Load Rating Concrete Bridges Without Plans using Image Fusion of Multiple NDT Methods

Session 18, Load Rating

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Northwest Transportation Conference

Oregon State University, Corvallis, OR – March 4-6, 2024

The patient

- Simply-supported, span ~ 48 ft
- Three side-by-side prestressed concrete hollow-core slabs (50’ x 21”)
- 12’ out to out roadway width
- Transverse post-tensioning bars

- How many strands? Spacing?
- How many voids? Size? Location?
- How many shear stirrups? Cover?

- **Only access to a recovery center for drug abuse and physical abuse victims**
- **Fire equipment and trash collection trucks unwilling to cross without a certified load evaluation**

ODOT LRFR Load Rating Manual, 2018

Section 15, Load Rating Concrete Bridges without Existing Plans

For concrete bridges without plans that have been in service 20 years or more without visual distress, the safe load capacity can be assumed to be equal to legal loads up to and including SU4.

Allowed	
Type 3 Truck, 2-axles	25 tons
Type 3S2, 5 acles	40 tons
Type 3-3, 6 axles	40 tons
SU4, 4 axles (garbage truck)	27 tons
Emergency Vehicles, EV2, 2 axles	28.75 tons

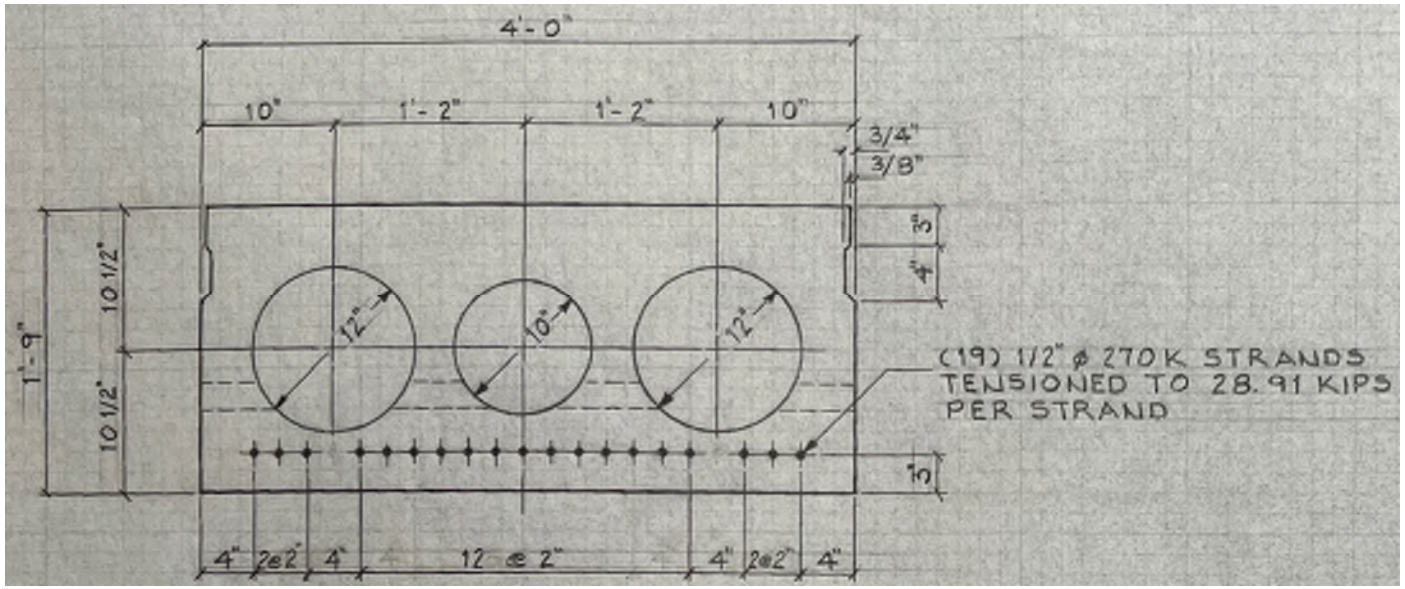
Not Allowed	
Emergency Vehicles, EV3, 3 axles	43 tons
Permit Trucks	46+ tons

Ratio of maximum moments method restricts fire equipment.

Research to find drawings:

- Land Owner Records
- County Public Works files
- Knife River (RB Johnson files)
- Other prestress plants

Best guess based on age (1960s similar bridge beam drawing from Knife River):



Let's Try Non-Destructive Testing:

Multi-NDT approach using:

- Ground Penetrating Radar (GPR)
- Acoustic Methods, such as Impact Echo or a relatively new technique: Ultrasonic Echo Array (UEA) Testing

With some minimal Invasive testing

- *May need some method of verification to ground truth these methods*

- *Consider drilling into the concrete to verify bar size*

New Concepts in Non-destructive Testing (NDT)

- **NDT Imaging** can help us figure out **what's inside a structure** by providing **a visual representation**:
  - Member geometry: Thickness
  - Material properties: Modulus of elasticity
  - Inclusions: Air voids, cracks, reinforcing bars, etc.
  - Deterioration (maybe)

- **Image Fusion** merges images from different measurement techniques or different sides into a single **composite image**

Ground penetrating radar (GPR)

Used instrument:

GSSI StructureScan Mini XT

Wave type: Electromagnetic

Central pulse frequency*: 2.7 GHz

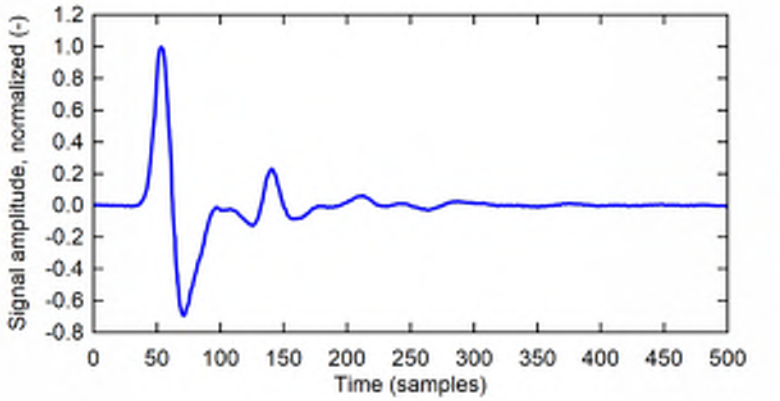
Sampling interval: 0.0164 ns

Spatial resolution: 2.54 mm

Number of transducers/rows: 2/1

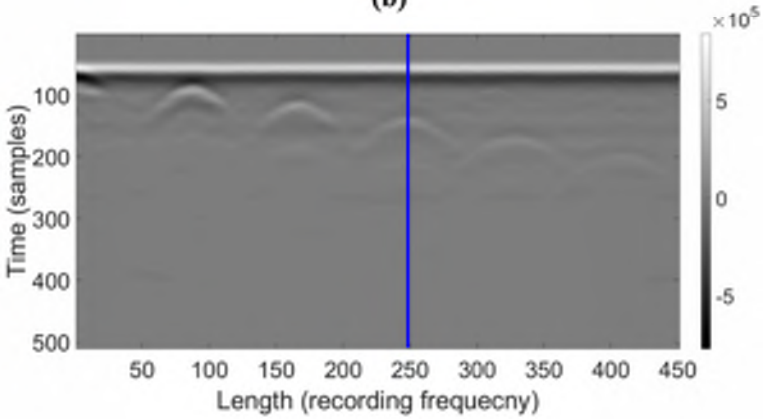
Transducer spacing: 40 mm

(a)



(b)

(c)



(d)

*Trade off – High Frequency for resolution vs Lower Frequency for penetration

Electromagnetic waves reflect from boundaries between materials with dissimilar dielectric constants ⇨ Ideal for detecting **metallic objects**

Ultrasonic echo array (UEA) testing

Used instrument:

Proceq Pundit 250 Array

Wave type: Stress (shear) waves

Central pulse frequency: 40 kHz

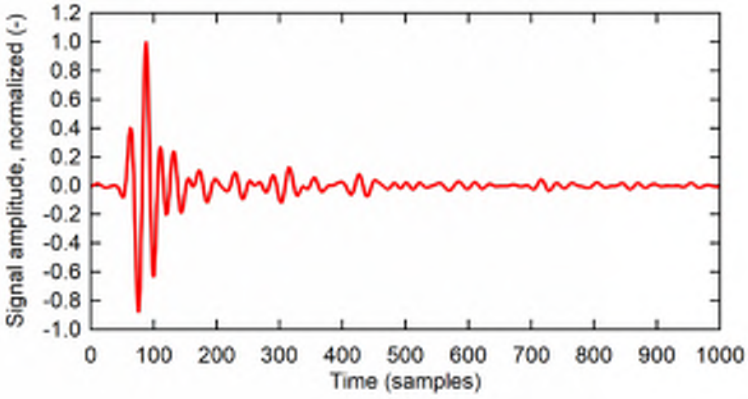
Sampling interval: 1 ms

Spatial resolution: 10 mm

Number of transducers/rows: 8/3

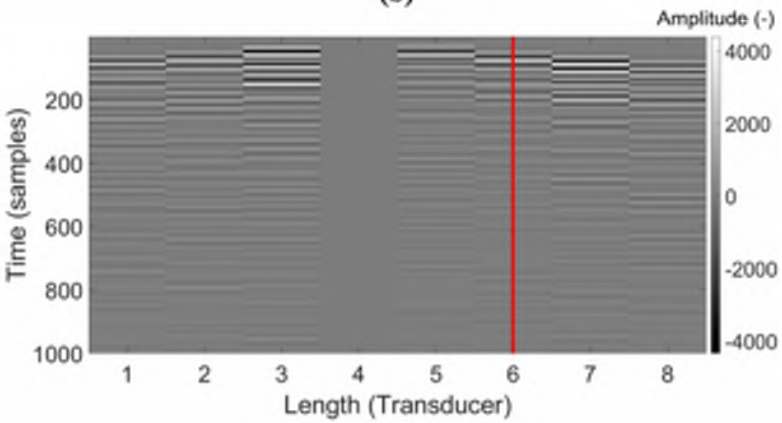
Transducer spacing: 30 mm

(a)



(b)

(c)



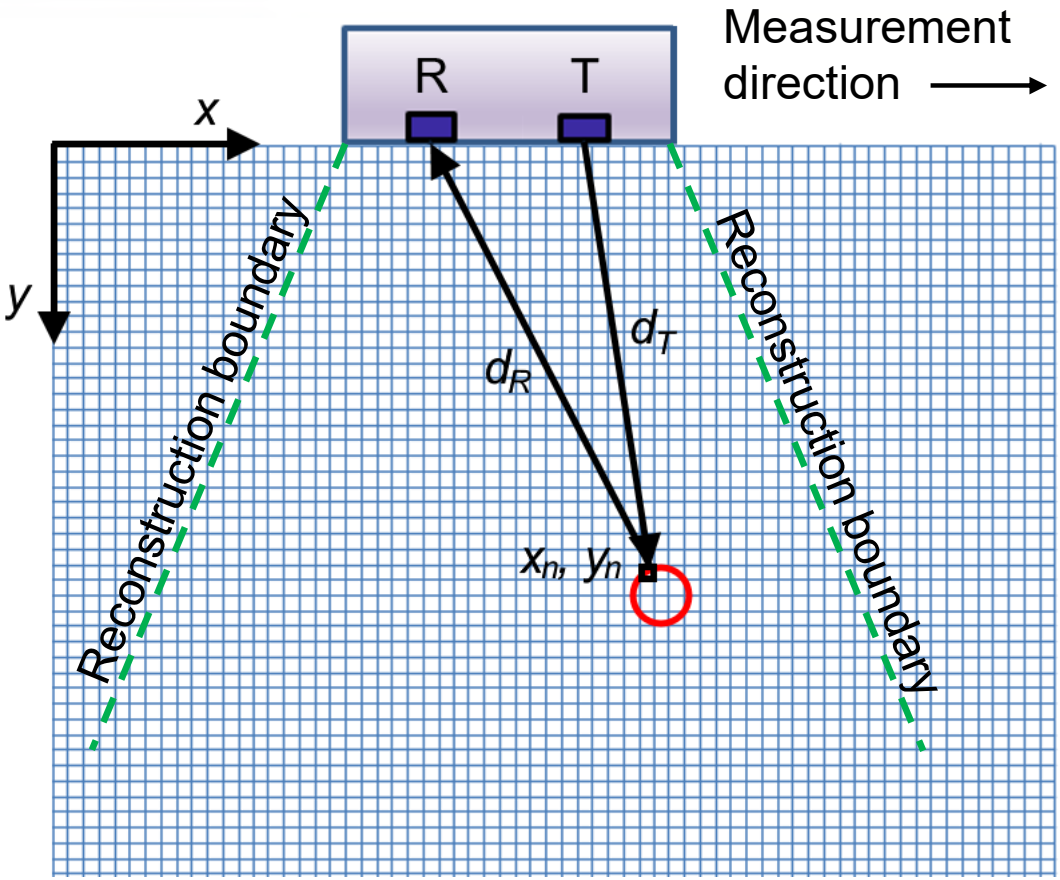
(d)

Ultrasonic waves reflect from boundaries between materials with dissimilar acoustic impedance ⇨ Ideal for detecting **air voids/boundaries**

Image reconstruction

SAFT/TFM: Amplitude (*A*) values for a recorded response are mapped to each pixel (x_n, y_n) on discrete grid of the scan line (*x*), depth (*y*) – plane based on the travel distance. This is repeated for each measurement location (and transducer couple) and superimposed to create a **map (or image) of reflectors**.

- Each pixel is treated as a potential reflector
- Variables: **Wave speed (*c*)** and **time off-set**
- Processing: Reconstruction angles, suppression of direct wave, back-signal amplification, image contrast, many more…



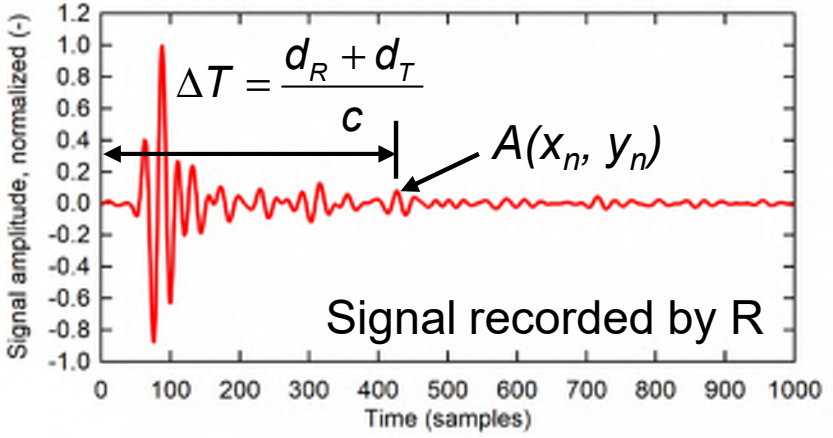
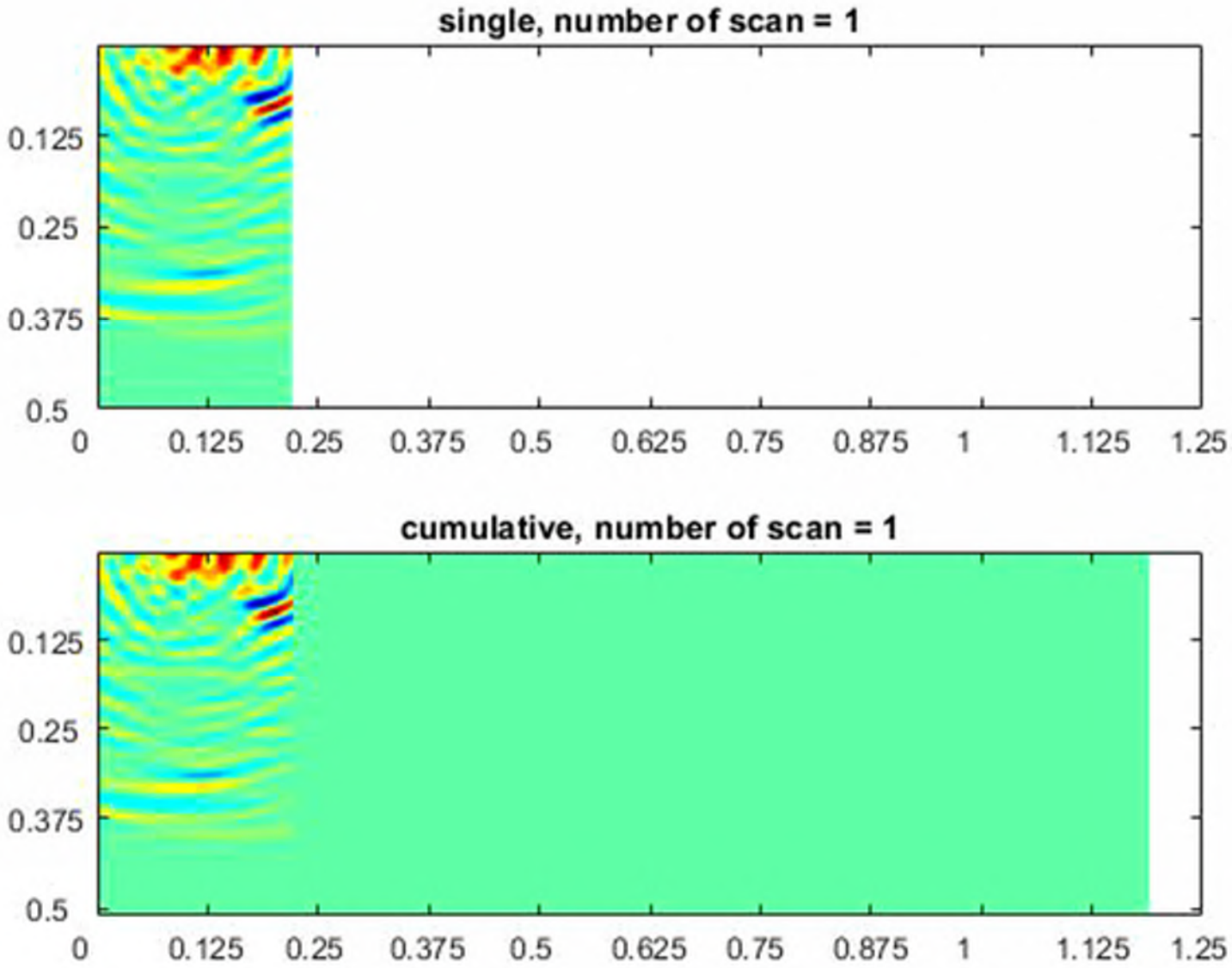


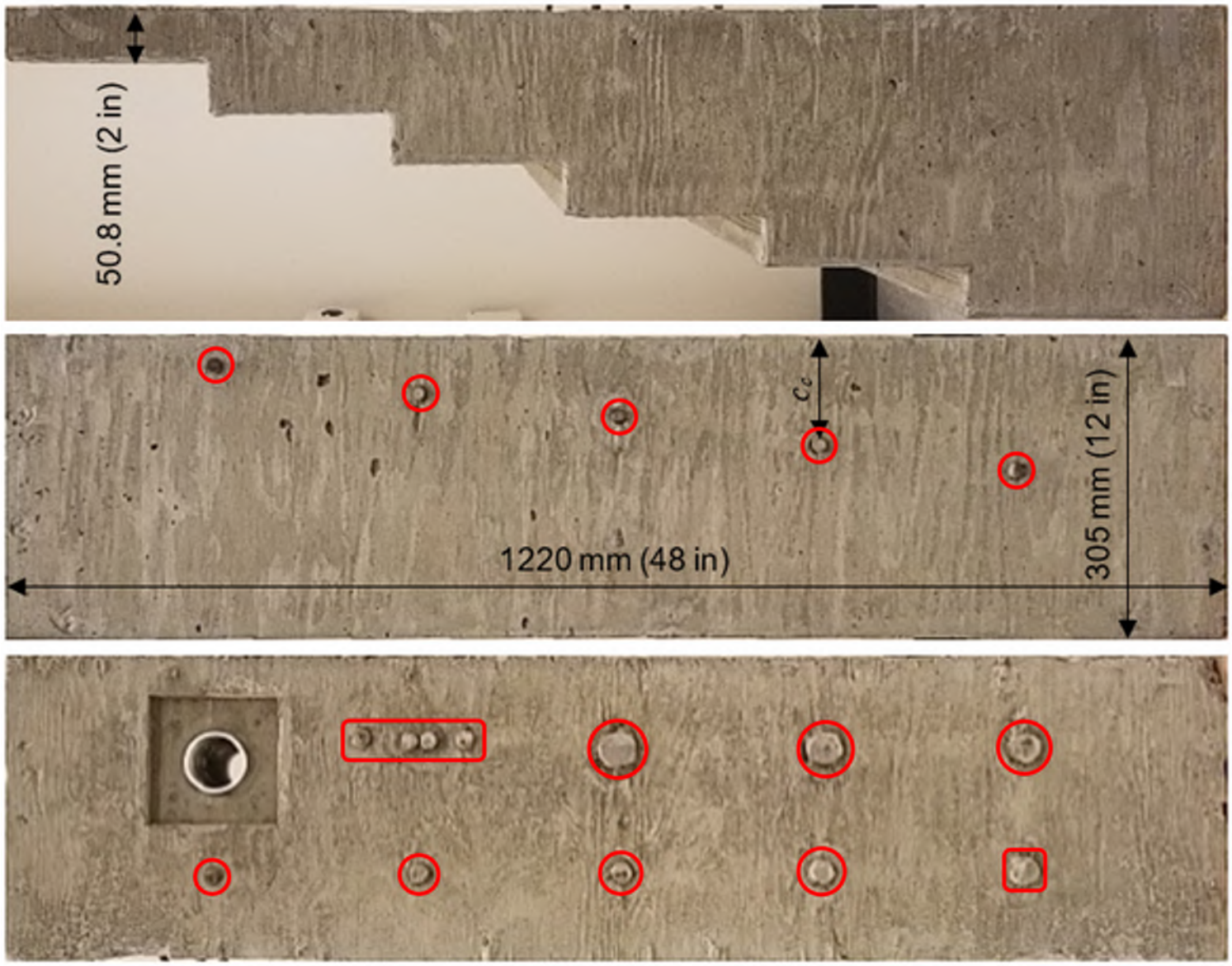
Image reconstruction (cont.)

Courtesy: Sina Mehdinia



Laboratory study

Source: Mehdinia et al., 2021.



Laboratory study (cont.)

Source: Mehdinia et al., 2021.

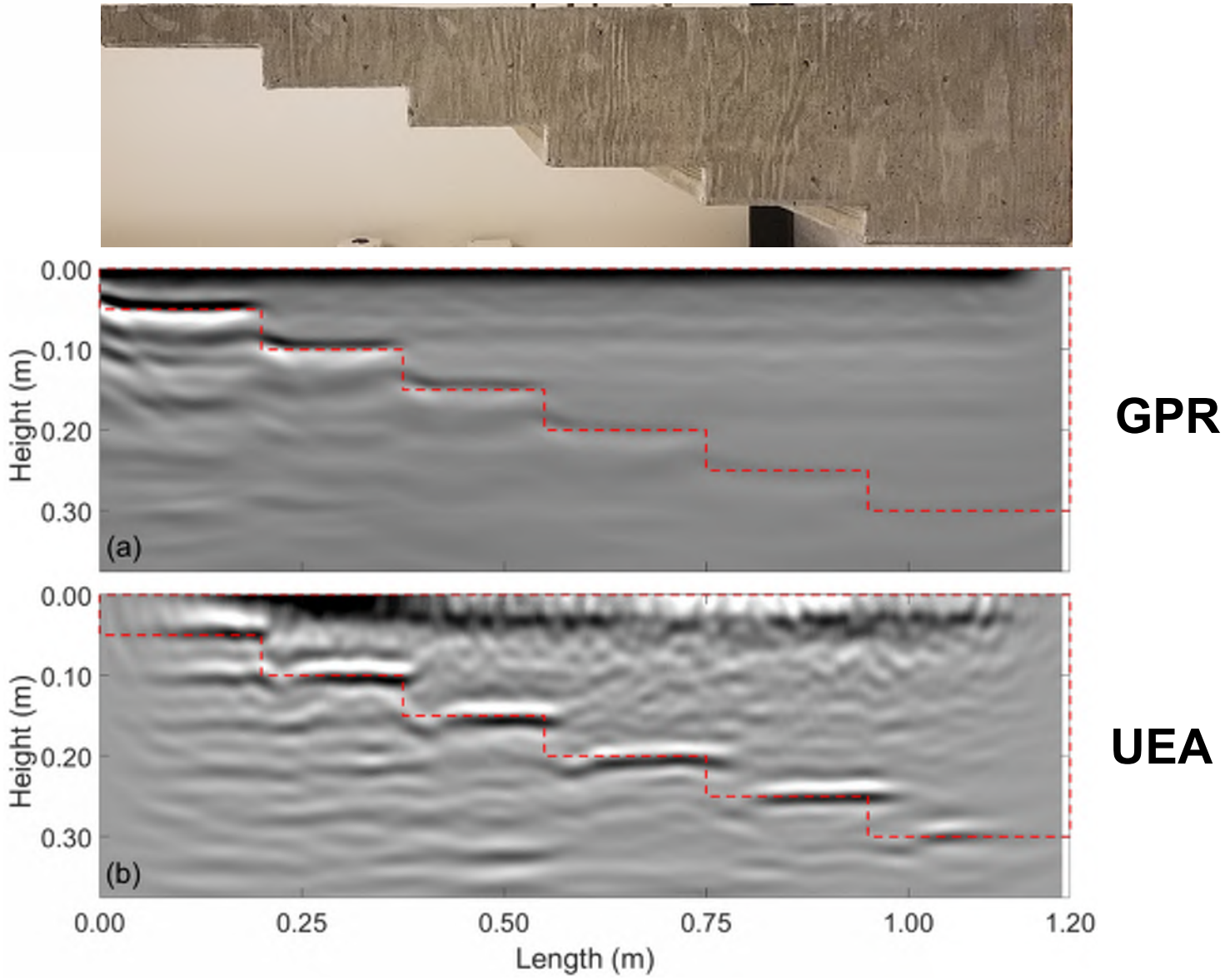


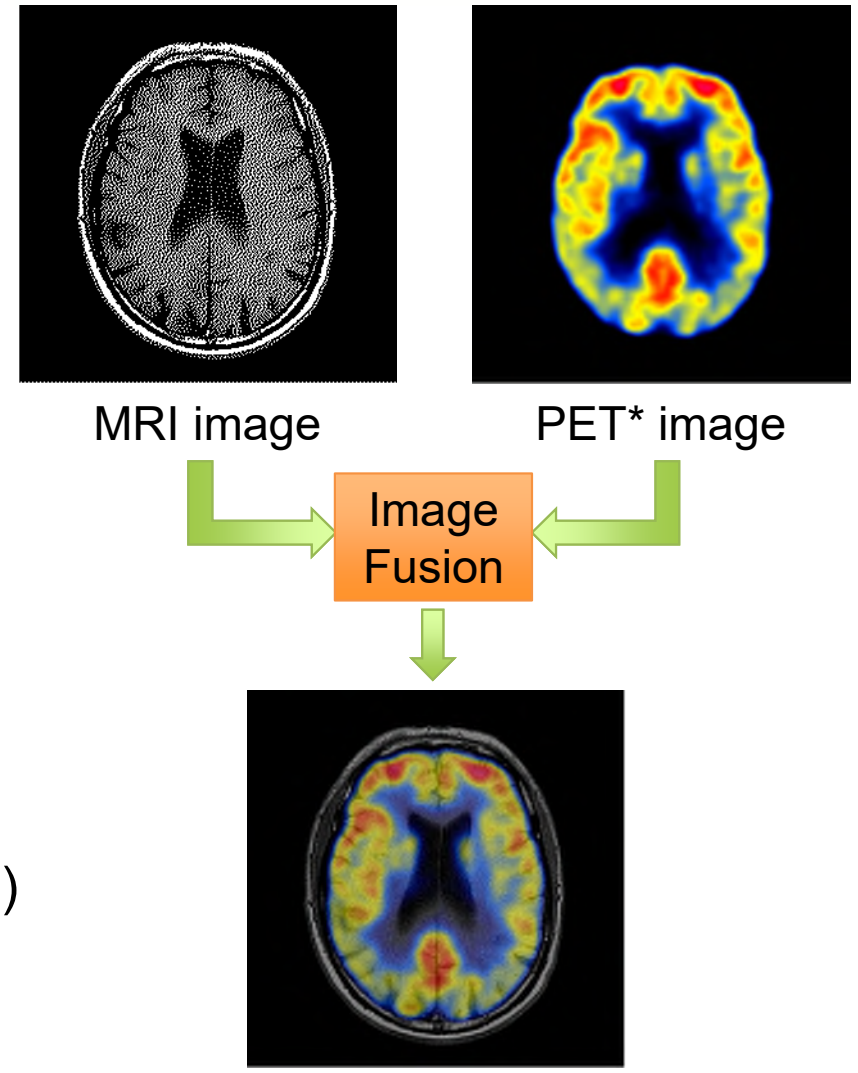
Image fusion

Why?

- Show **complementary information** from multiple input images in a single composite image.
- Achieve **improved visual representation** of an image having higher overall quality, leading to improved human ability to determine important features in an image.

How?

- Image registration (scaling, cropping, resizing) ⇨ pixel-based fusion
- Traditional arithmetic operations (mean, max, product)
- IHS and Brovey transforms (used in the medical fields)
- **Discrete wavelet transform (DWT)-based**



Source: https://doi.org/10.1155/2020/8279342

* Positron Emission Tomography

Image fusion rules

Source: Mehdinia et al., 2021.

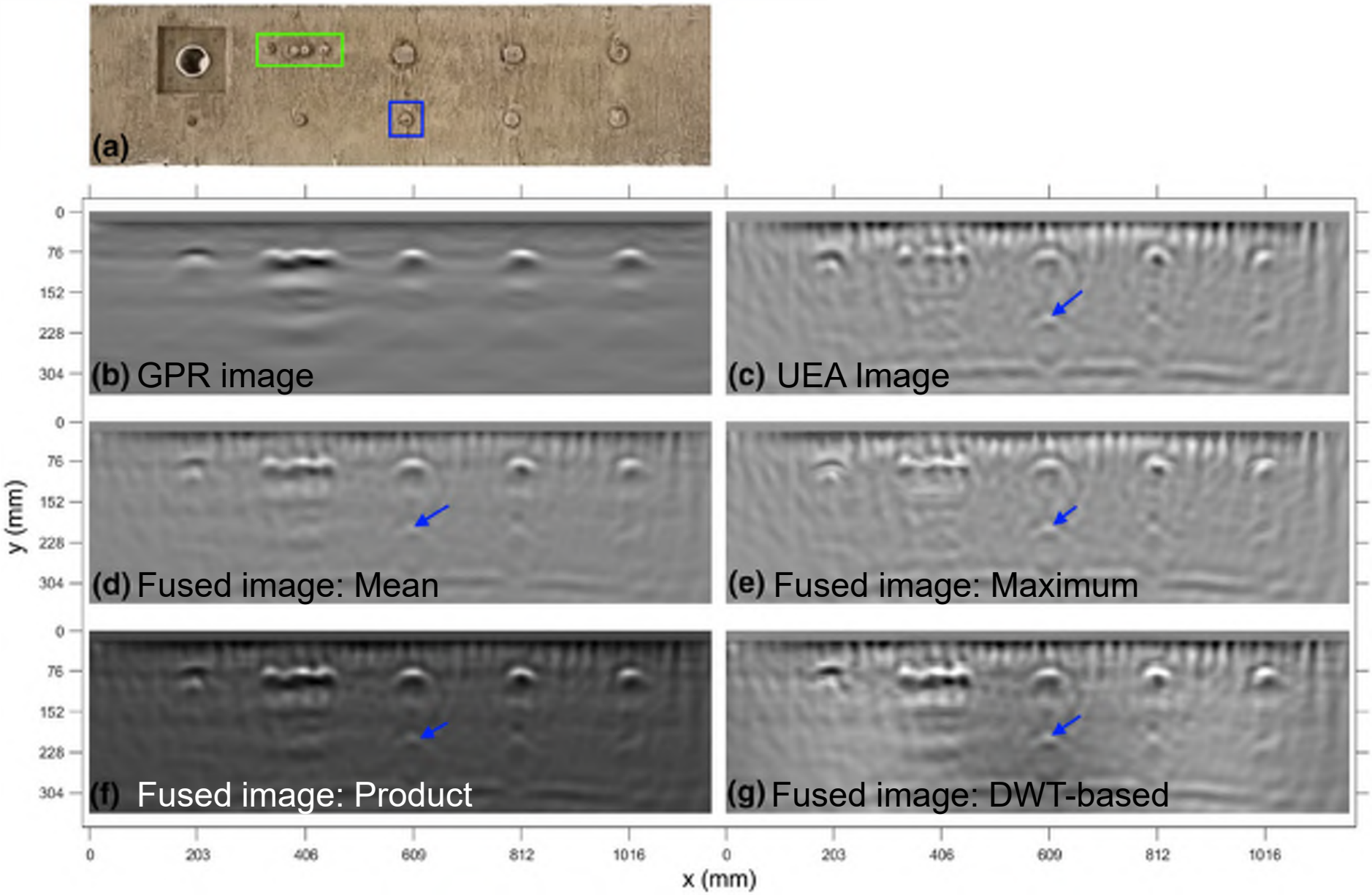
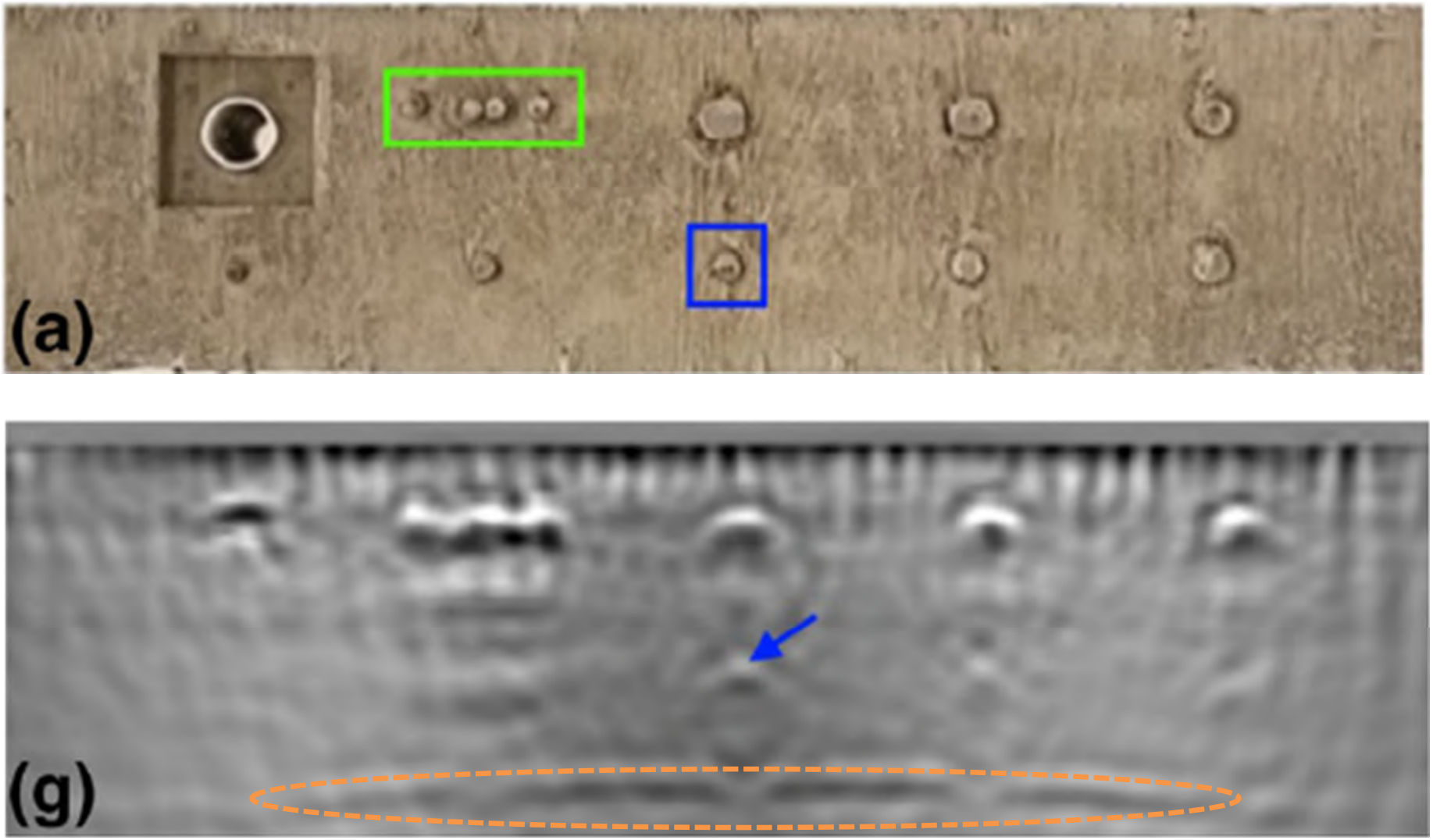


Image fusion rules (cont.)

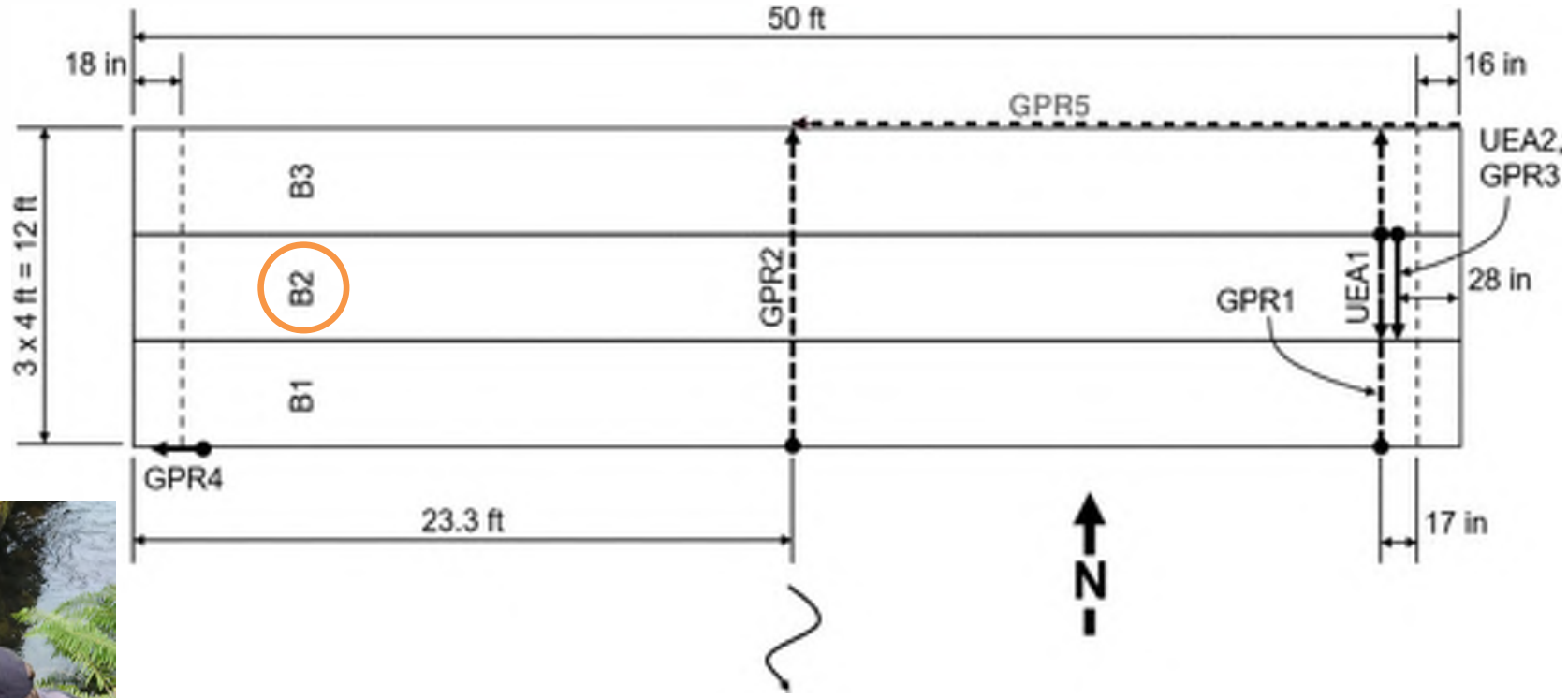
Source: Mehdinia et al., 2021.



Fused: DWT-based

Private Prestressed concrete bridge with no plans

Measurements



GPR1/UEA1 Used to determine bottom rebar and void size & location

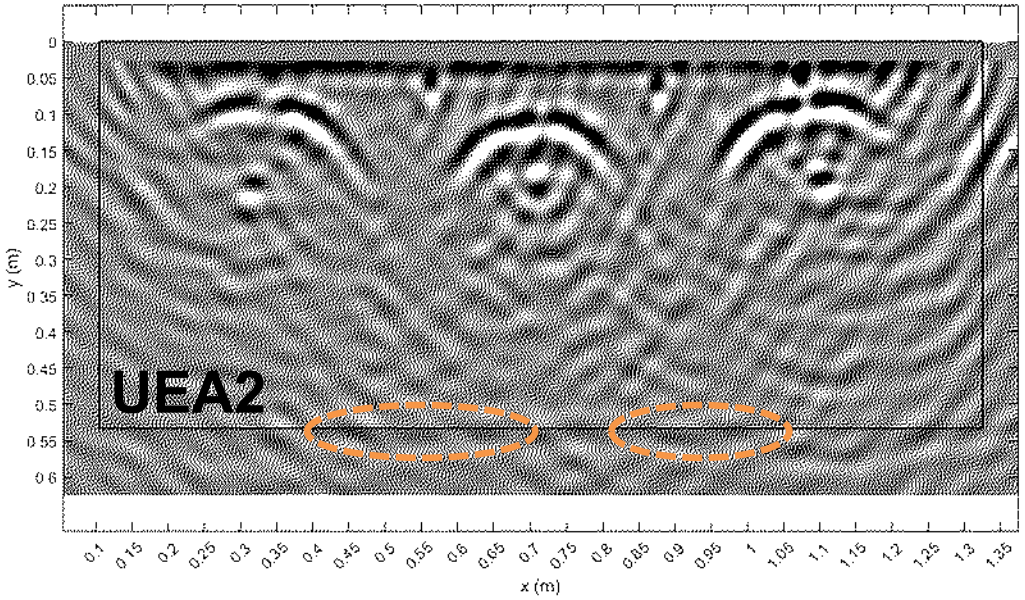
GPR2 Used to verify mid-span configuration

GPR3/UEA2 Used to determine top strand and void size & location

GPR4 Used to verify concrete cover and calibrate NDT measurements

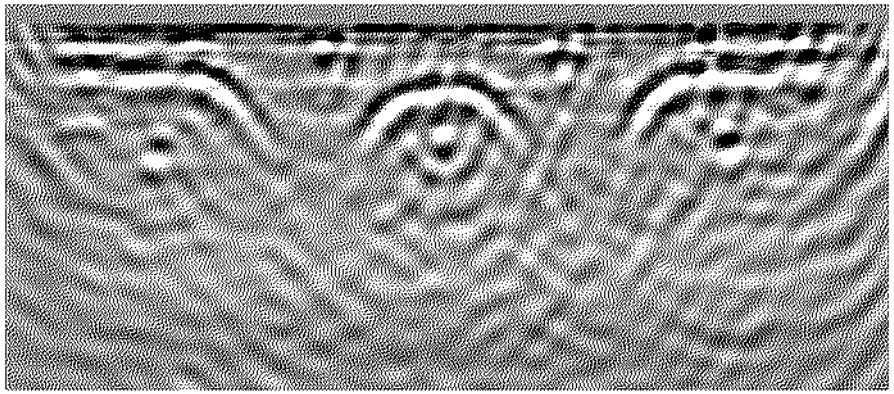
GPR5 Used to determine shear stirrup spacing

Images of B2 from roadway

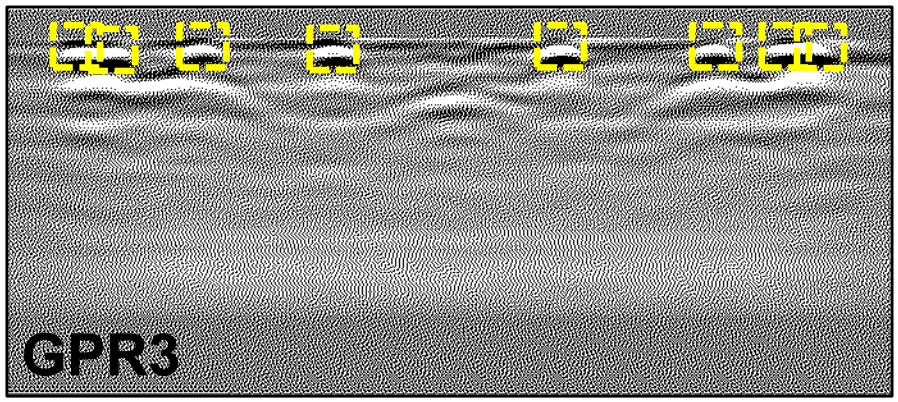


Calibrated shear wave speed:
c_s = 2700 m/s

IF

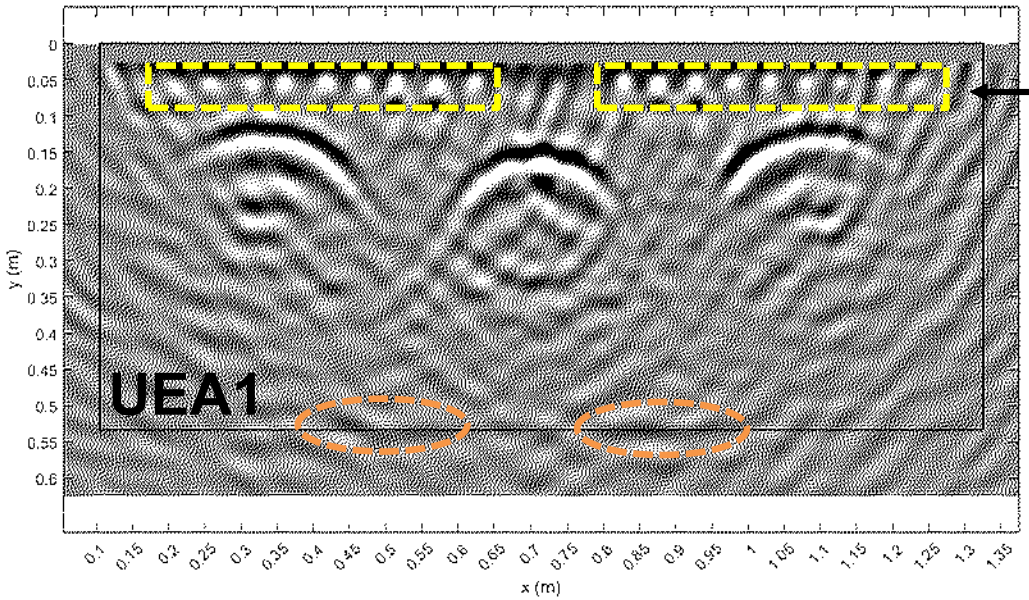


Fused (from roadway)



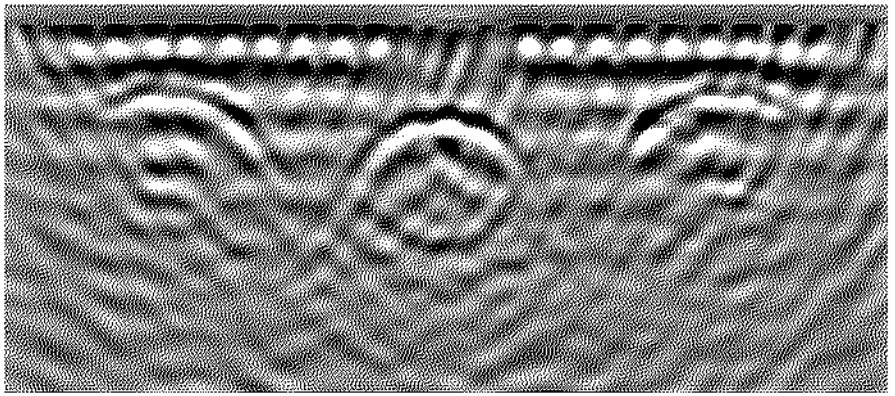
Calibrated EM wave speed:
c_s = 4.43 m/ns

Images of B2 from soffit

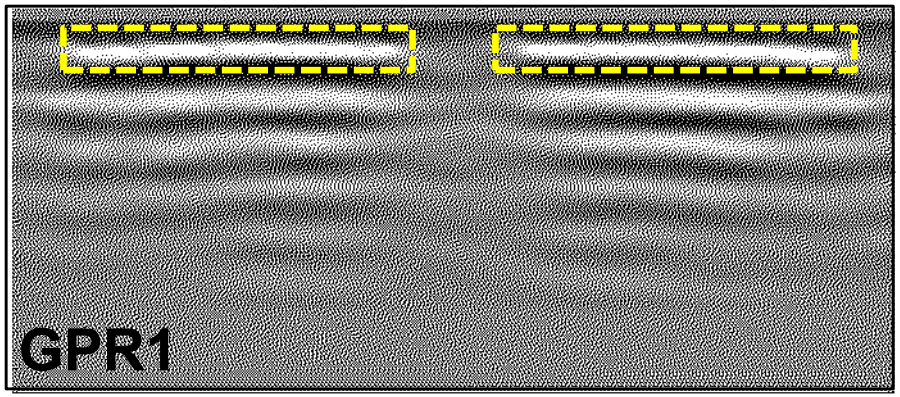


Bottom strands

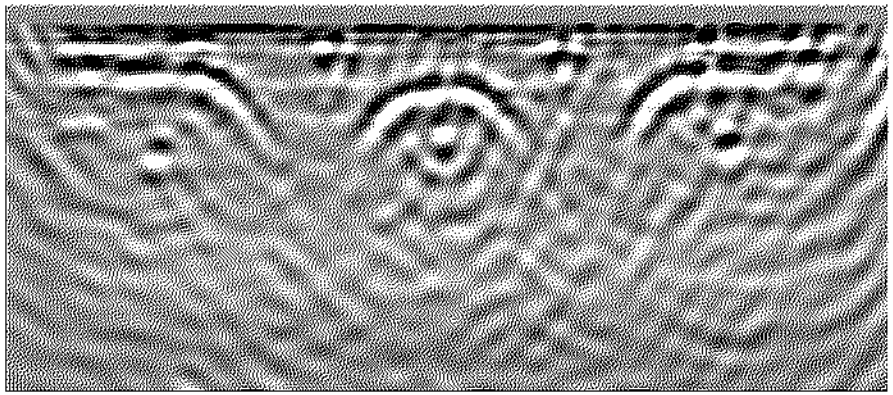
IF



Fused (from soffit)

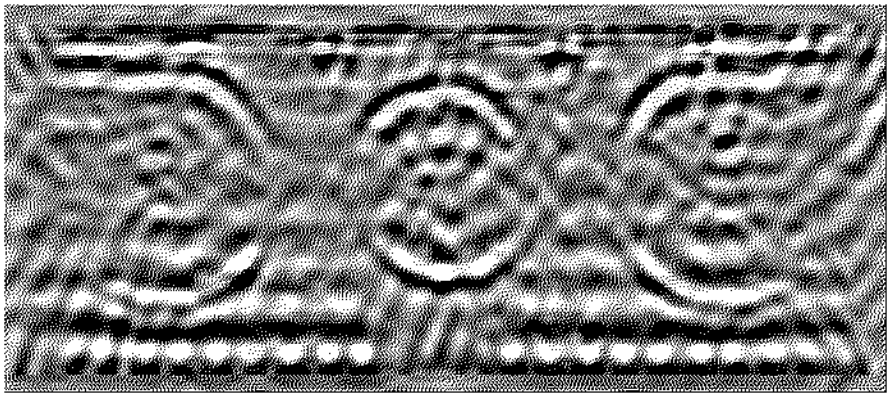


Fusion of fused images from B2

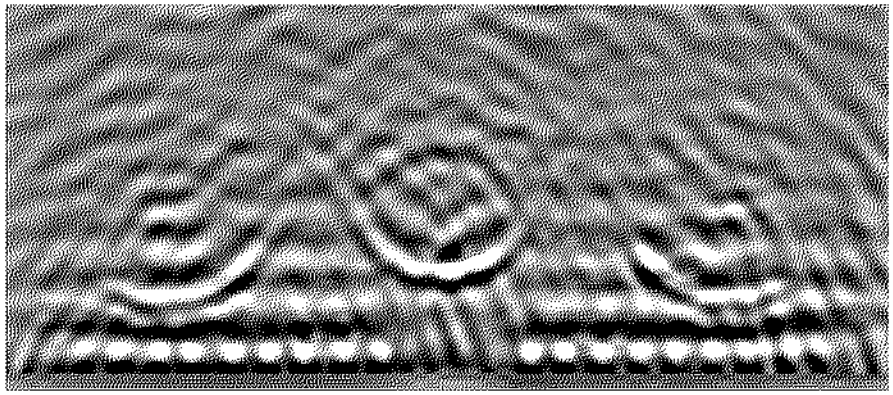


Fused (from roadway)

IF

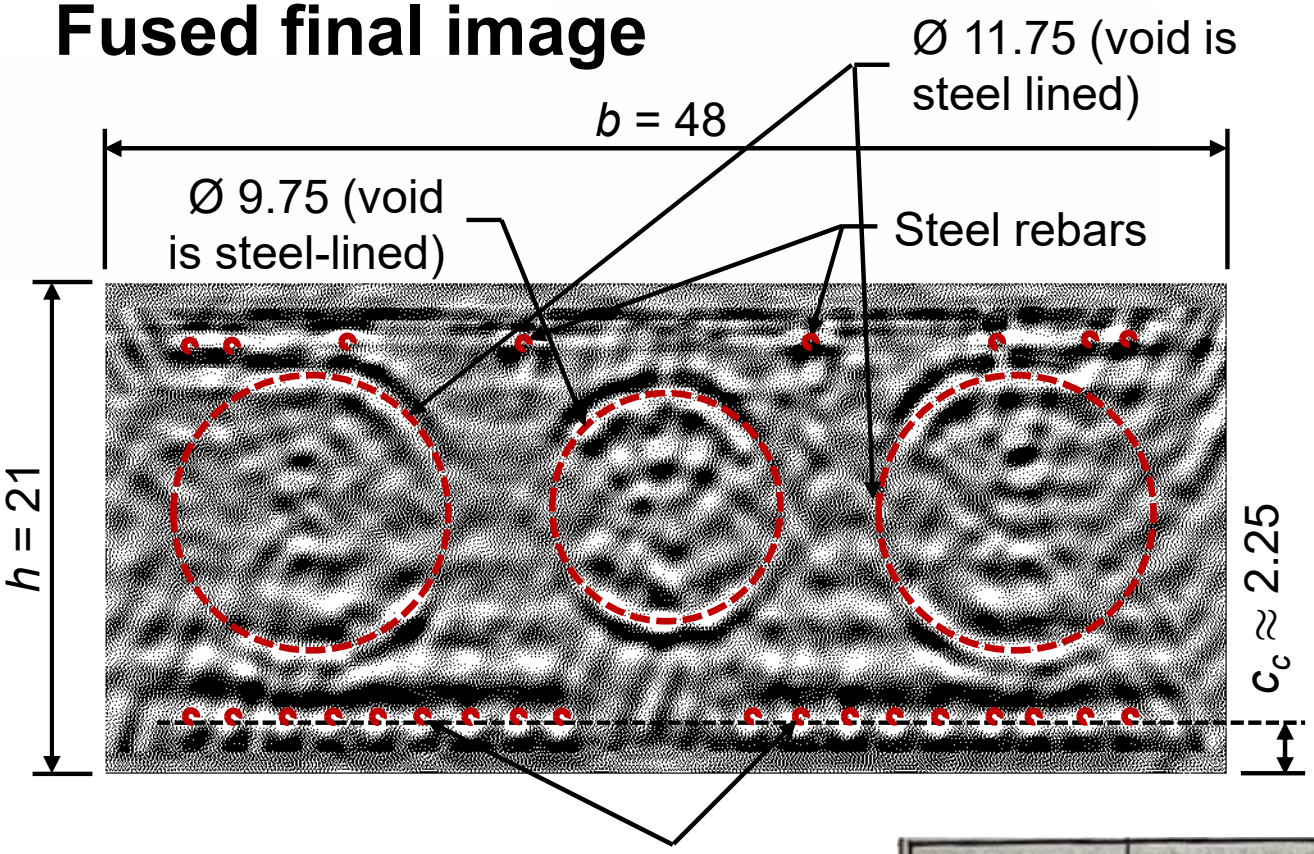


Fused (final)

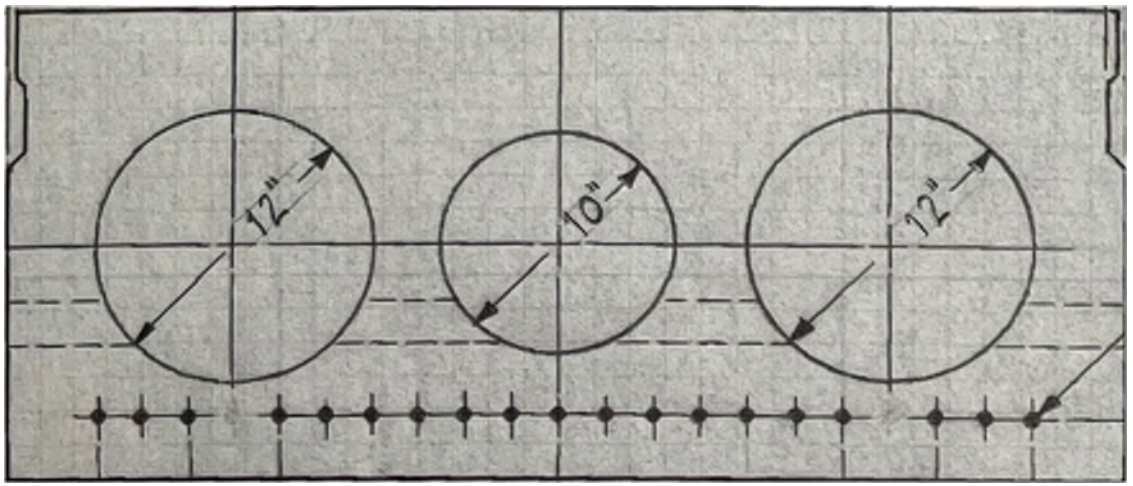


Fused (from soffit, rotated 180º)

Fused final image



Reflections suggest that pipes are steel lined, which would be rather unusual but possible given the era



All dimensions in (inch)

Validation and Calibration - Rebar size and cover dimension (Minimally invasion testing)

Summary

Multi-NDT-based image fusion provided a detailed cross-section of the prestressed slab **making it possible to conduct a traditional load rating analysis** calculation to establish reliable load capacity for all common rating vehicles. **The result was no restriction of emergency or service vehicles to the facility.**

Truck	Rating Factor	Load Factor	Tons	Controlling Point	No Plans Method
AASHTO1 (Type 3)	1.80	1.30	25	Stress at mid-span	1.0
AASHTO2 (Type 3S2)	1.74	1.30	40	Stress at mid-span	1.0
AASHTO3 (Type 3-3)	2.16	1.30	40	Stress at mid-span	1.0
Special Haul Veh's	1.17	1.30	*	Stress at mid-span	
Single Unit 4-axles	1.53		27		1.0
Single Unit 5-axles	1.44		31		0.95
Single Unit 6-axles	1.30		35		0.89
Single Unit 7-axles	1.22		39		0.85
Emerg. Veh.2	1.57	1.30	28.8	Stress at mid-span	1.0
Emerg. Veh 3	1.03	1.30	43	Stress at mid-span	0.69
Cont. Trip Permit-3	1.45	1.20	46	Stress at mid-span	0.95
Single Trip Permit-4A	1.43	1.20	46.5	Stress at mid-span	0.90

Cost

Load Rating Analysis and Report with Plans	**$4,500 - $7,500**
Load Rating Analysis and Report with NDT	**+ $1600 - $2,400**
(Equipment rental, field data collection, data processing)	