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OF NEW JERSEY

Modulus of Rubblized Concrete from Surface Wave Testing

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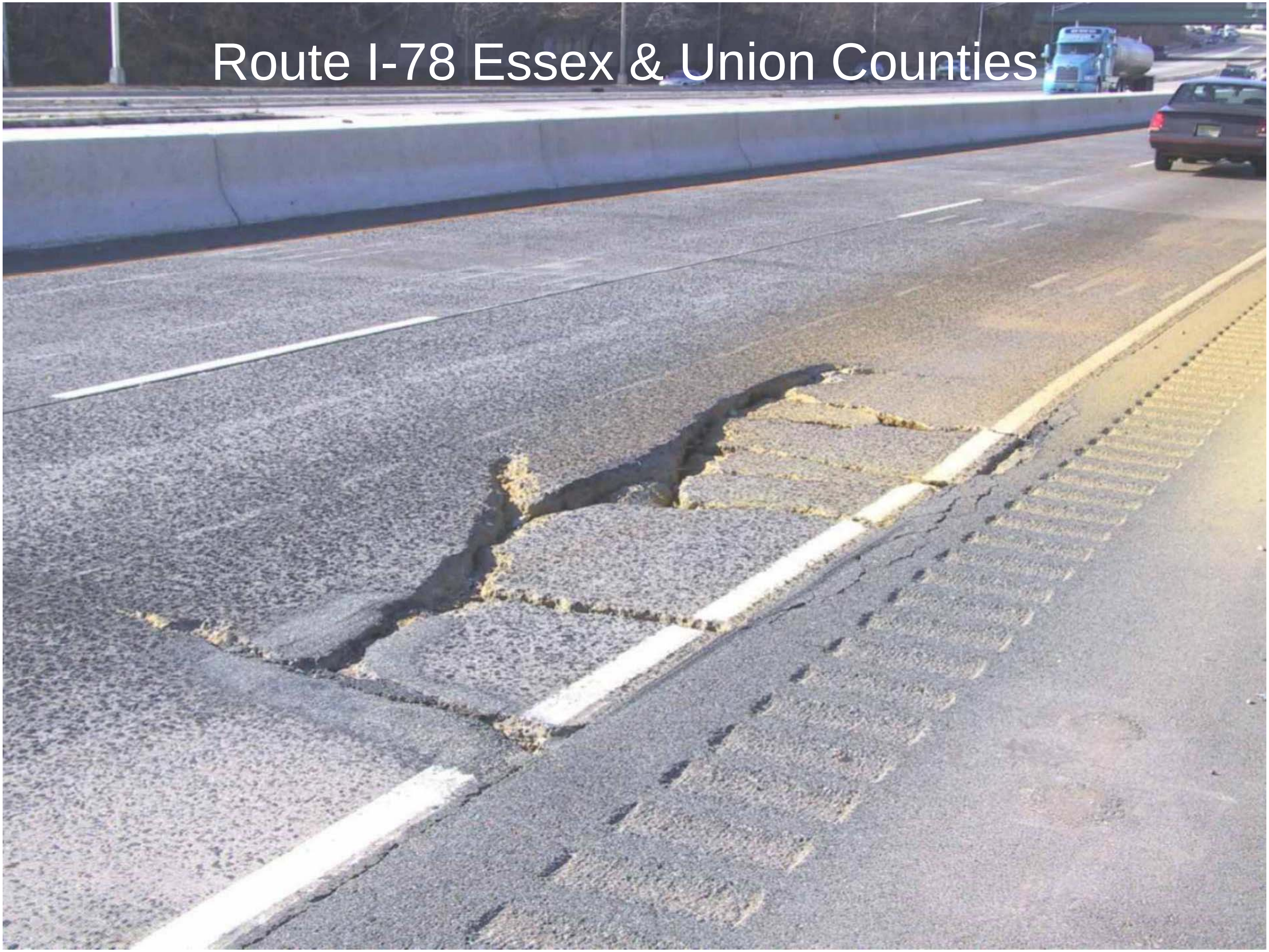
Route I-78 Essex & Union Counties



Route I-78 Essex & Union Counties

Route I-78 Essex & Union Counties

Rehabilitation of PCCP

- Prevailing strategy in NJ has been hot mix (HMA) overlays => Reflective cracking
- Alternatives to HMA overlays
  – Crack and seat and overlay
  – Break and seat and overlay
  – Rubblization with overlay

Outline

- Objectives and benefits of rubblization
- Typically used rubblization procedures
  - Multi-head breaker (MHB)
  - Resonant-frequency breaker (RFB)
- Previous information about RPCC modulus
- Seismic (surface wave) evaluation of RPPC modulus
- Moduli comparisons for RPCC and other base materials
- Conclusions

Objective of Rubblization

- Eliminate reflective cracking in the HMA overlay by the total destruction of the existing slab action
- Slab is reduced to small pieces and diminished to a high-strength granular base
- Restoration of structural capacity is accomplished with an HMA overlay

Why Rubblization?

- Rubblization is a viable, rapid, and cost-effective rehabilitation method for deteriorated PCC pavements
- Rubblization is cost effective when the amount of patching exceeds approximately 10 percent of the project area (NJ)
- Lower Risk to Owner and Contractor
  - Reduced subgrade exposure to moisture damage

Why Rubblization?

- Rubblization Saves Time
  - Typical rubblization process recycles one lane mile per day, with no material hauling
  - 4X faster than breaking, excavating, hauling and placing DGA using traditional methods
- Rubblization Saves Money
  - Approximately 50% cost savings compared to reconstruction with PCCP
  - Approximately 33% cost saving compared to reconstruction with HMA

Why Rubblization?

- Environmental Benefits
  - Water Consumption: 41% Reduction
  - Energy Consumption: 44% Reduction
  - CO_2 Emissions: 43% Reduction
  - NO_x Emissions: 26% Reduction
  - PM_{10} Emissions: 48% Reduction
  - SO_2 Emissions: 40% Reduction
  - CO Emissions: 38% Reduction

source: RMRC case study of a NHDOT project

When Rubblization?

- Wisconsin DOT considers rubblization when one or more of the following conditions are met:
  - Greater than 20% of the concrete pavement joints are in need of repair;
  - Greater than 20% of the concrete surface has been patched;
  - Greater than 20% of the concrete slabs exhibit slab breakup distress; and
  - Greater than 20% of the project length exhibits longitudinal joint distress greater than 4-in. wide

Rubblization Procedures (Equipment)

Two types of equipment typically used:

1. Multi-head breaker (MHB)
   - Rubblization through drops of multiple hammers on the slab
2. Resonant frequency breaker (RFB)
   - Rubblization through application of high (resonant) frequency energy to the slab through a shoe

Multi-Head Breaker (MHB)

- MHB is a self-propelled unit with multiple drop-hammers mounted at the rear of the machine.
- Hammers are set in two rows, and strike the pavement approximately every 4.5 in.
- 1,200 lb - 1,500 lb hammers have variable drop heights and variable cycling speeds.
- Can break pavement up to 13 ft wide in a single pass.

Multi-Head Breaker (MHB)

- Production level is approximately 1.0 lane-mile per day.
- Z-pattern steel grid roller, a vibratory roller with a grid pattern, must be used in conjunction with the MHB to complete the breaking process.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Rubblized PCCP – I-78

Rubblized PCCP - Route I-78


CATERPILLAR


60-84
2487

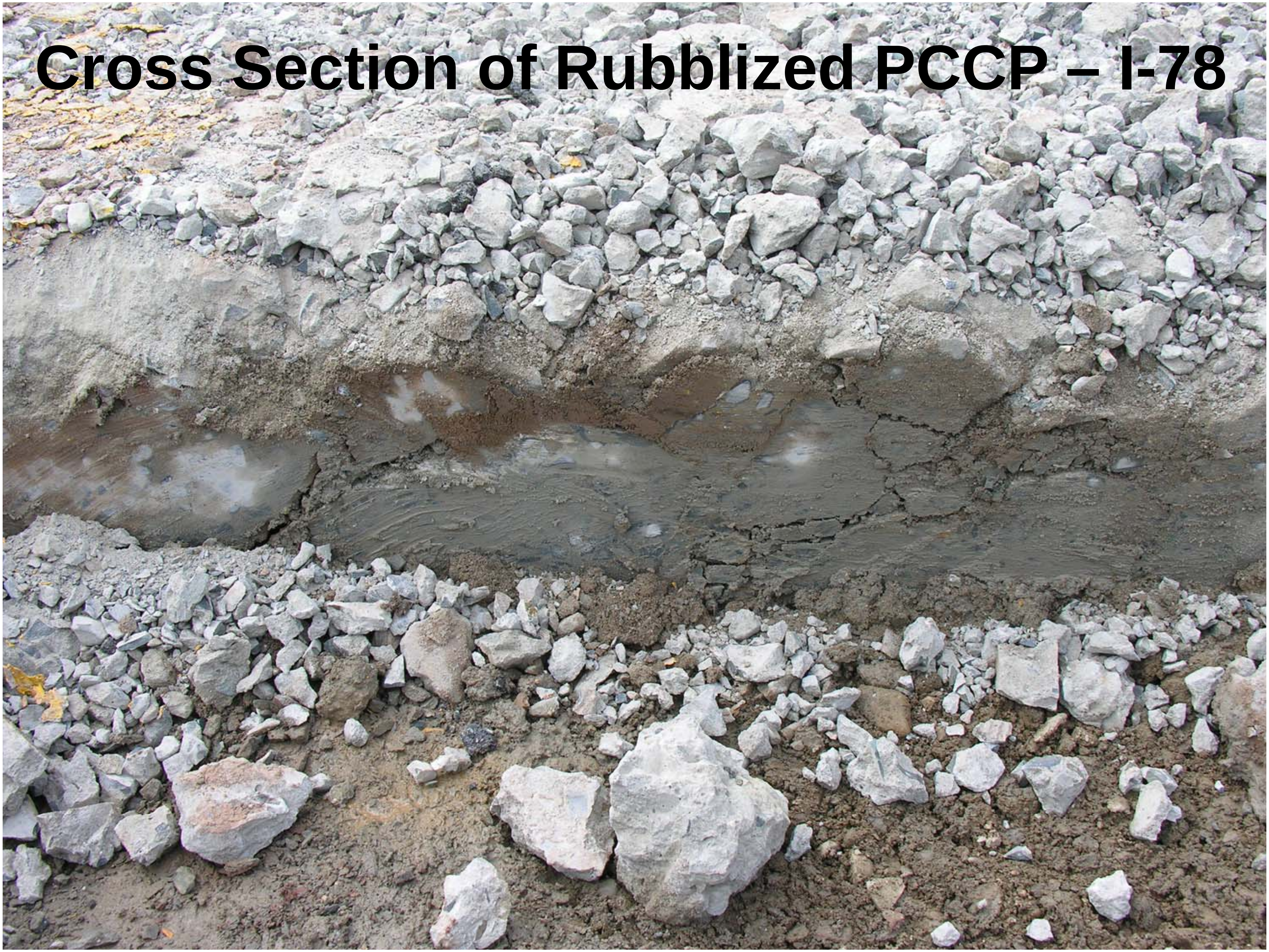
Rubblized and Z-Roller Compacted PCCP – I-78


TAMPO


Rubblized and Compacted
PCCP – I-78

Cross Section of Rubblized PCCP
I-78

Cross Section of Rubblized PCCP – I-78

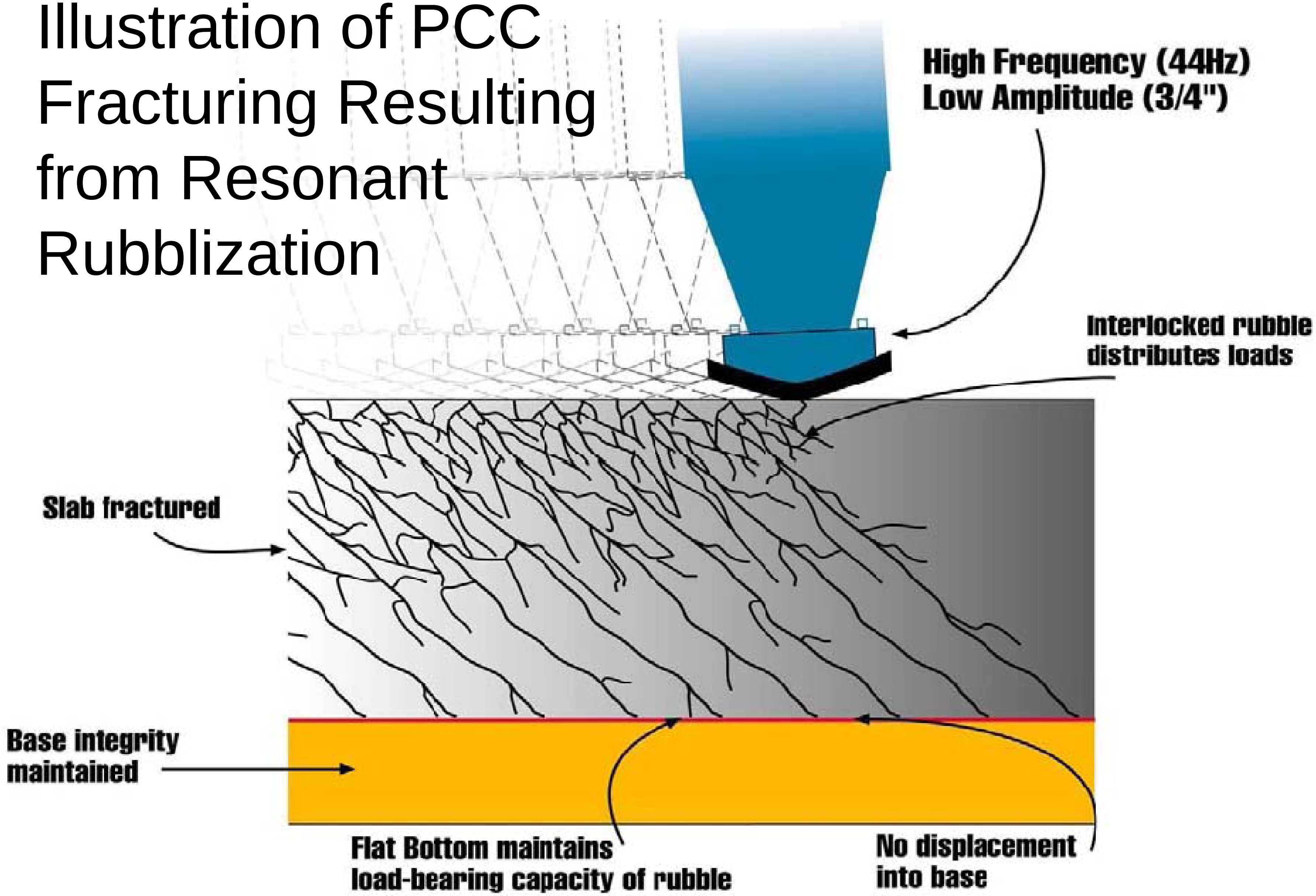


Resonant Pavement Breaker (RPB)

- High frequency vibrations induce high tension in the top of the slab causing the slab to fracture along a number of shear planes.
- Breaking pattern is approximately 8 inches wide, and requires 18 to 20 passes to break a 12-foot lane width.
- Resonant breaker hinders traffic flow because the machine encroaches 3 to 5 feet on the adjacent lane when rubblizing the centerline.
- 20,000 lb wheel load and 60,000-70,000 lb weight can damage rubblized pavement.


RB 500

Illustration of PCC Fracturing Resulting from Resonant Rubblization




RPB Rubblized PCC Pavement

Some of the Questions

- What value of the RPCC modulus should be used in the (mechanistic-empirical) pavement design?
- How the modulus of RPCC compares to moduli of traditional base materials? (Especially dense graded aggregate base.)
- What are the means to measure it?

What Do We Know About RPCC Modulus?

- Rubblized modulus appears to be influenced by the slab thickness; thicker slabs tend to provide higher modulus.
- Rubblized modulus related to the pre-rubblized PCC modulus, retained modulus.
- No differences in RPCC moduli between the two types of rubblization equipment (MHB and RPB).

What Do We Know About RPCC Modulus?

- AASHTO M-E Design Guide for Highways 150 ksi for PCCP 8 to 12 inches thick
- Asphalt Institute Airfield Project 2007
  - Slabs 6 to 8 in. thick: Moduli from 100 to 135 ksi
  - Slabs 8 to 14 in. thick: Moduli from 135 to 235 ksi
  - Slabs >14 in. thick: Moduli from 235 to 400 ksi

What Do We Know About RPCC Modulus?

- For thicker slabs, rubblized particles tend to be larger and interlocked stronger, leading to a higher modulus
- For thinner slabs on subgrade, reduced support results in poor particle interlock leading to a lower modulus

Why Seismic Testing?

WAVE VELOCITY ⟺ MODULUS

Shear Wave Velocity ⟷ Shear Modulus

Compression Wave Velocity ⟷ Young's Modulus, Constrained Modulus

Rayleigh Wave Velocity ⟷ Shear Modulus

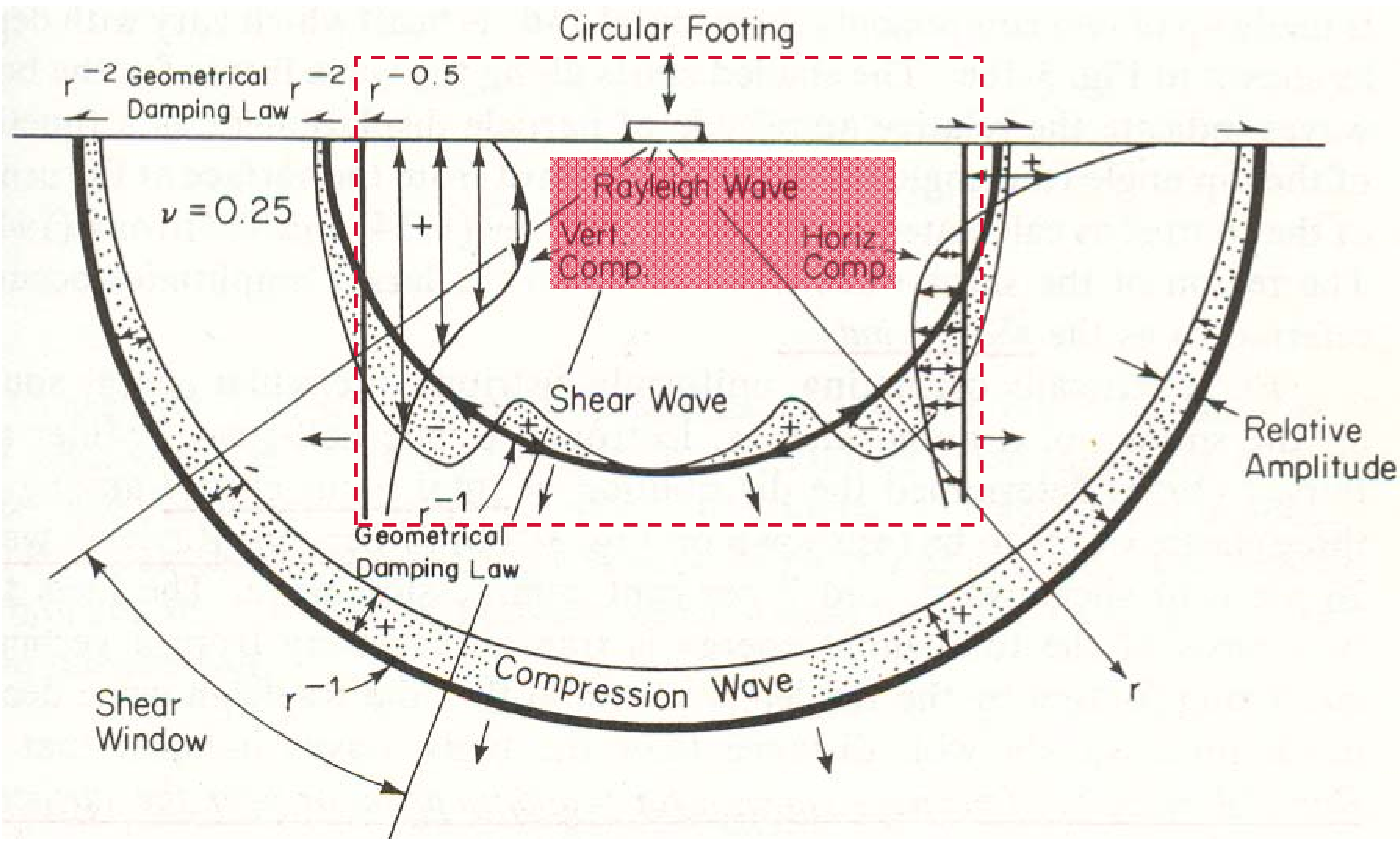
Surface (Guided) Wave Velocity ⟷ Shear Modulus of Layered Systems

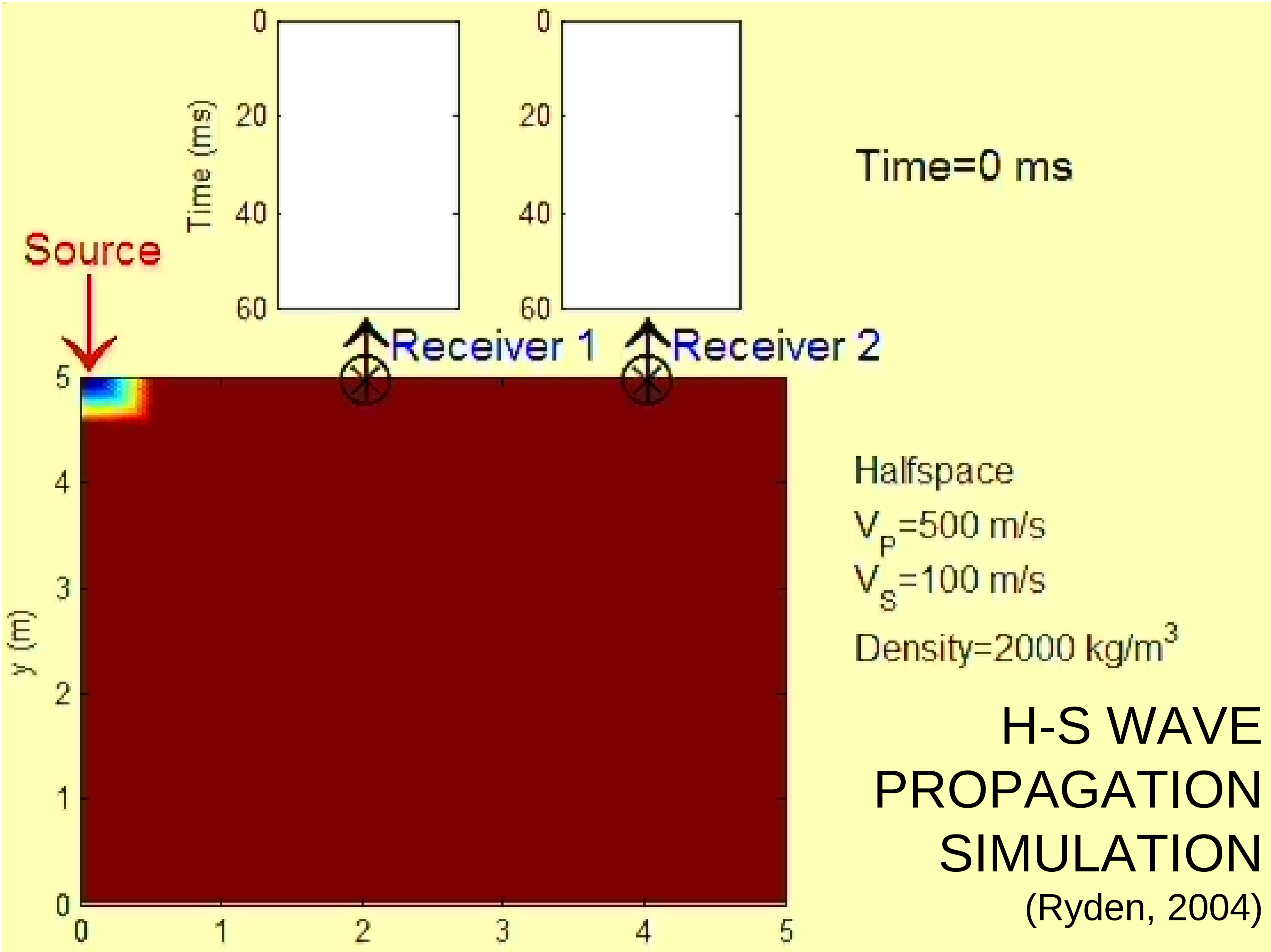
Why Seismic Testing?

- Rapid
- Repeatable
- Nondestructive
- Economical
- Can be applied directly on RPCC
- Field and lab tests the same

Waves in Elastic Half-Space

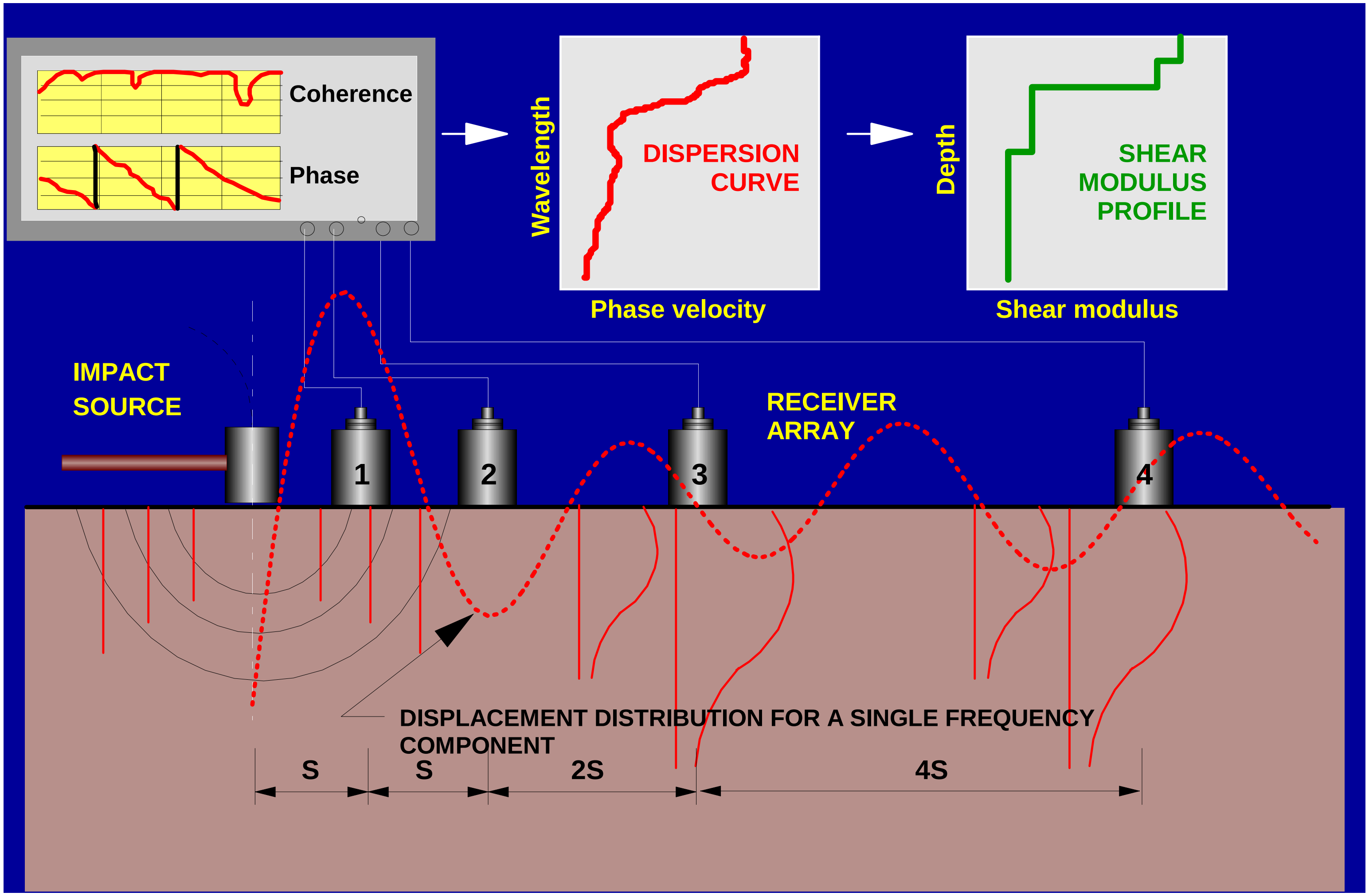
(from Richart *et al.*, 1970)





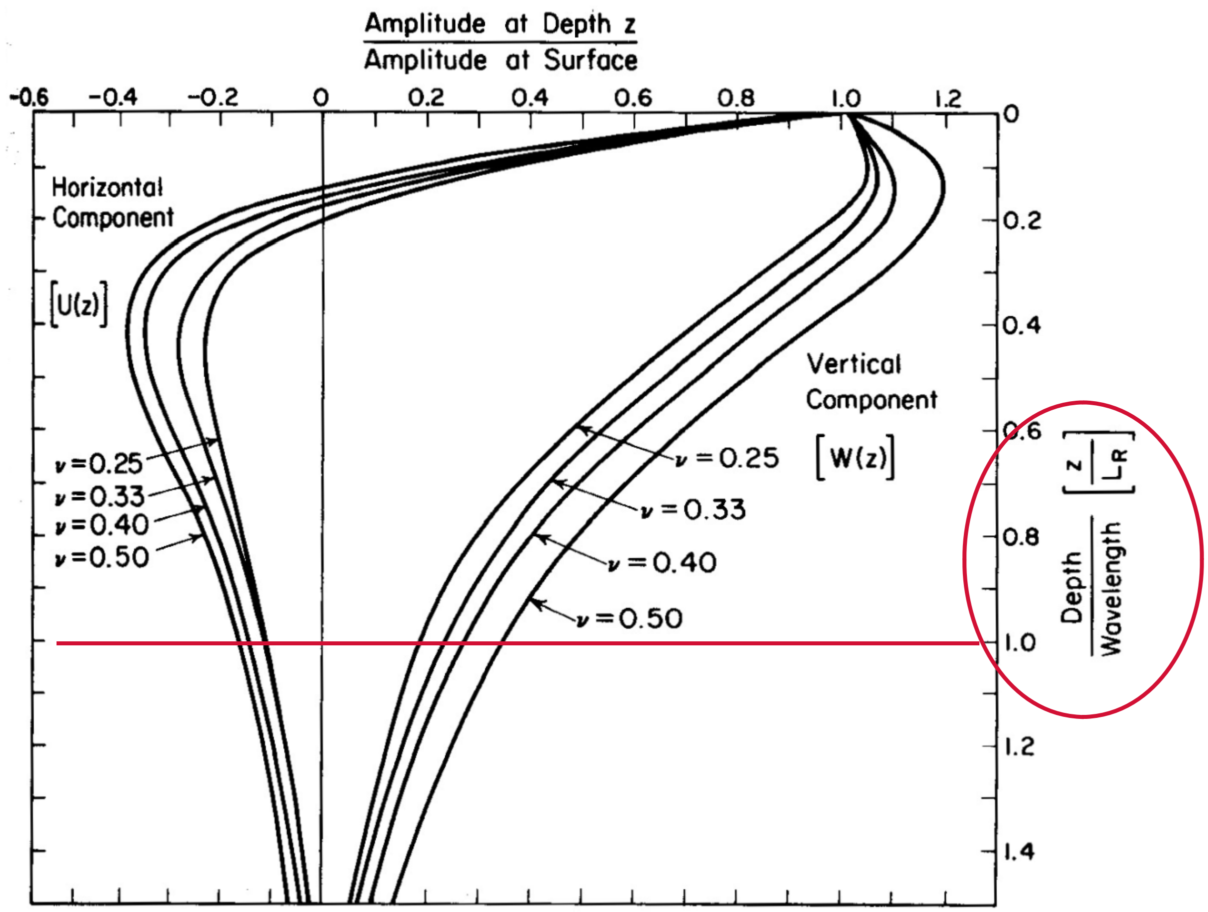
H-S WAVE PROPAGATION SIMULATION
(Ryden, 2004)

SASW Method

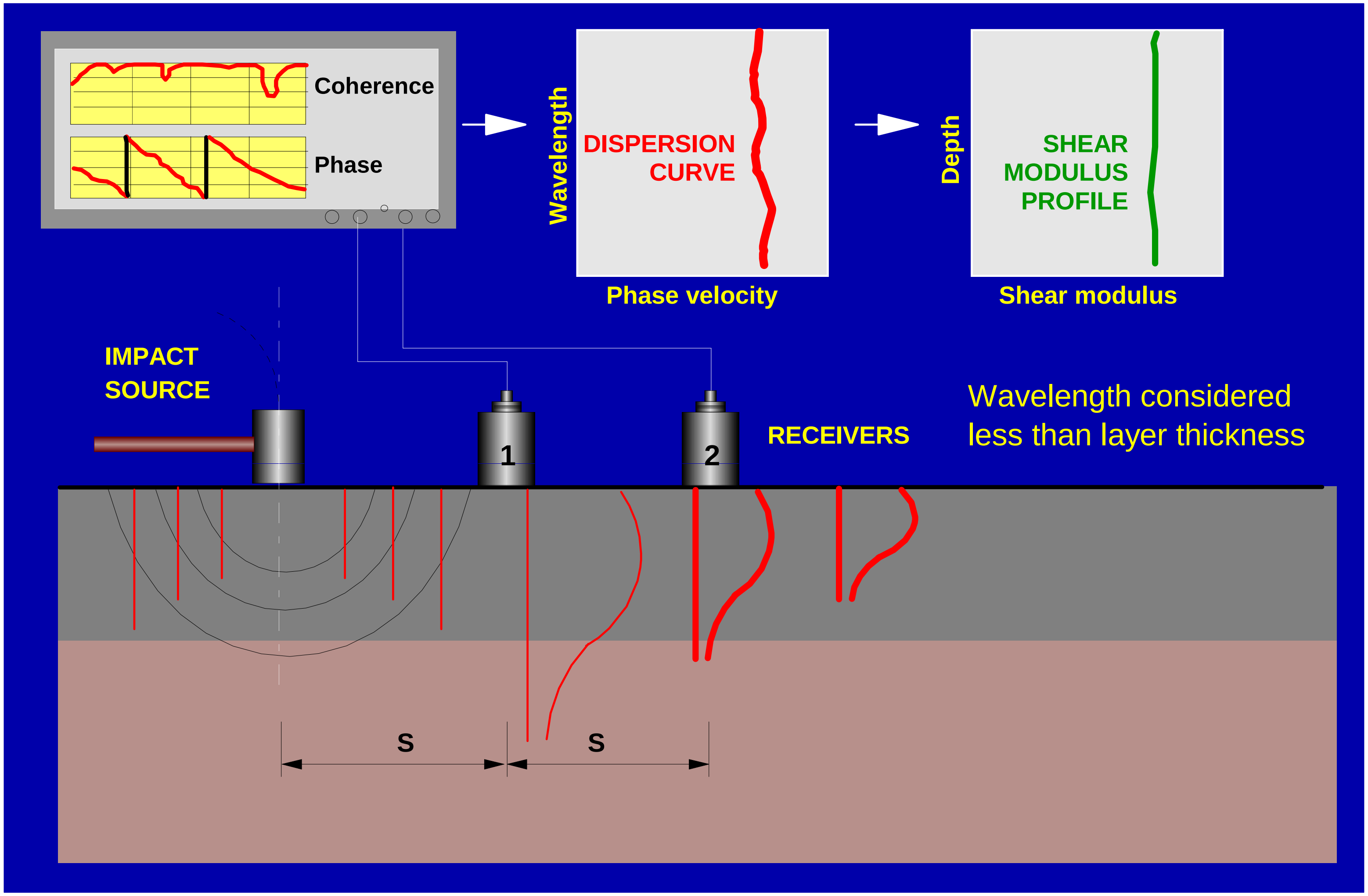

Coherence
Phase
Wavelength
DISPERSION CURVE
Phase velocity
Depth
SHEAR MODULUS PROFILE
Shear modulus
IMPACT SOURCE
RECEIVER ARRAY
1
2
3
4
DISPLACEMENT DISTRIBUTION FOR A SINGLE FREQUENCY COMPONENT
S
S
2S
4S

Body of R-wave as a Function of ν

(from Richart *et al.*, 1970)



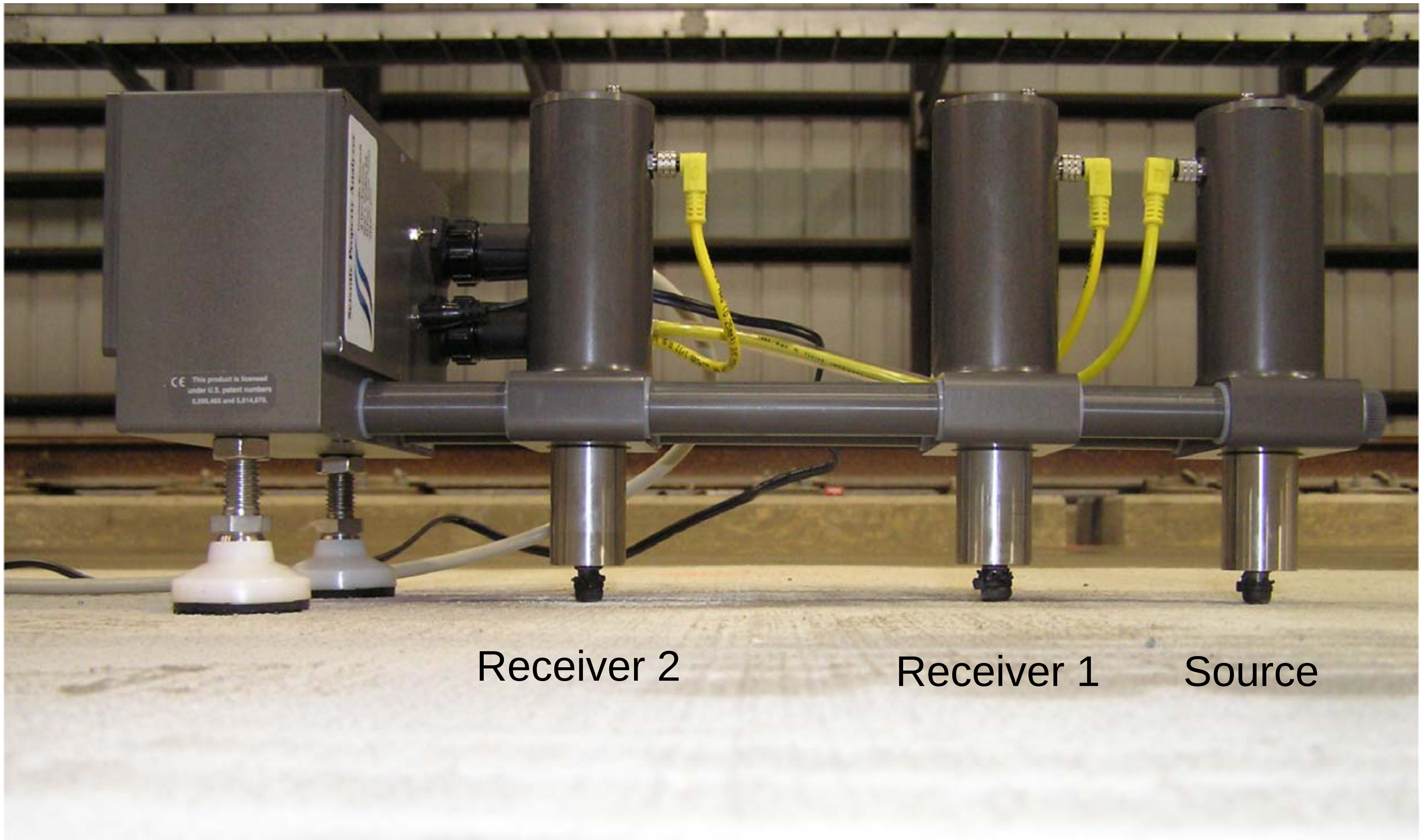
Ultrasonic Surface Wave Method



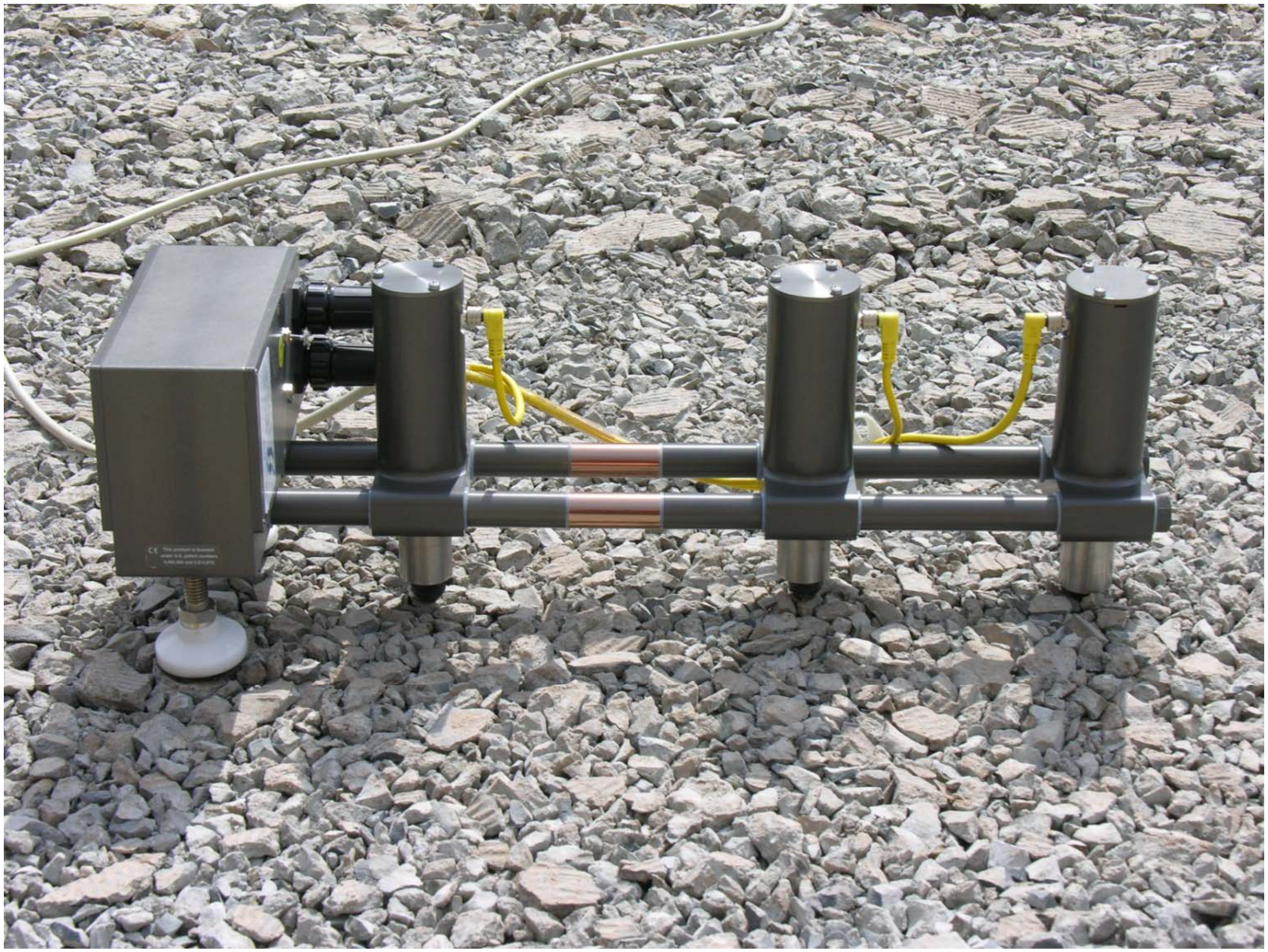
Portable Seismic Property Analyzer (PSPA)

- Main pavement and bridge deck applications
  - Evaluation of layer elastic moduli and thickness
  - Detection of overlay delamination
  - Detection of concrete bridge deck delamination
- Seismic methods used
  - Ultrasonic surface waves (USW)
  - Ultrasonic body wave (UBW)
  - Impact echo (IE)

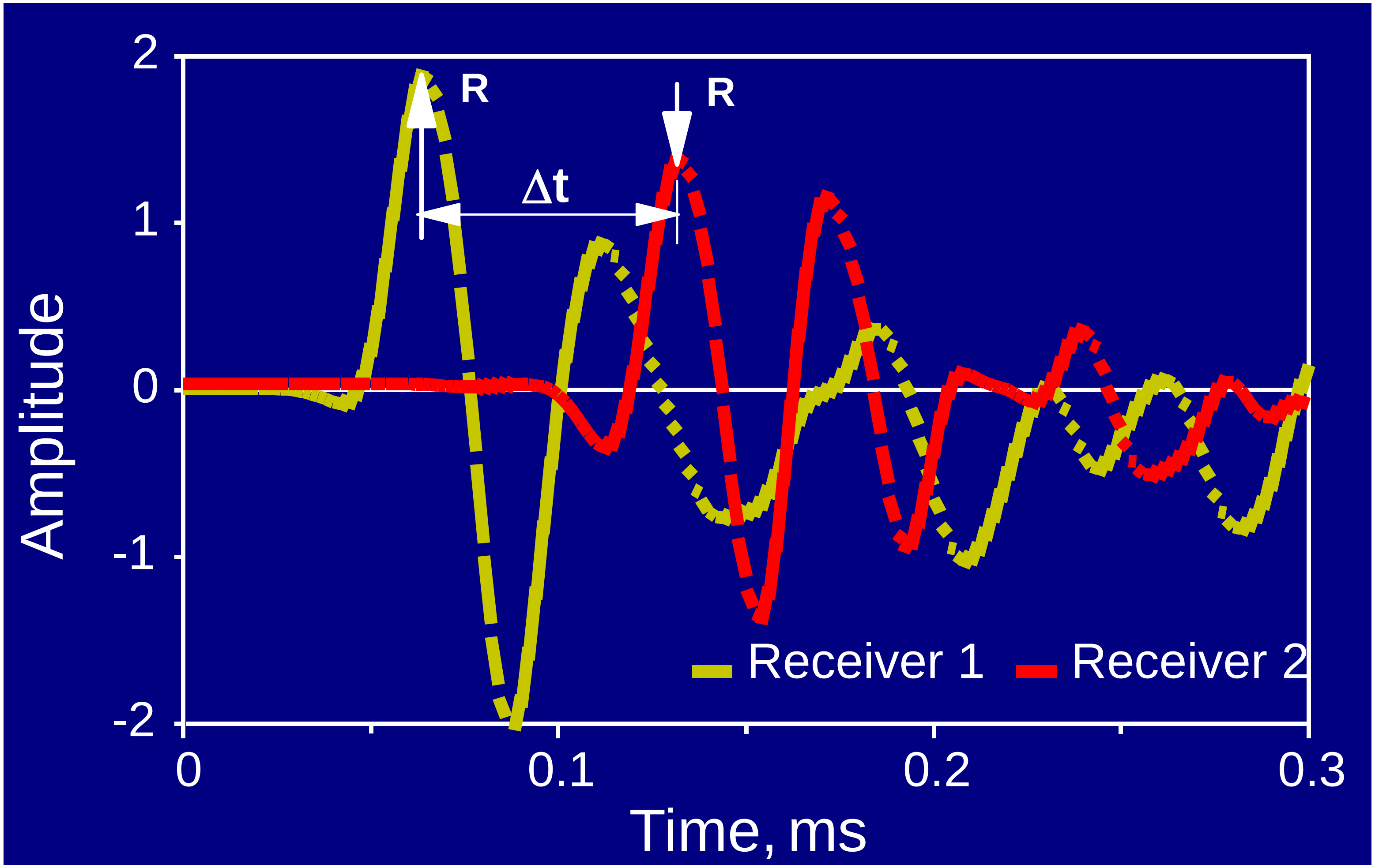
PSPA



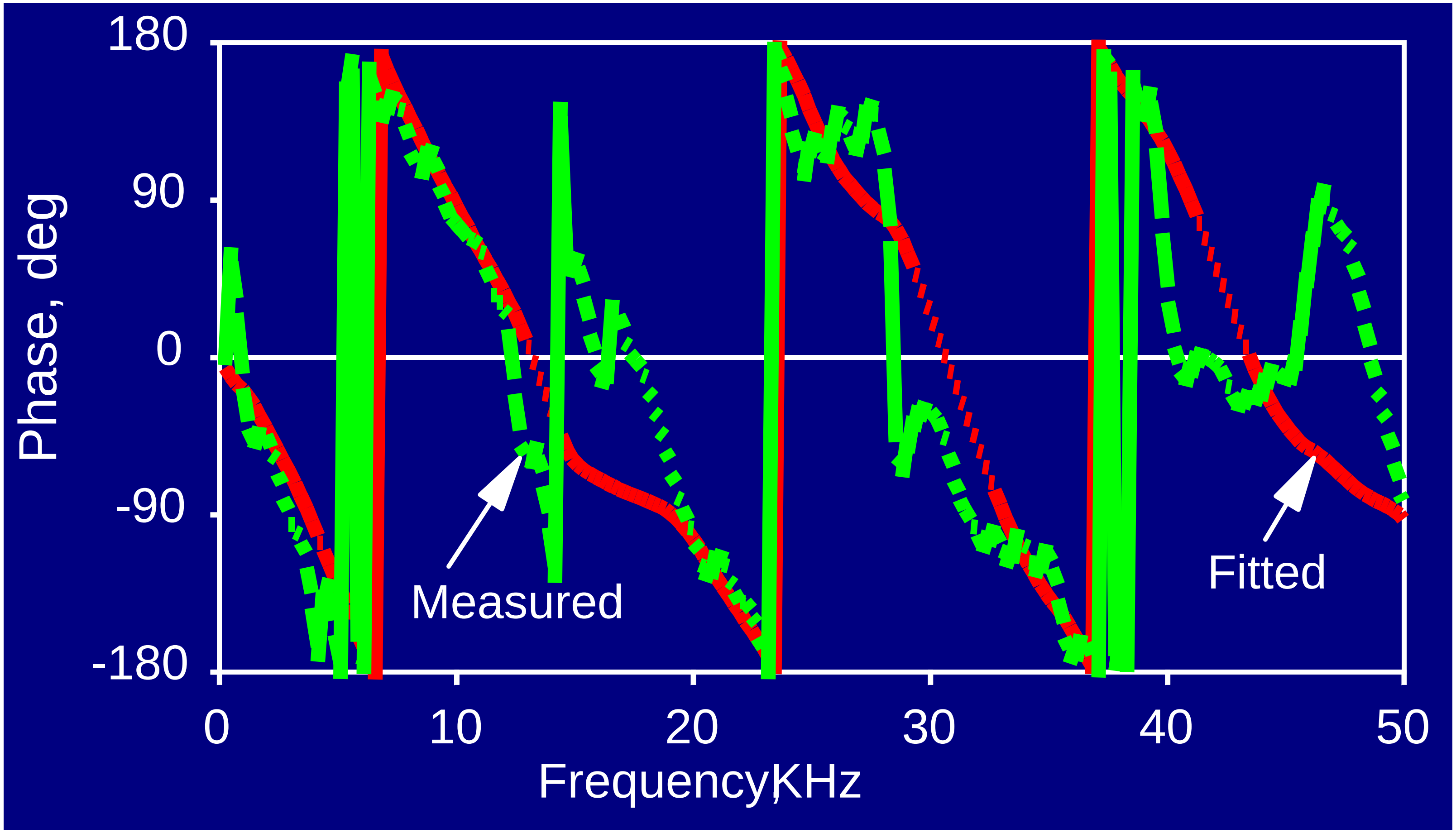
PSPA Evaluation of RPCC on I-78



Surface Wave Arrivals



USW – Cross Power Spectrum Phase



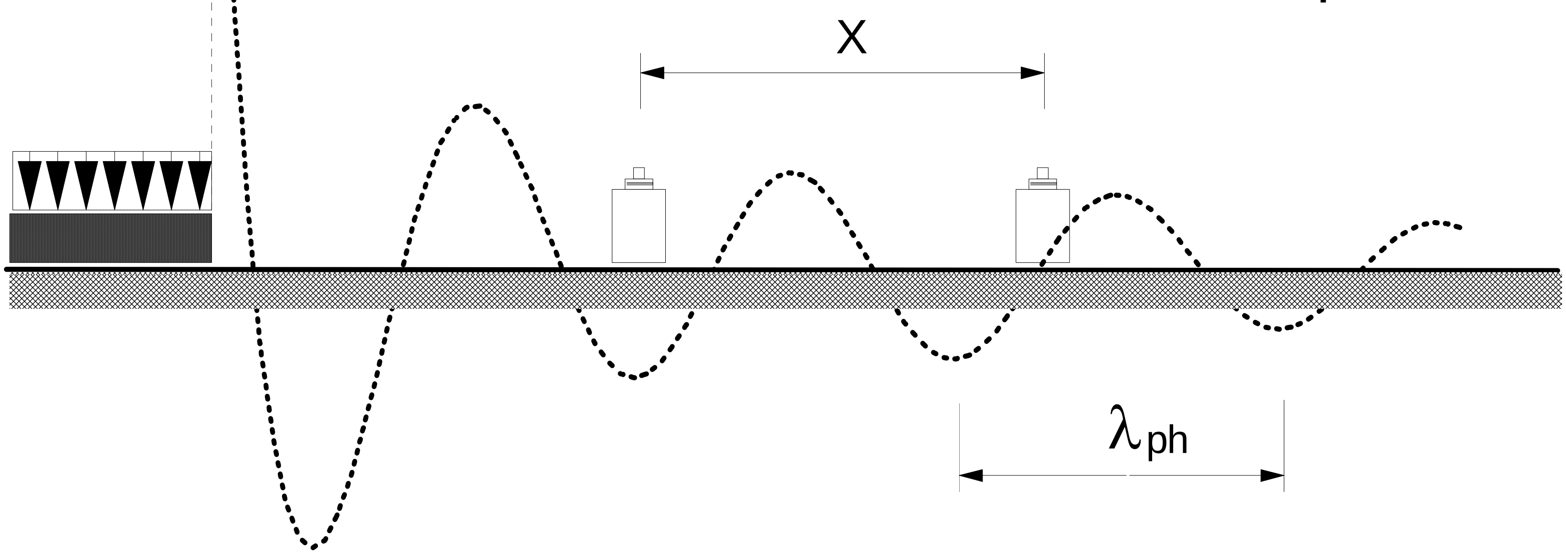
Calculation of Phase Velocity from Phase

$$\frac{X}{\lambda_{ph}} = \frac{\beta}{360^0}$$

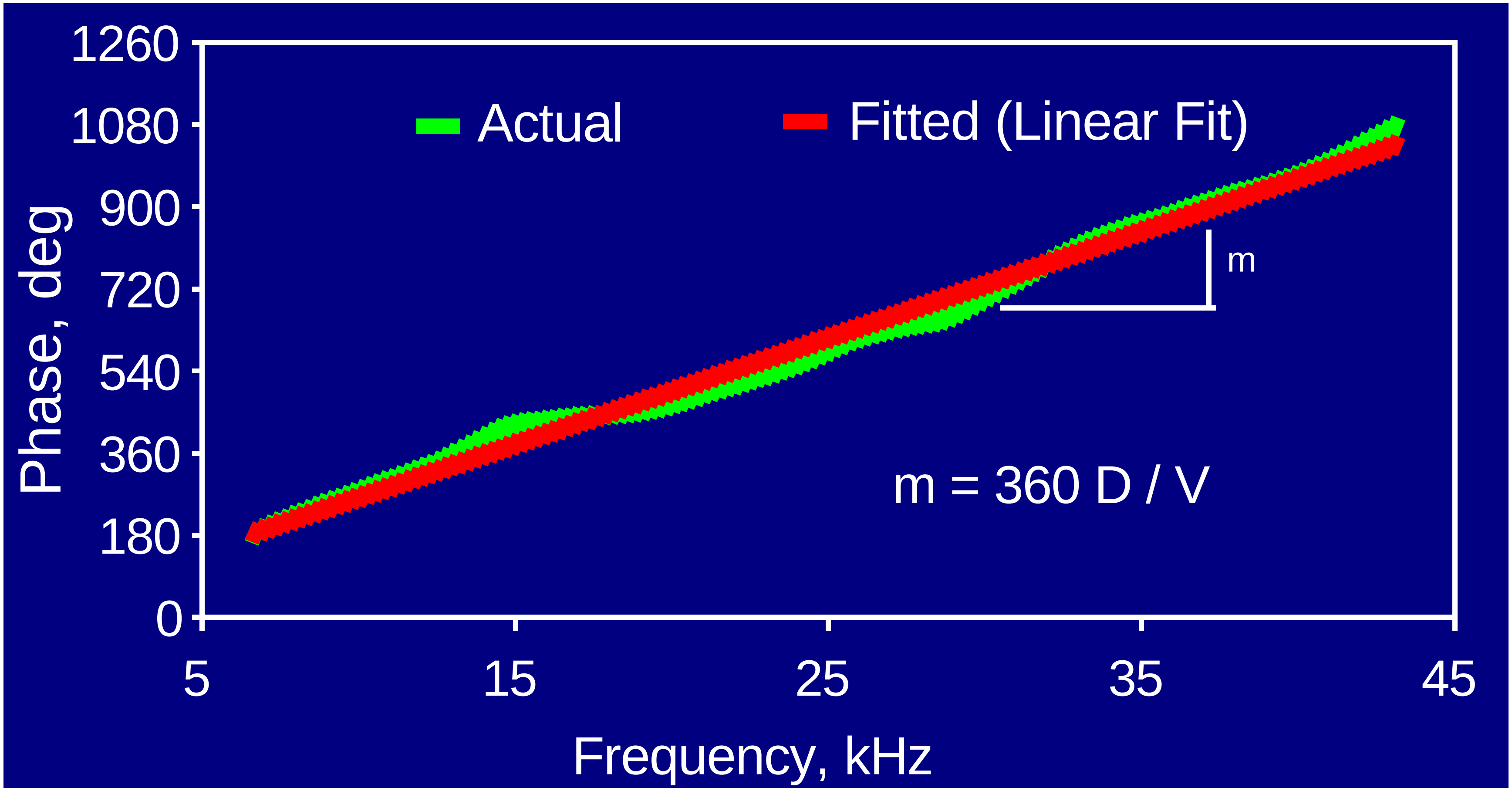
$$V_{ph} = f\lambda_{ph}$$

Phase velocity $V_{ph} = \dfrac{360\ X\ f}{\beta}$

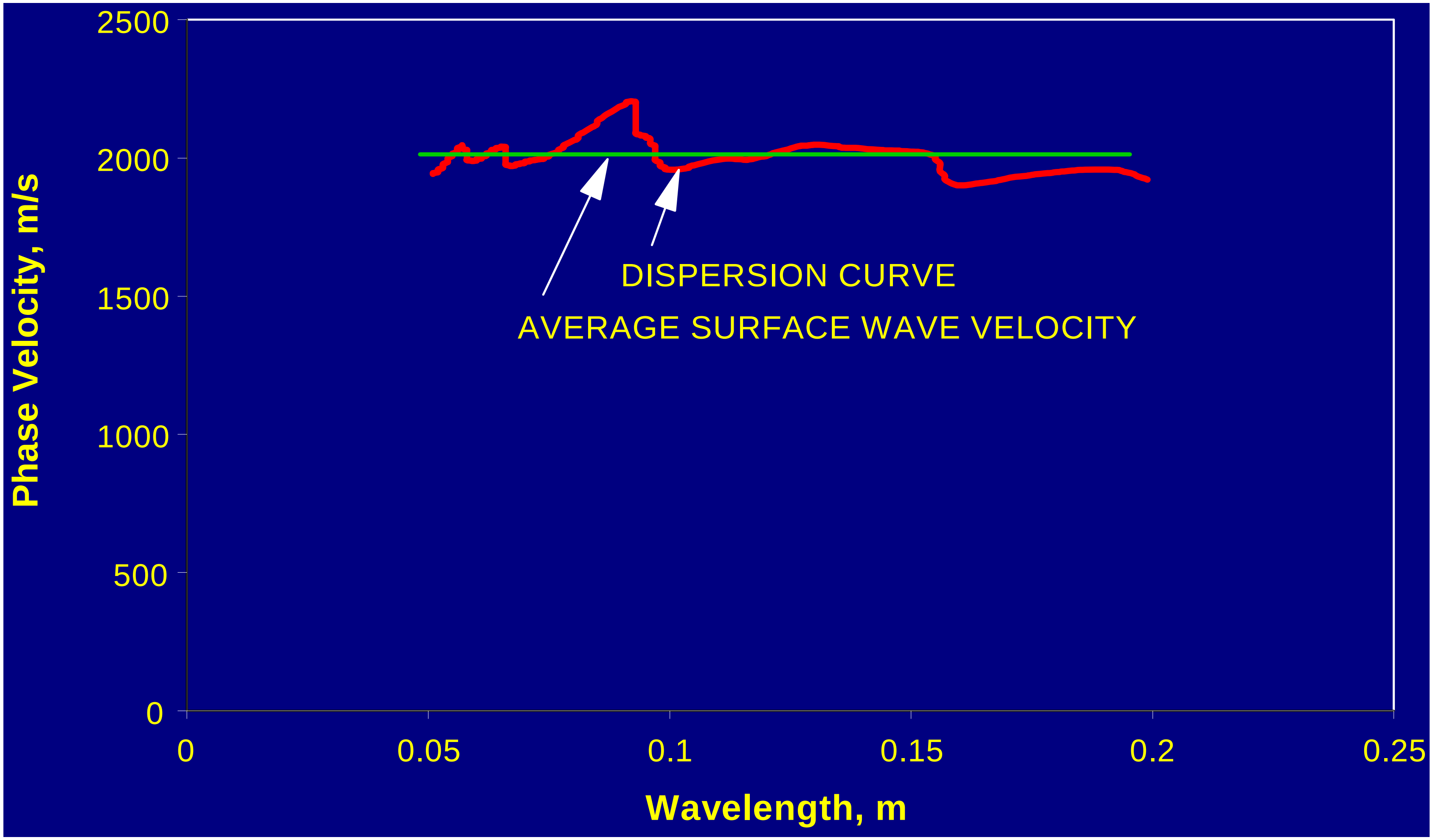
Wavelength $\lambda_{ph} = \dfrac{V_{ph}}{f}$



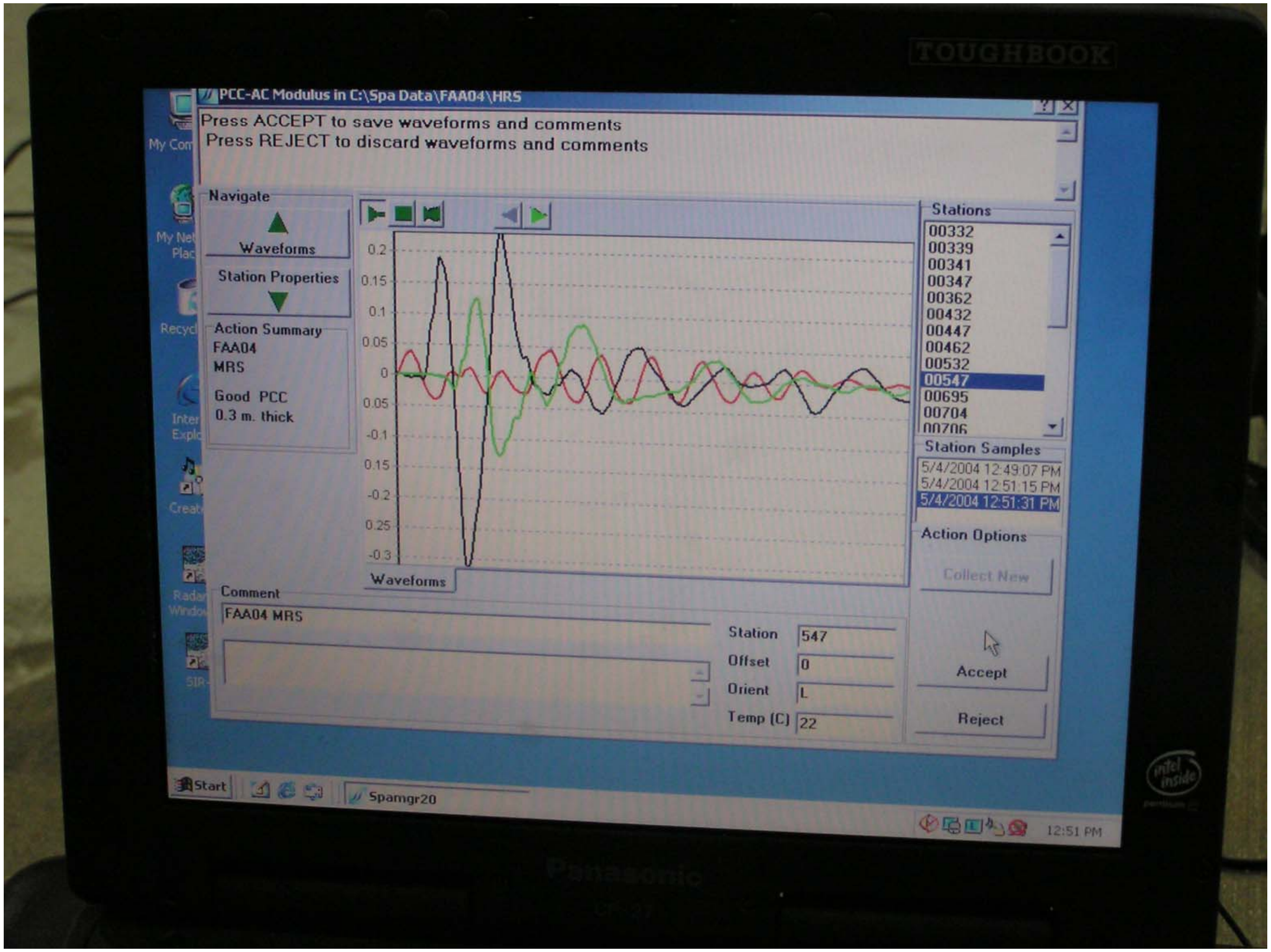
USW – Unwrapped Cross Power Spectrum Phase



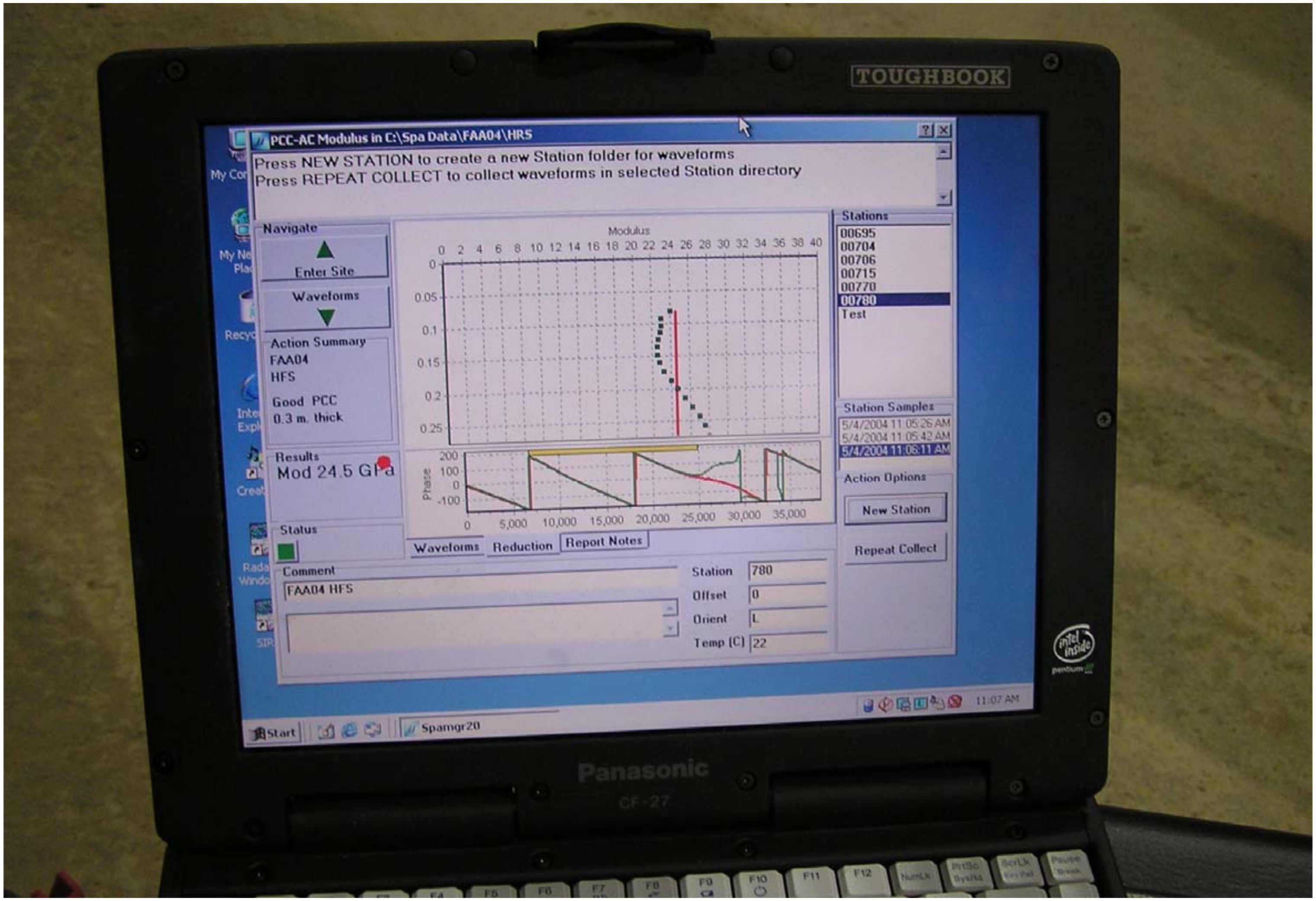
USW – Average Surface Wave Velocity



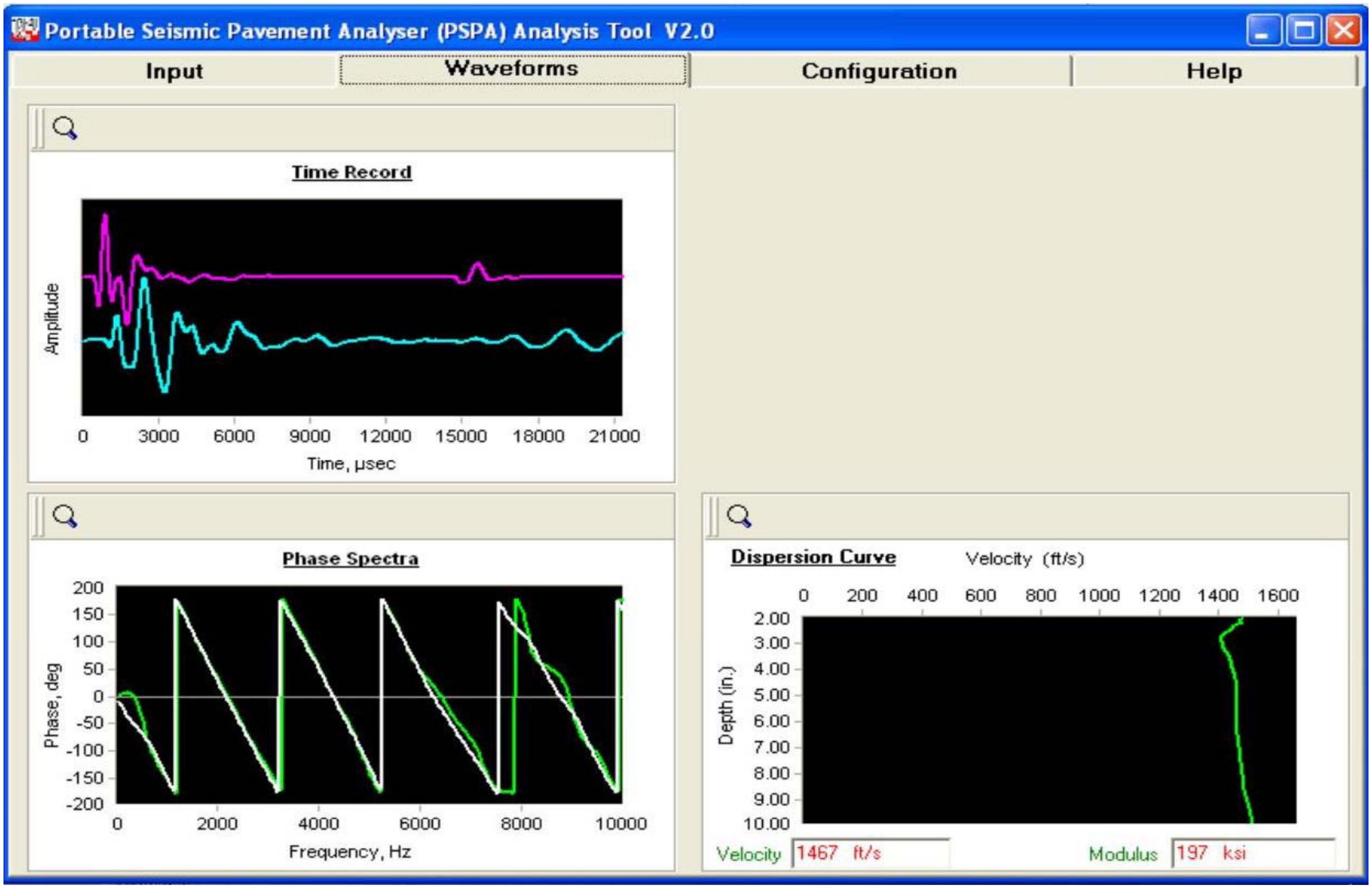
PSPA Waveforms



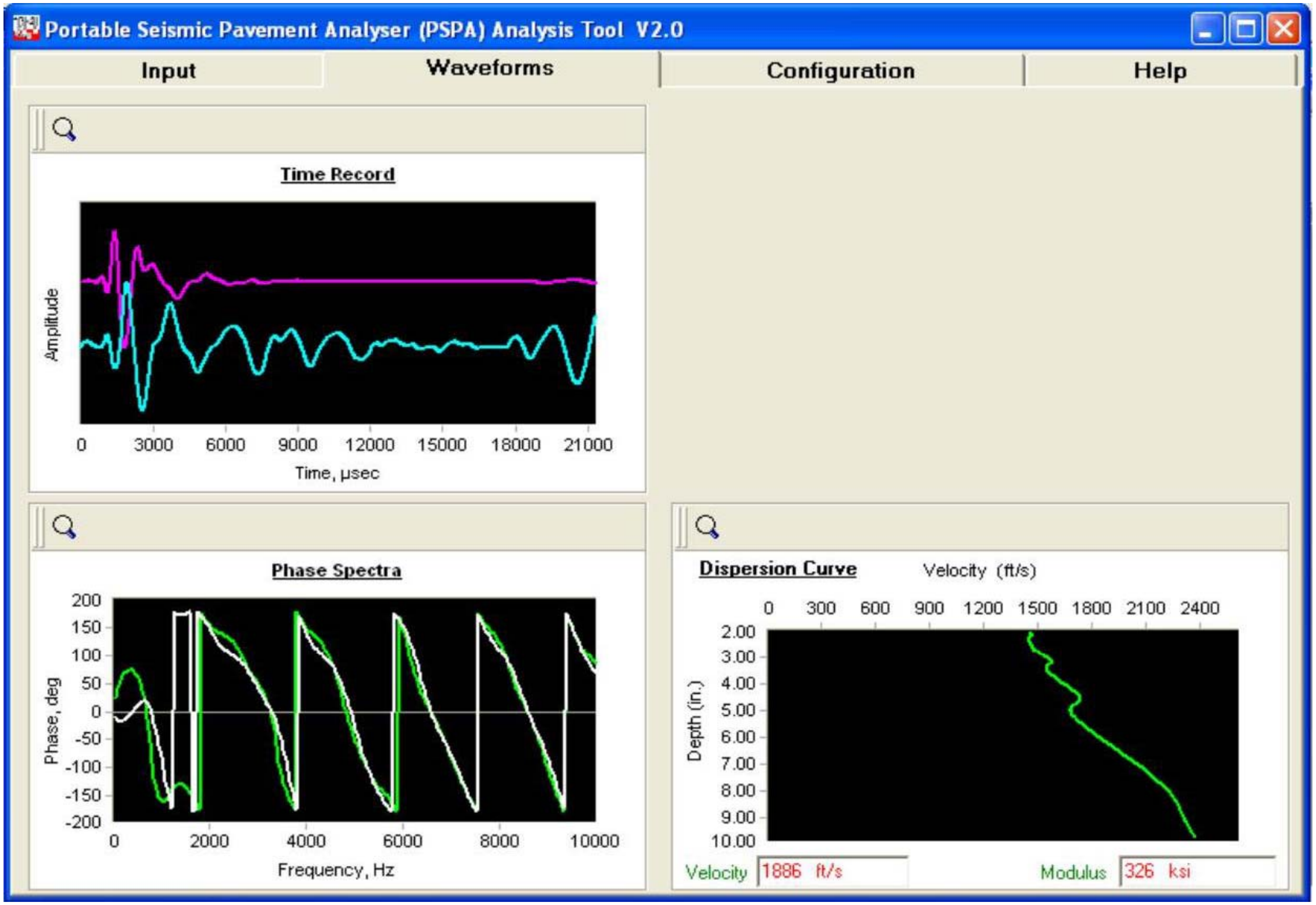
Dispersion Curve and Modulus



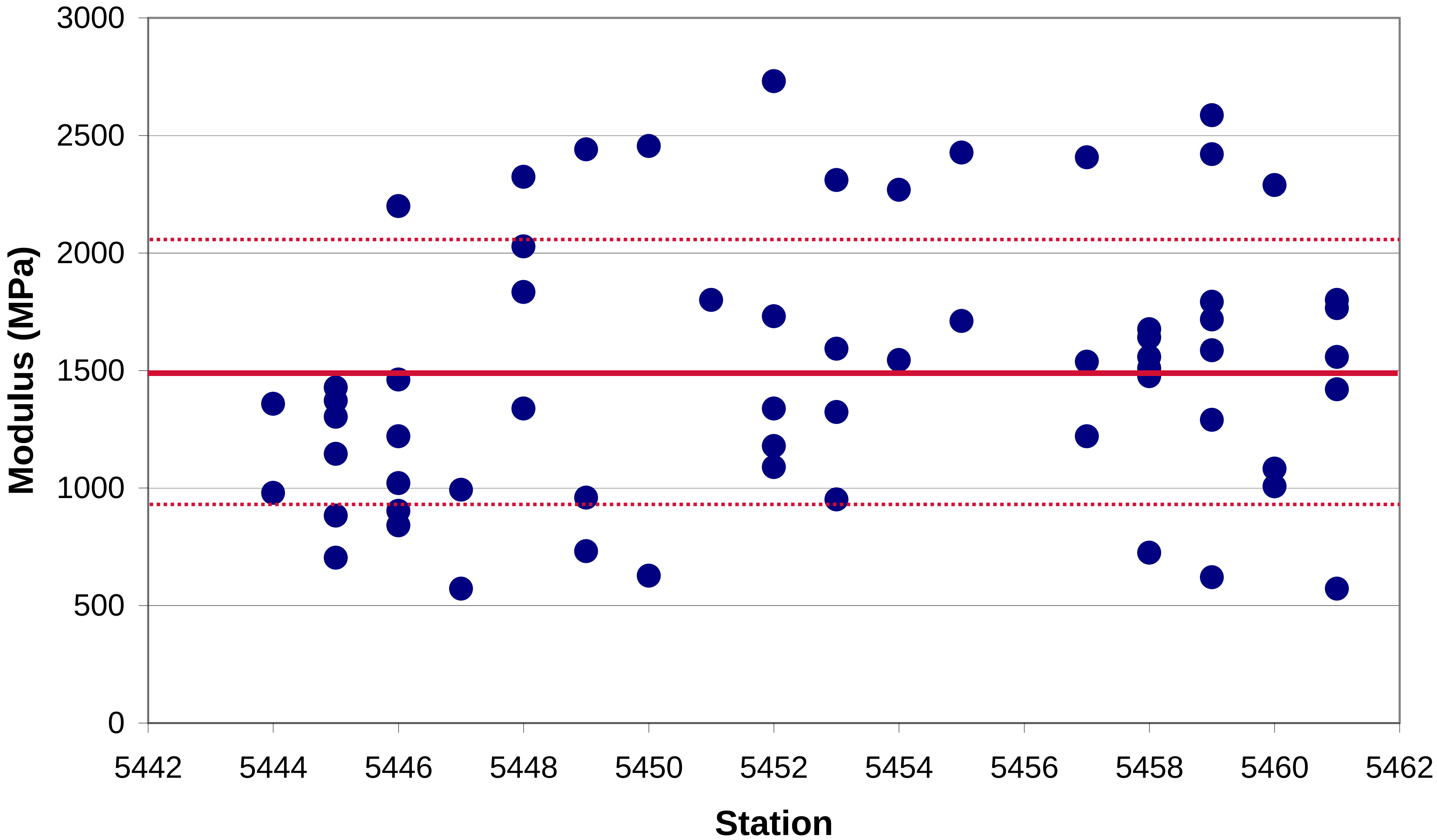
PSPA Reanalysis (RPCC)



PSPA Reanalysis (RPCC)

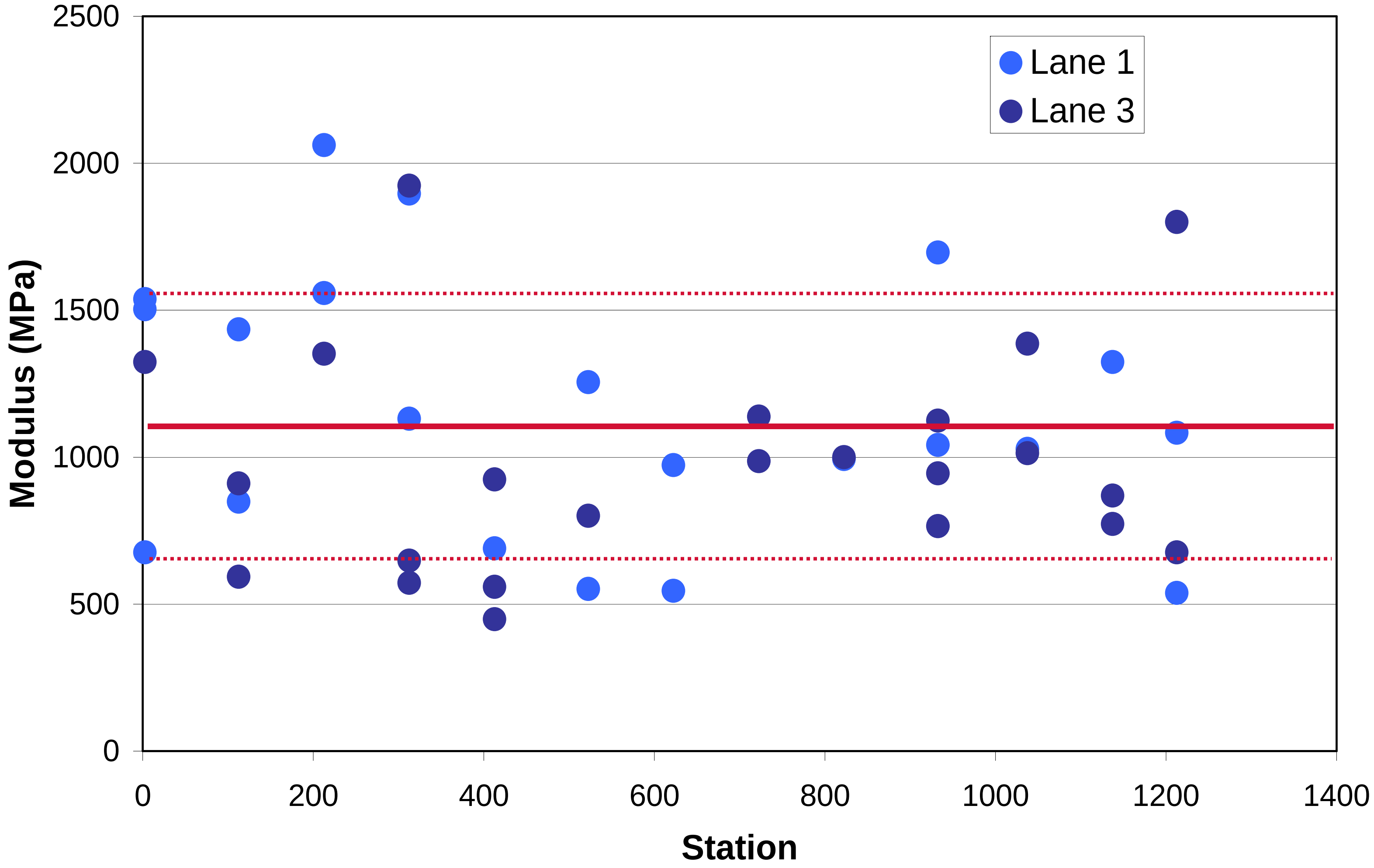


RPCC's Modulus – I-78



Cross Section of Rubblized PCCP

RPCC's Modulus – I-295



Modulus of Various Base Materials

Type of Base	Modulus of Elasticity in MPa (ksi)
Granular base	220-950 (32-138)
Sandy gravel base	170-230 (25-33)
Limestone base	210-3450 (30-500)
Lime stabilized limestone base	8250-9250 (1200-1340)
Cement stabilized limestone base	17200-23400 (2500-3400)
Rubblized PCC – surface waves (this study)	550-2800 (80-400)
Rubblized PCC – FWD (*5*)	390-1450 (57-209)
Rubblized PCC – FWD (*6*)	620-2400 (90-350)
Rubblized PCC – FWD (*2*)	480 (70)
Rubblized PCC – FWD (*10*)	830-11450 (120-1660)
Rubblized PCC – FWD (*11*)	1380 (200)
Rubblized PCC – FWD (*12*)	240-820 (35-120)
Sandy base	28-48 (4-7)

Conclusions

- Elastic modulus of rubblized PCCP can be efficiently evaluated using seismic testing.
- Modulus is evaluated from the average velocity of surface waves (USW method).
- Seismic modulus is a low strain modulus, reductions should be made to describe it as resilient modulus.

Conclusions

- Seismic modulus varied between 550 and 2800 MPa (80 and 400 ksi), with an average value between 1030 and 1500 MPa (150 and 217 ksi) for all sections tested.
- Other studies based on FWD evaluation of paved RPCC suggest a modulus between 240 and 11500 kPa (35-1660 ksi).
- Modulus of RPCC is higher than modulus of typical granular bases, but lower than modulus of lime or cement stabilized bases.


Thank You!!