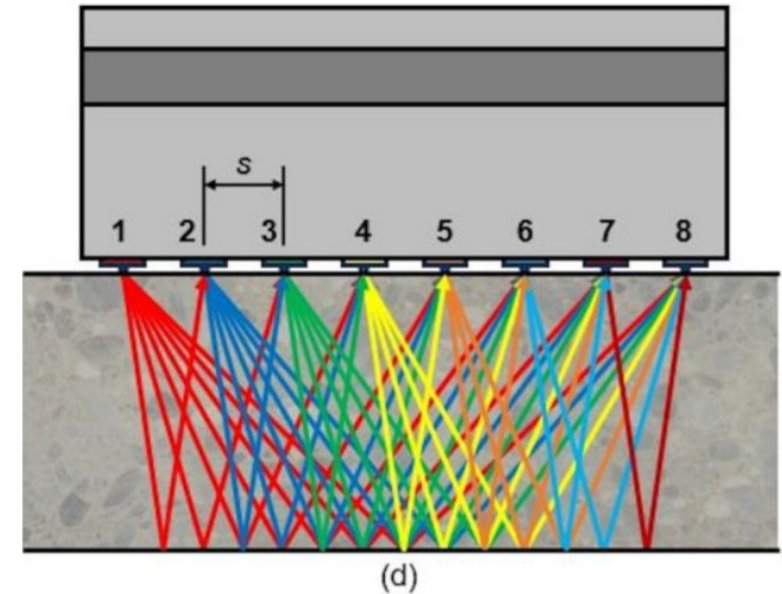
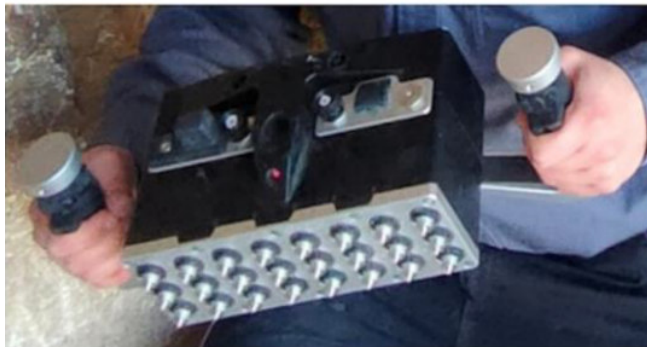
Ultrasonic testing (UST) using array

Source: Schumacher, 2024

Instrument: Proceq Pundit 250 Array

Wave type:	Elastic stress
Central pulse frequency:	40 kHz
Sampling frequency:	1 MHz
Spatial resolution ^(*) :	10 mm
Number of transducers/rows:	8/3
Transducer spacing:	30 mm

(*) Based on measurement step of 50 mm

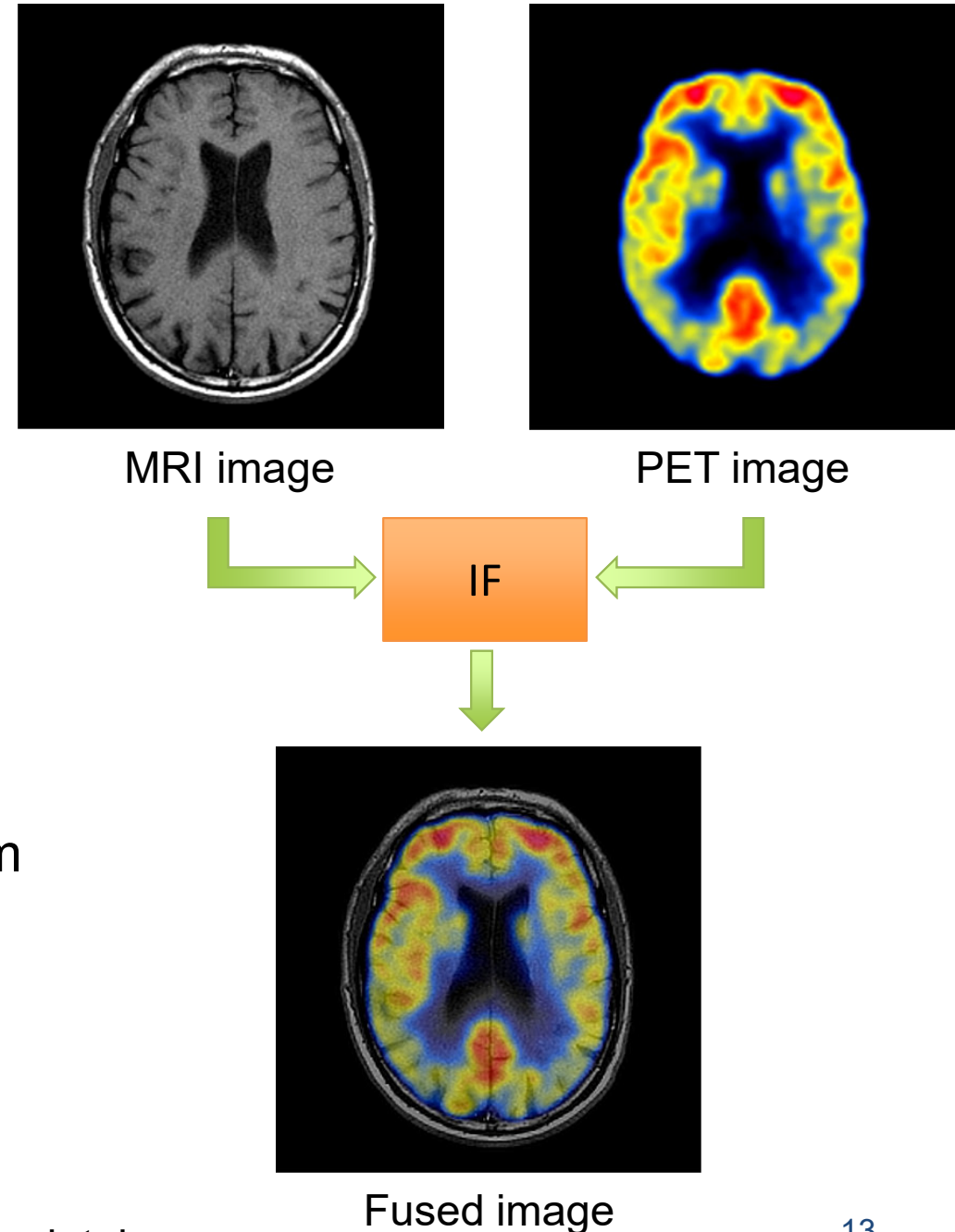


⇒ Stress waves ideal for detecting **air voids and boundaries**.



Case study 1: Imaging and image fusion (cont.)

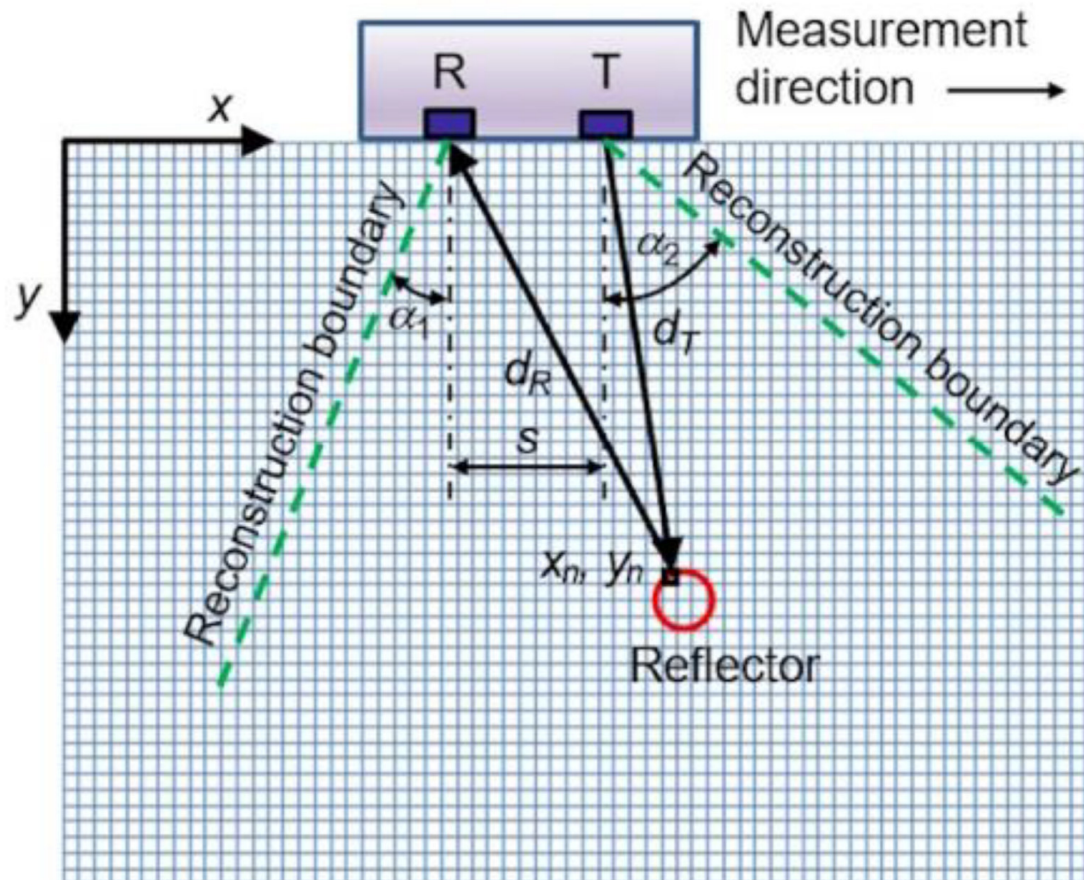
- **Imaging** can reveal **what's inside a concrete structure** by means of a **visual representation**:
 - Member geometry
 - Material properties
 - Reinforcement
 - Voids, cracks
- **Image fusion** merges images from different measurement techniques **into a single composite image**



Case study 1: Imaging and image fusion (cont.)

Synthetic aperture focusing technique (SAFT)

- Technique that generates a focused image of reflectors
- Unknown variables: **Wave speed** and **time off-set**
- Lots of processing options \Rightarrow **There is no “one way” to create an image!**



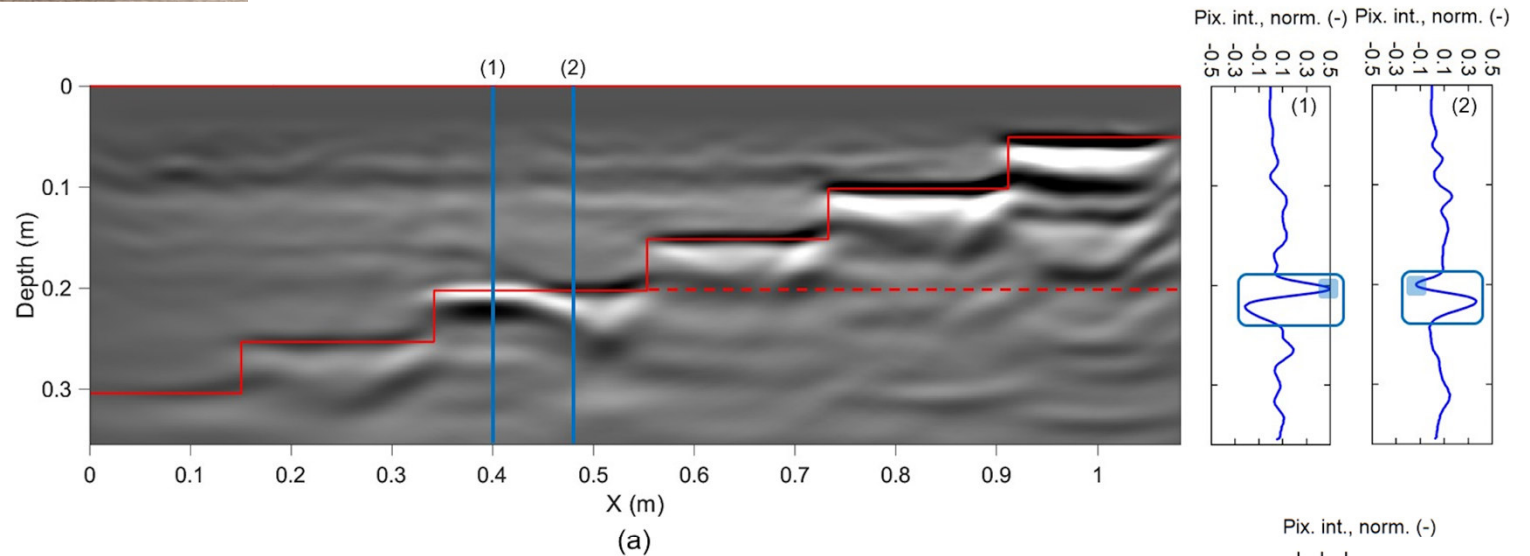


Case study 1: Imaging and image fusion (cont.)

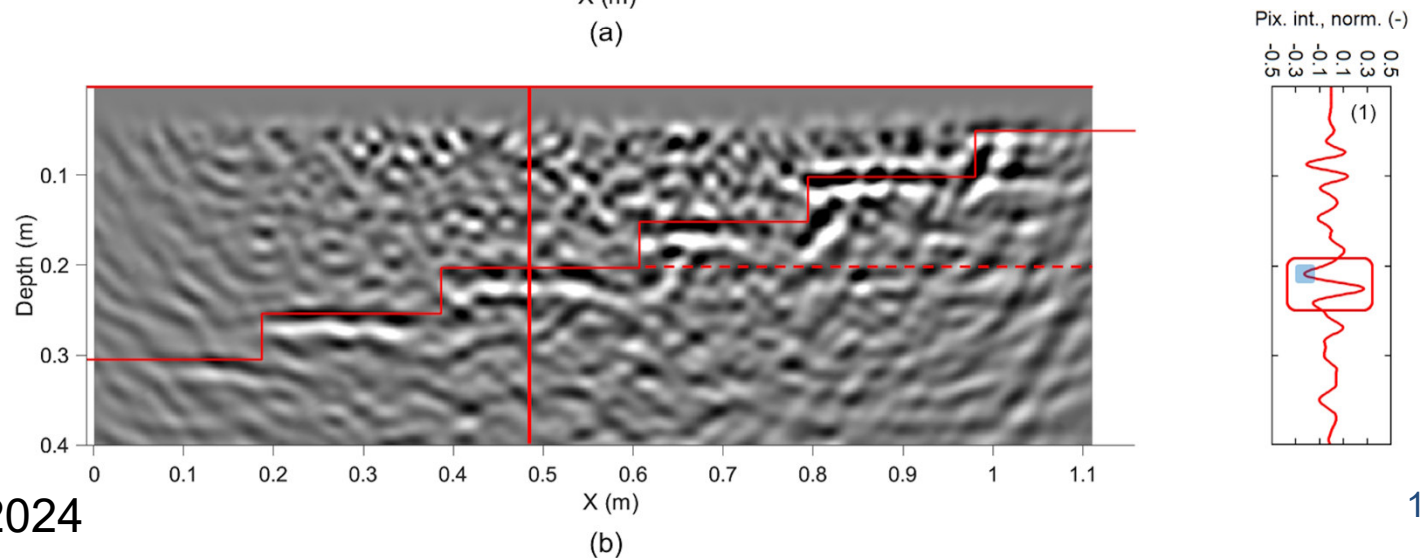
Calibration



GPR



UEA

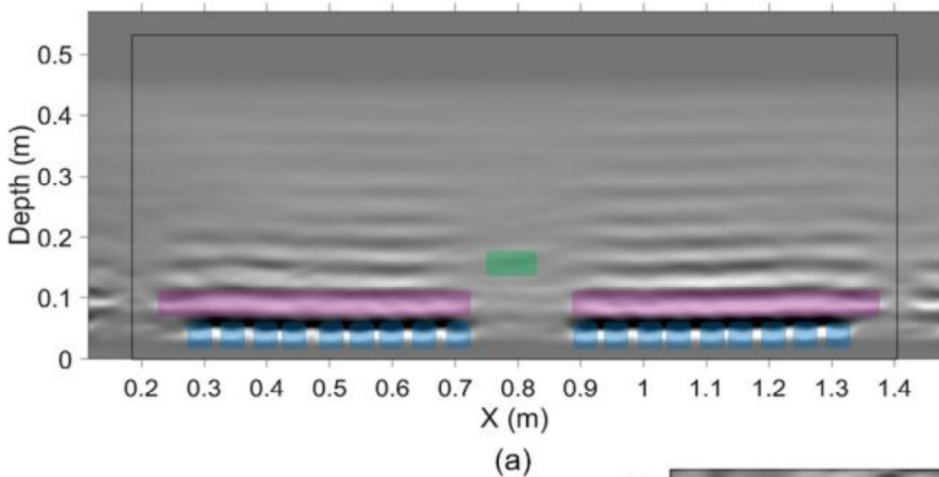




Case study 1: Imaging and image fusion (cont.)

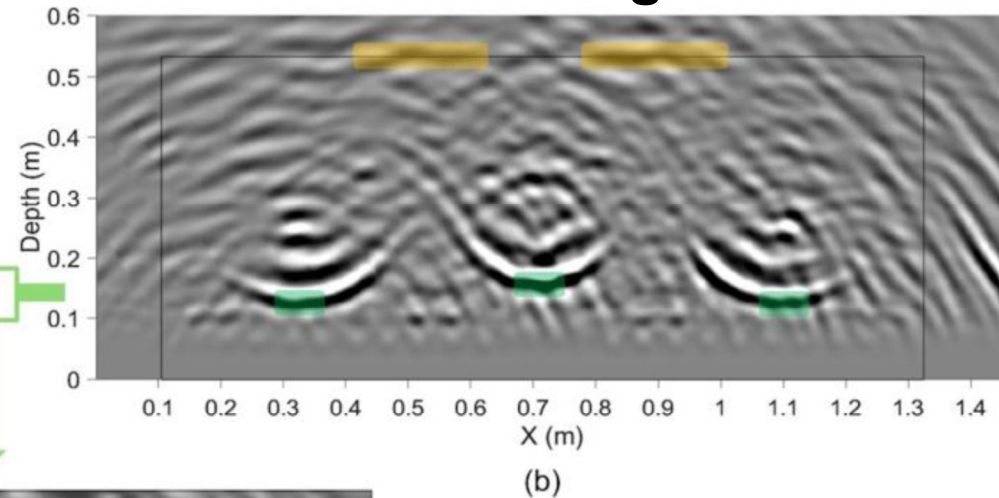
Measurements taken from bottom

GPR image

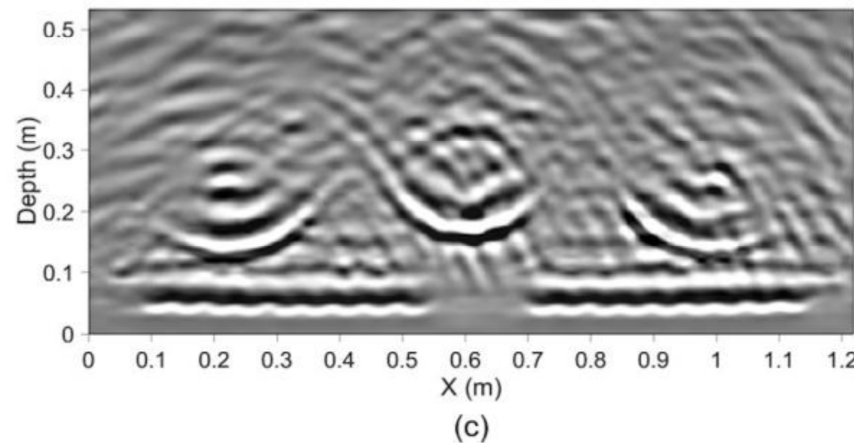


Calibrated EM
wave speed:
 $c = 3.48 \text{ in/ns}$
($88.5 \text{ m}/\mu\text{s}$)

UEA image



Calibrated shear
wave speed:
 $c_s = 103 \text{ in/ms}$
(2.62 m/ms)



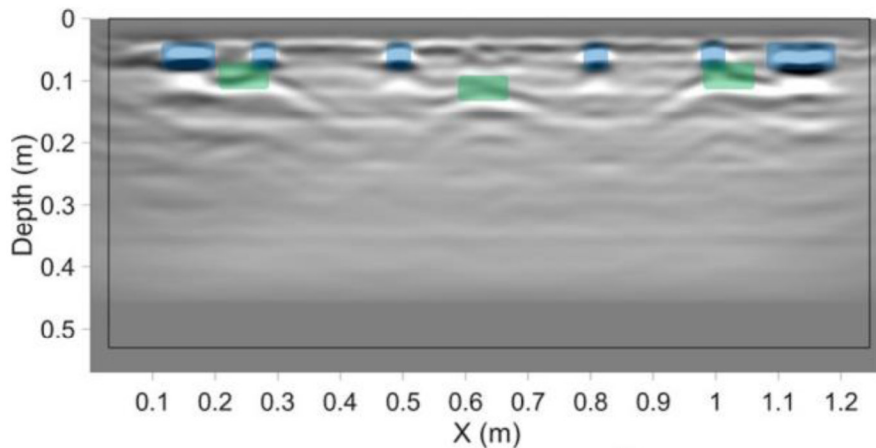
Fused image (bottom)



Case study 1: Imaging and image fusion (cont.)

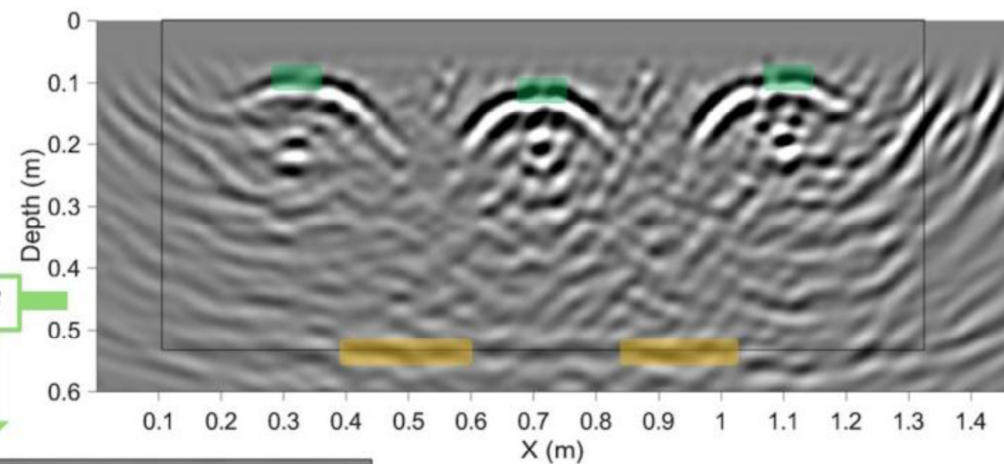
Measurements taken from top

GPR image

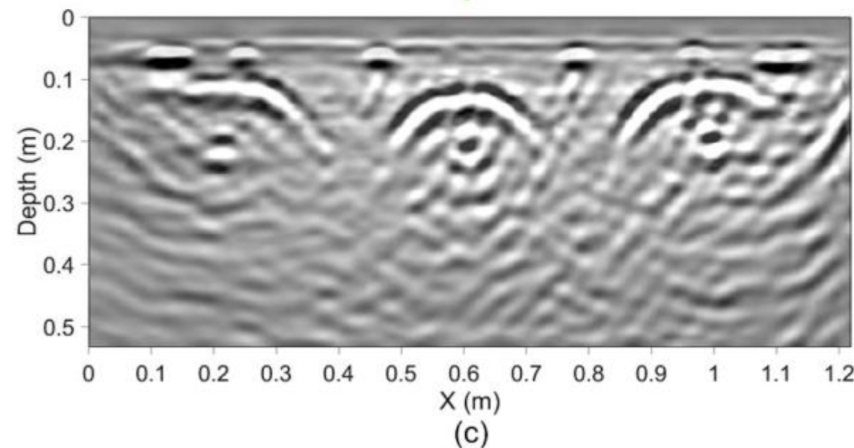
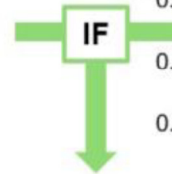


(a)

UEA image



(b)



(c)

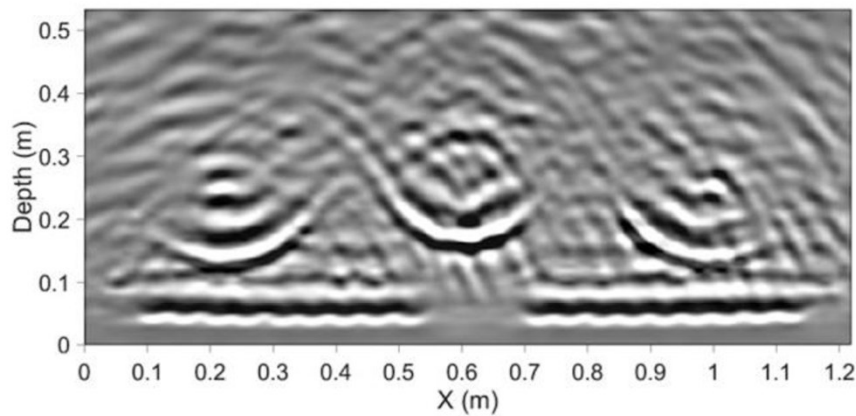
Fused image (top)



Case study 1: Imaging and image fusion (cont.)

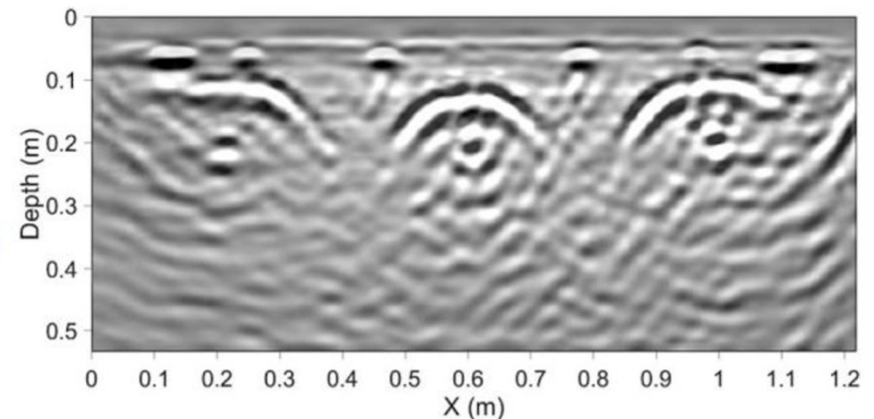
Fusion of fused images

Fused image (bottom)

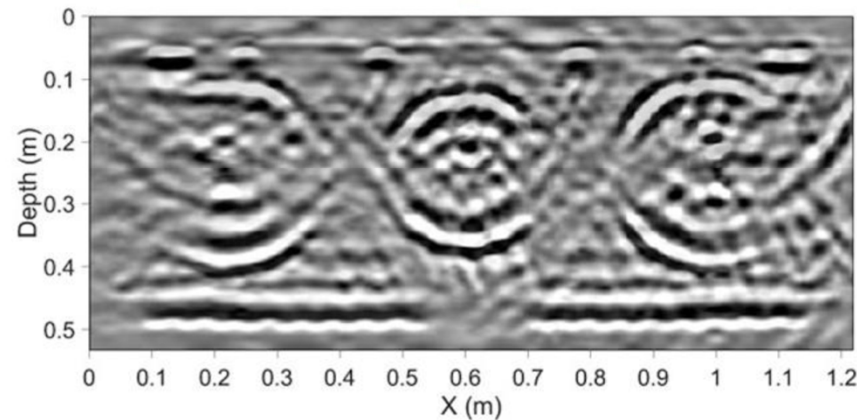


(a)

Fused image (top)



(b)



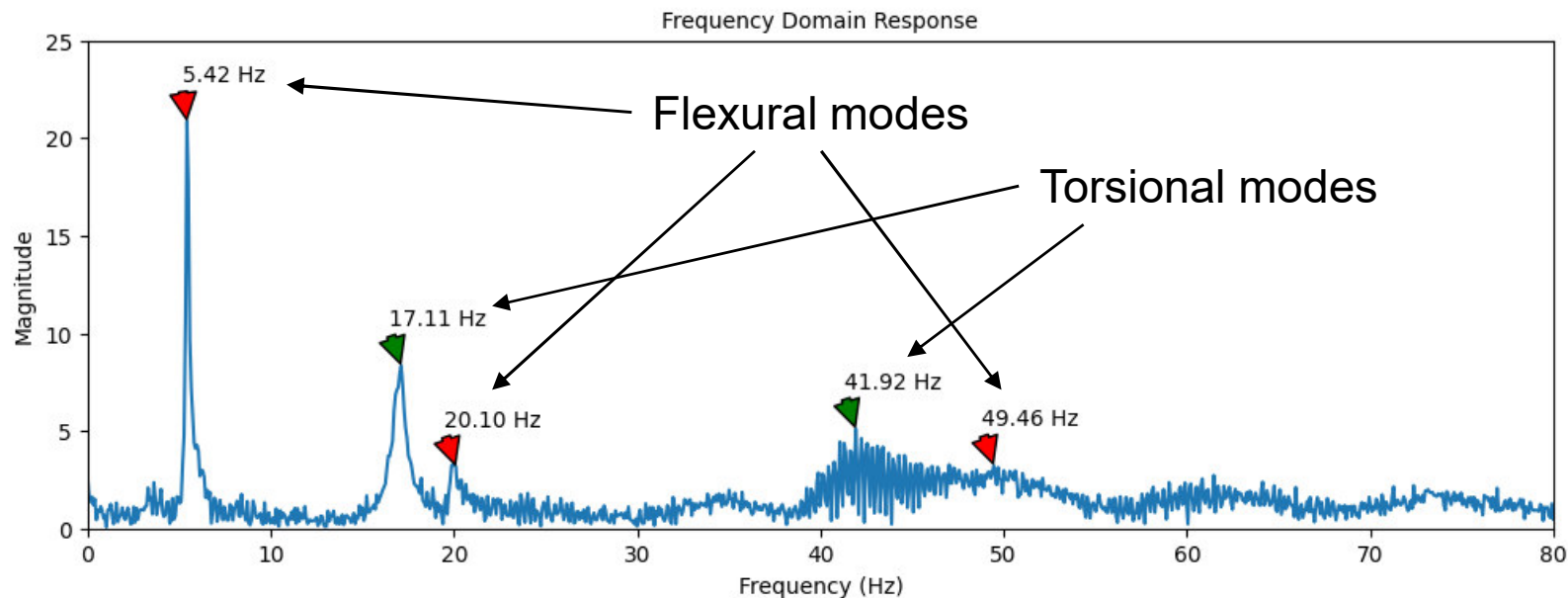
(c)

Final fused image



Case study 1: Additional measurements

- Vibration testing (phone-based accelerometer)



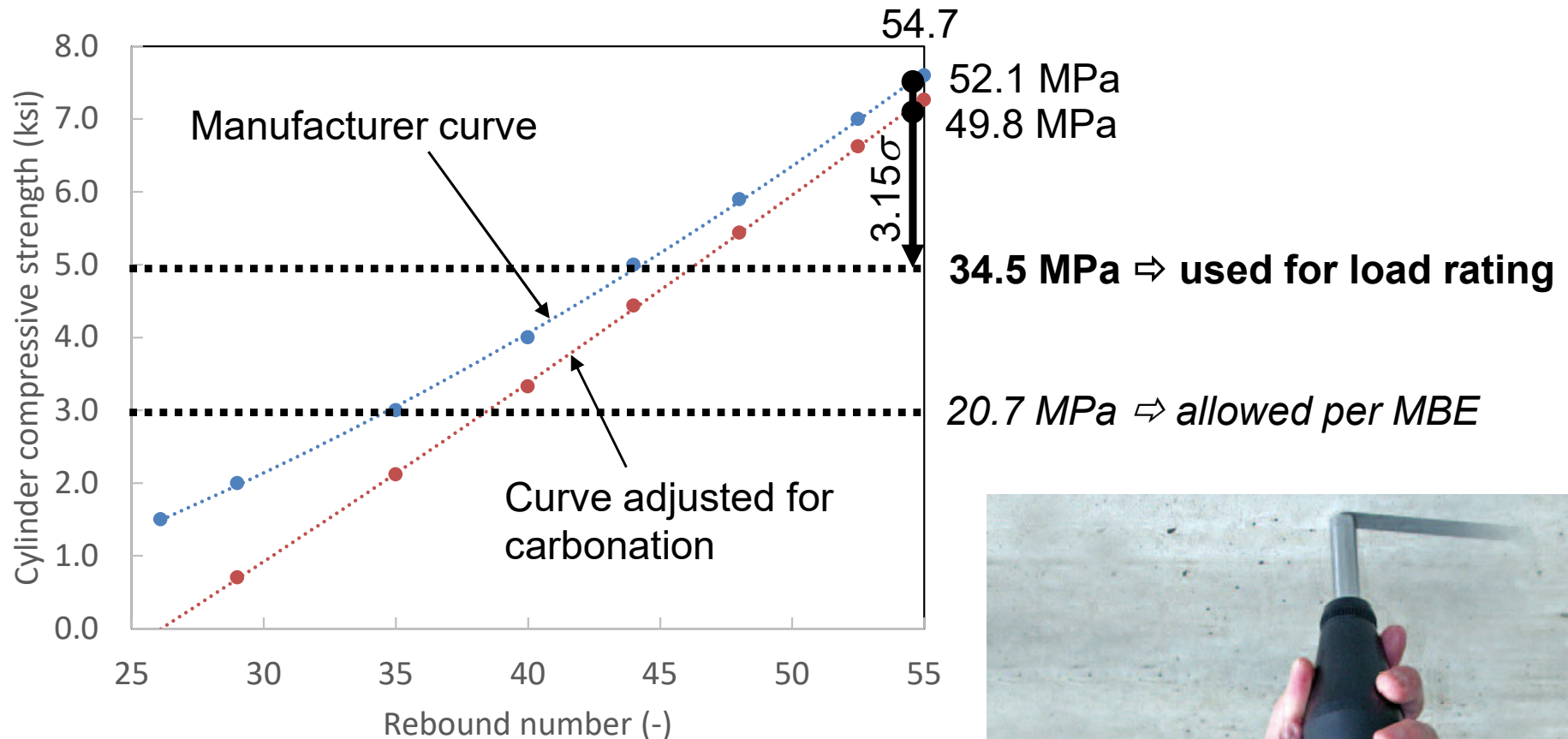
Best-fit values based on measurement (FE slab model):

$L = 14.6$ m, Poisson's ratio = 0.24, $E_{dyn} = 40$ GPa, voids are air-filled



Case study 1: Additional measurements (cont.)

- Rebound number (James Instruments)



\Rightarrow 20 measurements at random locations

Remark: Testing was not performed in acc. with ASTM C805-18 but only to get a qualitative sense of surface hardness and concrete quality.





Case study 1: Additional measurements (cont.)

- Rebar detector (Proceq Profoscope)
 - Mean concrete cover across all 18 strands = 36 mm, C.V. = 3.5%



Source: <https://www.screeningeagle.com/>

- Drilling hole into middle void from slab soffit
 - Void was present and dry
 - Formwork material fibrous board
 - Distance from slab soffit to bottom of void = 0.157 m

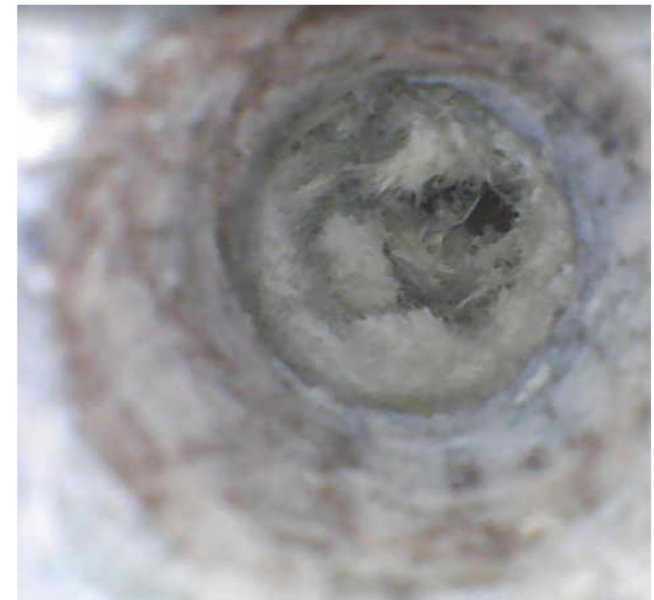
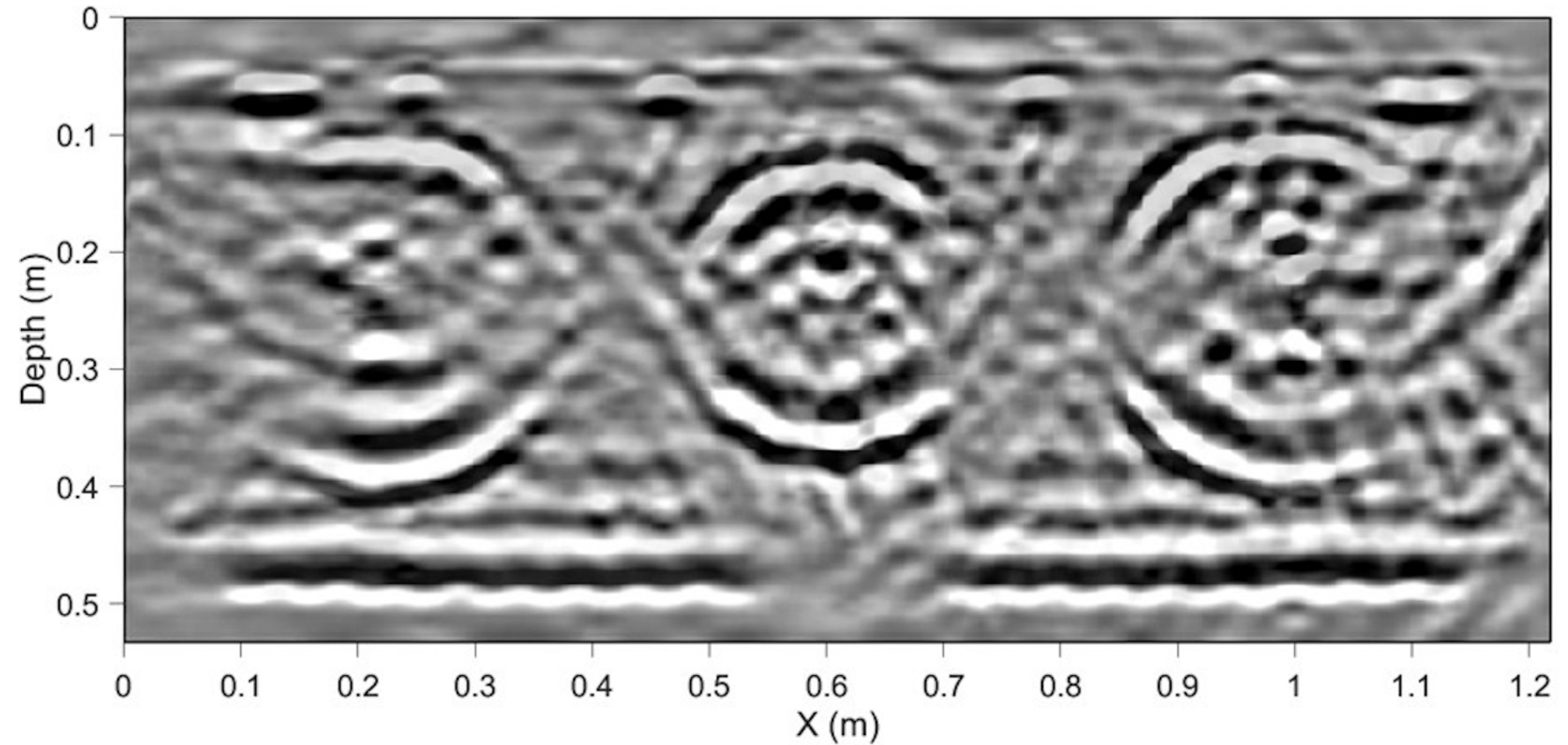


Photo from phone-based borescope

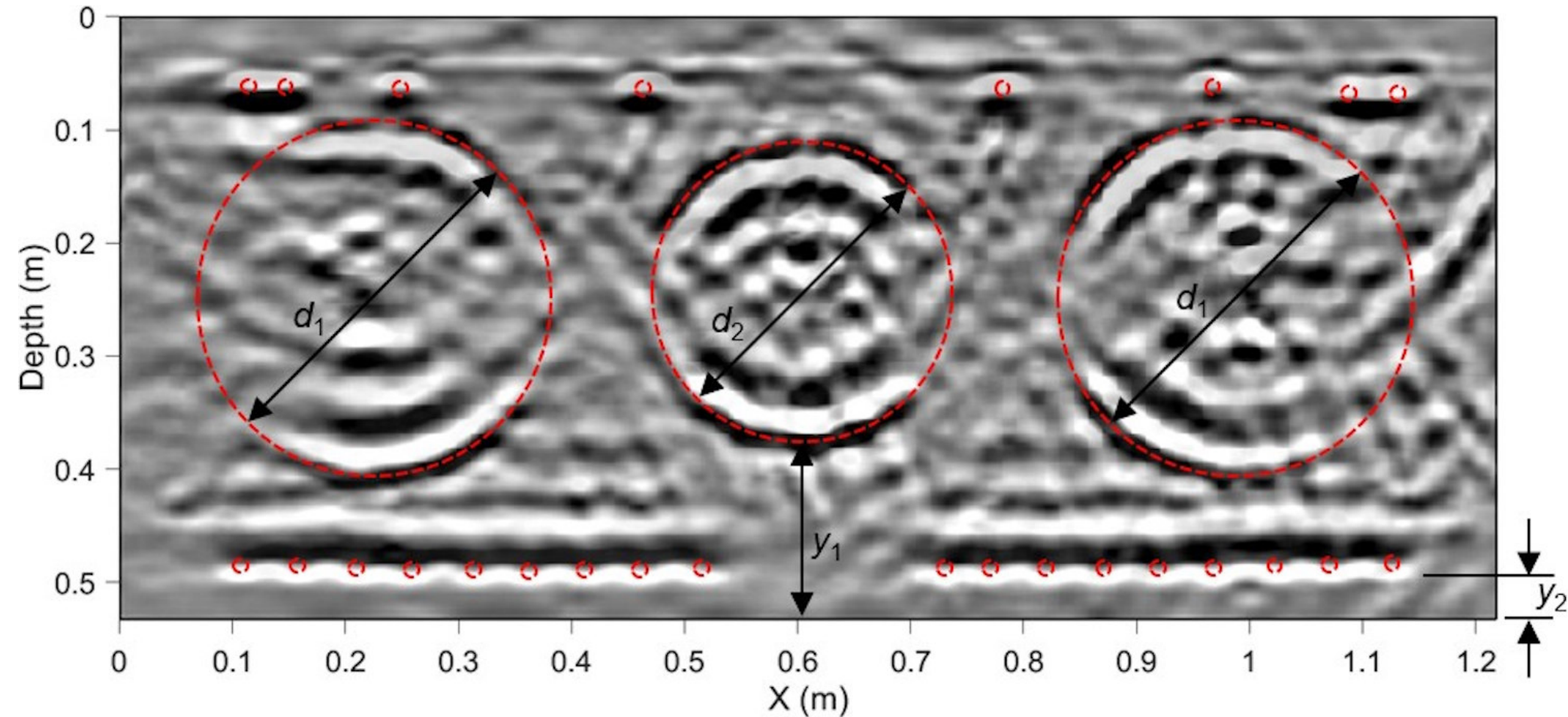


Case study 1: Final confirmed fused image





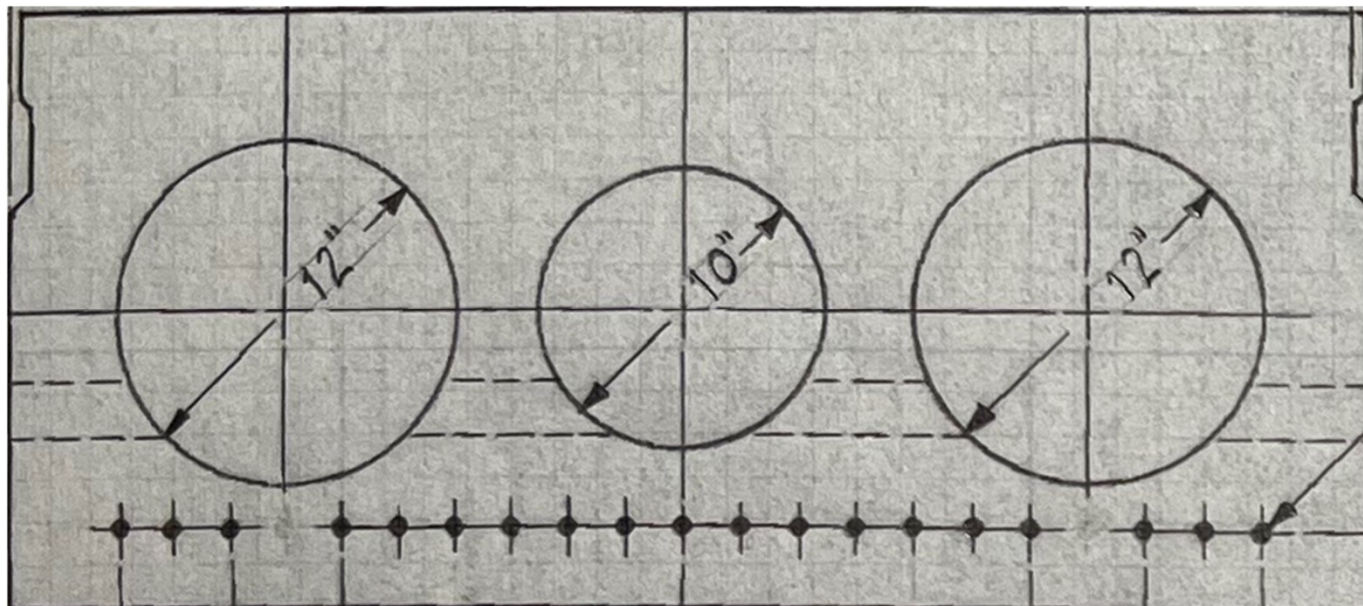
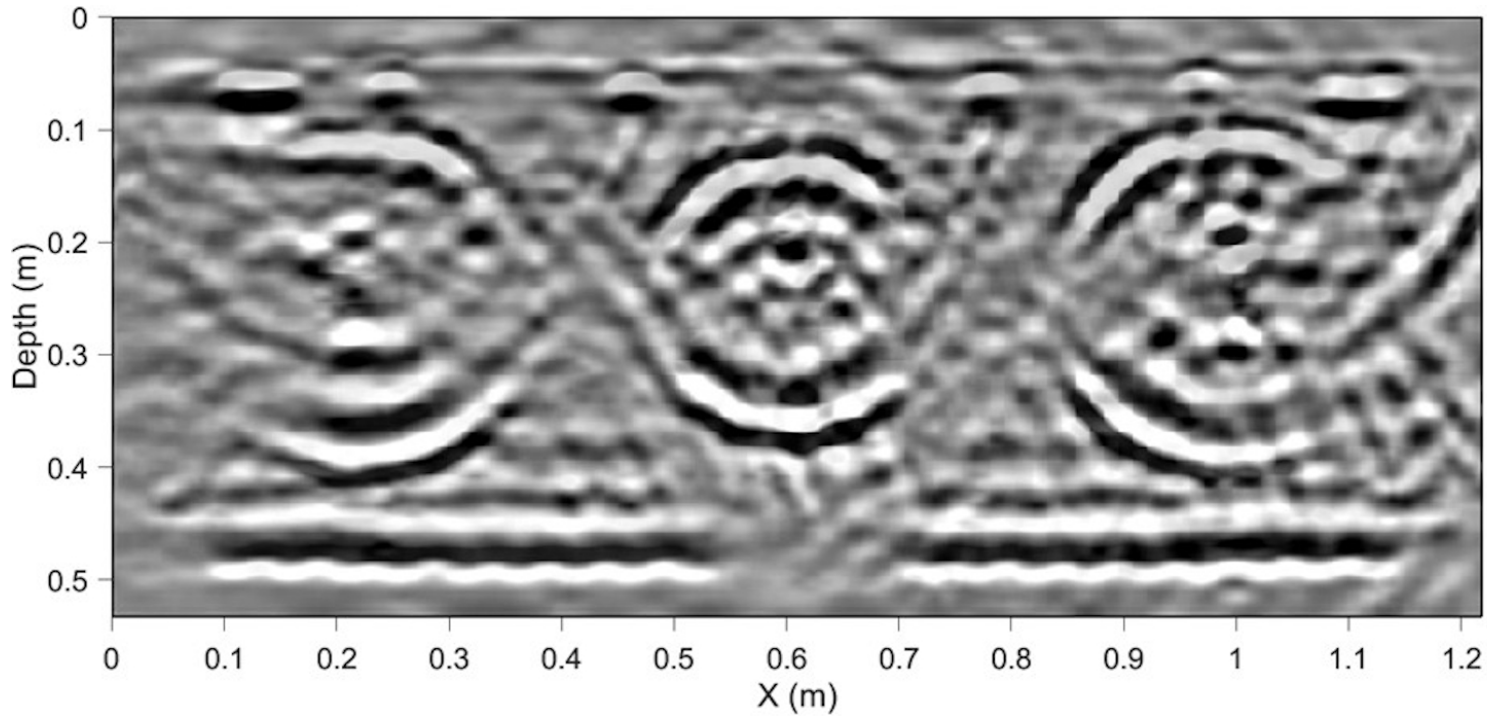
Case study 1: Final confirmed fused image (cont.)



Extracted dimensions:

- $d_1 = 0.31 \text{ m}$
- $d_2 = 0.26 \text{ m}$
- $y_1 = 0.155 \text{ m}$ (confirmed by drilling)
- $y_2 = 38 \text{ mm}$ (confirmed by rebar detector)

Case study 1: Comparison with guessed cross-section





Case study 1: Load rating by structural analysis with NDT data

Comparison:

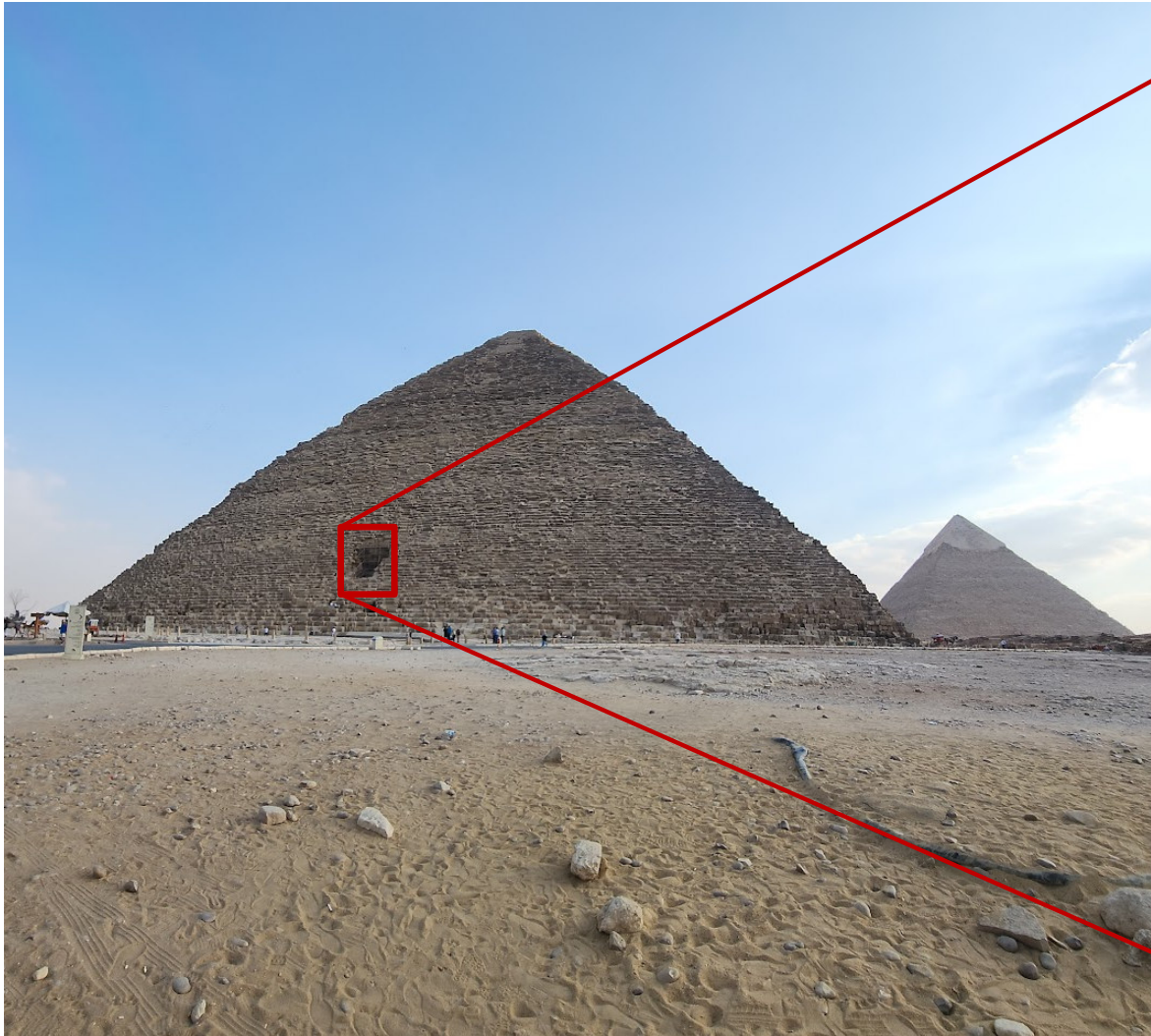
	No plans method	Load rating by structural analysis with NDT data			
Truck	Rating factor	Rating Factor	Load Factor	Tons	Controlling Point
AASHTO1 (Type 3)	1.00	1.80	1.30	25.0	Stress at mid-span
AASHTO2 (Type 3S2)	1.00	1.74	1.30	40.0	Stress at mid-span
AASHTO3 (Type 3-3)	1.00	2.16	1.30	40.0	Stress at mid-span
Special Haul Veh's		1.17	1.30	*	Stress at mid-span
Single Unit 4-axles	1.00	1.53		27.0	
Single Unit 5-axles	0.95	1.44		31.0	
Single Unit 6-axles	0.89	1.30		35.0	
Single Unit 7-axles	0.85	1.22		39.0	
Emerg. Veh.2	1.00	1.57	1.30	28.8	Stress at mid-span
Emerg. Veh 3	0.69	1.03	1.30	43.0	Stress at mid-span
Cont. Trip Permit-3	0.95	1.45	1.20	46.0	Stress at mid-span
Single Trip Permit-4A	0.90	1.43	1.20	46.5	Stress at mid-span
HL-93 (Operating)		1.25	1.75	45.0	Stress at mid-span

Using this refined approach, bridge passes load rating!



Case study 2: The ScanPyramids Mission

2020 to 2024: Confirmation of North Face Corridor campaign



Khufu's Pyramid (Khafre's Pyramid in background)



Chevron above original entrance

Case study 2: Results from muon tomography predict two previously hidden voids



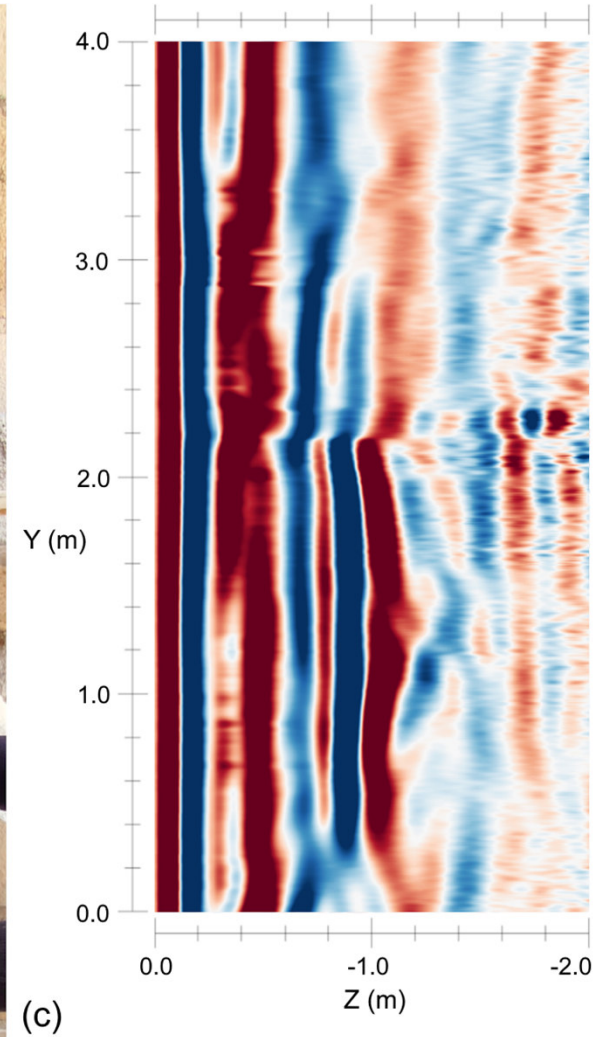


- Ground penetrating radar (GPR)
- Ultrasonic testing (UST)
- Electrical resistivity tomography (ERT)

[illegible]

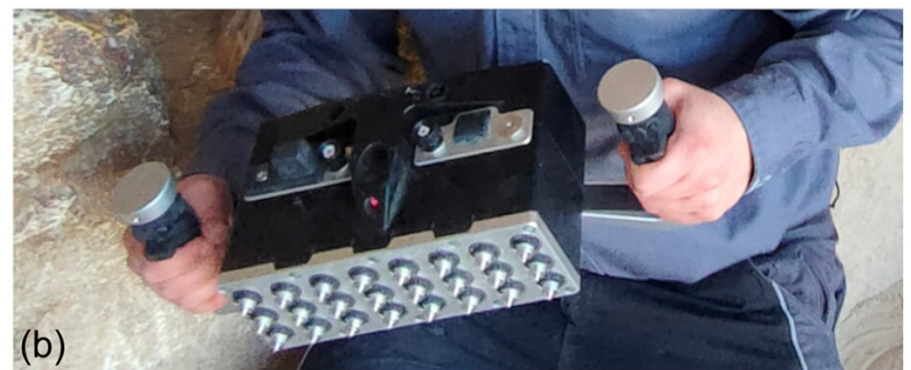
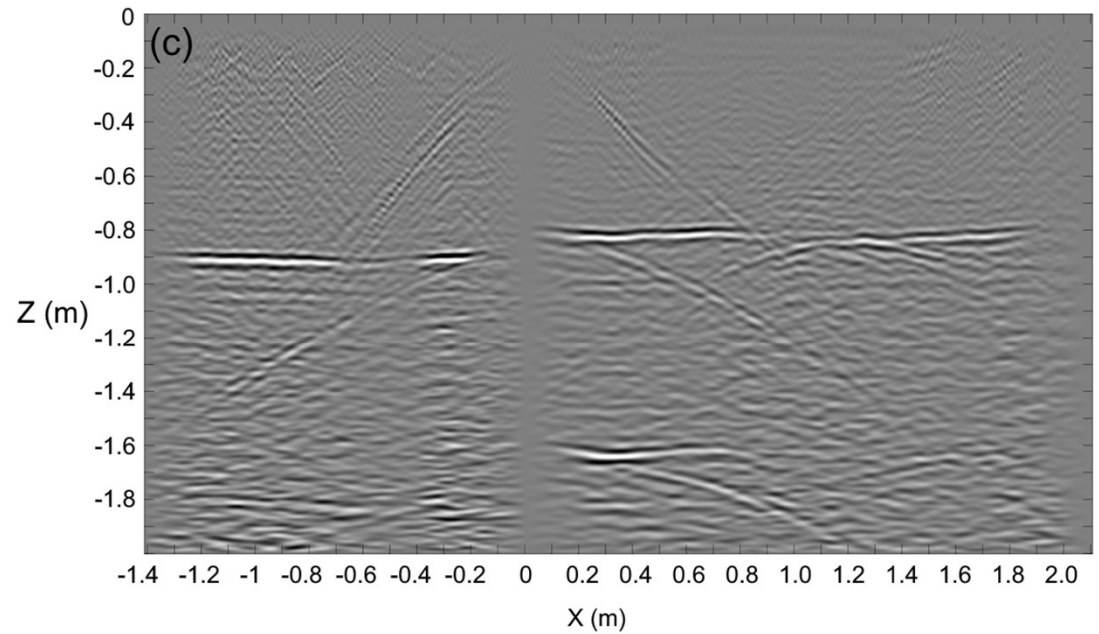
Source sketch: Dormion, 2012.

Case study 2: Measurements (cont.)



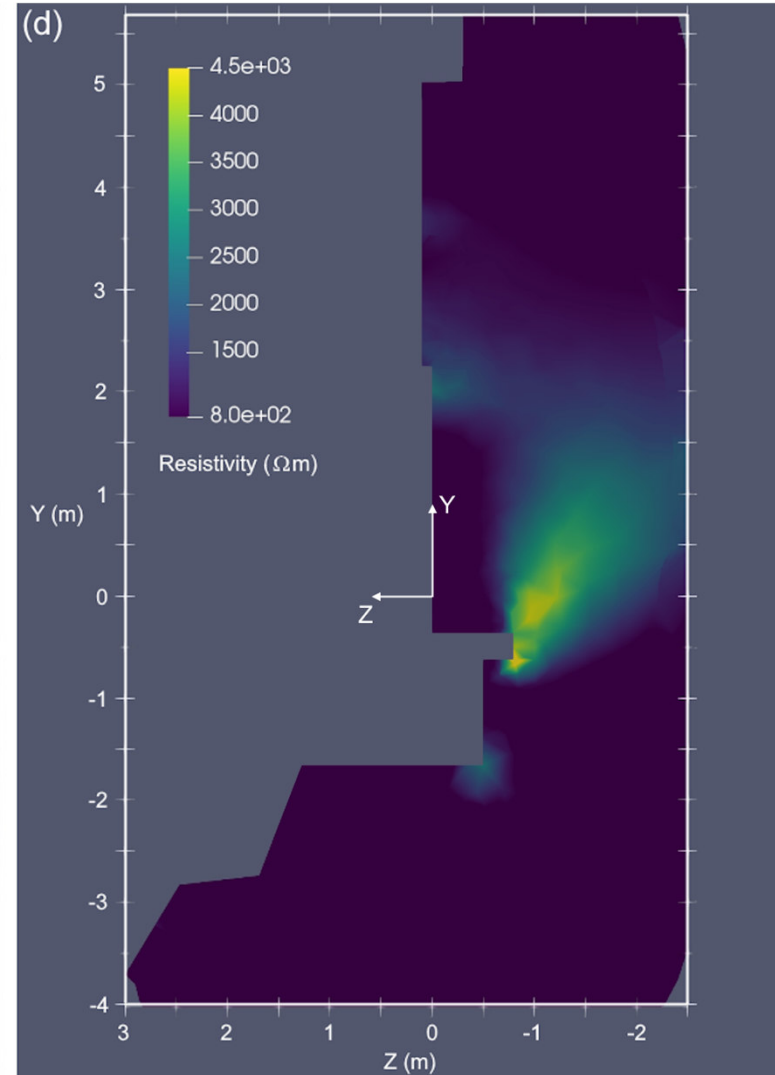
GPR measurements

Case study 2: Measurements (cont.)



UST measurements

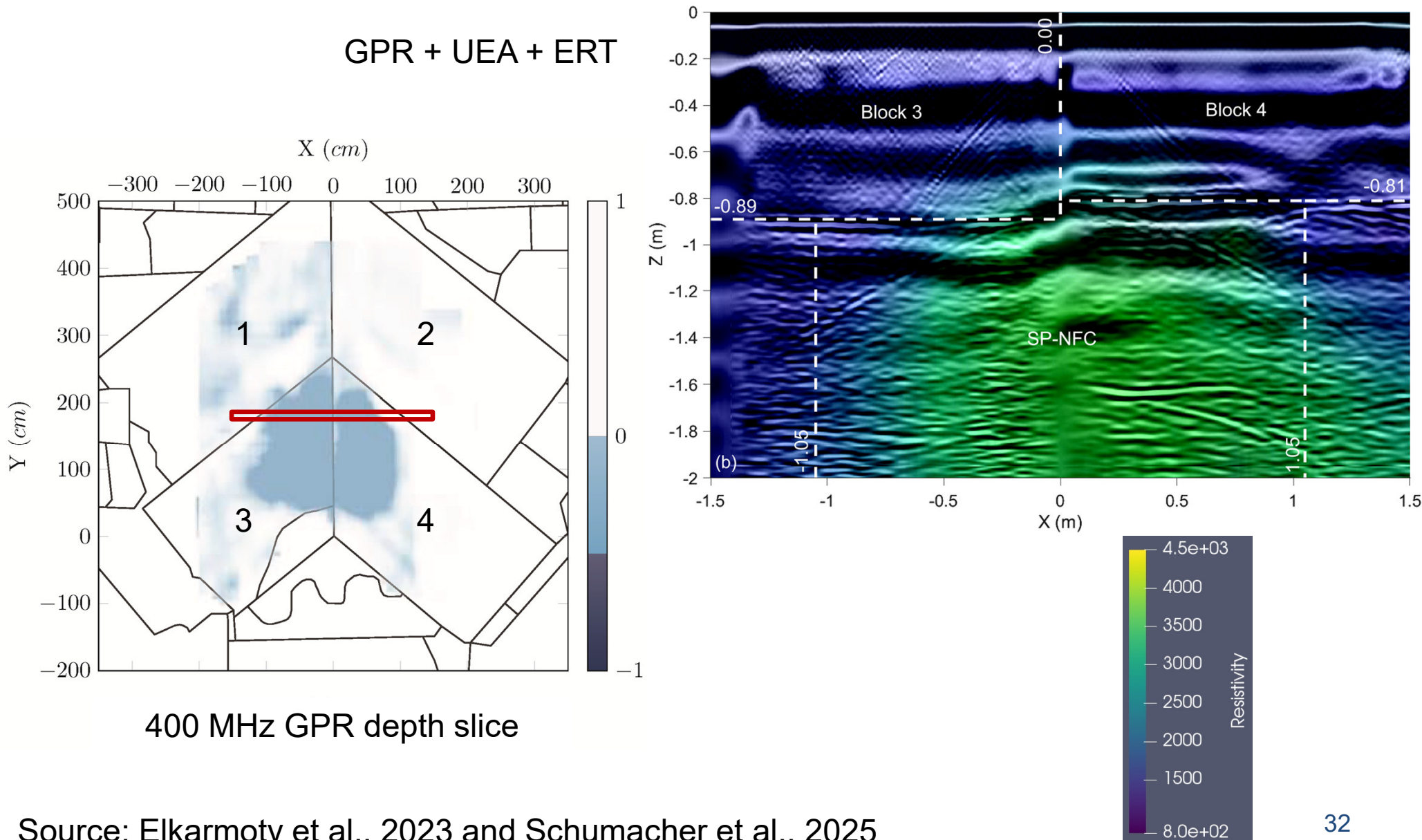
Case study 2: Measurements (cont.)



ERT measurements



Case study 2: Imaging and image fusion confirm existence of a hidden secret!



Source: Elkarmoty et al., 2023 and Schumacher et al., 2025



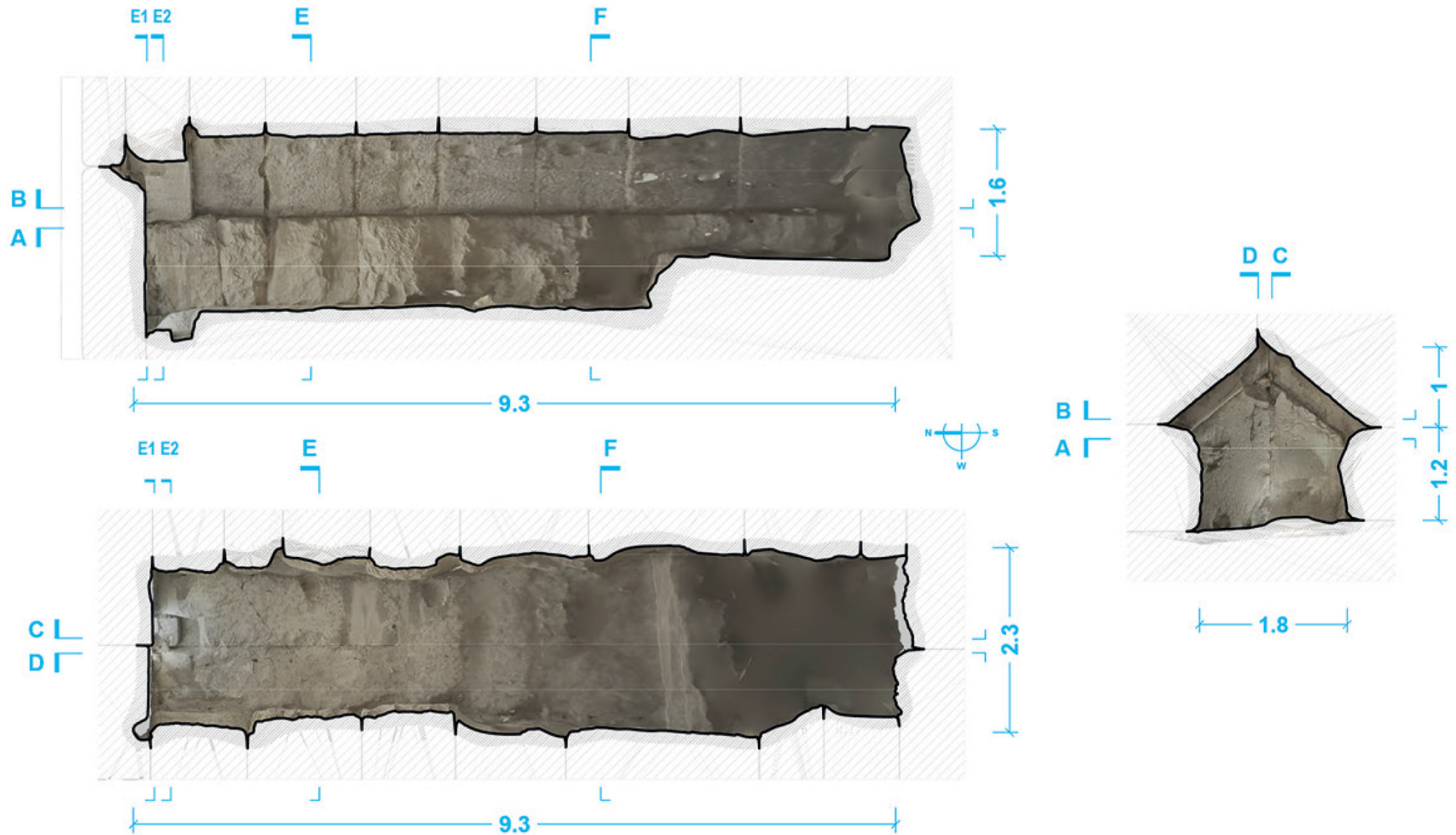
Case study 2: The big reveal

March 2, 2023: Scientists reveal hidden corridor in the Great Pyramid of Giza (Featured on Reuters, BBC, CNN, PBS, ...)





Case study 2: Photogrammetric reconstruction



ScanPyramids Mission Scientific Partners



Collaborators

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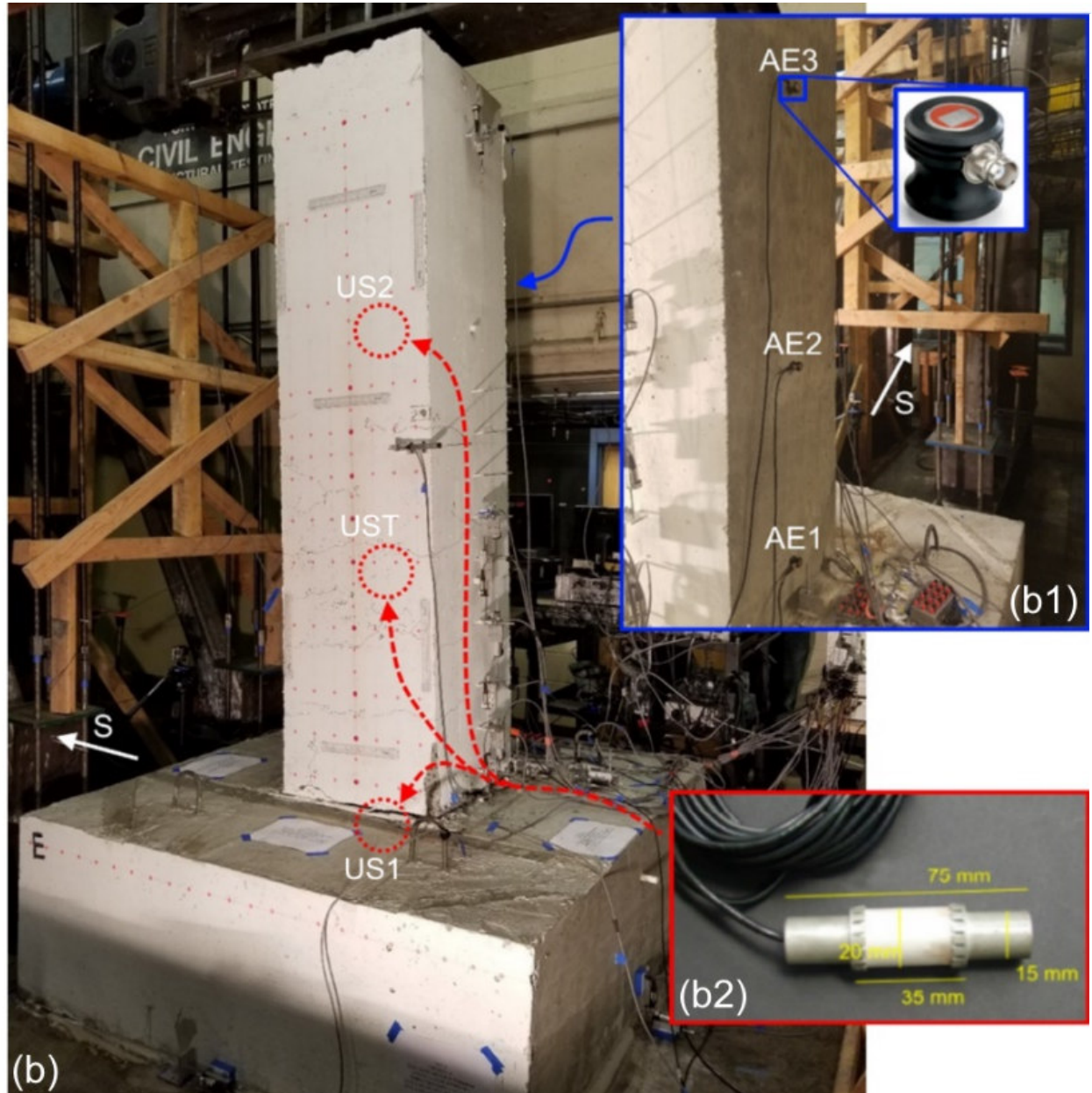
Long-term SHM of Indian River Inlet Bridge. Source: Skanska USA.

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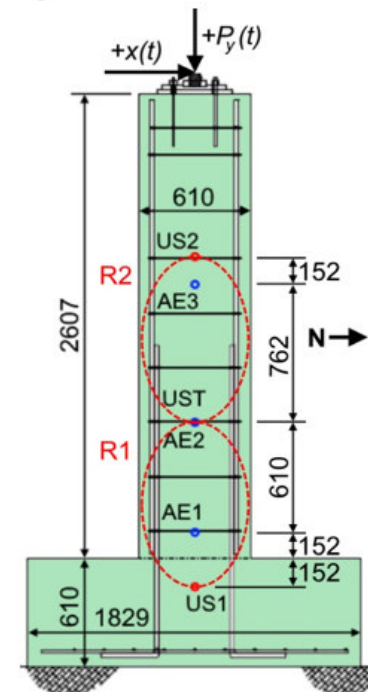
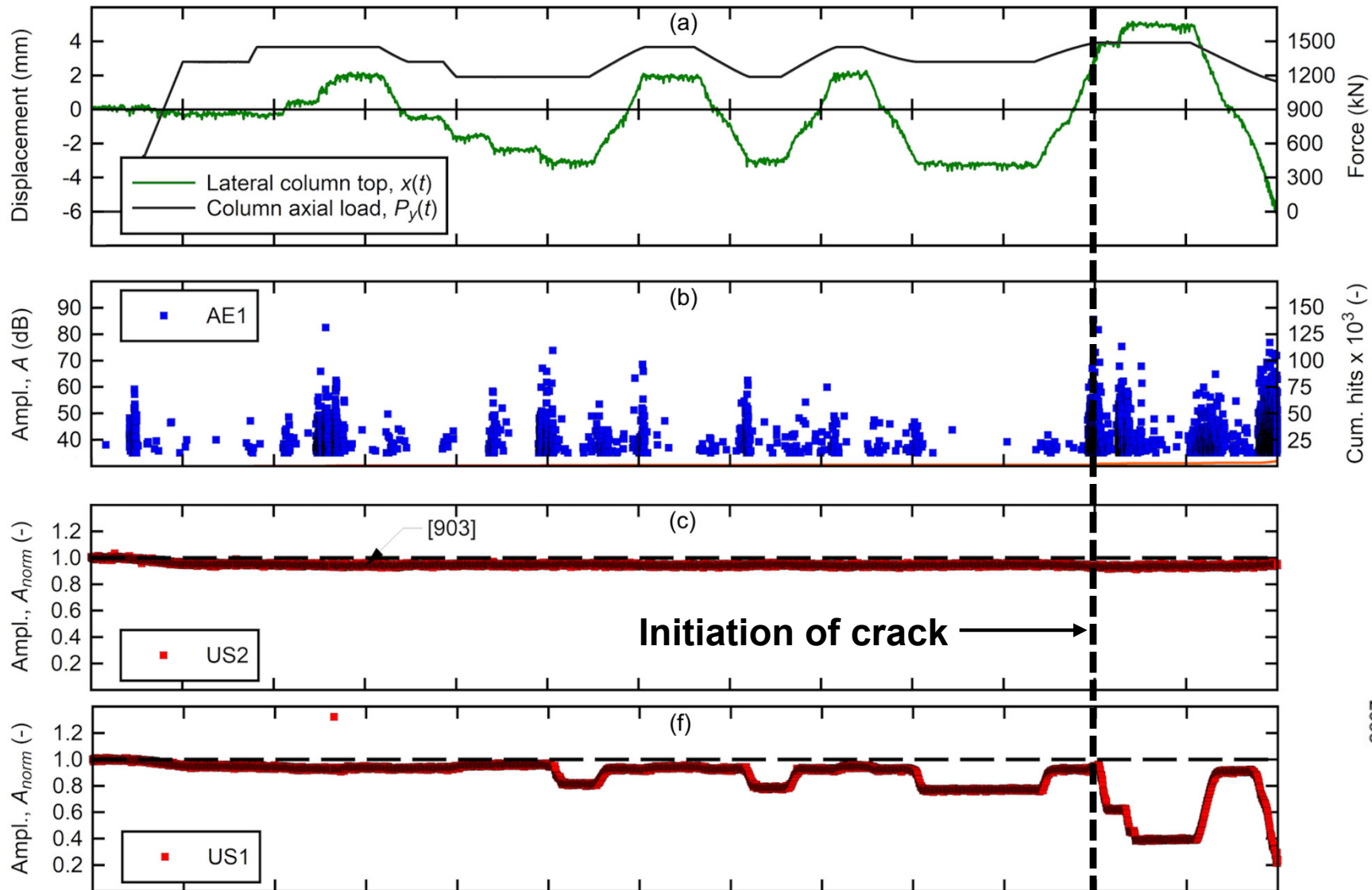
Case study 3: Ultrasonic-based monitoring experiment



- Determine behavior of RC bridge piers with pre-1990s detailing under Cascadia mega-thrust earthquake
- Monitoring using embedded ultrasonic transducers to track degradation during loading



Case study 3: Ultrasonic-based monitoring exp. (cont.)



Combined passive and active ultrasonic monitoring can tell when and where cracking starts

Case study 4: Monitoring for service-life extension

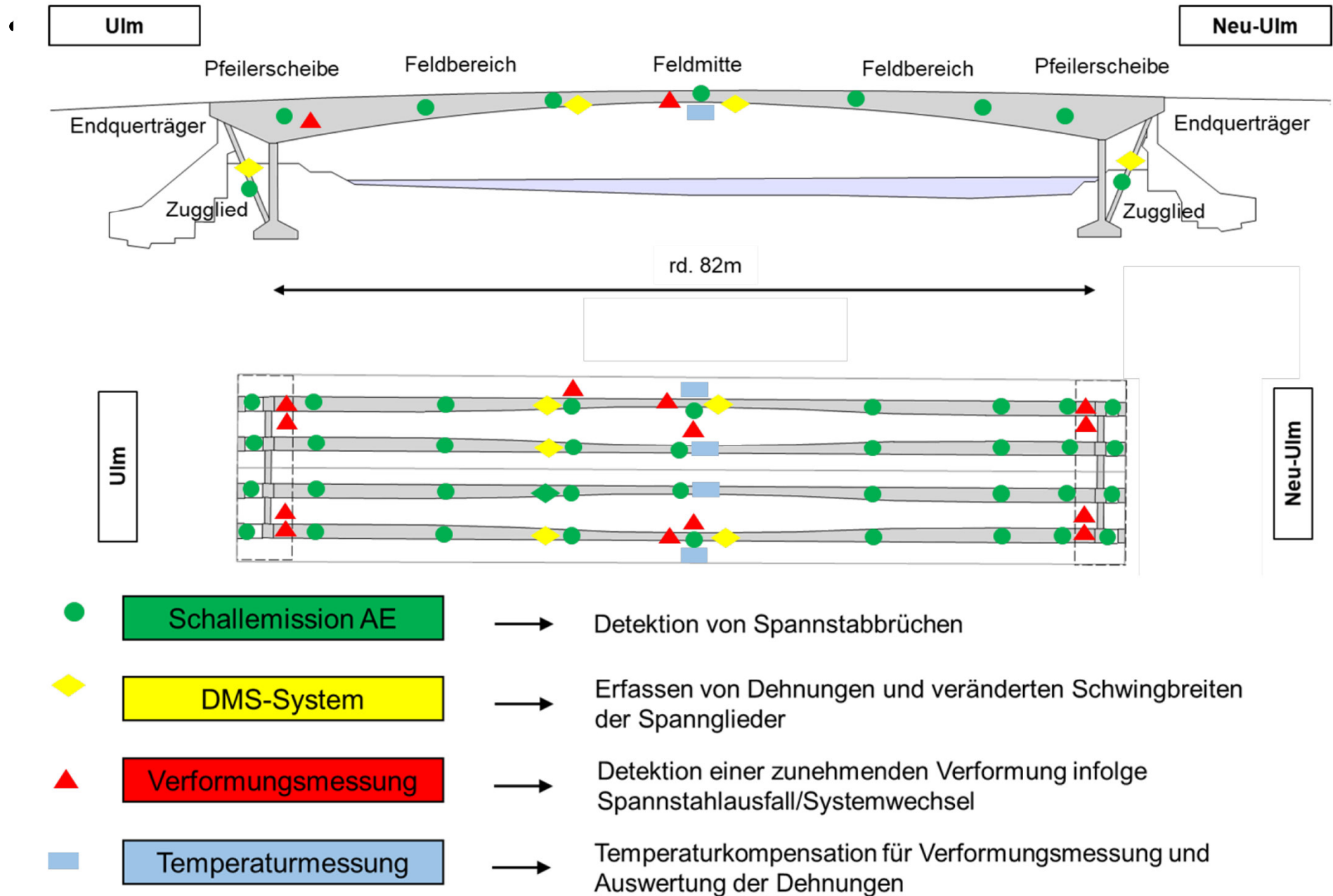
- **Monitoring of Gänstorbrücke, Ulm, Germany**

Objective: Monitor prestressing system of bridge (severe corrosion detected) until it is replaced with new bridge to ensure public safety.

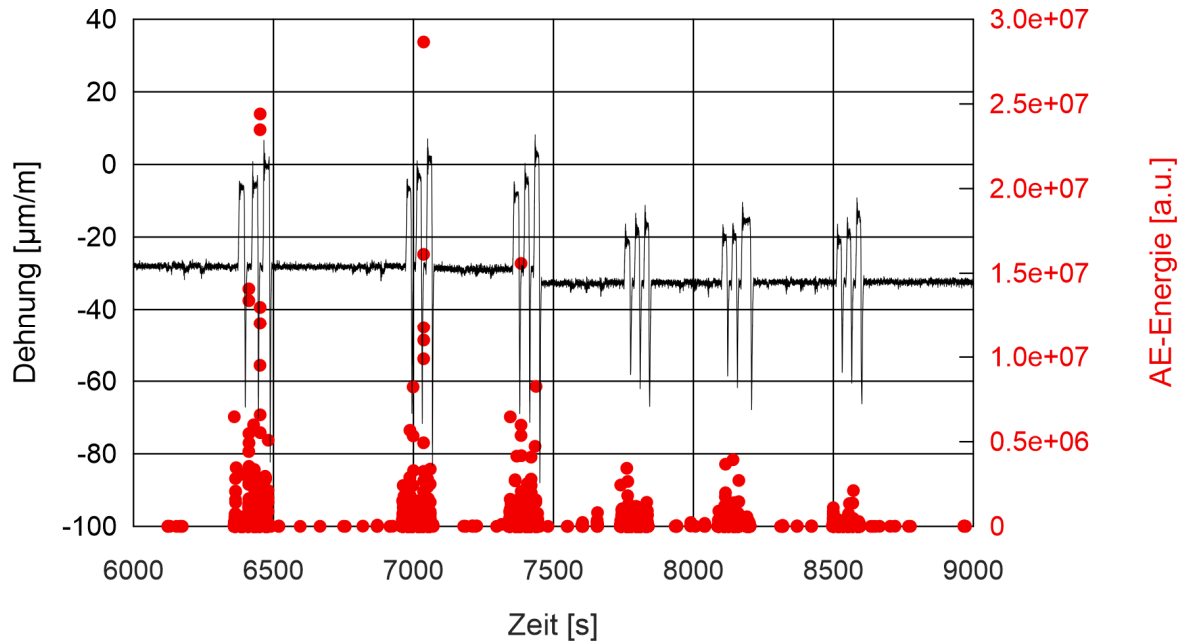


Source: <https://www.ulm.de>

Case study 4: Instrumentation

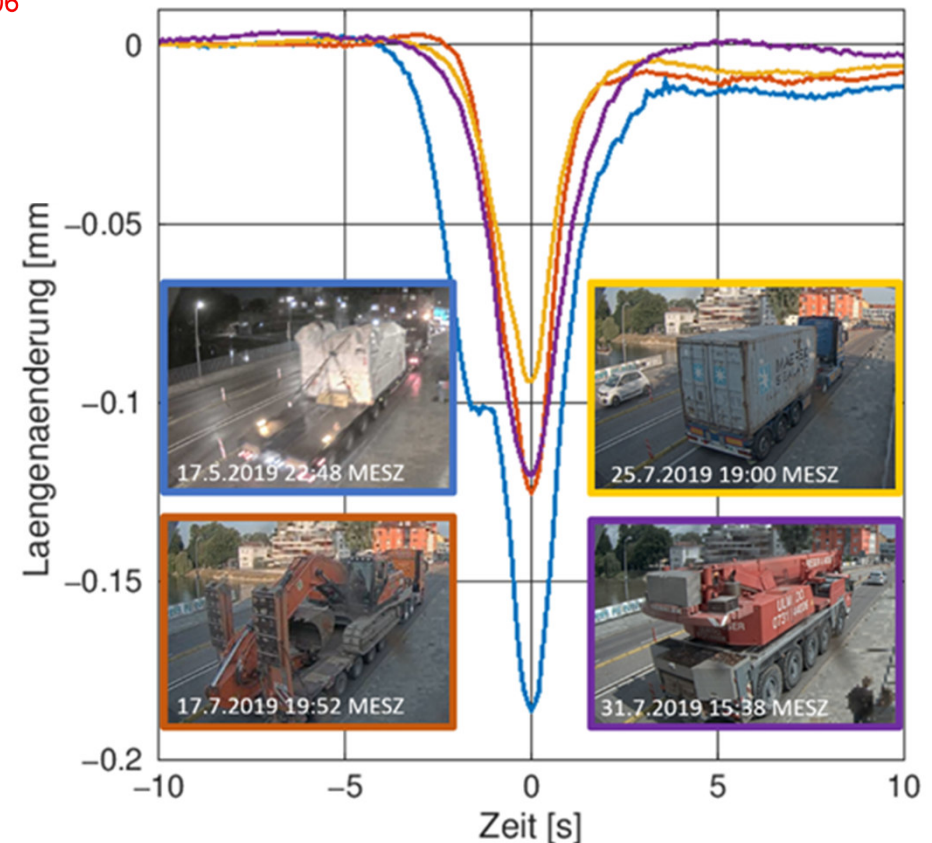


Case study 4: Sample data



Exceedance of specific thresholds initiate video recording of passing vehicle, allowing legal enforcement if necessary.

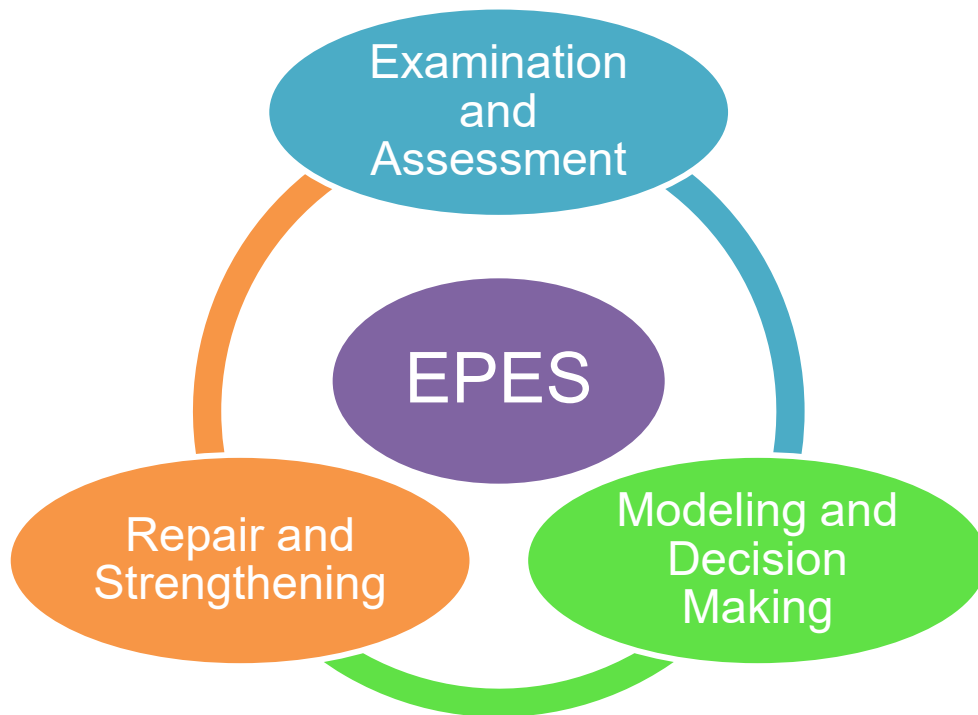
Determination of baseline values for displacement



Conclusions and outlook

- NDE is an important **support tool** in the engineering and preservation of existing structures
- NDT and SHM are complementary approaches:
 - NDT provides a **snapshot of geometric information and structural condition**
 - SHM provides information regarding the **change of structural performance**
- Imaging and image fusion using multiple NDT methods can help creating an **accurate digital cross-section** of a member examined
- Application of multiple NDT methods allows **cross-validation of measurements** and **reducing uncertainty**

M.S. focus area: Engineering and Preservation of Existing Structures



45-credit M.S. Degree in CE

Underlying themes:

- *Sustainability*
- *Data science*
- *Asset management*



Or contact presenter:

thomas.schumacher@pdx.edu

Thank you!



References:

Latourell Creek Bridge. Source: <https://www.hoodriverhistorymuseum.org>

Schumacher, T. (2024). Imaging and Image Fusion Using GPR and Ultrasonic Array Data to Support Structural Evaluations: A Case Study of a Prestressed Concrete Bridge. *NDT*, 2(3), 363-377. DOI: <https://doi.org/10.3390/ndt2030022>. **Open access. Data/codes available.**

Schumacher, et al. (2025). Confirmation of the ScanPyramids North Face Corridor in the Great Pyramid of Giza Using Multi-modal Image Fusion from Three Non-destructive Testing Techniques. *Scientific Reports*, 15, 9275. DOI: <https://doi.org/10.1038/s41598-025-91115-8>. **Open access.**