U.S. Department of Transportation
Federal Highway Administration

# Non-Destructive Testing for Concrete Paving

## CP Tech Center Tech Tuesday Webinar 11 August 2026

**David Merritt, P.E. Senior Engineer**
*The Transtec Group, A Terracon Company*

**Jim Grove, P.E., Manager**
*Concrete Technology Transfer, LLC*

# Disclaimers

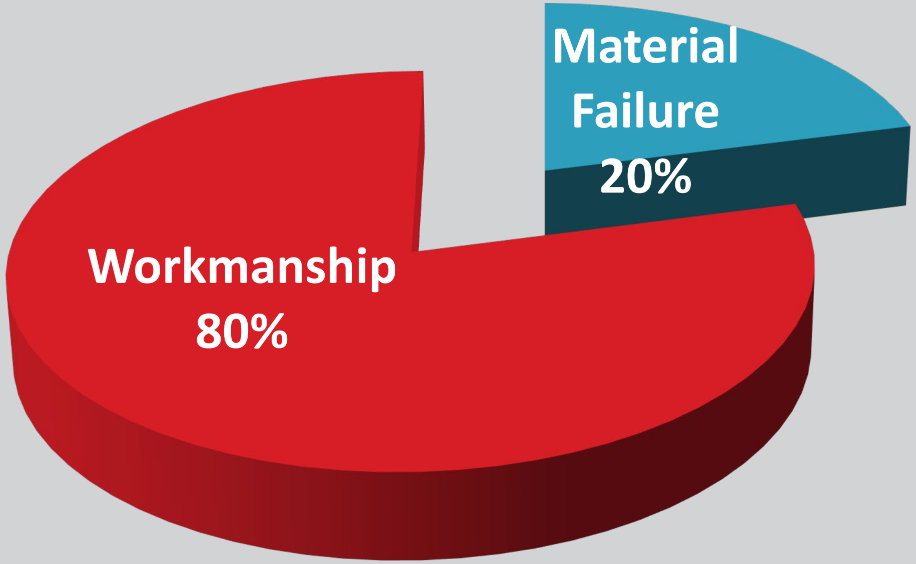
- The contents of this presentation do not have the force and effect of law and are not meant to bind the public in any way. This presentation is intended only to provide information to the public regarding existing requirements under the law or agency policies.
- The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers’ names appear in this presentation only because they are considered essential to the objective of the presentation. They are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.
- Unless noted otherwise, FHWA is the source for all images in this presentation.

# Upcoming FHWA NDT Pilot Workshops

1) International Society for Intelligent Construction (ISIC) 2026 North American Conference
    - Louisville, KY
    - August 24, 2026 (8a-noon)
    - www.IS-IC.org

2) National Concrete Consortium (NCC) Fall 2026 Meeting
    - Kansas City, MO
    - October 1, 2026 (8a-noon)
    - www.cptechcenter.org/nc2-meetings

# Factors for Premature Pavement Failure




Source: ASCE Survey

NDT & ICT Help Overcome Workmanship Issues

# Benefits of NDT for Concrete Pavement Construction

- Real-time feedback for improvement.
- More coverage measurements vs. limited random spot sampling.
- Improve quality
  - Increase potential for higher pay factors & incentives (contractors).
  - Increase service life and reduce lifecycle costs (agencies).
- Verify design parameters.
- Reduce risk and uncertainties.

# Categories of NDT for Concrete Pavement Construction

- Durability
- Strength, Modulus
- Thickness
- Dowel Bar Alignment
- Opening to Traffic
- Sawcutting
- Consolidation and Defects
- Smoothness

# Strength, Modulus, and Durability (Permeability)

## Standard Test Methods

*Strength and Modulus:*

- Field cast beams and cylinders.

*Durability:*

- Rapid Chloride Penetrability Test.

## Limitations

*Strength and Modulus:*

- Field cast specimens are time-consuming, heavy, and fragile.
- Difficult to cast, transport, and test.
- Modulus tests are specialized and subject to error.
- Specimen curing does not always reflect actual pavement curing conditions.

*Durability:*

- Even rapid tests can take days to generate results.

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration
RESOURCE CENTER
Office of Innovation Implementation

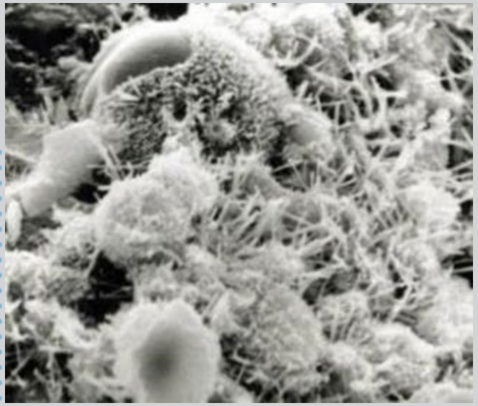
# Resistivity

## *Permeability*

# Resistivity – What it Does


Source: Gilson Co..

- Resistivity is an indicator of permeability and durability.
- Permeability is the ease with which fluids can penetrate the concrete.
- Durability damage is governed by permeability.
- Easily measures the right property



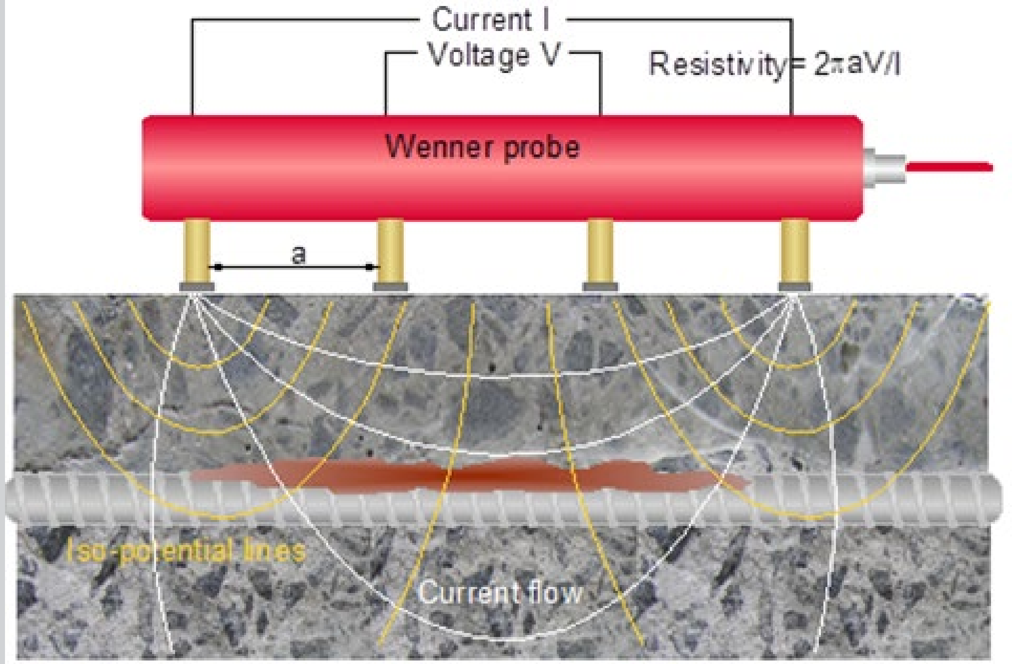
Source: FHWA.

## Standards and Guidance:

AASHTO T 402 (Bulk)

AASHTO T 358 (Surface)

# Resistivity – How it works




Source: FHWA

- Can be surface or bulk.
- Using measured currents and voltages, electrical resistivity can be calculated.

Critical That the cylinders are cured in water and maintained in water until testing.

Source: FHWA

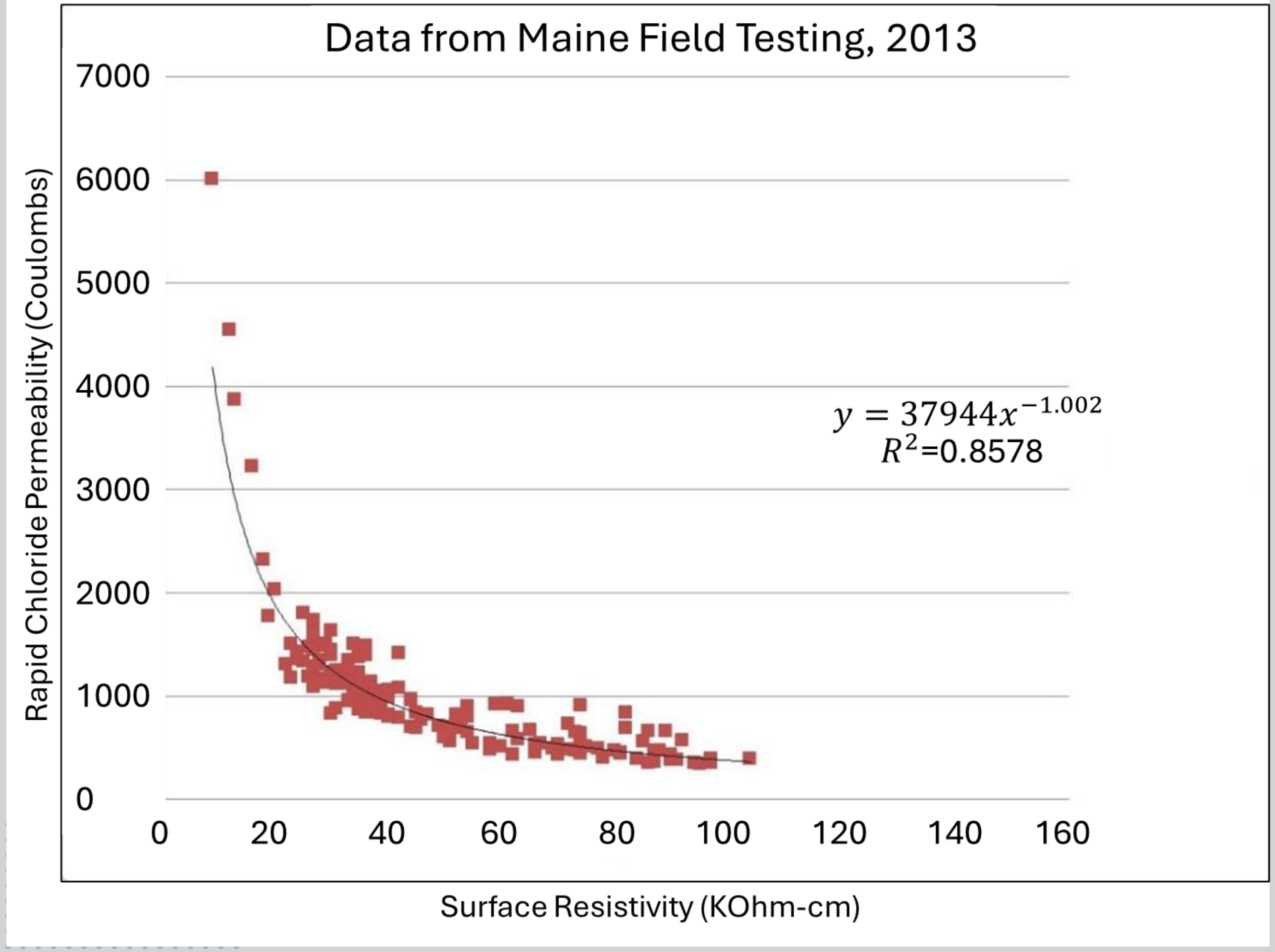
**Surface Resistivity**


Source: FHWA

**Bulk Resistivity**

# Resistivity – Use in Construction

- Some states are using resistivity for acceptance during Mix Design, and some during construction, but it is used by several DOTs for lab testing of field specimens.
- Excellent correlation to Rapid Chloride Penetrability tests.




Source: Maine DOT

# Resistivity – Benefits

- Significantly faster test than conventional methods. Instant results on hardened concrete.
- Low equipment and labor costs.
- Excellent correlation to Rapid Chloride Penetration results with consistent testing and curing.
- Multiple manufacturers available.
- No chemicals involved.
- Standardized test methods available.

**Surface Resistivity**

Source: FHWA

AASHTO T 358

**Bulk Resistivity**

AASHTO T 402

Source: FHWA

U.S. Department of Transportation
Federal Highway Administration

# Maturity

## *Strength, Opening to Traffic*

# Maturity – What it Does

**What it is:**

- NDT Test Method for ESTIMATING in-place concrete
- Early age strength only
- (flexural or compressive).

**Why it's used:**

- Opening to traffic.
- Curing in cold weather.
- Any activity that has strength-related requirements.

**How it works:**

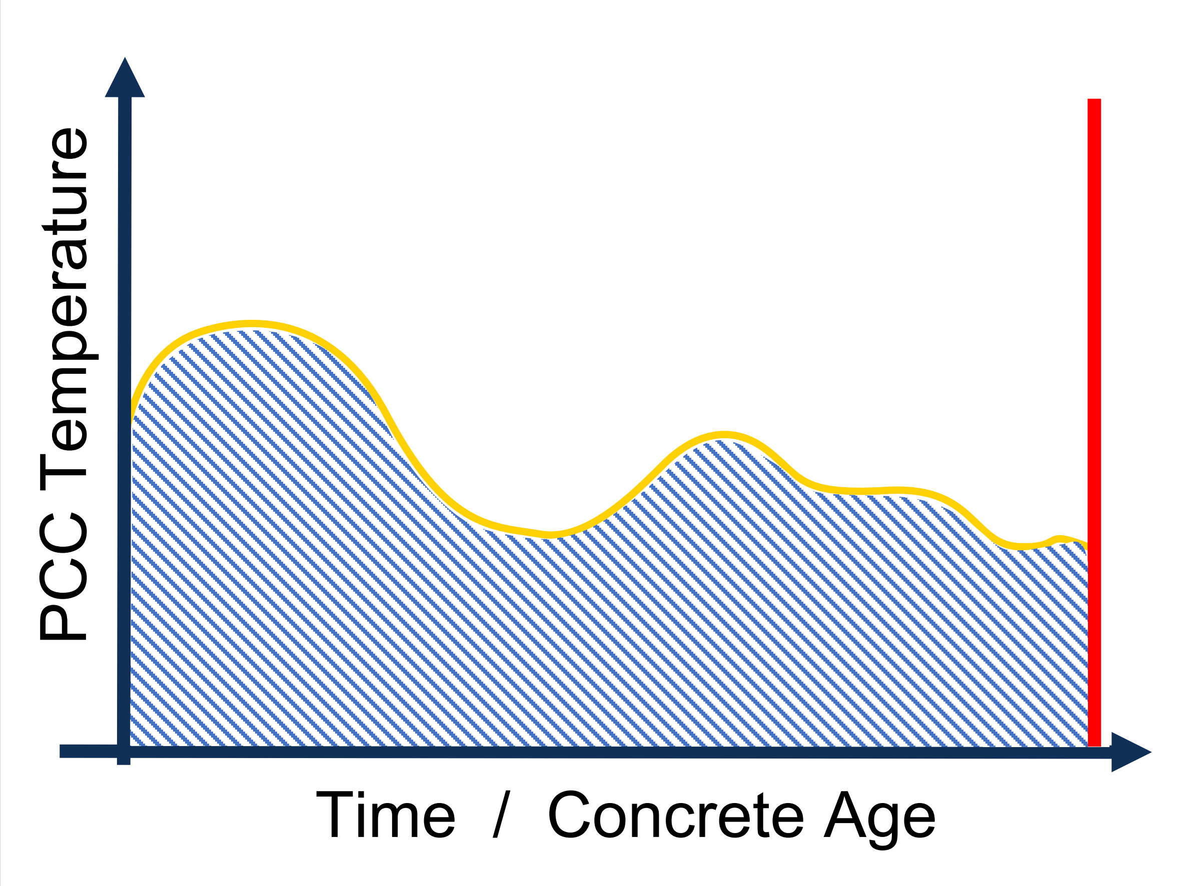
- Embedded sensors (wired or wireless).
- Data transmission to a computer.
- Software-based analysis.

**Standards:**

- Traditional Maturity Spec: ASTM C1074
- New Maturity Spec for Pavements:

AASHTO T413

# Maturity – How it Works




Source: COMMAND Center

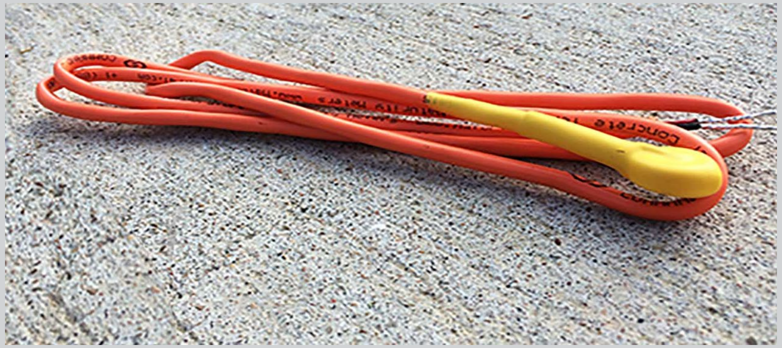
Relationship between thermal history and strength.

Nurse-Saul: TTF

$$M = \sum_{0}^{t} \left(T_C - T_o\right) \cdot \Delta t$$

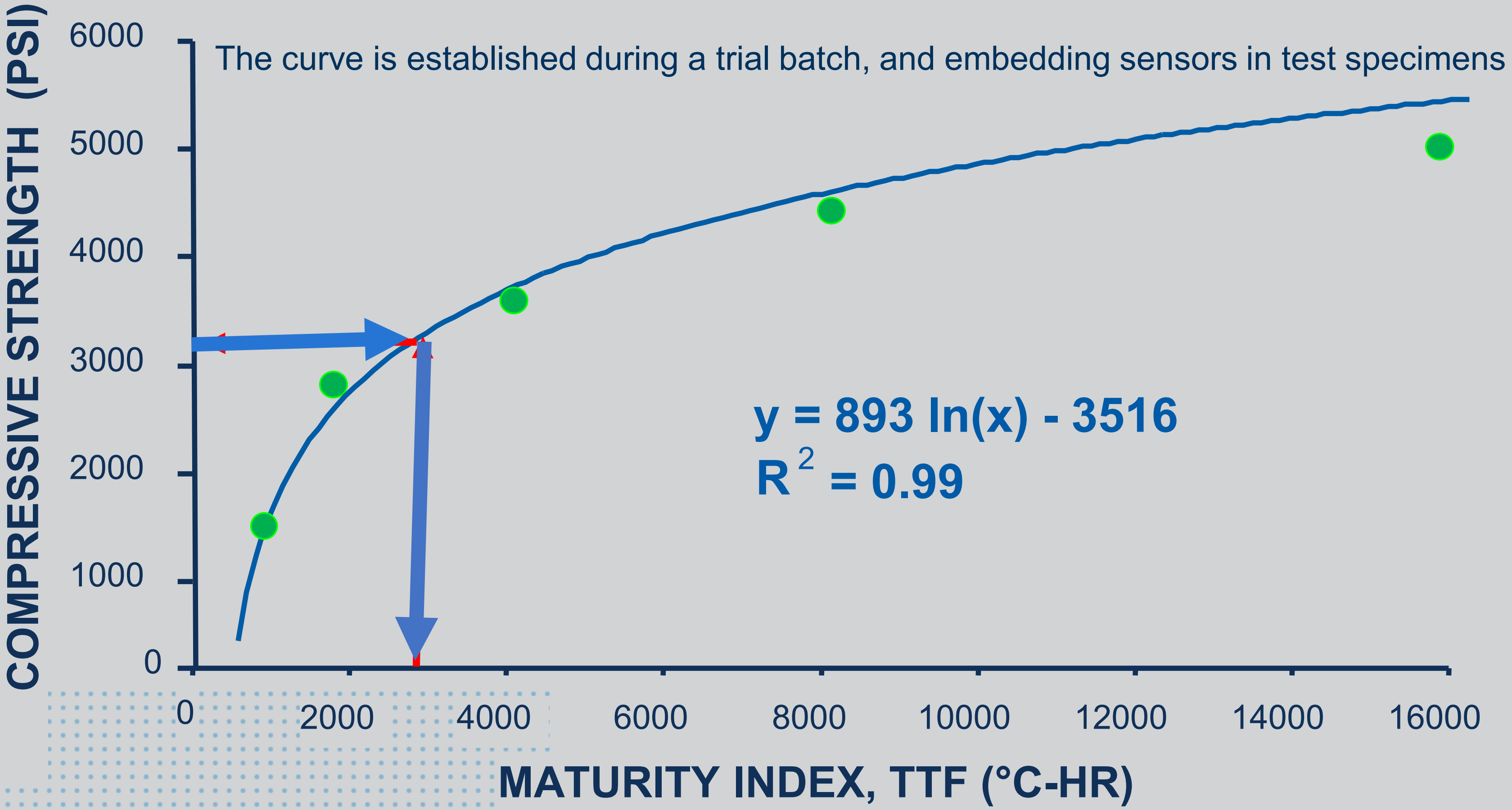
The maturity value is always mix specific

# Maturity – Use in Construction – Estimate Strength



Embedded sensors

Source: COMMAND Center




Source: COMMAND Center

# Maturity – Use in Construction – Opening to Traffic

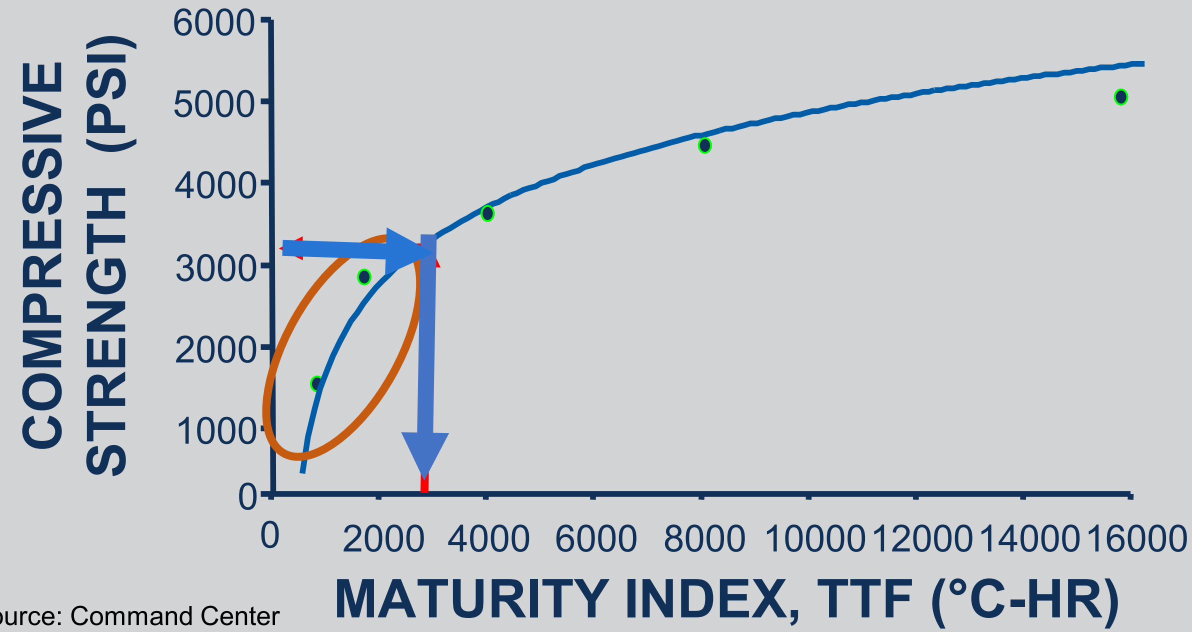
- Reduces the number of labor-intensive beam/cylinder samples. Only needed for the Time Temperature Factor - TTF.

- Real time monitor of strength to know sooner when strength is reached.

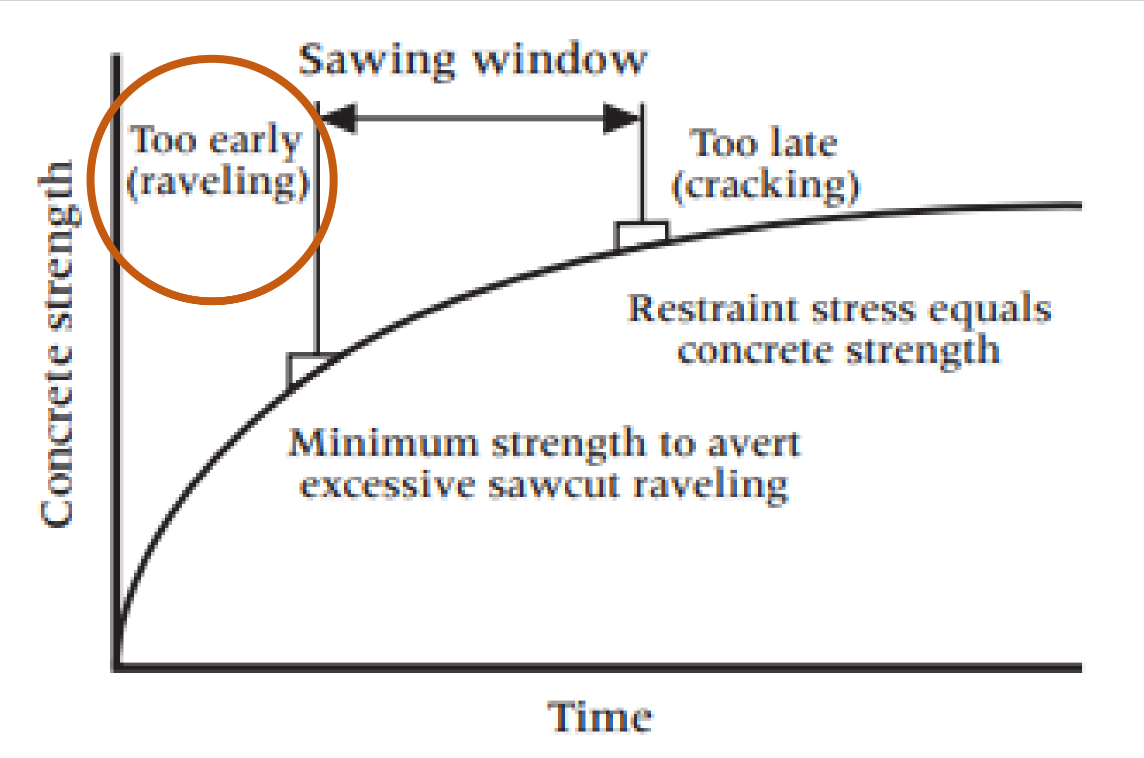
- Improve safety by reducing the time of traff1ic closures.

Source: Command Center

# Maturity – Use in Construction




Source: Command Center




Source: FHWA

AASHTO T413.

# Maturity - Benefits

- **Time and Money savings:**
  - Limits (or eliminates) number of cylinders or beams required (casting, transporting, stripping, testing).
  - Cast specimens at the plant sight on the first day of paving using plant produced concrete. (Not Labcrete)
  - Measures the temperature of the actual in-place concrete slab, which has more mass and may reach opening strength faster than test specimens.
  - **Factor of Safety**
  - Air content at the batch plant will be higher than the content at the paver
  - **Acelerates Construction:**
  - Start shouldering sooner.

Source: FHWA

**Safety:**

- Finish the project sooner.
- Reduced construction activity and exposure.
- Reduced traffic disruptions to the public.

Acurasy:

- Measures the temperature and thereby the strength of the in-place slab.

U.S. Department of Transportation
**Federal Highway Administration**

U.S. Department of Transportation
**Federal Highway Administration**

# Ground Penetrating RADAR (GPR)

## *Thickness, Defects*

# GPR – What it does

## What it is:

- Generates electromagnetic pulses (1-3 GHz) directed at the pavement.
- Records the reflections at layer interfaces in the A-Scan.

## How it works:

- Transmitter antenna
- Receiver antenna
- Data collector

## Why it's used:

- Can be used to calculate thickness.
- Can be used to determine dowel location and cover.

## Standards and Guidance:

ASTM D4748-10 (2020)

AASHTO R 37-04 (2022)

# GPR – Use in Construction

- Can be used to assess the thickness of concrete slab
- Accuracy depends on the velocity estimate
- Recent advancements in automated layer interface detection software may make thickness verification with GPR more consistent and reliable.
- Air-launched versions (cart or truck mounted) can significantly improve data collection speed.

Ground-Coupled 3D GPR | Source: Infrasense

Air-Launched 3D GPR | Source: Infrasense

Handheld 2D GPR | Source: GSSI

U.S. Department of Transportation
Federal Highway Administration

# GPR – Use in Construction – Air Voids

## Voids in Concrete

- Small voids - distinct targets
- Large voids - continuous layers , deficient consolidation gaps, mud balls

## Air-Filled Voids

- Produce white–black–white reflection pattern
- Black (negative) peak has higher amplitude than first white peak
- Velocity increases and phase reverses

## Slab/Grade Contact

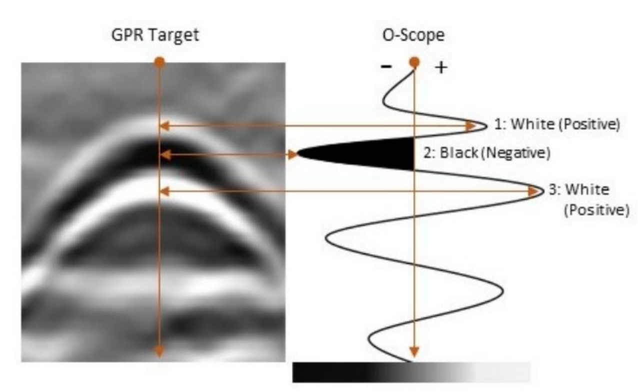
- Typically shows black–white–black reflection pattern
- Velocity decreases (assuming normal moisture content)

## Water-Filled Voids

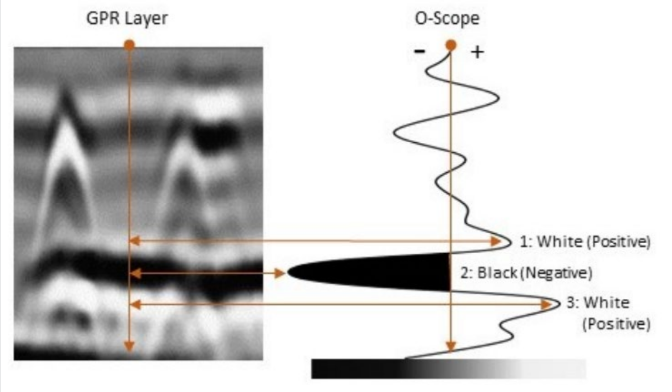
- Hard to distinguish from slab/grade contact
- Same reflection pattern, but higher amplitude
- Often appears as a more complex layered reflection

Not Air entrained voids

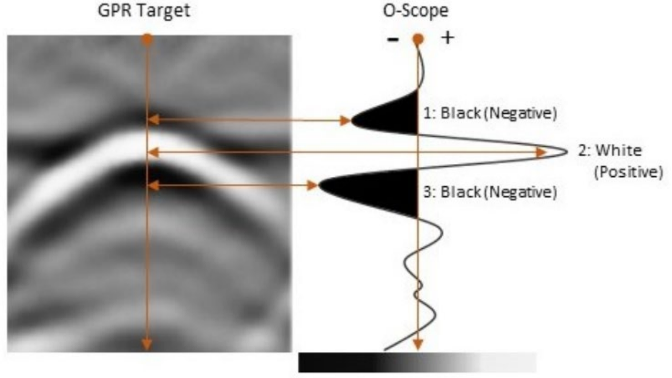
Small Air Void




Large Air Void




Water-filled Void




Source: GSSI

# GPR - Benefits

- Quick test, especially if air-launched version is used instead of the ground-coupled antenna
- Can detect air voids and delamination. Not Air entrained voids
- Does not require targets (for thickness determination).
- Fast data collection and processing.
- Reliable and repeatable results.
- Established test procedures for collecting field data.

Source: FHWA

U.S. Department of Transportation
Federal Highway Administration

# MIT-Scan-T3

## *Thickness*

# MIT-Scan-T3 – What it does

**What it does:**

- Generates time-dependent magnetic field that penetrates pavement layer.
- Induces eddy currents in the target plate placed at the bottom of the pavement layer.
- Thickness is assessed from the strength of the magnetic field generated due to the induced eddy current.

**Common components:**

- Transmission Coil
- Target Plate
- Measurement sensor
- Distance/Position sensor

**Standards and Guidance**

AASHTO T359/E209

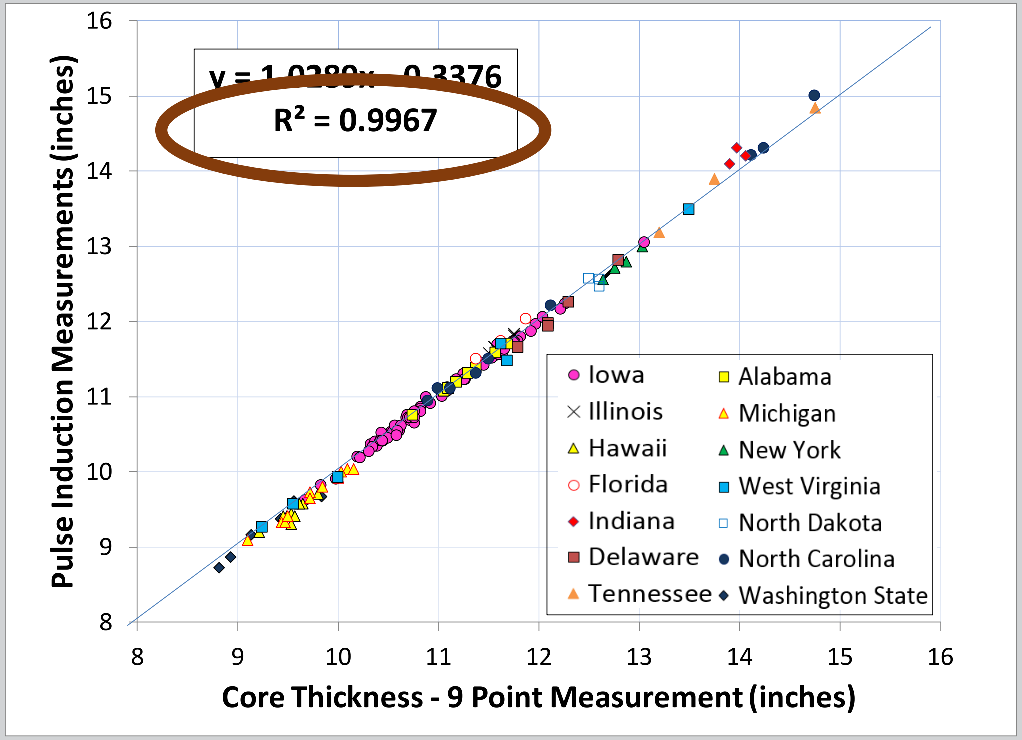
ASTM E3209

# MIT-Scan-T3 – Use in Construction

- Used to measure thickness of the concrete slab at the location of target plate. New construction only.

Source: FHWA

Source: FHWA



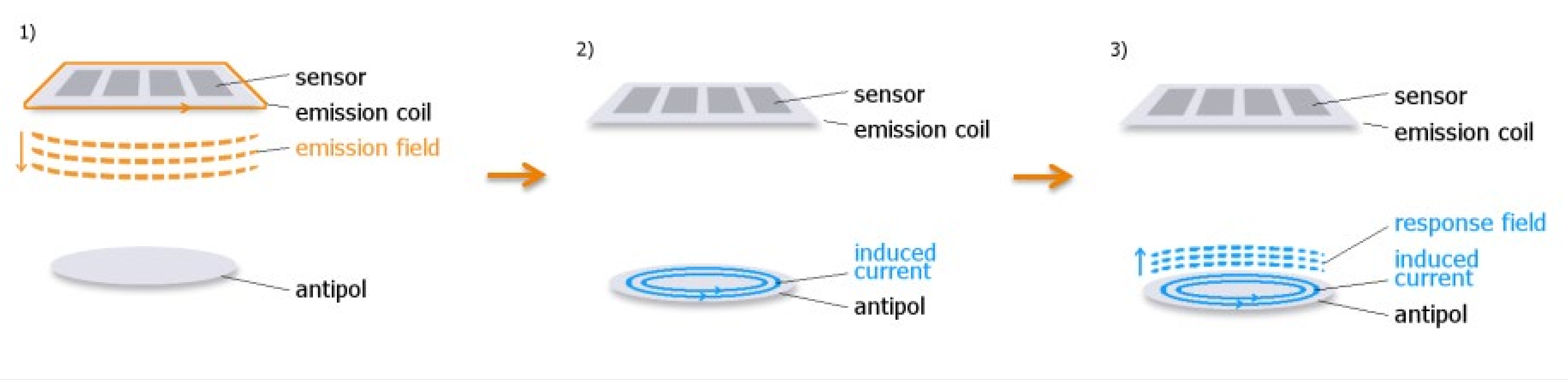

Based on FHWA MCTC data

- Target plate must be installed prior to placement of the slab.

Source: FHWA

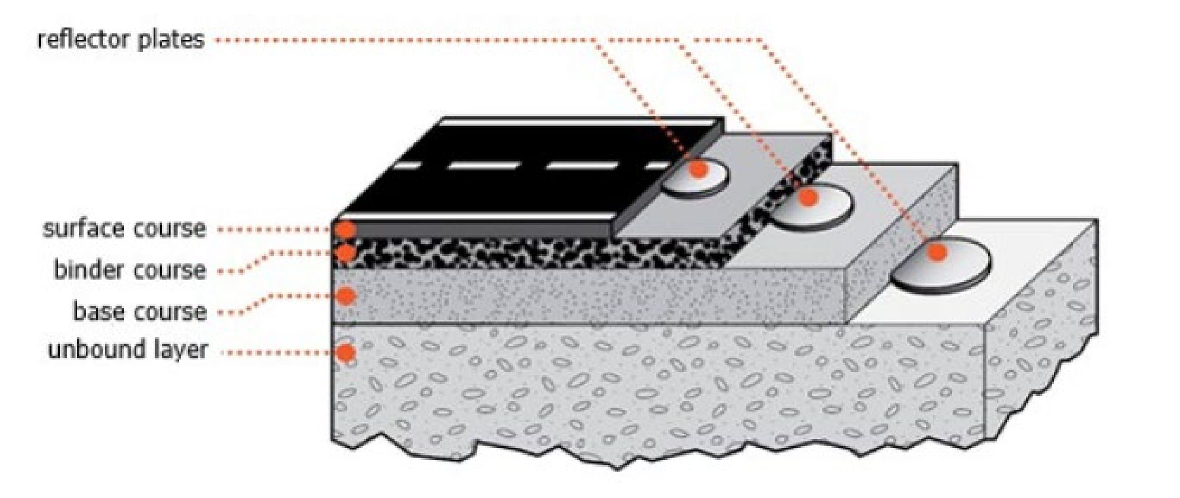
  - Typical accuracy* is ±(1 mm + 0.5% of measured thickness)

# MIT-Scan-T3 – How it Works




Source: Kessler

Source: Kessler




Source: Kessler

Measured response is converted to thickness using manufacturer calibration

# MIT-Scan-T3 – Benefits

- The measurement is independent of the paving materials
- Displays measurements in real time and records the data.
- Requires no data processing.
- Target plate location saved with GPS.
- Can be used to find a general location of dowels or tie bars

Source: FHWA

(MNDOT requires MIT-Scan $T_3$ to locate dowel and tie bars in plastic concrete)

U.S. Department of Transportation
Federal Highway Administration

# MIT-Dowel-SCAN

## *Dowel Bar Alignment*

# MIT-Dowel-SCAN What it does

## How it works:

- Transmits a pulsating magnetic signal field.
- When metal enters the field, it produces "Eddy Currents".
- Signal strength is measured by the sensors as the device moves over the dowel.

## Common components:

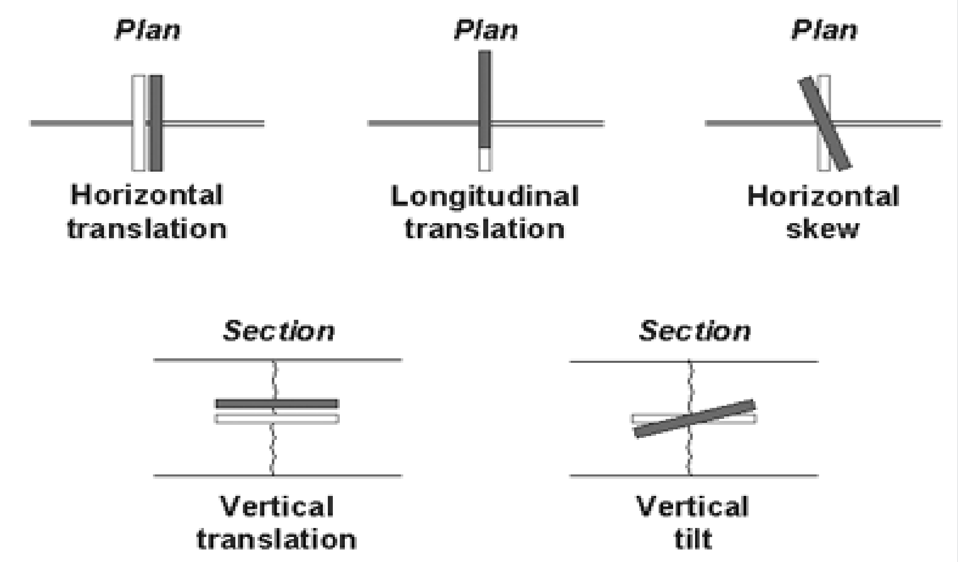
- Dowel-SCAN Measuring device
- MagnoProof 6 software
- Detachable Data Collector
- Laser

## Standards and Guidance

ASTM E3013

# Why Measure Dowel Alignment?

- Dowel bars provide long-term load transfer.
- Misalignment (beyond certain tolerance) is detrimental to long-term pavement performance.
- Extreme tilt or skew can restrict slab movements at joints causing joint lockup, mid-panel cracking, and/or widening of joints.
- Dowel misalignments can also increase faulting potential if they no longer span the joint.
- Translational misalignments can cause loss in shear capacity and joint stiffness resulting in faulting, cracking, or spalling.




Source: FHWA Tech Brief

# Standard Test Methods and Limitations

**Standard Test Methods**

- Probing behind the paver
- Coring the hardened concrete
- Cover Meter*
- GPR*

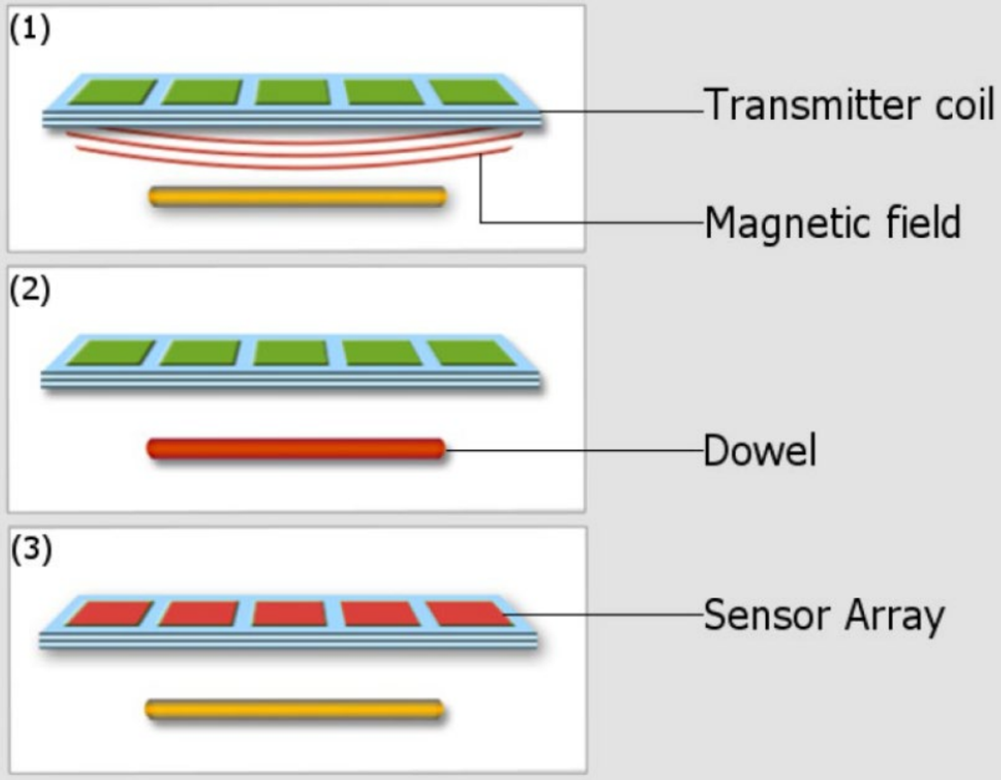
**Limitations**

- Destructive
- Very limited coverage
- Time-consuming
- Not very accurate

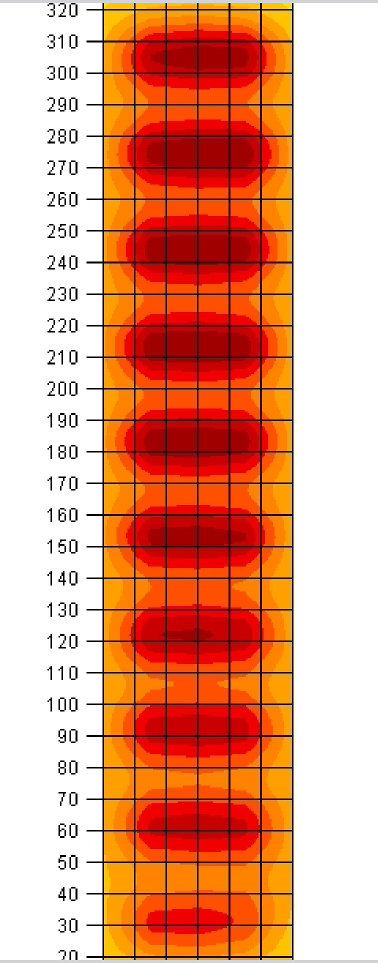
*Cover Meter and GPR are NDT devices currently being used and the limitations don't apply to them

# MIT-Dowel-SCAN – How it Works

Source: Kessler




Source: Kessler




Source: Kessler

Measured response is converted to dowel depth using manufacturer software - Magnaproof

# MIT-Dowel-SCAN – Use in Construction

- Used to measure dowel alignment – skew, tilt, translational.
- Project Testing part of the contractor's Quality Control Plan – document process control.
- State DOT testing on selected joints to verify that the contractor's QC Program is working correctly.
- Forensic Investigations.

Source: FHWA

# MIT-DowelSCAN – Benefits

- Real-time results
- Alignment of all dowels in a joint
- Quick set-up in the field
- Faster advancement of the testing
- Single person operation
- Auto-steer along laser line
- Advanced processing using software


Source: FHWA

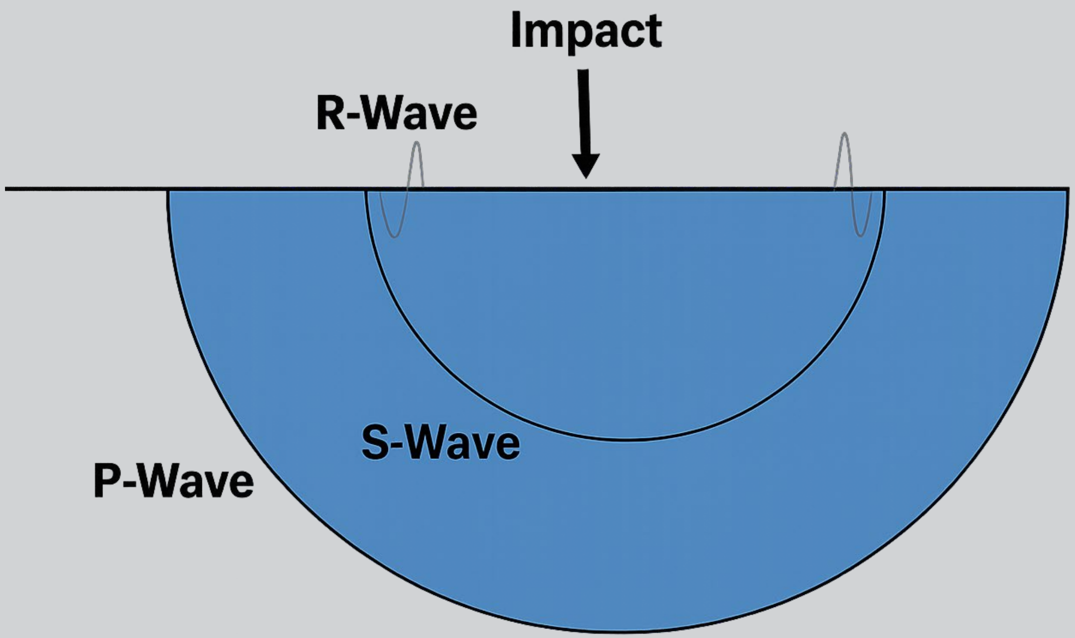
U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration
RESOURCE CENTER
Office of Innovation Implementation

# Ultrasonic Pulse Velocity (UPV)

## *Modulus*

# Seismic Waves Basics




Source: Adapted from Olson Engineering

- P-Wave: Also called Primary Wave, Compression Wave, Sound Wave, Longitudinal Wave.
- S-Wave: Also called Shear Wave, Transverse Wave.
- R-Wave: Also called Surface Wave or Rayleigh Wave.

# UPV – What it Does

- Measures travel times of a pulse of ultrasonic (sound) P-Wave, or “speed of sound” through material.

Common components:

- Two ultrasonic transducers
- Measuring instrument.

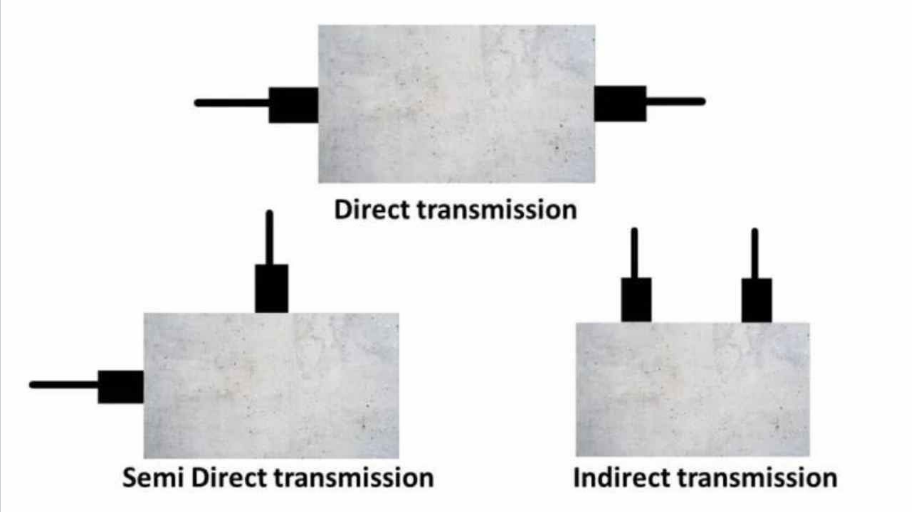
Can be used to determine:

- Modulus or Strength

Standards and Guidance

ASTM C 597

# UPV – How it Works




Source: Adapted from Civil Engineers World

- Three modes of transmission (see figure).
- Specimens can be testing with direct transmission and is most accurate.
- Indirect is used for pavements and is the weakest signal.

$$V = \sqrt{\frac{E(1-\mu)}{\rho(1+\mu)(1-2\mu)}}$$

$V$ = pulse velocity or compression wave velocity
$E$ = dynamic modulus of elasticity
$\mu$ = dynamic Poisson's ratio
$\rho$ = density

Remains constant

# UPV – Use in Construction –Estimate Modulus or Strength

- Not currently used for construction.
- Can be correlated to elastic modulus or strength.
- Can track PCC strength and modulus over time.

# UPV- Benefits

- Low variability/high repeatability.
- Results can be correlated to strength or elastic modulus.
- May be combined with other NDT, like maturity, for more data on strength gain over time.

Source: ACS.

Source: ACS.

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration
RESOURCE CENTER
Office of Innovation Implementation

# Spectral Analysis of Surface Waves (SASW)

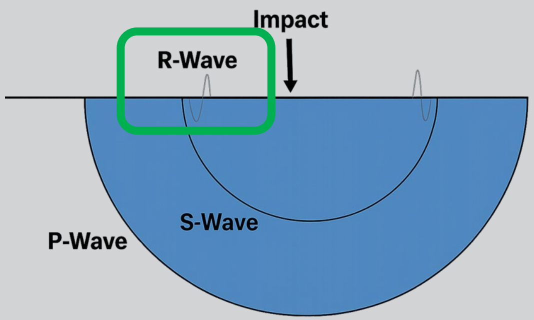
## *Strength, Modulus*

# SASW – What it Does

- Uses Surface Waves (R-Wave) to determine the variation of shear wave velocity, which can be used to measure stiffness.
- Can calculate Shear and Young’s Modulus.
- Can correlate to strength or other NDT modulus values.

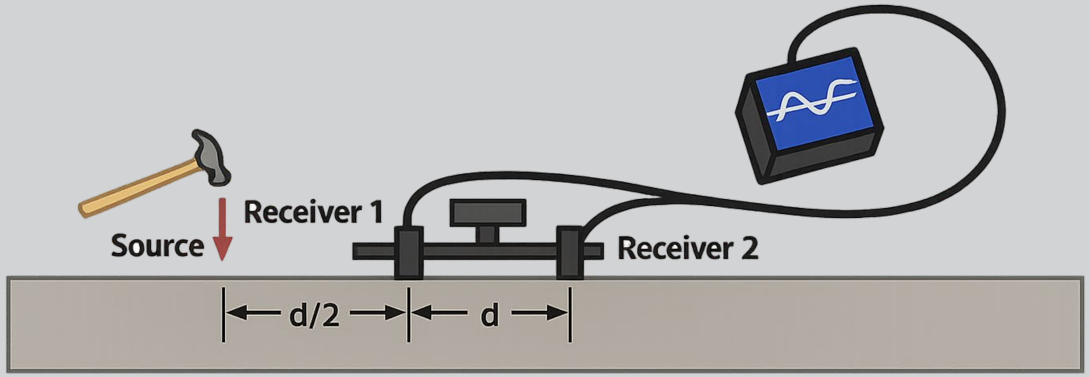
- Common components:
  - Two receivers.
  - Hammer/impactor.
  - Data collector.
- Standards and Guidance

ACI 228.2R




Source: Adapted from Olson Engineering

# SASW – How it Works

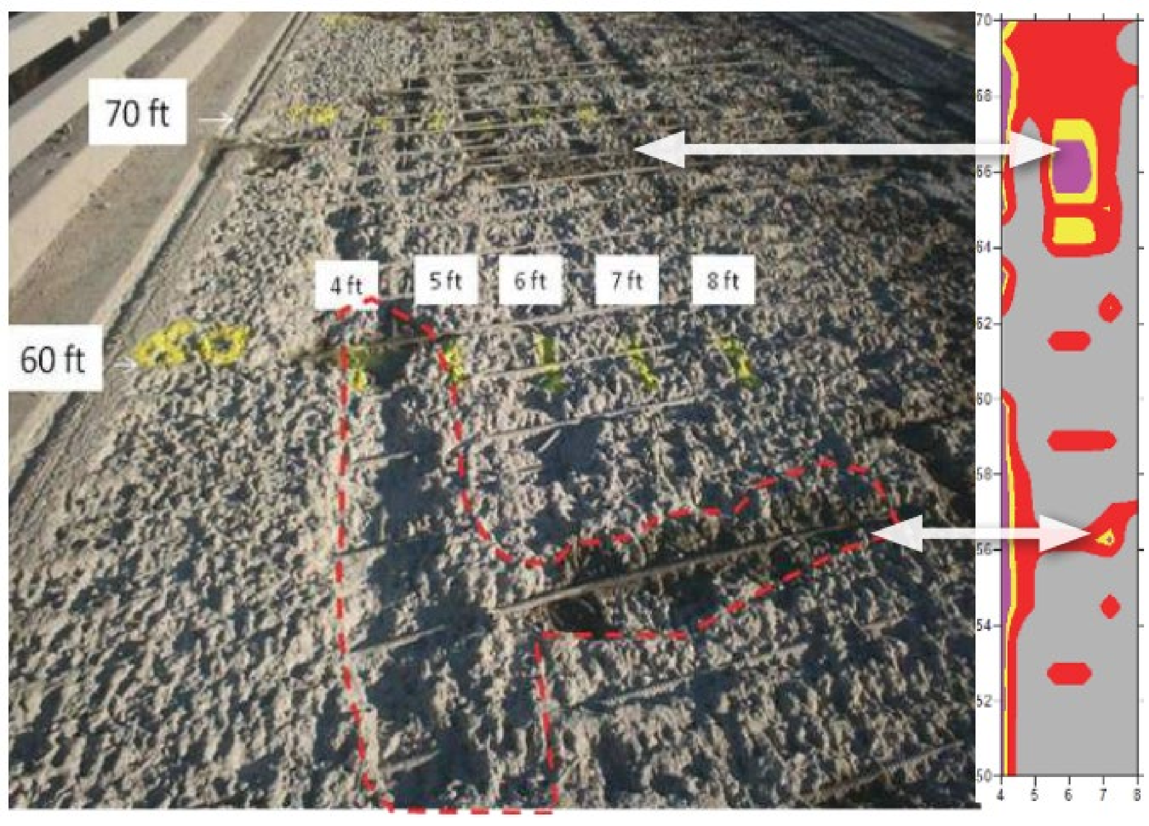



Source: Adapted from Olson Engineering

- Waves move faster through stiffer materials.
- Waves move slower through softer or damaged materials.
- SASW compares how long the waves take to travel between sensors.
- Simple calculations can estimate Shear Modulus and Young's Modulus (ACI 228.2R)
- Can be correlated to strength.

# SASW – Use in Construction – Calculate Modulus and Estimate Strength

- Could be used to assess uniformity of stiffness during construction.



# SASW – Benefits

- Has been used for decades and is an established test method.
- Recent advancements in cart-based equipment show promising applications for continuous measurement.
- Integration of GNSS allows data to be georeferenced, which can create digital as-built information.

Source: Adapted from Olson Engineering

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration
RESOURCE CENTER
Office of Innovation Implementation

# Impact Echo (IE)

## *Modulus, Thickness, Defects*

# IE – What it Does

## Generates Compression

- Waves (P-Wave) which reflects back from the back of tested member (bottom of layer) or from a discontinuity.
- Can be used to calculate thickness and defects.
- Can be used to estimate modulus or strength (if thickness is known).

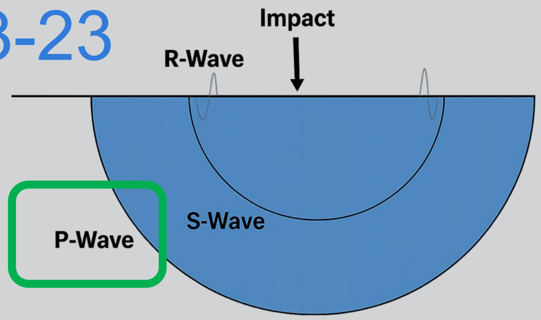
## Common components

- One receiver.
- Hammer/impactor.
- Data collector.

## Standards and Guidance

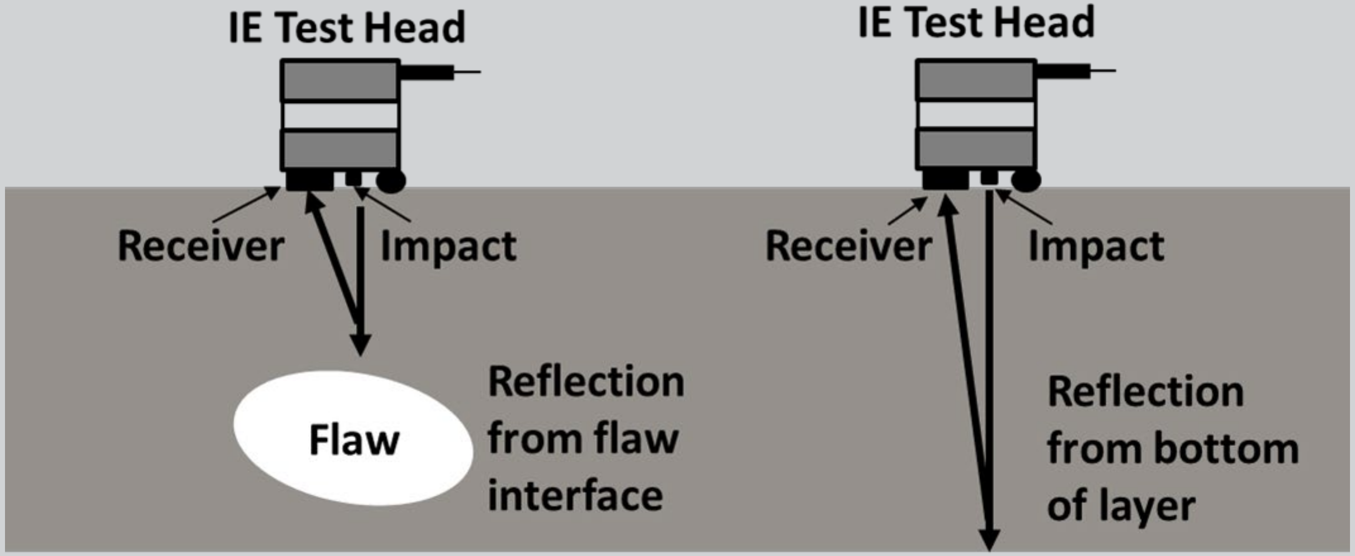
ACI 228.2R

ASTM C1383-23

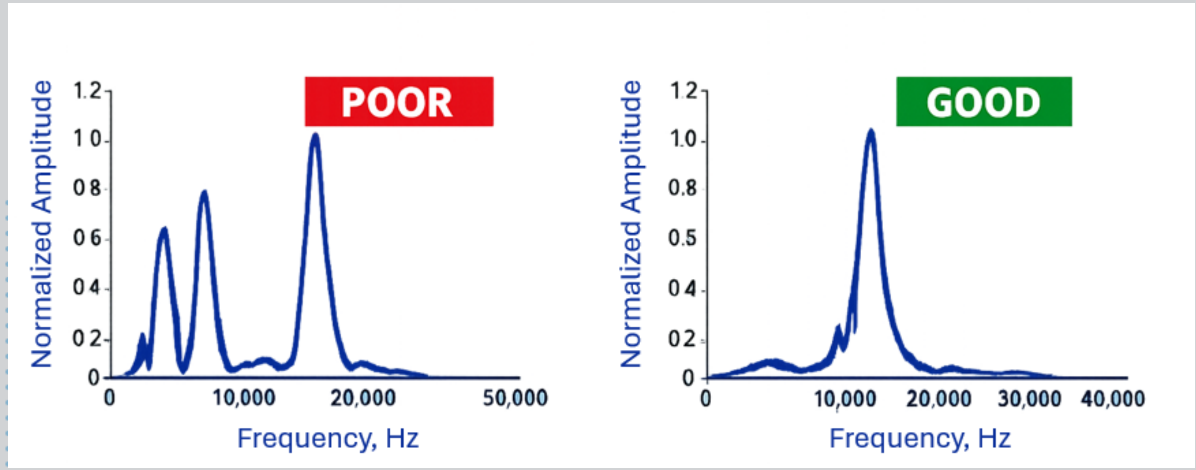



Source: Adapted from Olson Engineering

# IE – How it Works




Source: Adapted from Olson Engineering

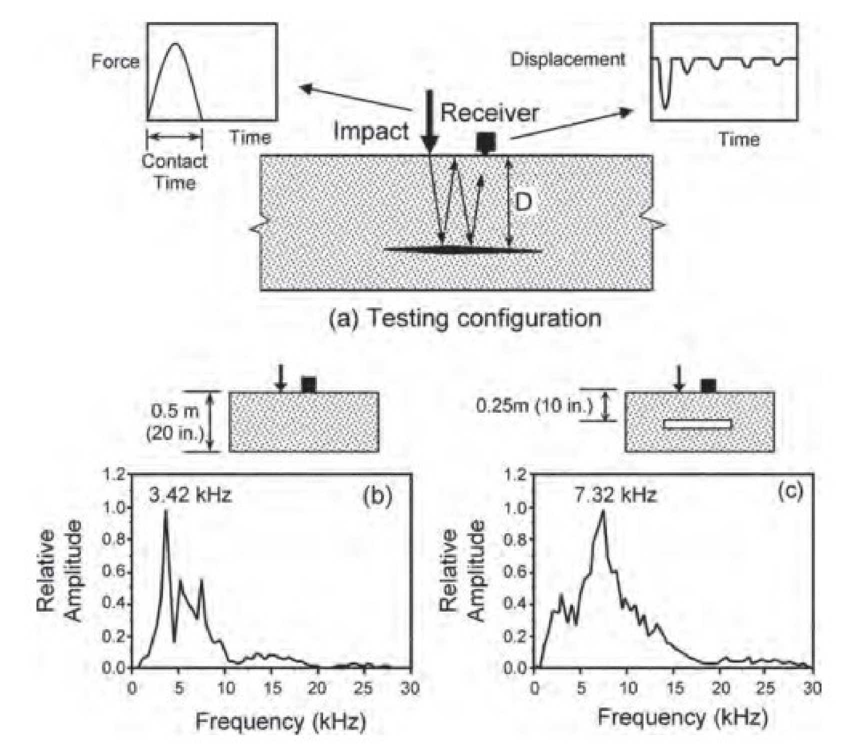



Source: Adapted from FHWA

- Impact generates Compression Wave.
- Receiver records “echo” from either flaw interface or bottom of layer.
- Reflection from bottom layer occurs at a lower frequency than the shallower flaw interface.

# IE – Use in Construction

- Can be used to measure thickness of the concrete slab at the location of testing.
- Can be used for evaluating shallow defects such as voids, delamination, debonding, or honeycombing.
- Rolling transducer and automated impactor for near-continuous flaw detection.



# IE - Considerations

## Thickness

- Limits determined by transducer response characteristics and impactor size.
- Typical testable thickness ~ 24 inches

## Zone of Measurement

- Conical detection zone, radiating downward from impact/sensor location.
- Rule of thumb: Defect must be larger than half the wavelength (typical wavelengths ~50 mm to 2,000 mm)

## Other considerations

- Not applicable to structures with overlays
- Shallow delamination is harder to quantify
- Requires skilled interpretation
- Surface must be clean and air-dry
- Subgrade detection requires sufficient acoustic impedance contrast

# IE Benefits

## Testing & Assessment:

- Nondestructive – no coring or cutting required.
- Measures both thickness and internal defects from a single test.
- Only requires access to one surface of the pavement.

## Standards & Guidance:

ACI 228.2R

ASTM C1383-23

## Operational:

- Portable – single-operator field deployment.
- No surface preparation or embedded targets needed.
- Straightforward frequency-domain data interpretation.

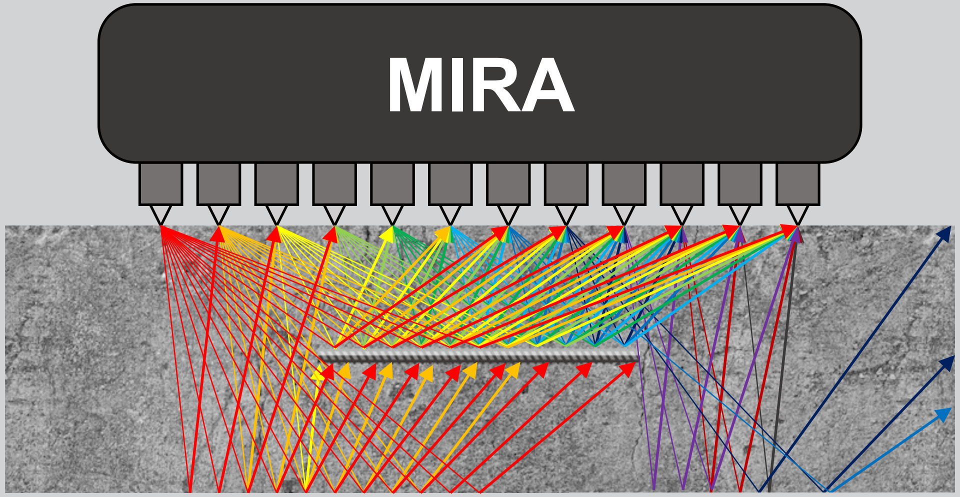
## Considerations:

- Can supplement or reduce the need for destructive coring.
- Construction QA adoption is still developing; best used alongside established methods.

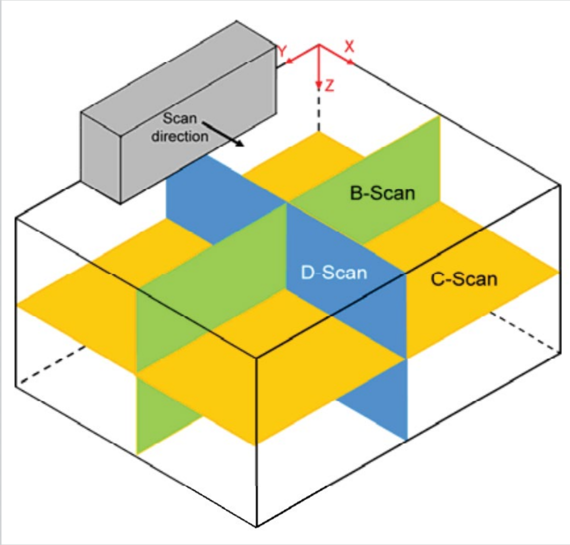
# Multi-Impulse Ray Analysis (MIRA)

## *Thickness, Defects, Opening to Traffic, Sawcutting*

# MIRA – How it Works




Source: Adapted from FHWA



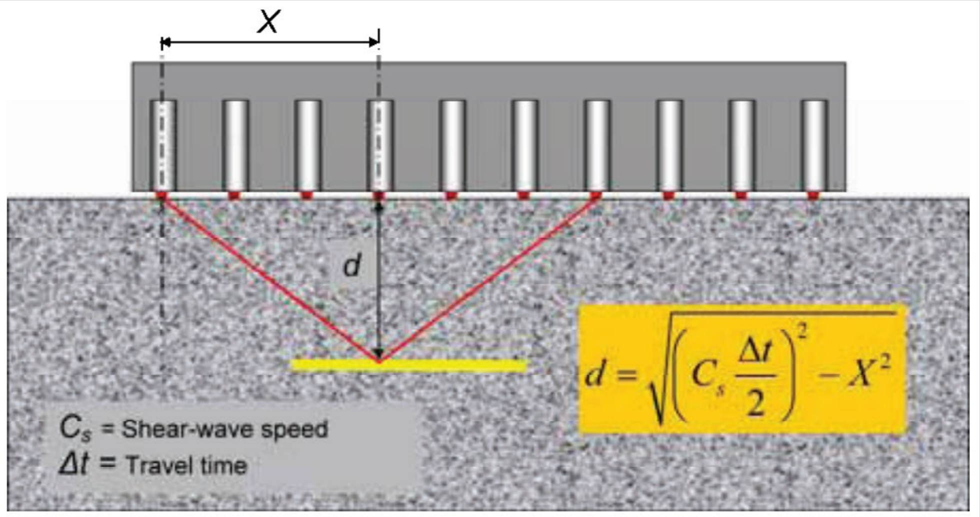

Source: Adapted from FHWA

- When the ultrasonic shear waves encounter an interface (acoustic impedance change), part of the waves is reflected.
- A-scans are repeated between each pair of transducers.

U.S. Department of Transportation
Federal Highway Administration

# MIRA – Use in Construction

- Can be used to measure thickness of the concrete slab at the location of testing.
- Estimation of bound layer depth.
- Can be used for evaluating defects such as voids, delamination, debonding, or honeycombing.
- May be used to detect reinforcement location (not dowel alignment).



# MIRA – Use in Construction

- MIRA uses ultrasonic shear waves (S-waves) to look beneath the sawcut notch.
- It can detect whether a crack has actually formed under the notch — meaning the contraction joint has "activated."
- This gives contractors a way to verify joint activation, even though the crack is invisible at the surface.
- Knowing whether the joint has activated tells you:
    - Sawcut timing was appropriate.
    - Sawcut depth was adequate to trigger the crack

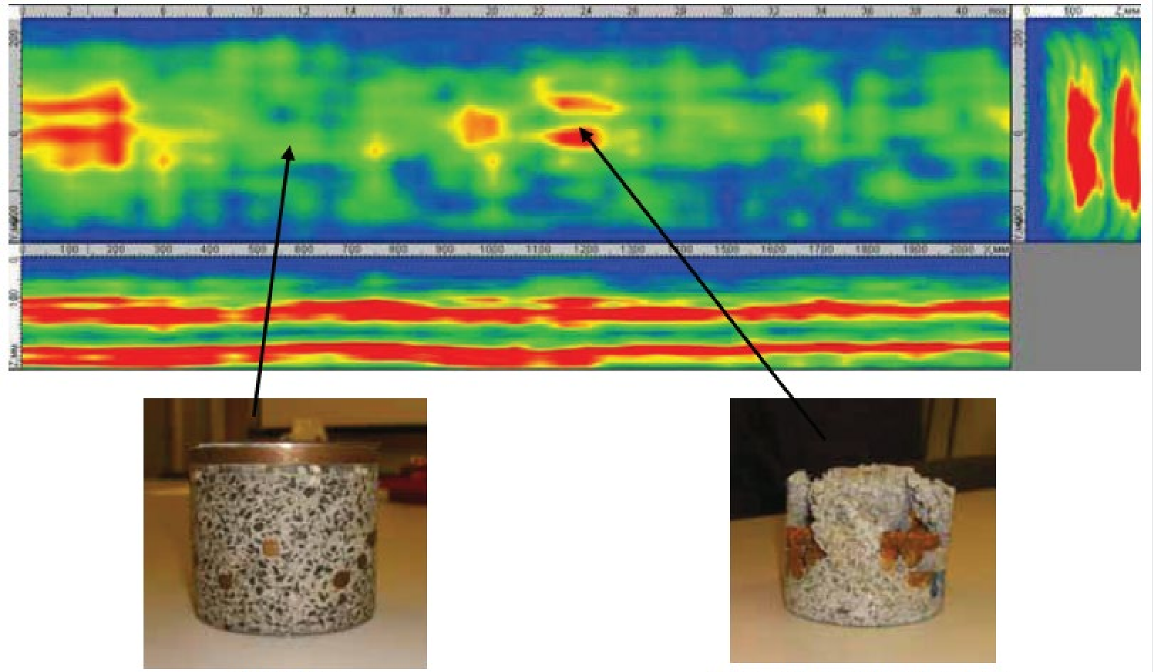
Limited application, promising research

Source: CPTech Center

When the joint is not "activated" cracking can happen outside the joint – MIRA can help detect joint activation.

# MIRA – Use in Construction – Internal Defects

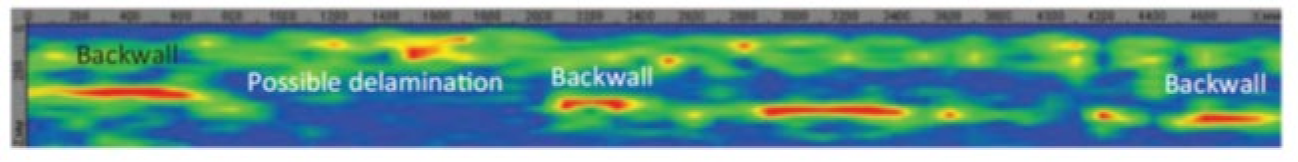
- Poor quality bond in overlays and repairs.
- Delamination appears as high-amplitude linear reflection shallower than the actual thickness.
- Voids and honeycombing in concrete members appear as high-amplitude reflections of finite size.



Solid Core

Core with voids below bars

Source: Germann Instruments




Source: FHWA

# MIRA - Considerations

## Thickness

- Imaging quality degrades with depth
- Max. depth ~80–100 inches
- Practical depth ~24–30 inches
- Not effective < 2 inches due to the wavelength of the 50 kHz shear waves

## Zone of Measurement

- Within or near the footprint of the transducer array (240 mm × 100 mm).
- Lateral resolution – transducer spacing (~30–40 mm near the surface) but degrades with depth

## Other considerations

- Very small voids (< 0.5 l) may not produce a clear reflection.
- Rebar interference
- Poor transducer coupling and noisy data on very rough, textured or tined surfaces
- Operator interpretation
- Individual measurement takes about 2–3 seconds (slower than continuous methods)

# MIRA – Benefits

- Real-time data collection and processing.
- Detailed 2D and 3D images.
- Detection of multiple types of flaws.
- Low to medium level of expertise required for equipment setup and data collection.

U.S. Department of Transportation
Federal Highway Administration

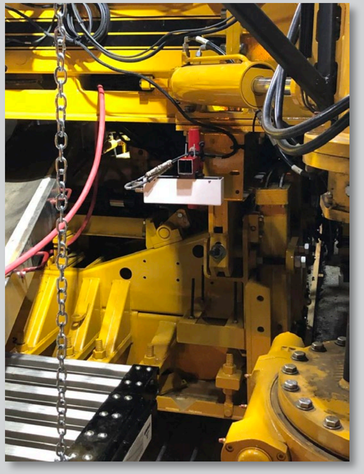
# Real-Time Smoothness

## *Smoothness/Ride Quality*

# RTS – What it Does

- Provides a general idea of smoothness (IRI) values during paving.
- Assesses the impact of changes to paving operations (e.g., mixture changes) on smoothness during paving.
- Identifies systematic paving factors that may be impacting smoothness.

- **<u>Common components:</u>**
  - Distance Measuring Instrument (DMI) and GPS
  - Data Collection and Feedback
  - Profiling Sensors

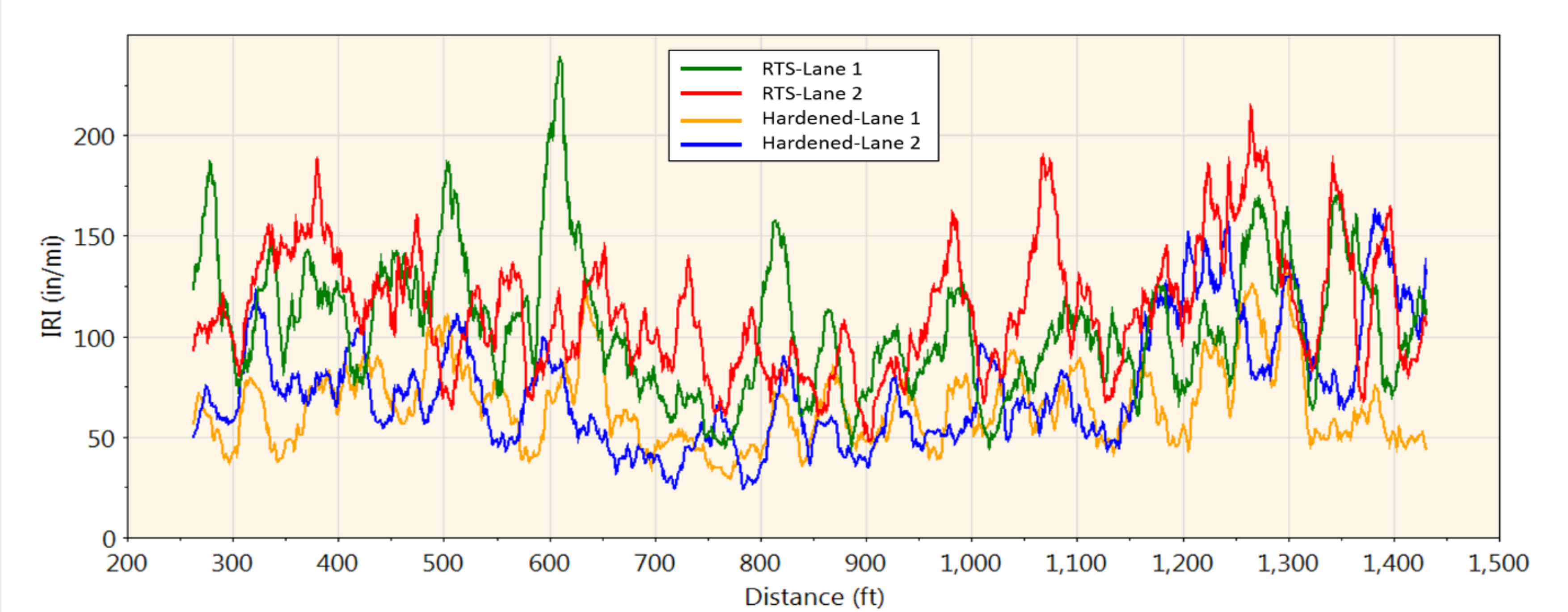



# RTS – How it Works

- A sensor system is attached to the paver, typically behind the main pan or trailing finish pan.
- As the concrete is placed, the sensors continuously measure the pavement profile behind the paver.
- The system instantly converts these measurements into a roughness value (IRI or PrI) and identified bumps and dips.
- The information is displayed in real time, so the contractor can see smoothness problems immediately.
- Paving operations (mixture, paver settings, etc.) can be adjusted based on the impact changes in operation have on smoothness.

# RTS – Capabilities

- Contractors use RTS to get an idea of final smoothness results.
- RTS results are generally higher, but trends are similar.



# RTS – Benefits

- **Contractors:**
  - Low initial startup and maintenance cost
  - Minimal initial training
  - No additional personnel to setup or monitor during paving
  - Reduced corrective action (diamond grinding, remove/replace)
  - Maximizing incentives/minimizing disincentives
- **Agencies:**
  - Superior final product from the contractor.
  - Smoothness is typically a key indicator of construction quality.
  - High level of smoothness relative to what is achievable.
  - Increased market competition

U.S. Department of Transportation
Federal Highway Administration

# Questions?

U.S. Department of Transportation
Federal Highway Administration

# Contact Information

David Merritt, P.E.
Senior Engineer
The Transtec Group, A Terracon Company
dmerritt@thetranstecgroup.com

Jim Grove, P.E.
Manager
Concrete Technology Transfer, LLC