2025 SOUTHEASTERN TRANSPORTATION GEOTECHNICAL ENGINEERING CONFERENCE

Williamsburg, VA

Visualizing Subsurface Complexity with Seismic Surface Wave Methods

Adam Gostic, PG

2025 STGEC

Agenda

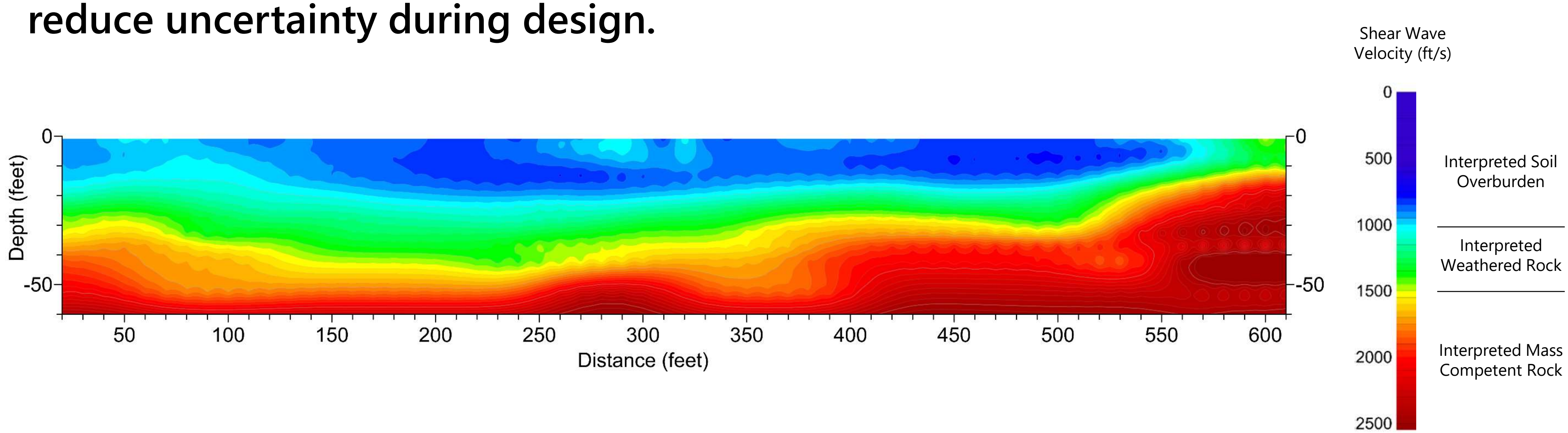
- Introduction to Surface Wave Methods
  - Overview
  - Applications
  - Benefits
- Project Spotlights
  - I-90 Pavement Replacement
  - I-40 Embankment Failure
- ~~Methodology~~
  - Dispersion Theory
  - Data Acquisition
  - Limitations

Introduction to Surface Wave Methods

Overview

Multichannel Analysis of Surface Waves (MASW) is a standard Seismic Surface Wave method for modelling Shear Wave Velocity (v_S).

Shear Wave Velocity (v_S) models are accessible, visually engaging tools that improve the clarity of complex subsurface conditions and reduce uncertainty during design.



Applications

Surface Wave Methods characterize the shear strength (stiffness) of soil and rock by modelling seismic velocity to evaluate subsurface stratigraphy.

1. **Transportation/Transmission Infrastructure**
2. Geotechnical Site Characterization
3. Environmental/Hydrogeological Assessment
4. Mineral and Energy Exploration
5. Geological Hazards

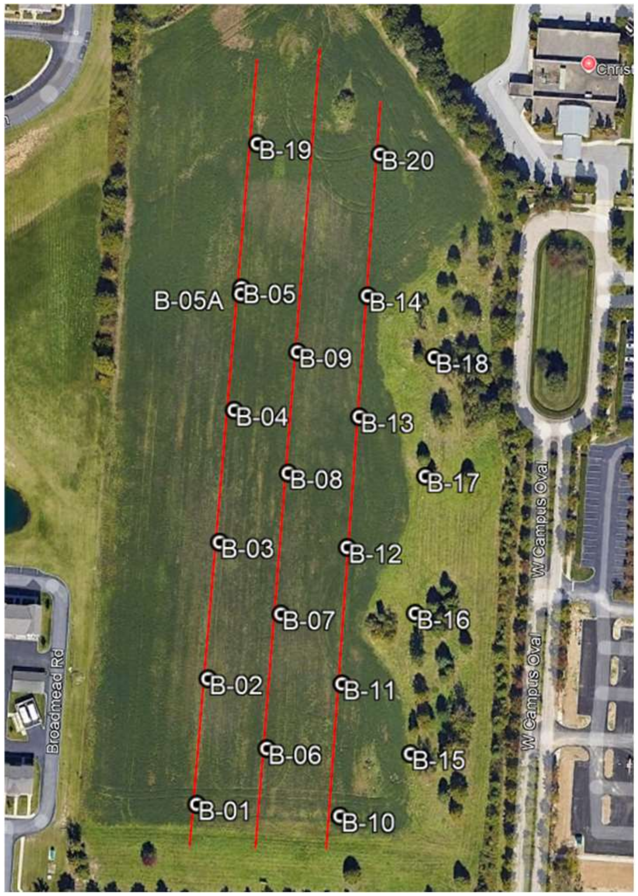
Applications

Surface Wave Methods characterize the shear strength (stiffness) of soil and rock by modelling seismic velocity to evaluate subsurface stratigraphy.

- **Top of Bedrock detection and mapping.**
- Subsurface profiling for foundation design.
- Determining Vs100 for Seismic Site Classification.
- Locating sinkholes/voids.
- Detecting weak/fractured zones or failure surfaces impacting slope stability.

Benefits

1. Rapid Data Acquisition



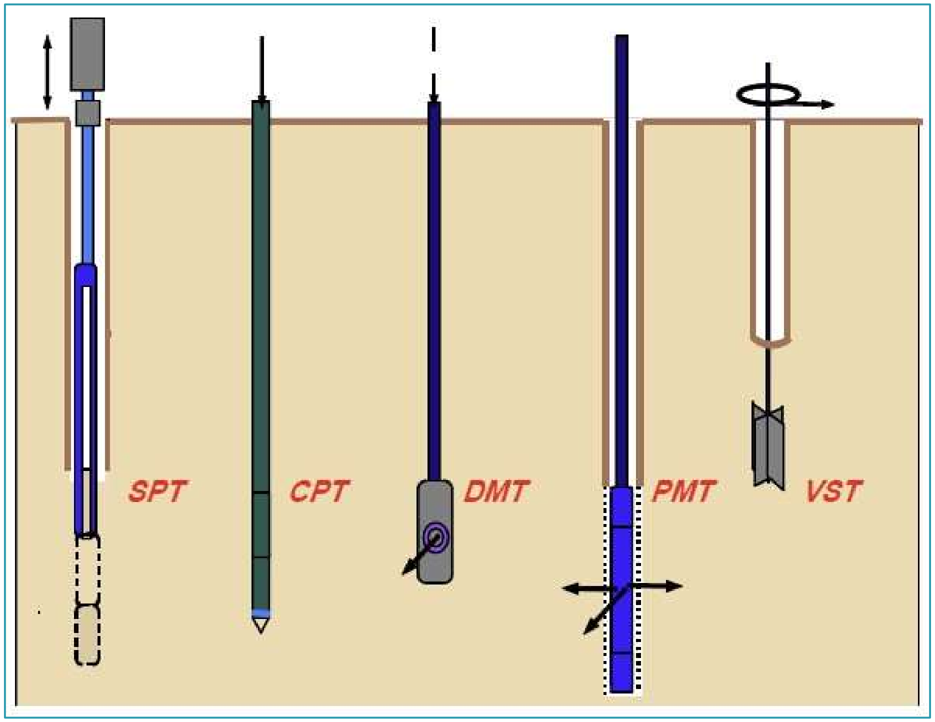
Introduction to Surface Wave Methods

Benefits

1. Rapid Data Acquisition
2. Minimal Site Impact

Benefits

1. Rapid Data Acquisition
2. Minimal Site Impact
3. No Tool Refusal

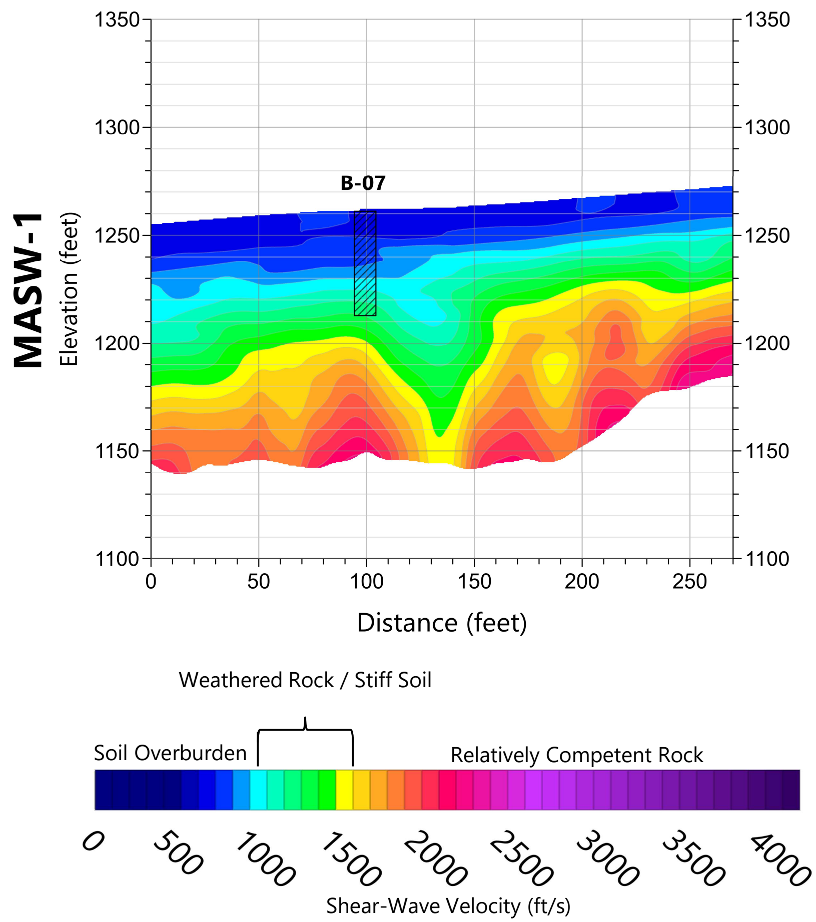


Common in-situ tests for geotechnical site characterization of soils (FHWA, 2002b)

Introduction to Surface Wave Methods

Benefits

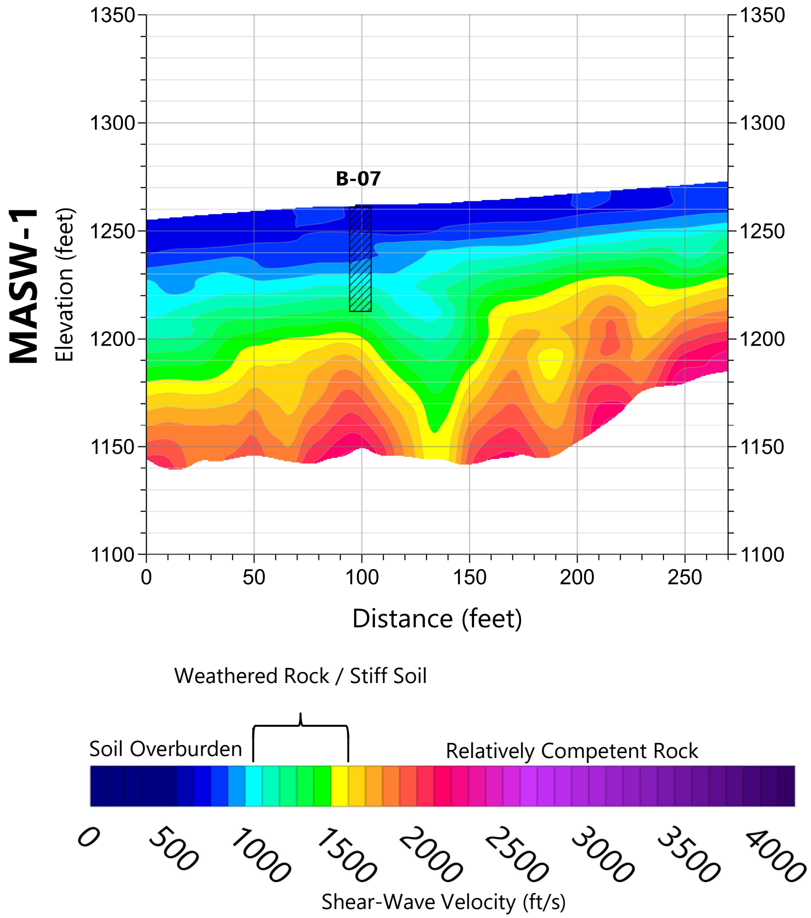
1. Rapid Data Acquisition
2. Minimal Site Impact
3. No Tool Refusal
4. Continuous Data Profiles



Introduction to Surface Wave Methods

Benefits

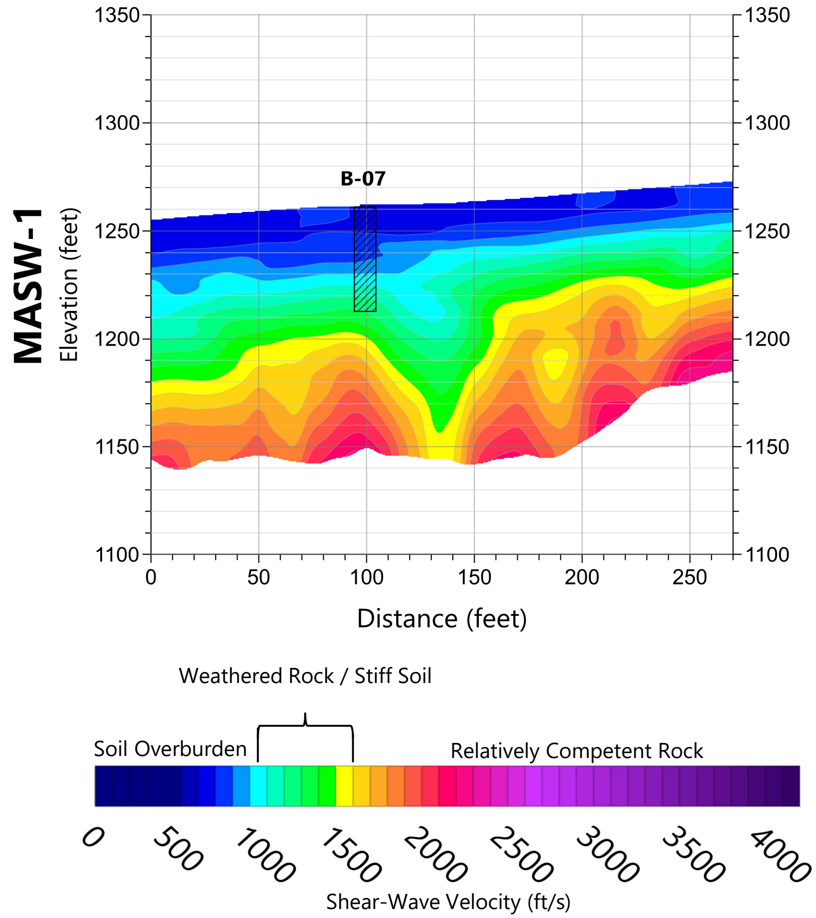
1. Rapid Data Acquisition
2. Minimal Site Impact
3. No Tool Refusal
4. Continuous Data Profiles
5. Accessible Figures



Introduction to Surface Wave Methods

Benefits

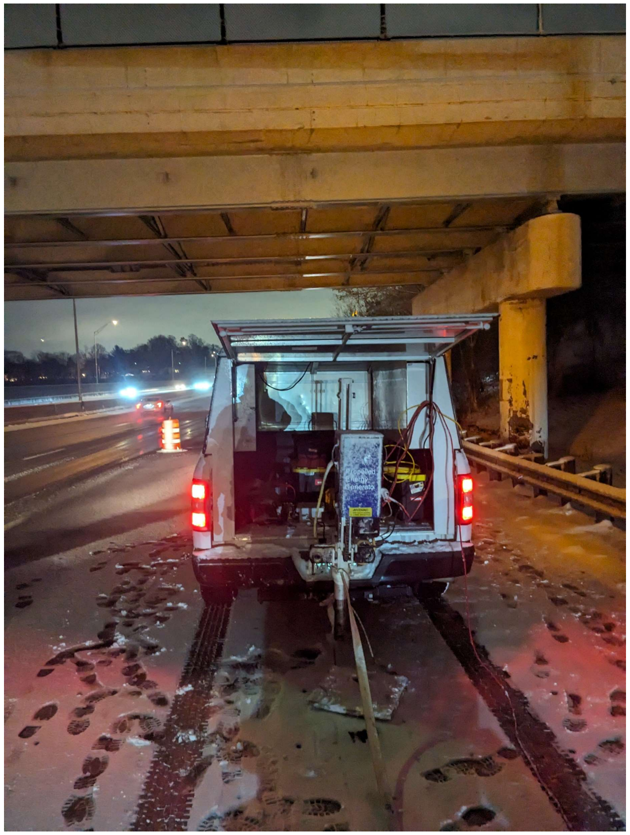
1. Rapid Data Acquisition
2. Minimal Site Impact
3. No Tool Refusal
4. Continuous Data Profiles
5. Accessible Figures
6. **Uncertainty Reduction**

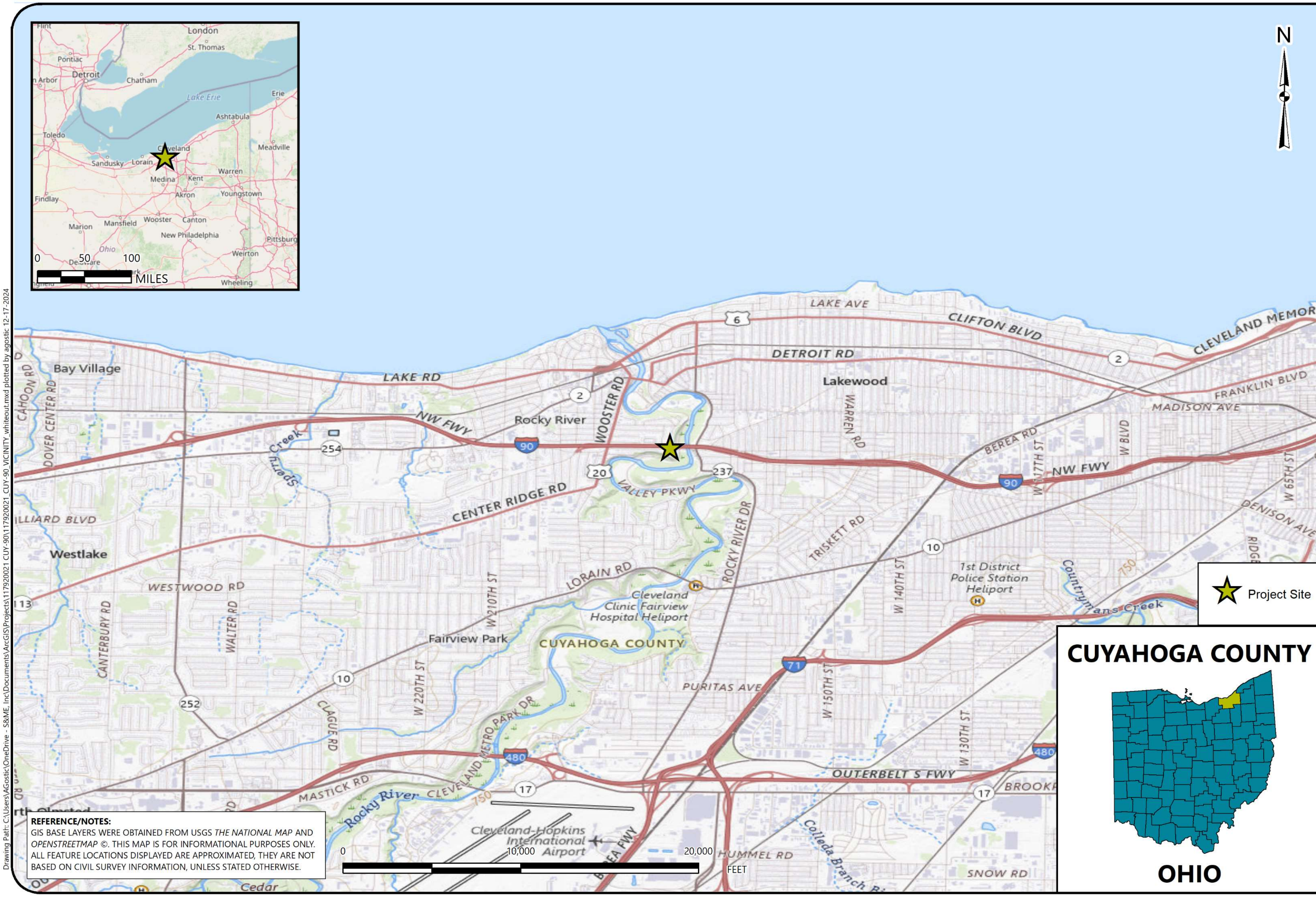


Project Spotlights

I-90 Pavement Replacement

- City of Cleveland planning storm drain installation along I-90 near span over Rocky River.
- Rocky River valley is ~150 feet deep.
- Borehole data indicates a significant change in bedrock depth over a short lateral distance.
- 2D MASW performed along I-90E shoulder to model bedrock depth variability for estimating rock excavation volume.





REFERENCE/NOTES:
GIS BASE LAYERS WERE OBTAINED FROM USGS *THE NATIONAL MAP* AND *OPENSTREETMAP* ©. THIS MAP IS FOR INFORMATIONAL PURPOSES ONLY. ALL FEATURE LOCATIONS DISPLAYED ARE APPROXIMATED, THEY ARE NOT BASED ON CIVIL SURVEY INFORMATION, UNLESS STATED OTHERWISE.

Drawing Path: C:\Users\AGostic\OneDrive - S&ME, Inc\Documents\ArcGIS\Projects\117920021 CUY-90\117920021_CUY-90_VICINITY_whiteout.mxd plotted by agostic 12-17-2024

VICINITY MAP

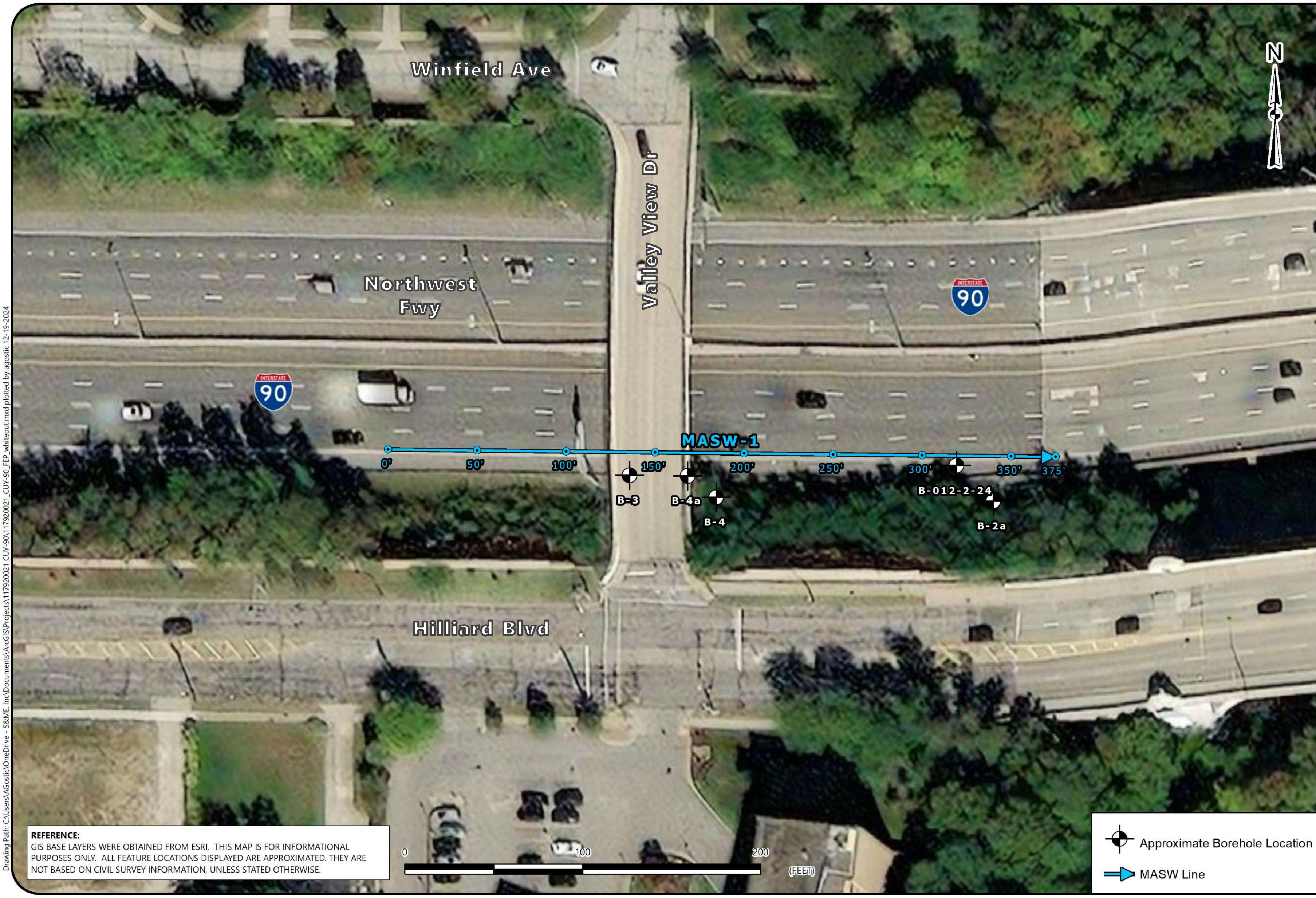
CUY-90-6.69 PAVEMENT REPLACEMENT
CLEVELAND, CUYAHOGA COUNTY, OHIO

SCALE:
1" = 10000'

DATE:
9/22/2025

PROJECT NUMBER
117920021

FIGURE NO.
16



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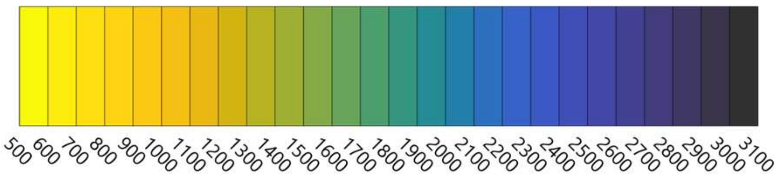
FIELD EXPLORATION PLAN

CUY-90-6.69 PAVEMENT REPLACEMENT
CLEVELAND, CUYAHOGA COUNTY, OHIO

SCALE:	1″ = 50′
DATE:	9/22/2025
PROJECT NUMBER	117920021
FIGURE NO.	17

Drawing Path: C:\Users\AGostic\OneDrive - S&ME, Inc\Documents\ArcGIS\Projects\117920021 CUY-90\117920021 CUY-90_FEP_whiteout.mxd plotted by agostic 12-19-2024

S-Wave Velocity (ft/s)



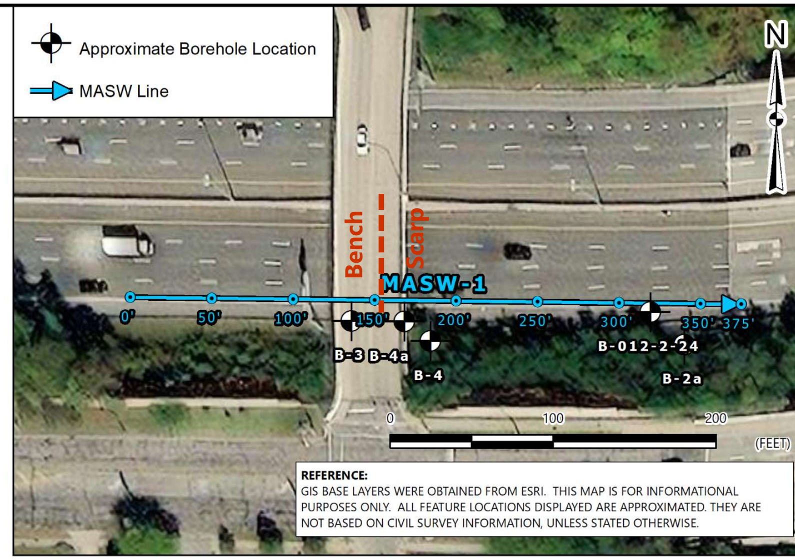
Borehole Position

Interpreted Top of Bedrock

Alluvium

Shale

Color Map: *CET-L20*
Peter Kovesi. Good Colour Maps: How to Design Them.
arXiv:1509.03700 [cs.GR] 2015Hosted at:colorcet.com



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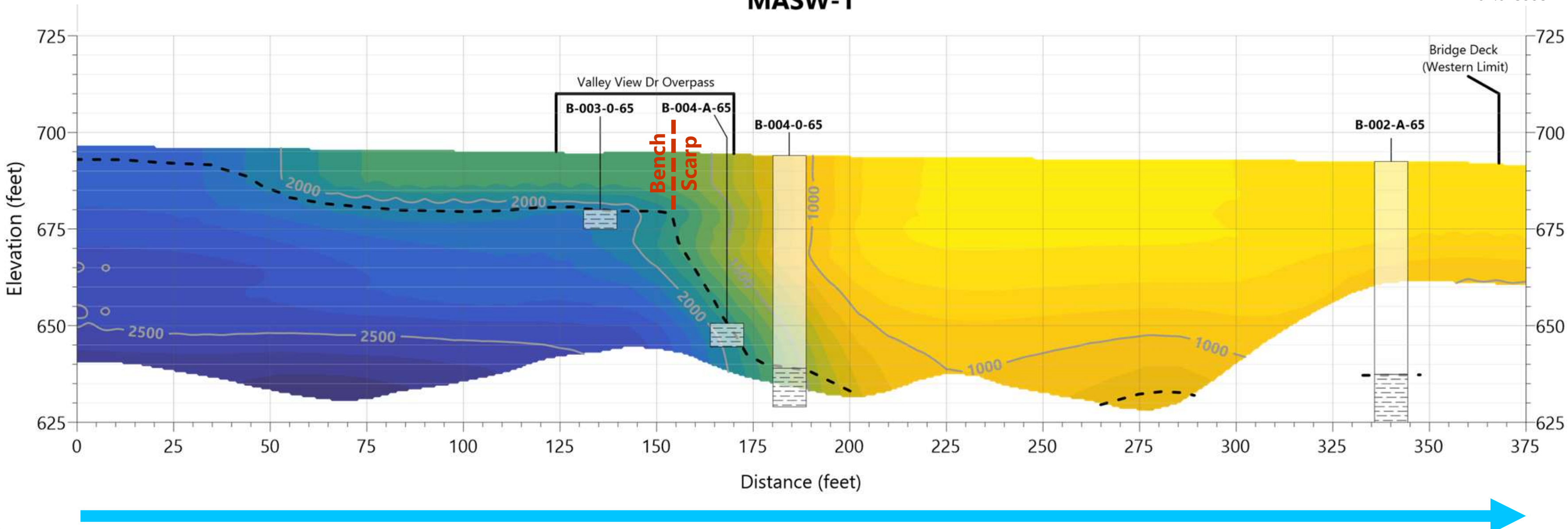
Geographic Coordinates System: WGS 1984

41.471786° N
81.827363° W

41.471767° N
81.825995° W

MASW-1



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MULTICHANNEL ANALYSIS OF SURFACE WAVES DATA PROFILE:
MASW-1

CUY-90-6.69 PAVEMENT REPLACEMENT
CLEVELAND, CUYAHOGA COUNTY, OHIO

SCALE:
AS SHOWN

DATE:
9/22/2025

PROJECT NUMBER
117920021

FIGURE NO.
18

Site 7 I-40 Roadway Embankment Failure

- One of seven I-40 embankment failures along Pigeon River near the Tennessee-North Carolina border during Hurricane Helene in 2024.
- Remediation efforts include the construction of a cantilevered retaining wall, but the exposed mixture of soil and weathered rock was not suitable for bearing or anchoring the wall foundation.
- Geotechnical investigation revealed variable depth to competent bedrock along embankment.
- 2D MASW performed along I-90E shoulder to model bedrock depth variability.

REFERENCE:
GOOGLE EARTH PRO AERIAL PHOTOGRAPH (FEBRUARY 20, 2025). THIS PLAN IS FOR INFORMATIONAL PURPOSES ONLY. ALL FEATURE LOCATIONS DISPLAYED ARE APPROXIMATE AND NOT BASED ON CIVIL SURVEY INFORMATION, UNLESS STATED OTHERWISE.

SITE VICINITY PLAN

I-40 ROADWAY EMBANKMENT FAILURE
SITE 7 (HURRICANE HELENE)
COCKE COUNTY, TENNESSEE

SCALE: AS SHOWN

DATE: 9/22/2025

PROJECT NUMBER 24430310

FIGURE NO. 20

REFERENCE:
GOOGLE EARTH PRO AERIAL PHOTOGRAPH (DATED FEBRUARY 20, 2025). THIS PLAN IS FOR INFORMATIONAL PURPOSES ONLY. ALL FEATURE LOCATIONS DISPLAYED ARE APPROXIMATE AND NOT BASED ON CIVIL SURVEY INFORMATION, UNLESS STATED OTHERWISE.

LEGEND

2D MASW Profile

Boring Location (S&ME 2025)

2D MASW SURVEY LOCATION PLAN

I-40 ROADWAY EMBANKMENT FAILURE
SITE 7 (HURRICANE HELENE)
COCKE COUNTY, TENNESSEE

SCALE: AS SHOWN

DATE: 9/22/2025

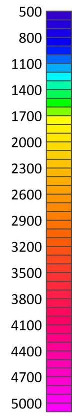
PROJECT NUMBER 24430310

FIGURE NO. 21

BORING LEGEND

■	Asphalt
(dotted pattern)	Mixture of boulders, cobbles, sand, and silt
(dashed/dotted pattern)	Siltstone

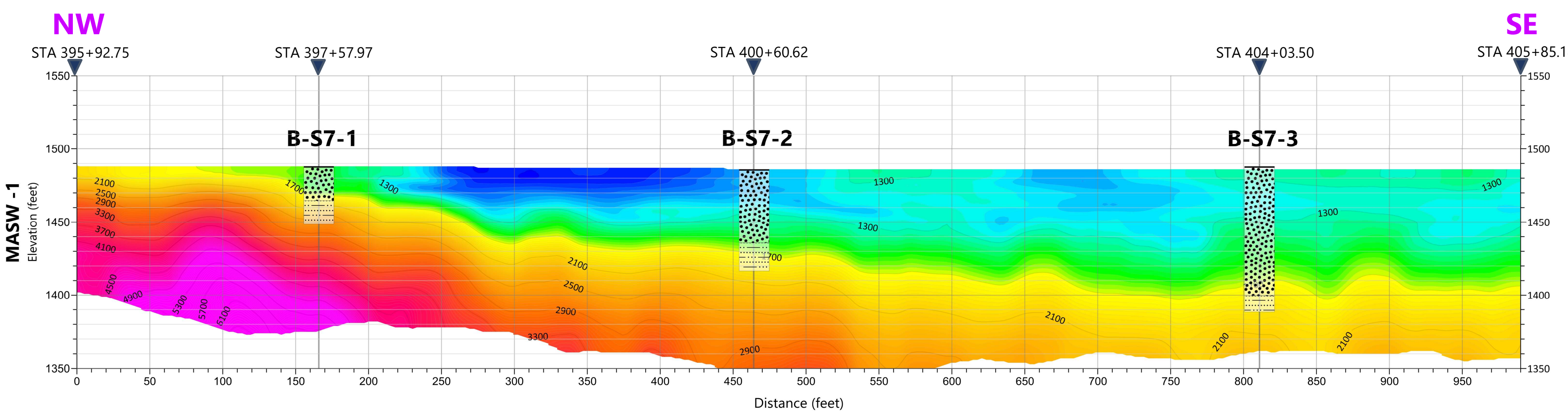
Shear Wave Velocity (ft/s)



Mixture of boulders, cobbles, sand, and silt

Siltstone

LEGEND 2D MASW Profile Boring Location (S&ME; 2025)

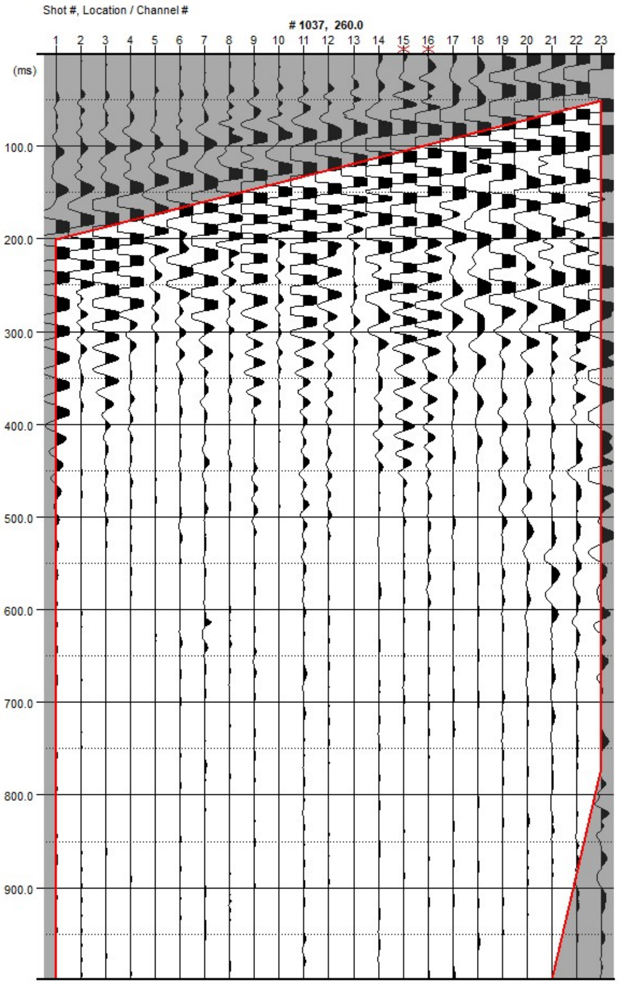


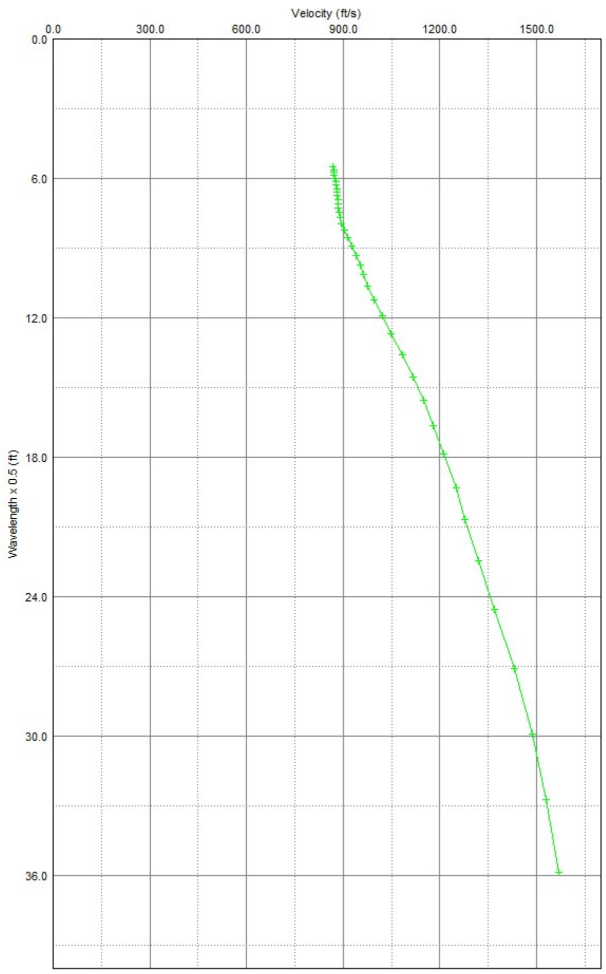
2D MASW SURVEY DATA – LINE 1

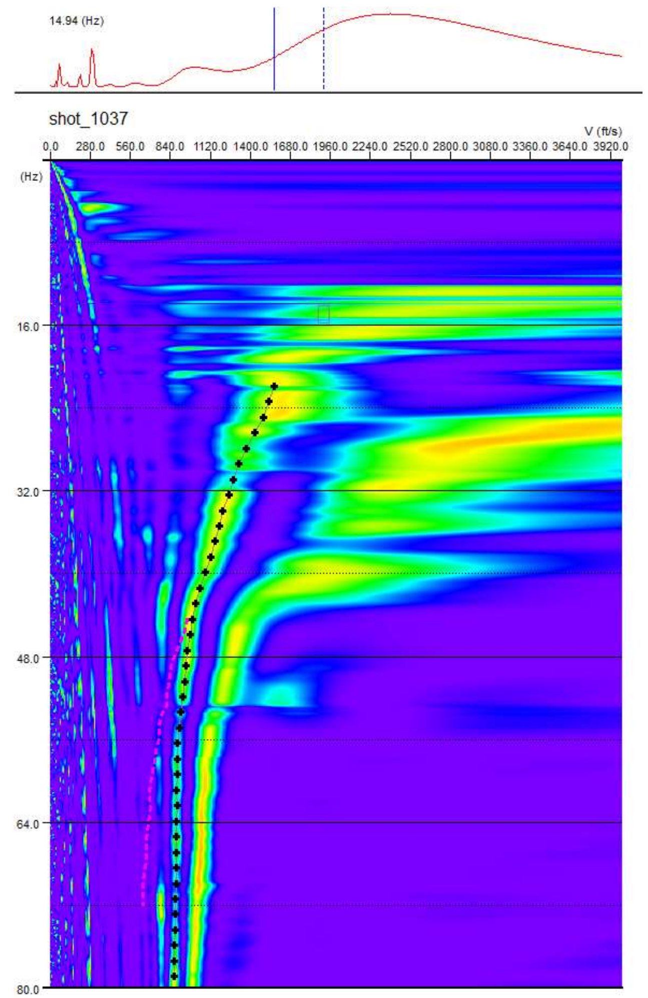
I-40 ROADWAY EMBANKMENT FAILURE
SITE 7 (HURRICANE HELENE)
COCKE COUNTY, TENNESSEE

SCALE:	AS SHOWN
DATE:	9/22/2025
PROJECT NUMBER	24430310
FIGURE NO.	22

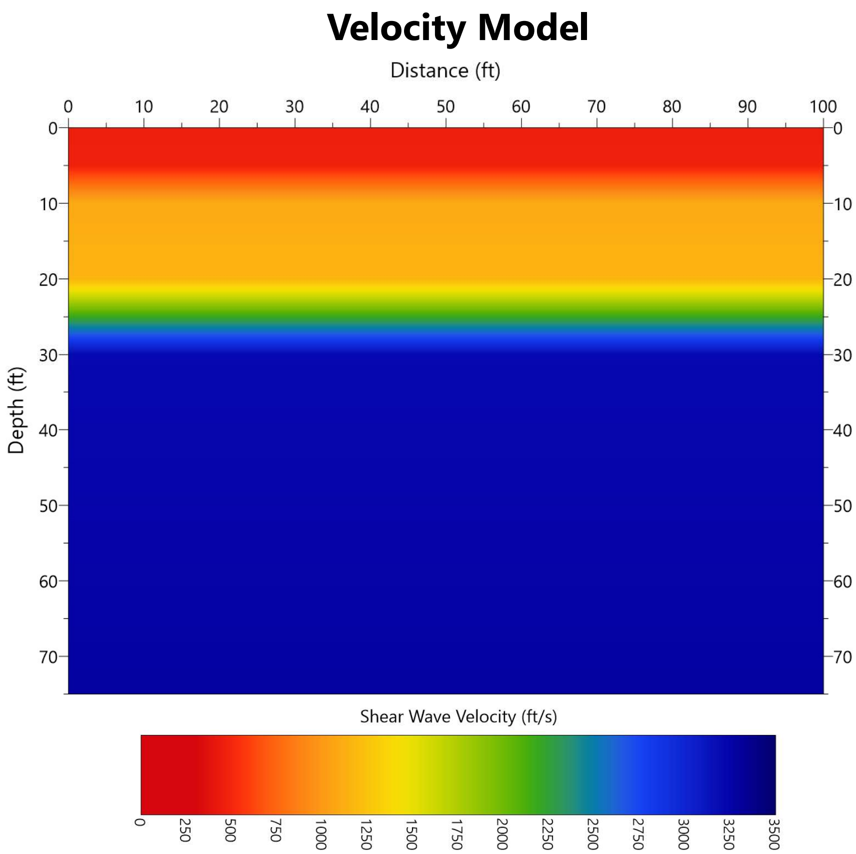
Methodology







Dispersion Theory

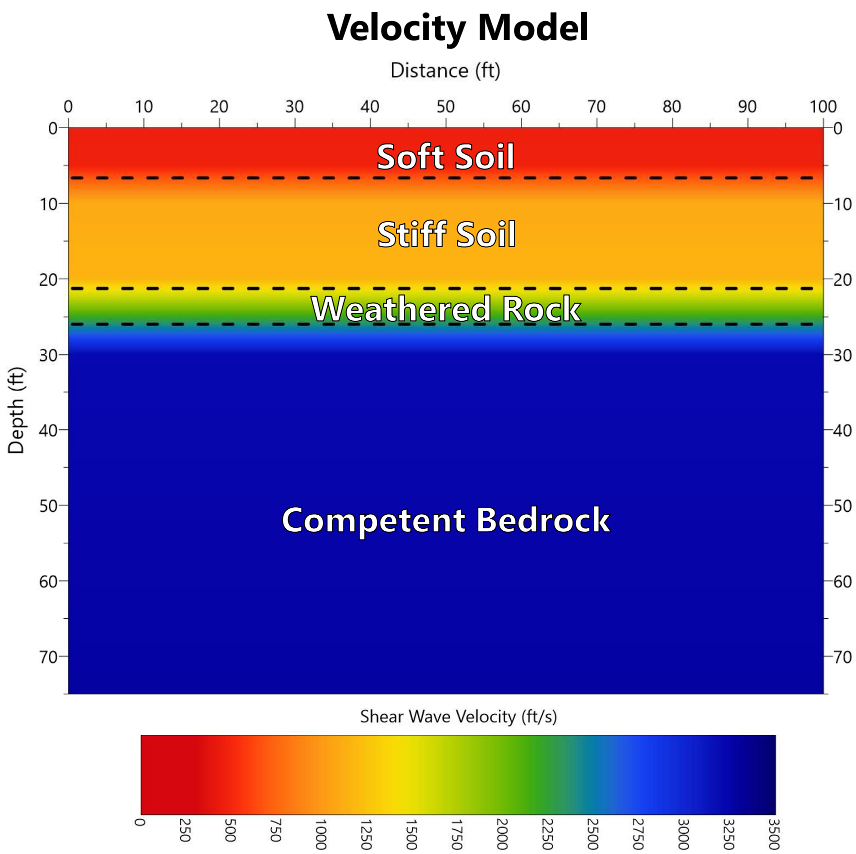


Surface Waves are *Dispersive*

- Velocity is dependent on frequency.
  1. Surface waves travel along the surface.
  2. Seismic velocity increases with depth.

Methodology

Dispersion Theory



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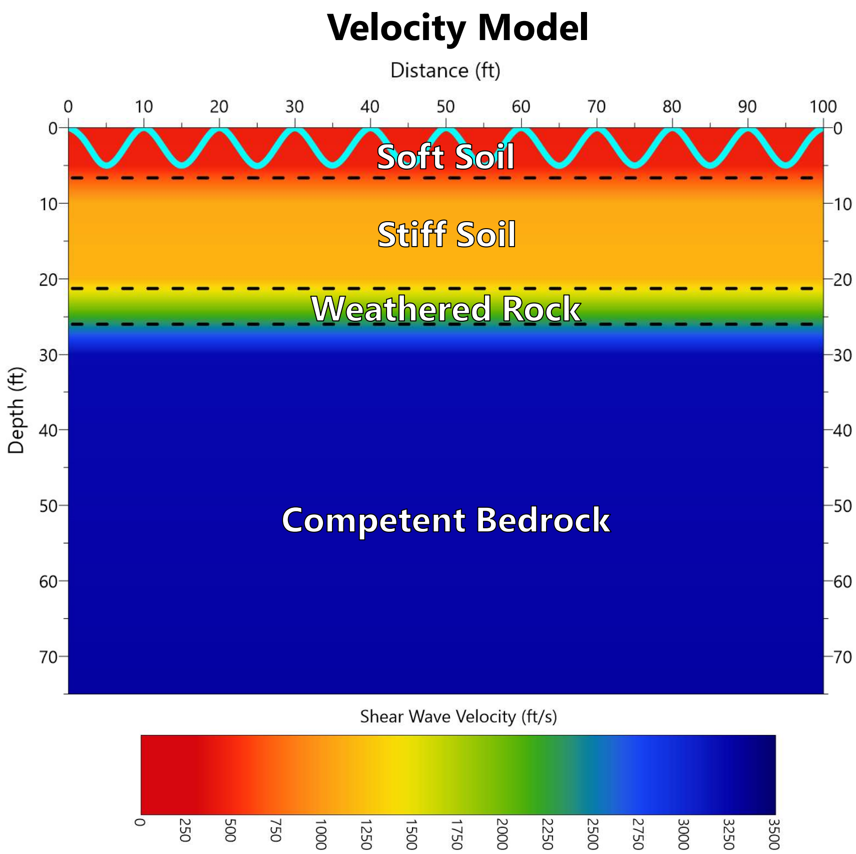

Surface Waves are *Dispersive*

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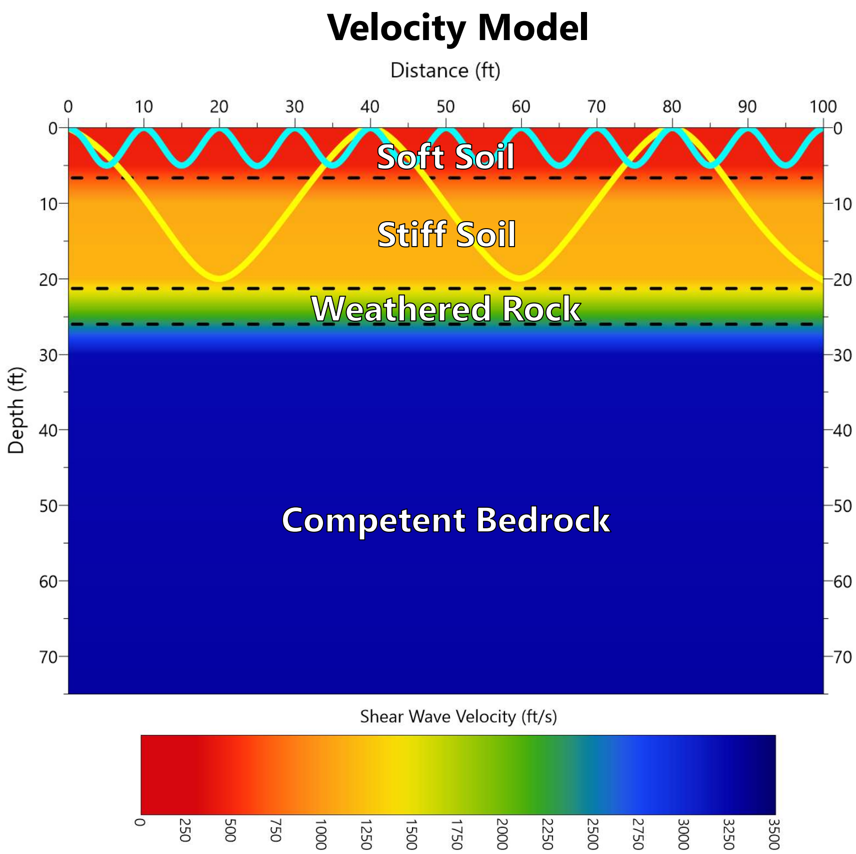
$v_s = 450$ ft/s

Dispersion Theory



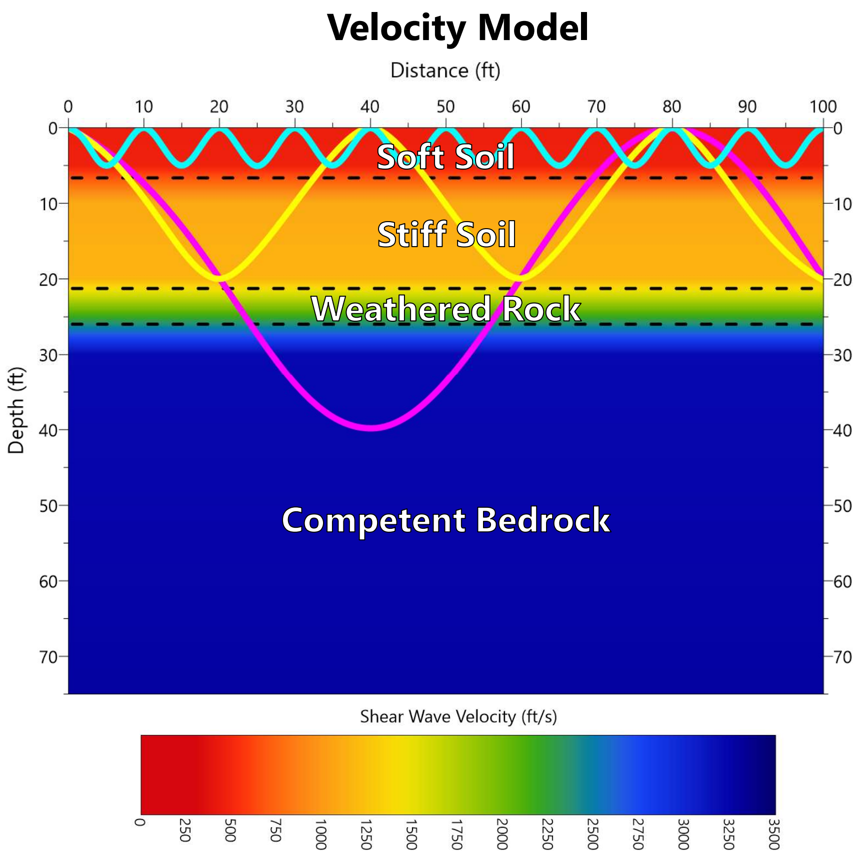
Surface Waves are *Dispersive*

- Velocity is dependent on frequency.
  1. Surface waves travel along the surface.
  2. Seismic velocity increases with depth.

v_s = 450 ft/s

v_s = 644 ft/s

Dispersion Theory



Surface Waves are *Dispersive*

- Velocity is dependent on frequency.
  1. Surface waves travel along the surface.
  2. Seismic velocity increases with depth.

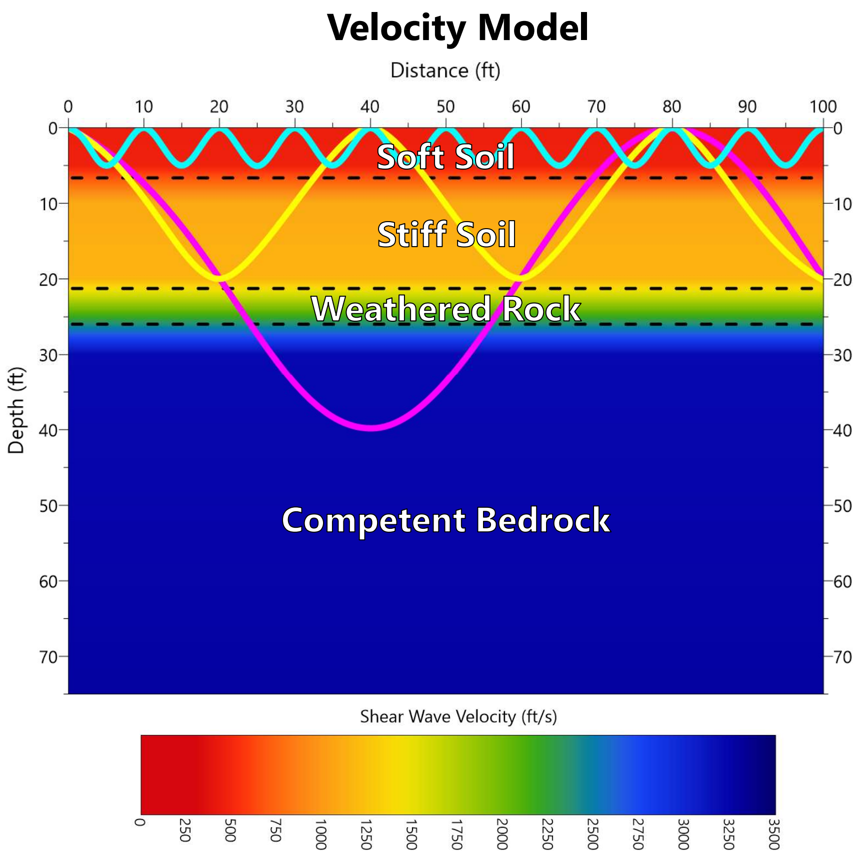
v_S = 450 ft/s

v_S = 644 ft/s

v_S = 981 ft/s

- Lower frequency → longer wavelength.
- Longer wavelength → greater penetration.
- Greater penetration → higher velocity.

Dispersion Theory



Surface Waves are *Dispersive*

- Velocity is dependent on frequency.
    1. Surface waves travel along the surface.
    2. Seismic velocity increases with depth.

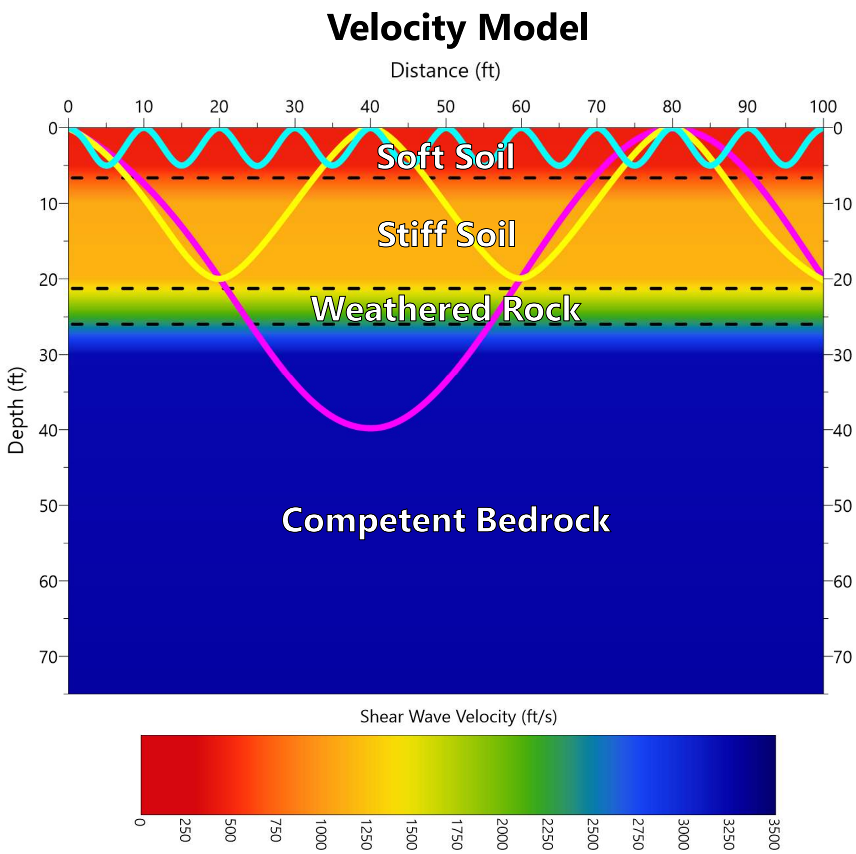
450 ft/s → 45.0 Hz

644 ft/s → 16.1 Hz

981 ft/s → 12.3 Hz

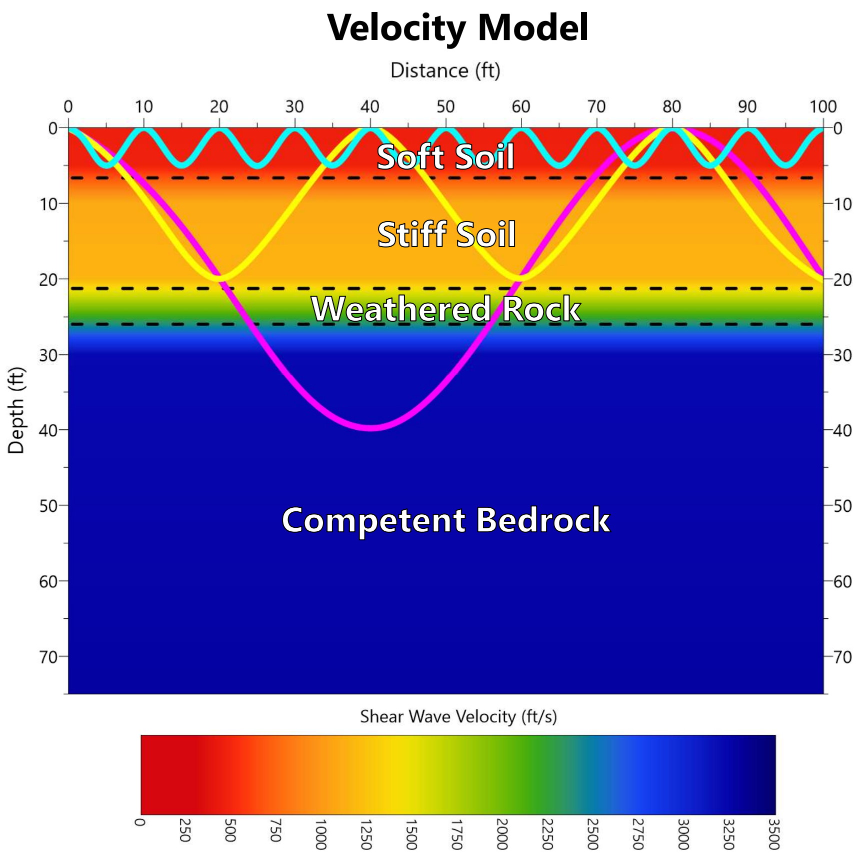
- Lower frequency → longer wavelength.
- Longer wavelength → greater penetration.
- Greater penetration → higher velocity.

Dispersion Theory



Velocity	Frequency
450 ft/s	45.0 Hz
644 ft/s	16.1 Hz
981 ft/s	12.3 Hz

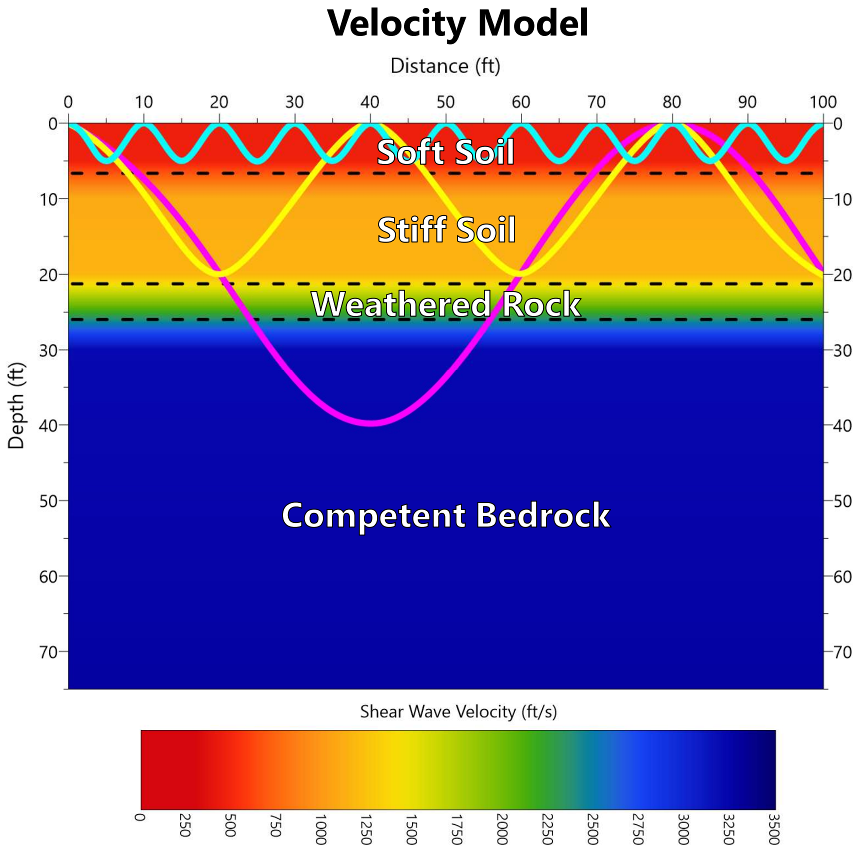
Dispersion Theory



Velocity	Wavelength
450 ft/s	10.0 ft
644 ft/s	40.0 ft
981 ft/s	80.0 ft

Methodology

Dispersion Theory



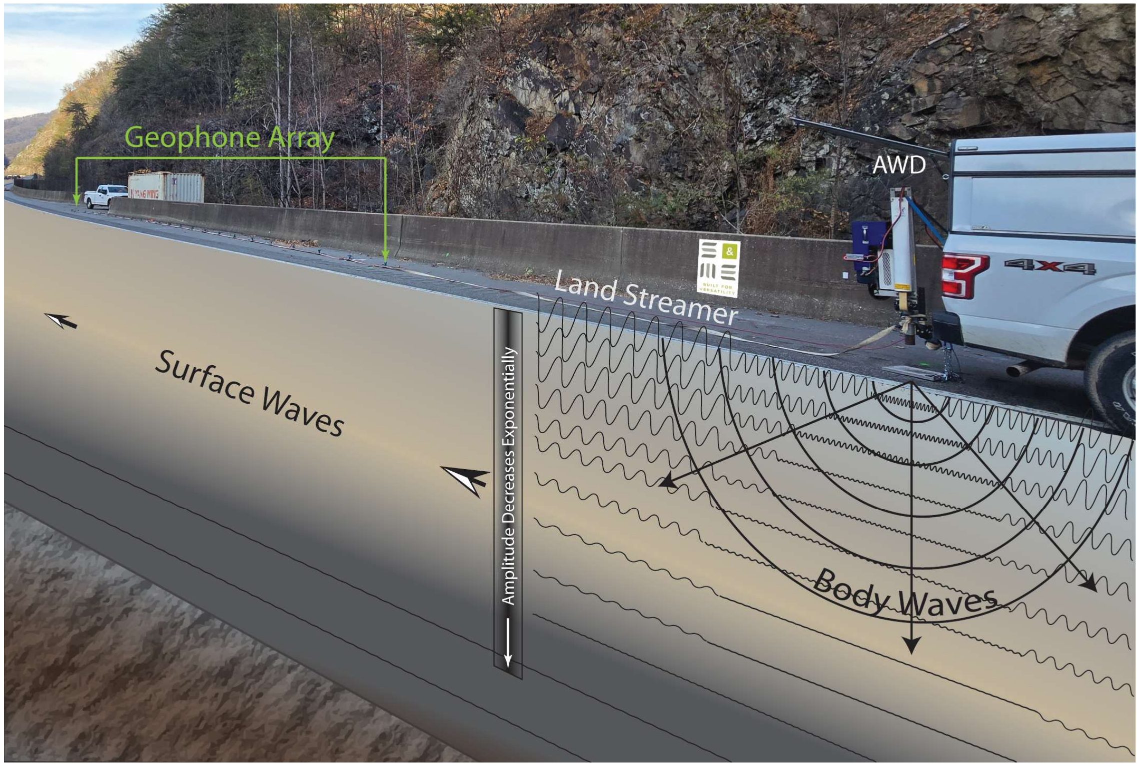
Velocity	Penetration Depth
450 ft/s	5 ft
644 ft/s	20 ft
981 ft/s	40 ft

(Depth is approximately half of wavelength)

Methodology

Data Acquisition

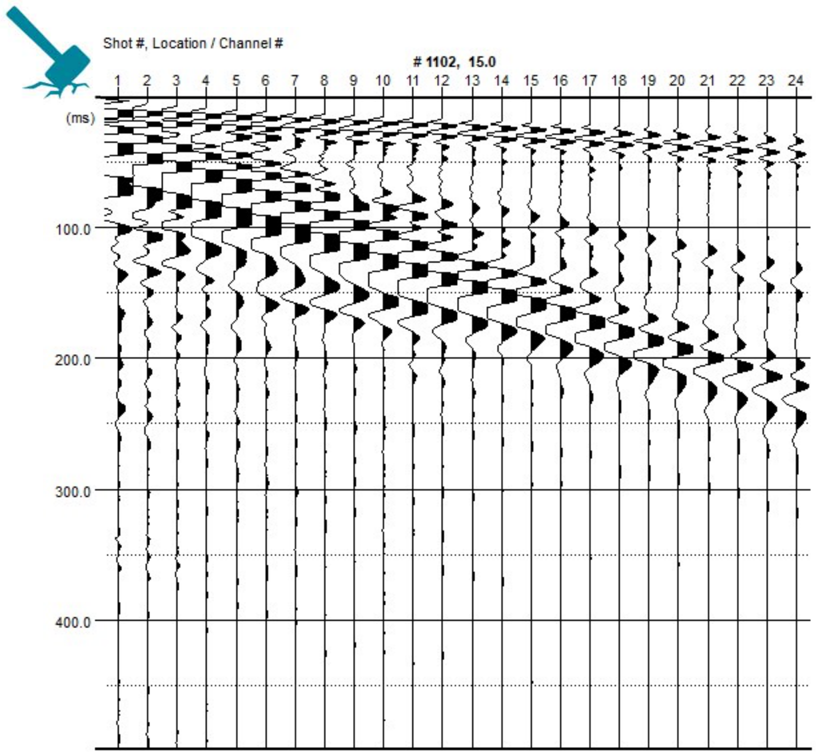
1. Deploy array of seismic receivers called geophones.
2. Generate surface waves using impulsive energy source
   - Sledgehammer
   - Accelerated Weight Drop (AWD)
3. Record surface wave arrivals along geophone array.
4. Reposition geophone array and/or energy source and repeat.

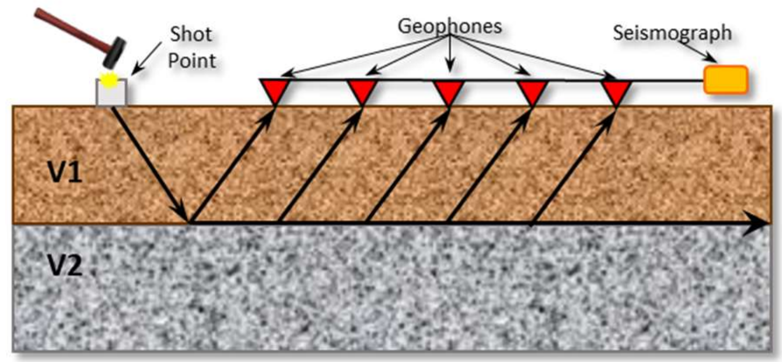


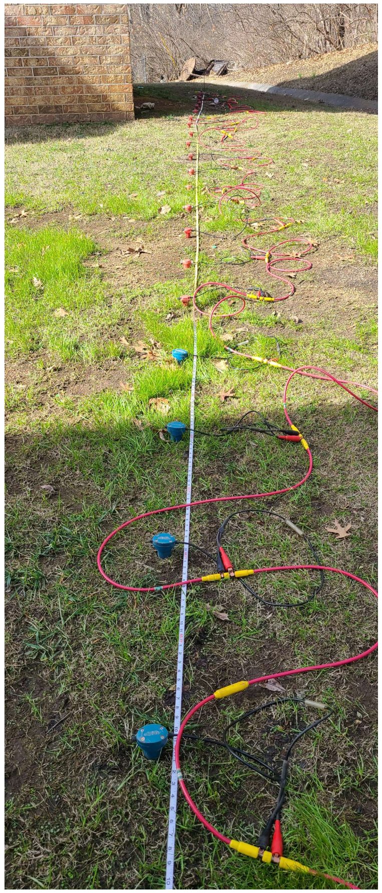
Methodology

Data Acquisition

Shot Gather



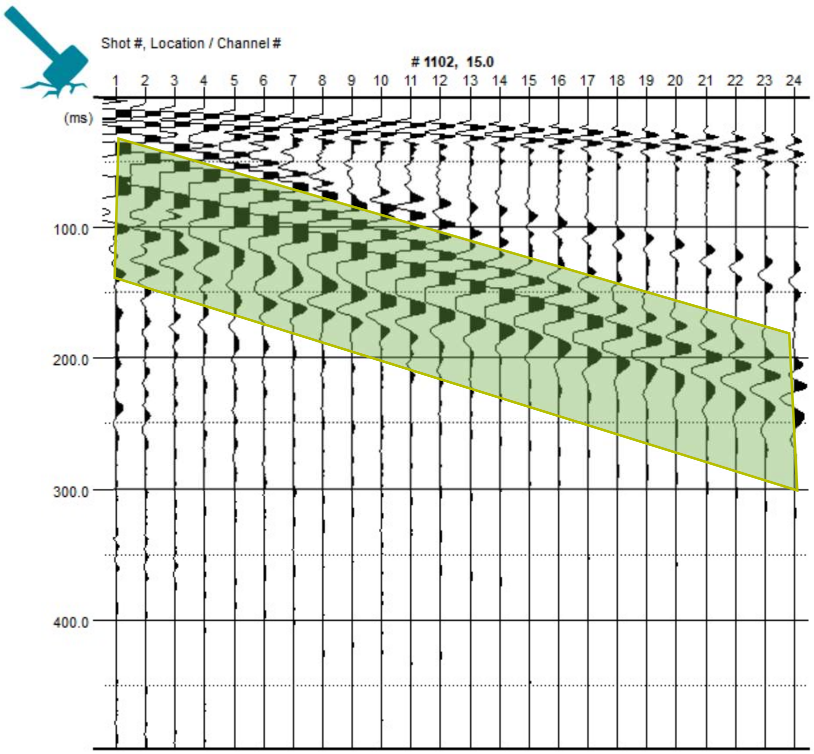


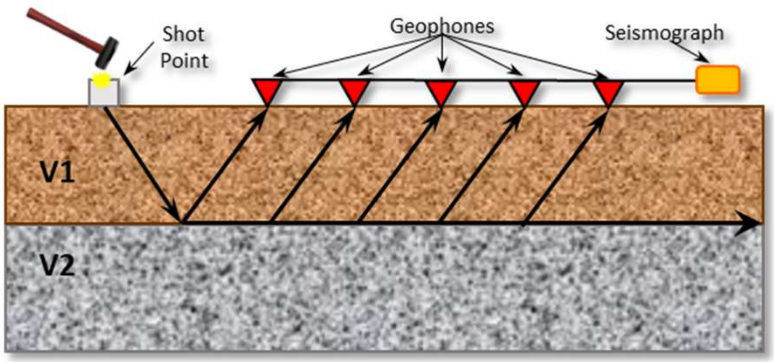


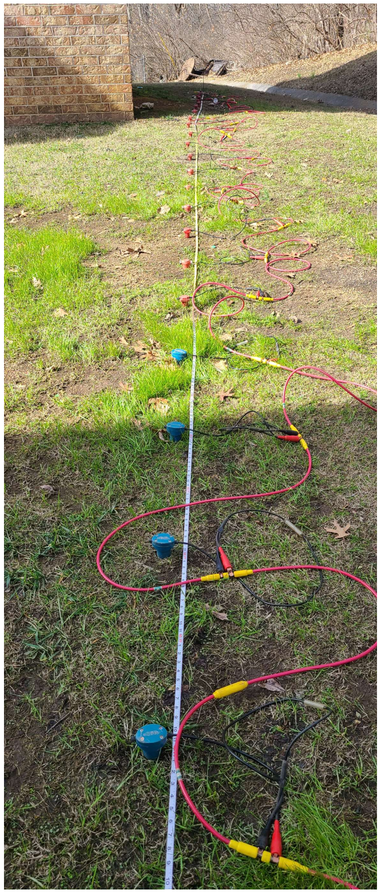
Methodology

Data Acquisition

Shot Gather







Methodology

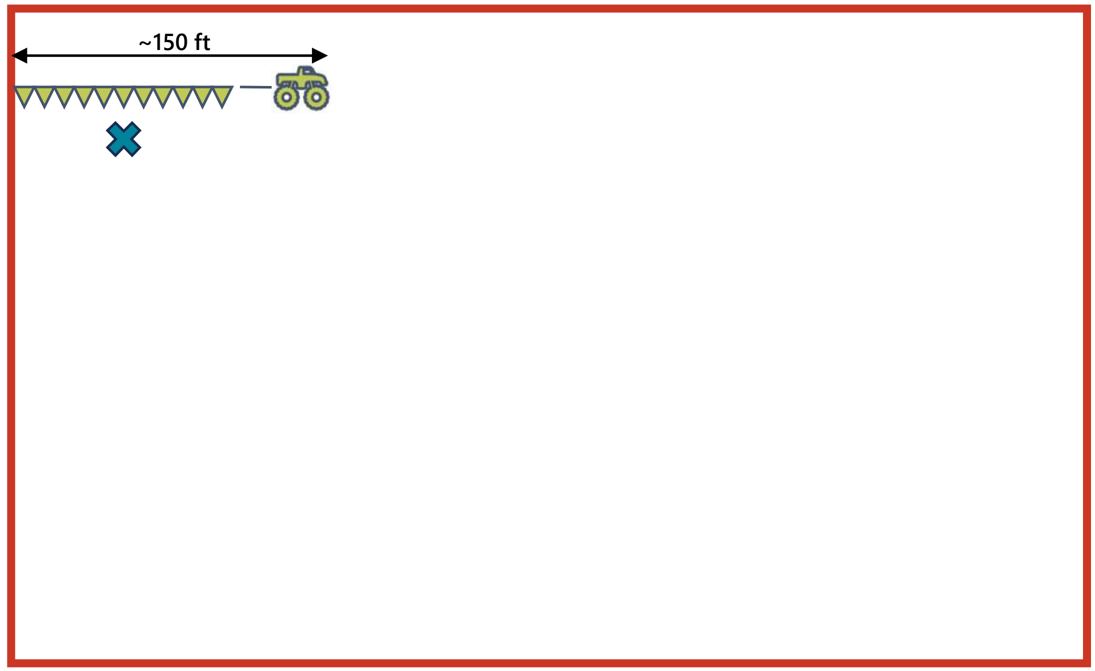
Limitations

- **Flat terrain preferred.**
  - Limited downhill grades.
  - Ruts, curbs, ditches, etc. are problematic.
- **Bare ground or pavement preferred.**
  - Incompatible with crops or thick vegetation.

Methodology

Limitations

- Flat terrain preferred.
  - Limited downhill grades.
  - Ruts, curbs, ditches, etc. are problematic.
- Bare ground or pavement preferred.
  - Incompatible with crops or thick vegetation.
- Data Limits < Equipment Limits
  - Difference ≈ 150 feet



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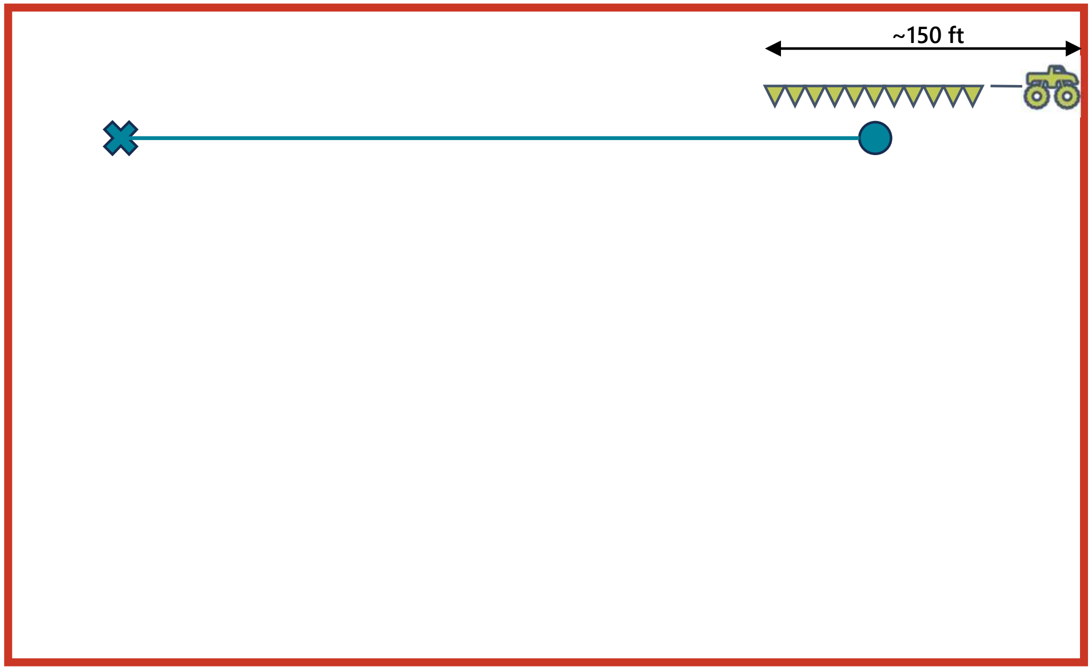

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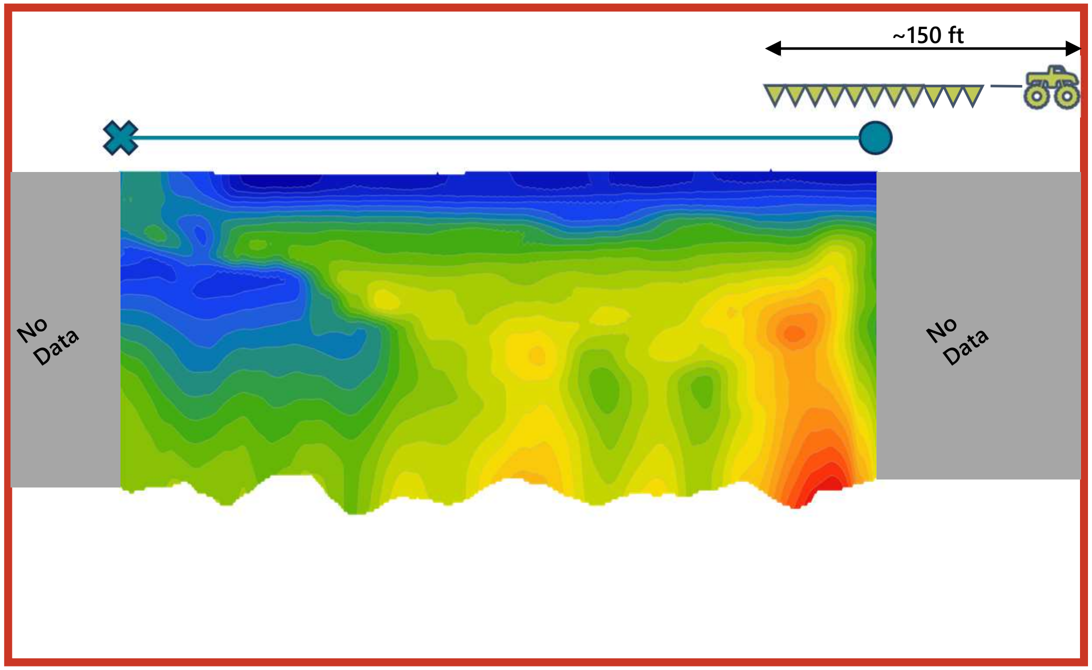
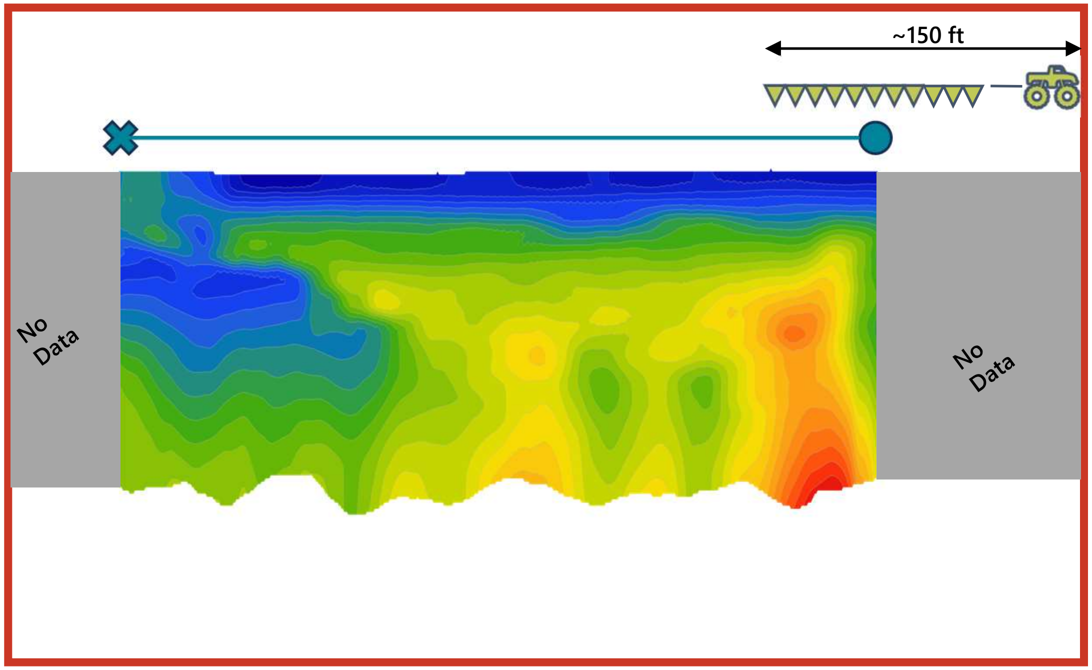


Limitations

- Flat terrain preferred.
  - Limited downhill grades.
  - Ruts, curbs, ditches, etc. are problematic.
- Bare ground or pavement preferred.
  - Incompatible with crops or thick vegetation.
- Data Limits < Equipment Limits
  - Difference ≈ 150 feet
- Lateral Heterogeneity
  - Data averaged over length of the geophone array.



Summary

1. Multichannel Analysis of Surface Waves (MASW) is a geophysical method that uses dispersive **seismic surface waves** to model seismic shear wave velocity.

2. MASW can be used to **reduce overall cost** by reducing the amount of geotechnical investigation needed to adequately characterize a project site.

3. A 2D velocity model enables the **visualization of subsurface complexity** with a product that is accessible and engaging.

4. Visualizations of subsurface complexity **reduce uncertainty** in planning and design, leading to more accurate estimates and a lower likelihood of requiring a costly change order.