

Comparative Study of the Refraction Microtremor (ReMi) Method: Using Seismic noise and standard P-wave refraction equipment for deriving 1-D S-wave profiles

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Refraction Microtremor Technique

- Based on two fundamental ideas
 - Standard refraction equipment deployed similar to a shallow P-wave refraction survey to record ambient noise (microtremor)
 - *4.5 to 14 Hz (or higher) vertical geophones depending on application. Depth of penetration is inversely proportional to natural frequency of geophones used.*
 - Slowness-frequency (p-f) transformation of the recorded microtremor
 - *Separate Rayleigh waves from other seismic arrivals and allow identifying true phase velocity against apparent velocities*

Why SeisOpt[®] ReMiTM

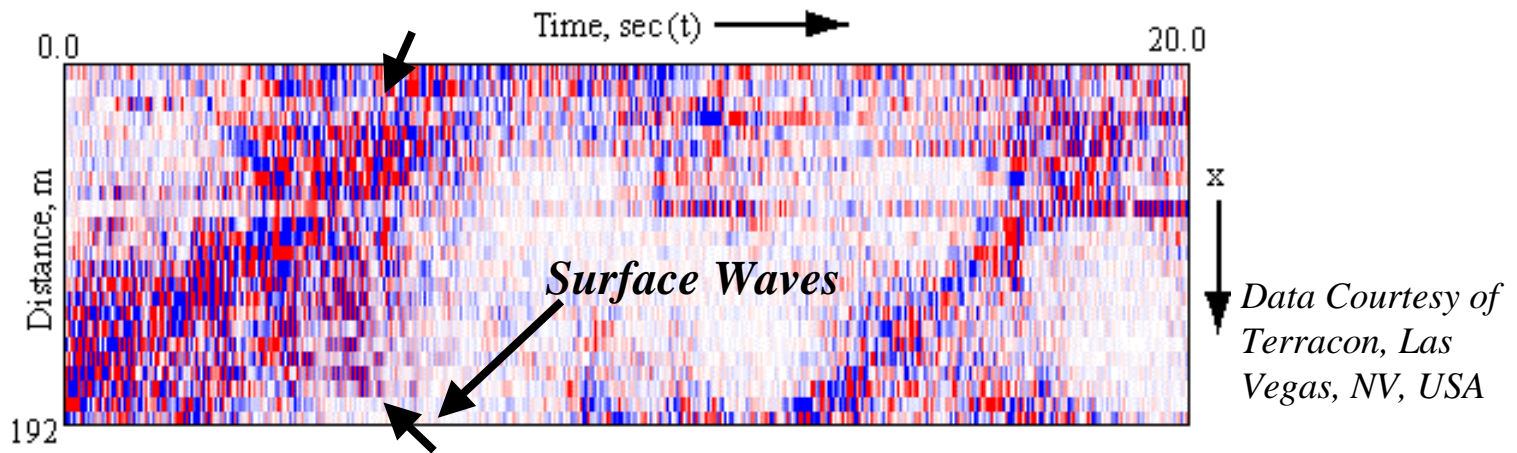
- **Disadvantages of commonly used methods**
 - Drilling and logging S-wave velocities (such as OYO logger)
 - *Expensive & time consuming*
 - *Permitting required*
 - *Physical restrictions*
 - Surface methods SASW & MASW
 - *Expensive & time consuming*
 - *Specialized recording equipment required*
 - *Artificial seismic source required*
- **Advantages of using SeisOpt ReMi**
 - Data acquisition and analysis takes about three hours
 - No physical restrictions beyond required 100 m to 200 m line deployment space, minimal permitting
 - *Data can be acquired along roads, in buildings & at active construction sites*
 - No specialized recording equipment required
 - *Standard refraction seismograph & refraction P-wave geophones*
 - No artificial seismic source
 - *Uses ambient noise: “Quiet” site not required*
 - Can be used offshore as effectively as on-shore

SeisOpt[®] ReMi[™] Method

- Acquire 15-20 seconds microtremor data along a linear array.
- Array length depends on depth of investigation – recommended minimum length 100m. Crooked line geometry can be handled.

Step 1: p- τ transformation or the Slant Stack operation (Thorson and Claerbout, 1985) of the vertical particle velocity

$$A(p=p_0+ldp, \tau=kdt) = \sum A(x=jdx, t=idt = \tau+px)$$



Step 2: Fourier transformation: p- τ to p-f domain (McMechan and Yedlin, 1981)

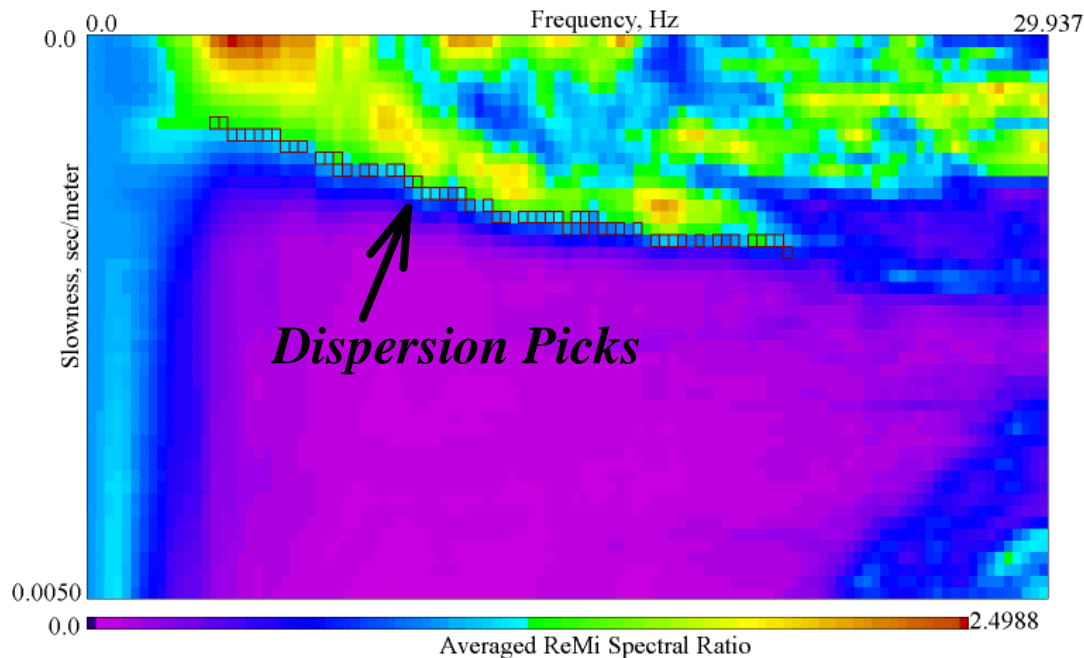
$$F_A(p, f = mdf) = \sum A(p, \tau=kdt) e^{i2\pi m df kdt}$$

SeisOpt[®] ReMiTM Method

Step 3: Velocity Spectral Analysis (Louie, 2001): Power spectrum

$$S_A(p, f) = F_A^*(p, f) F_A(p, f)$$

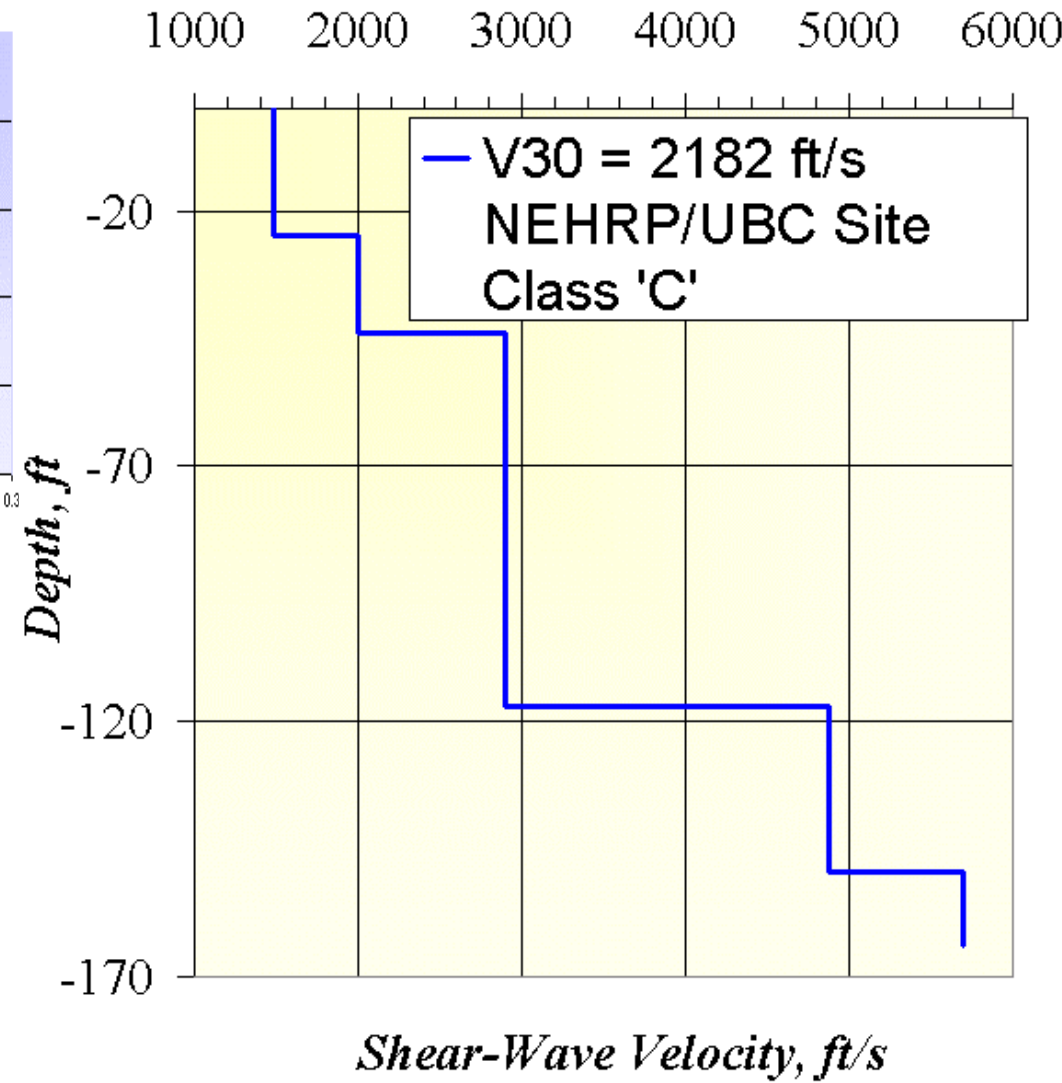
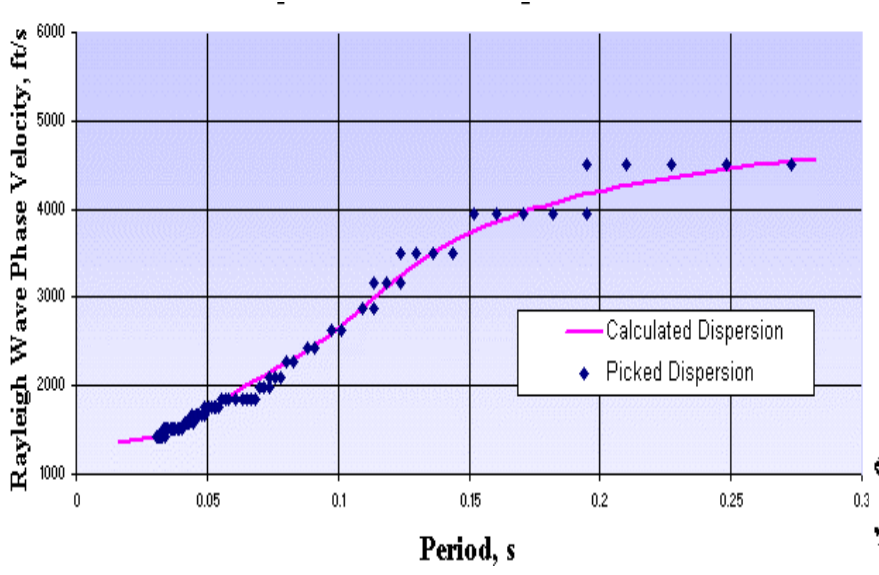
$$S_A(|p|, f) = [S_A(p, f)]_{p \geq 0} + [S_A(-p, f)]_{p < 0} \quad : \quad S_{total}(|p|, f) = \sum S_{A_n}(p, f)$$



- *Lower limit of the apparent phase velocities can be recognized as the true phase velocities (Louie, 2001)*

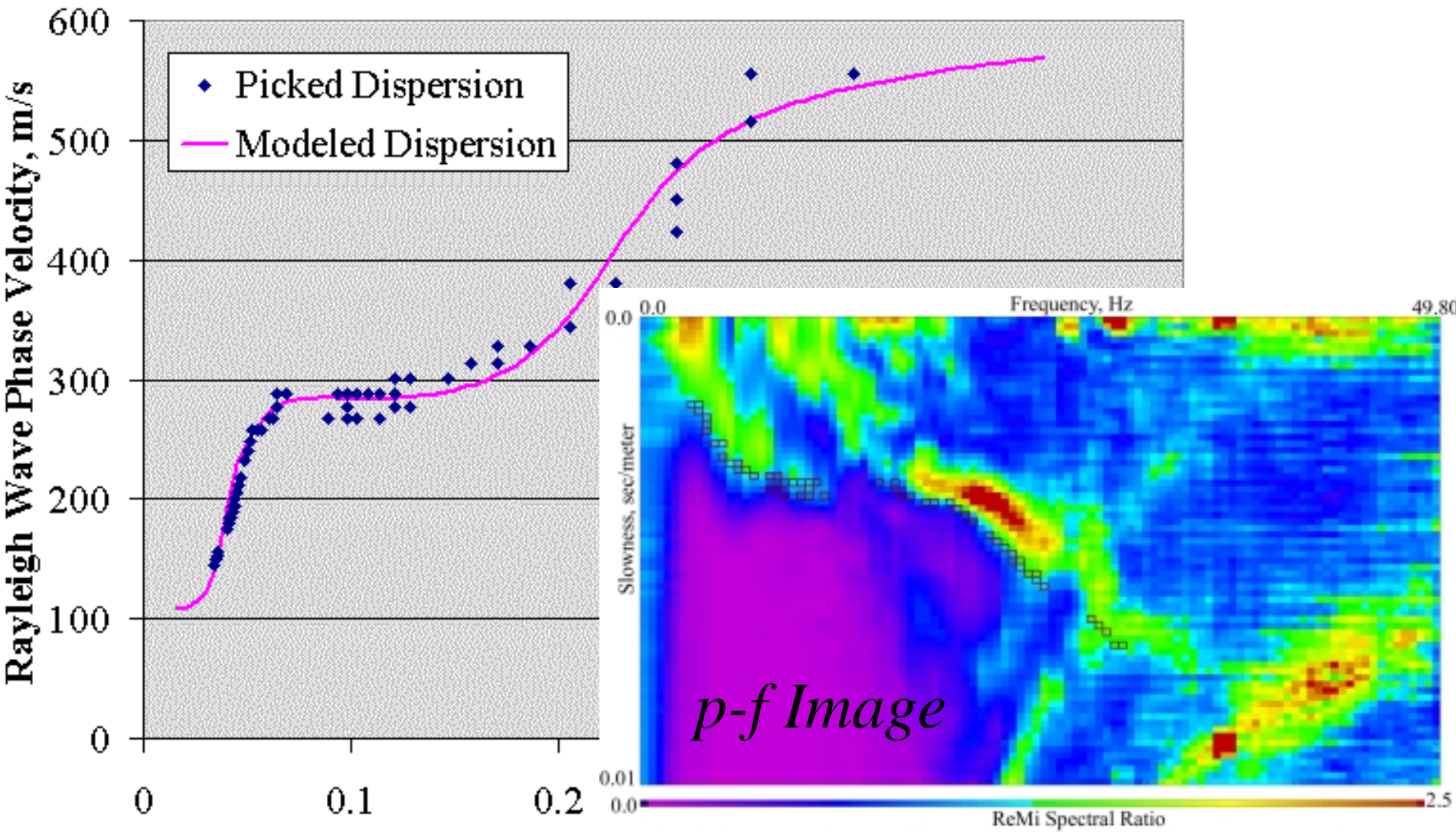
SeisOpt® ReMi™ Method

Step 4: Interactive Forward Velocity Modeling



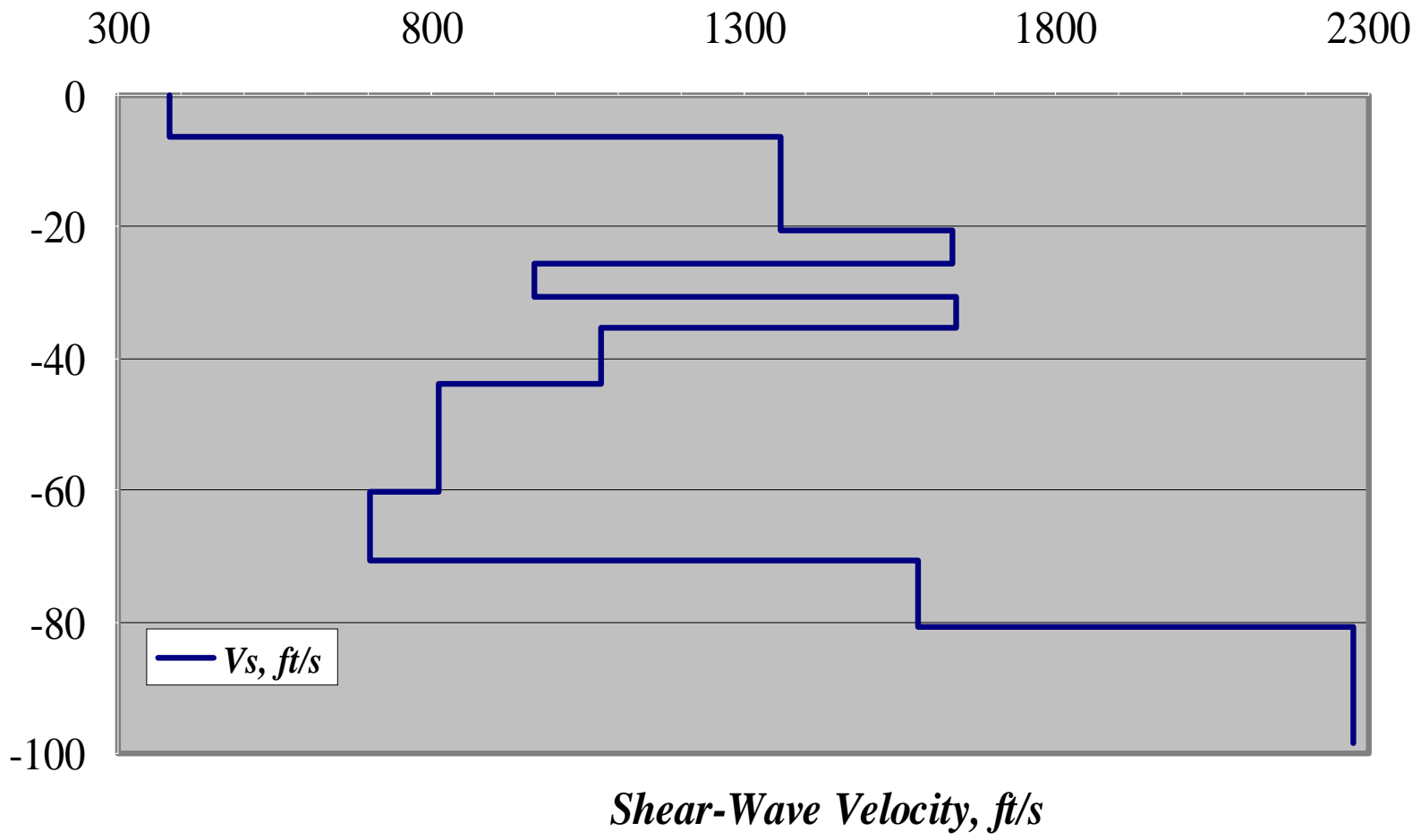
- *Avoids ambiguities associated with inversion, while providing the user with ability to include constraints while modeling*

Case Study: Oregon State University Geotechnical Engineering Field Research Test Site



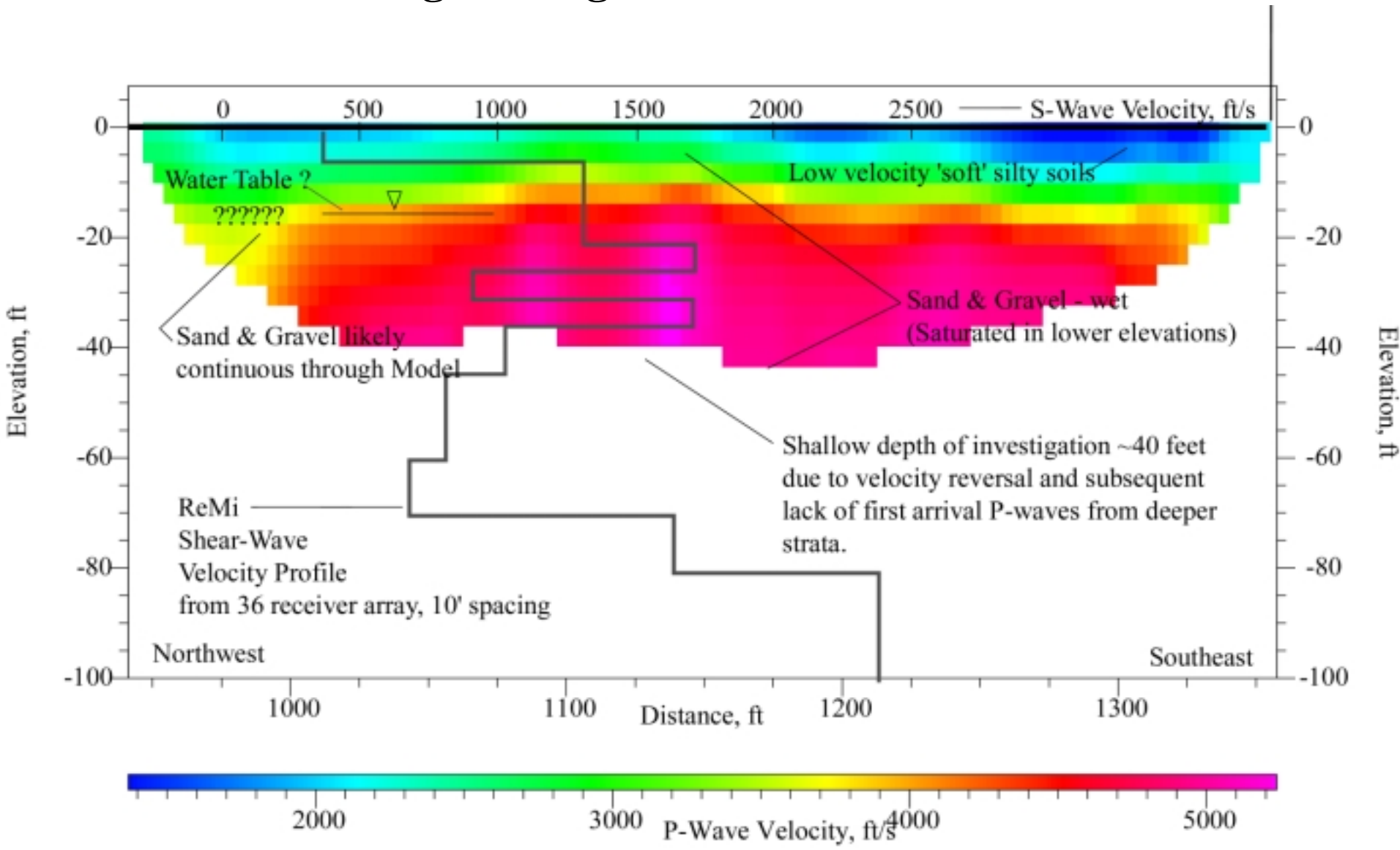
•36 10-Hz geophones with 10 ft spacing deployed along a linear array

Case Study: Oregon State University Geotechnical Engineering Field Research Test Site



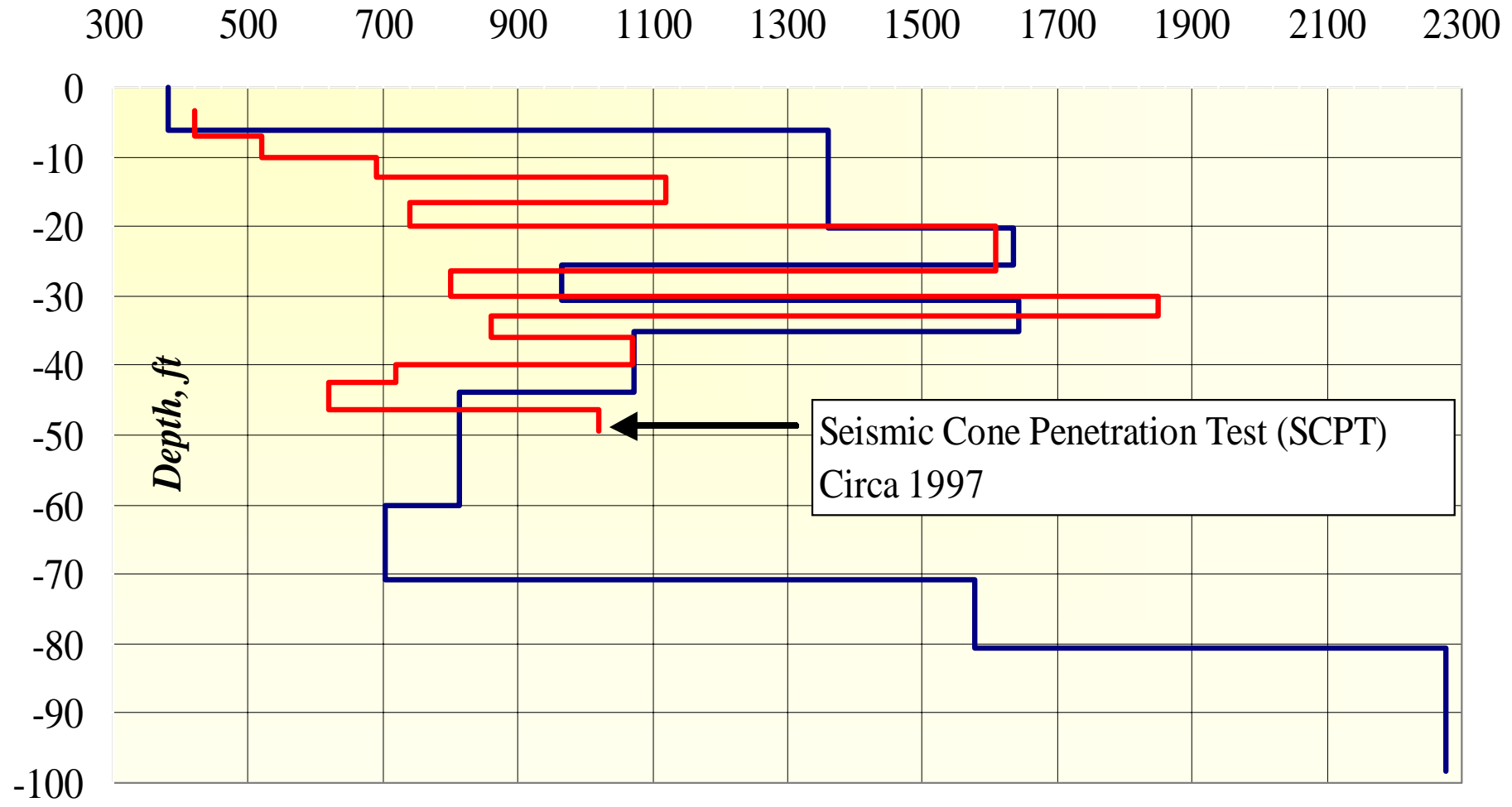
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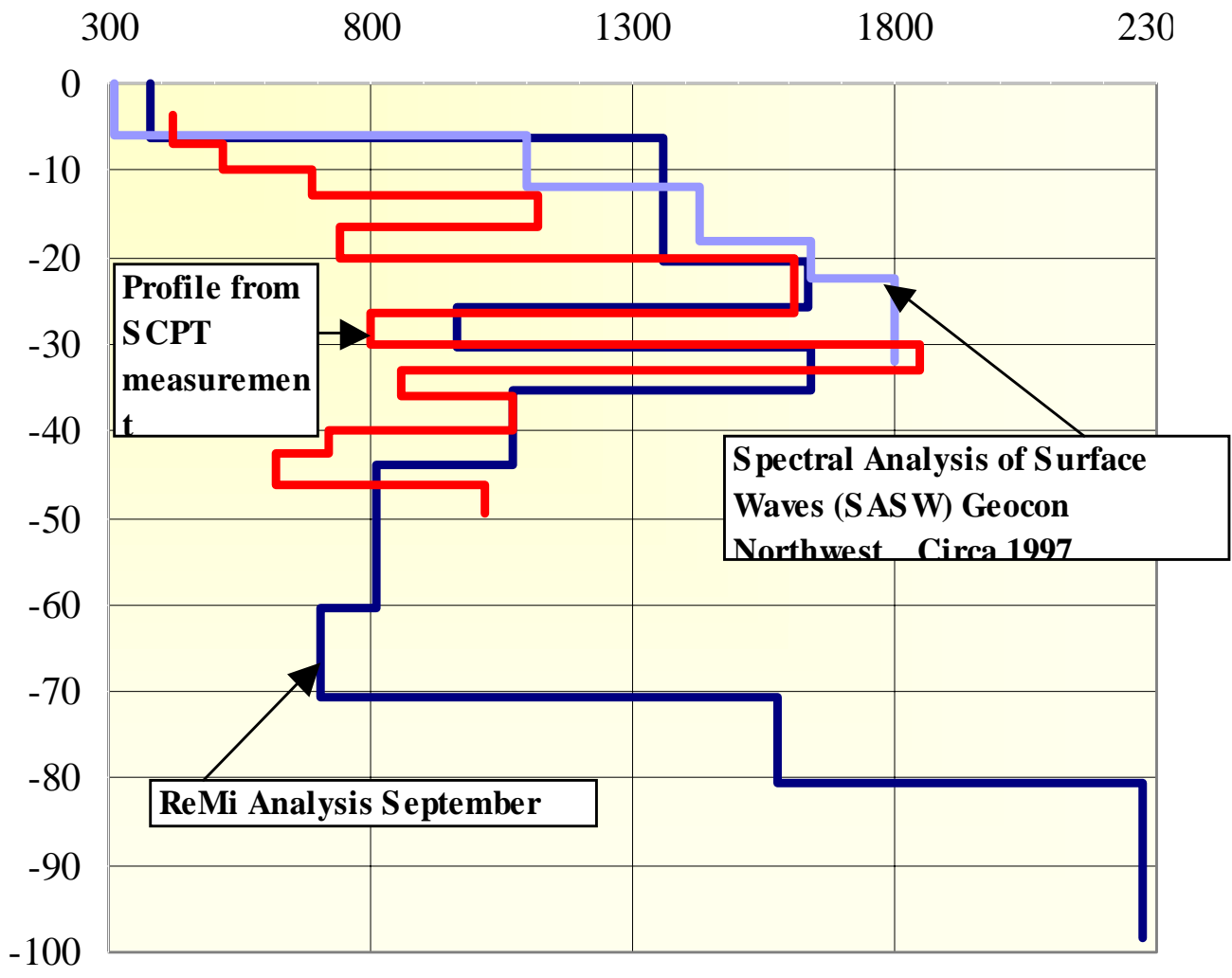


•Shear-wave profile from ReMi overlain on refraction velocity model from SeisOpt @2D

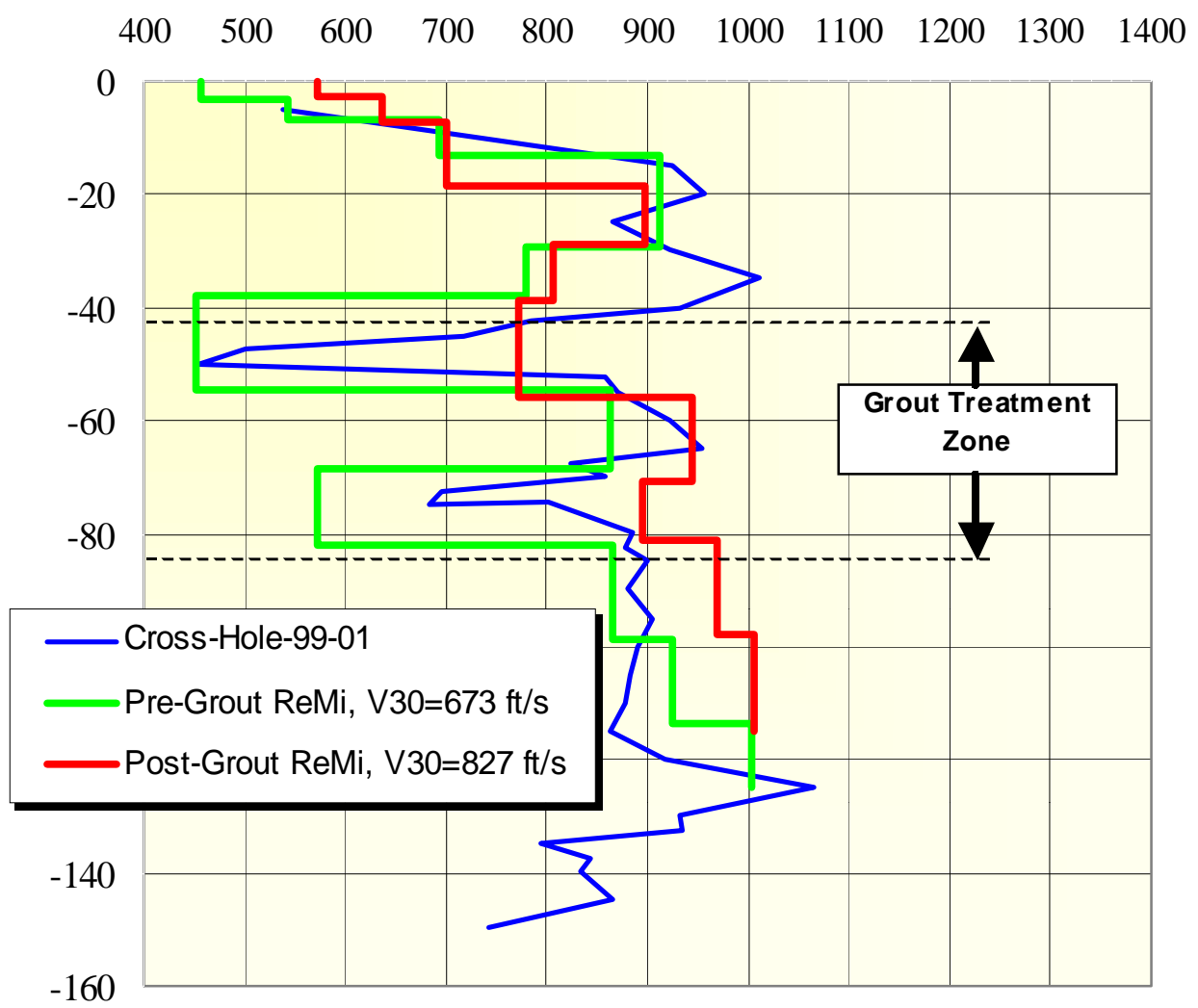
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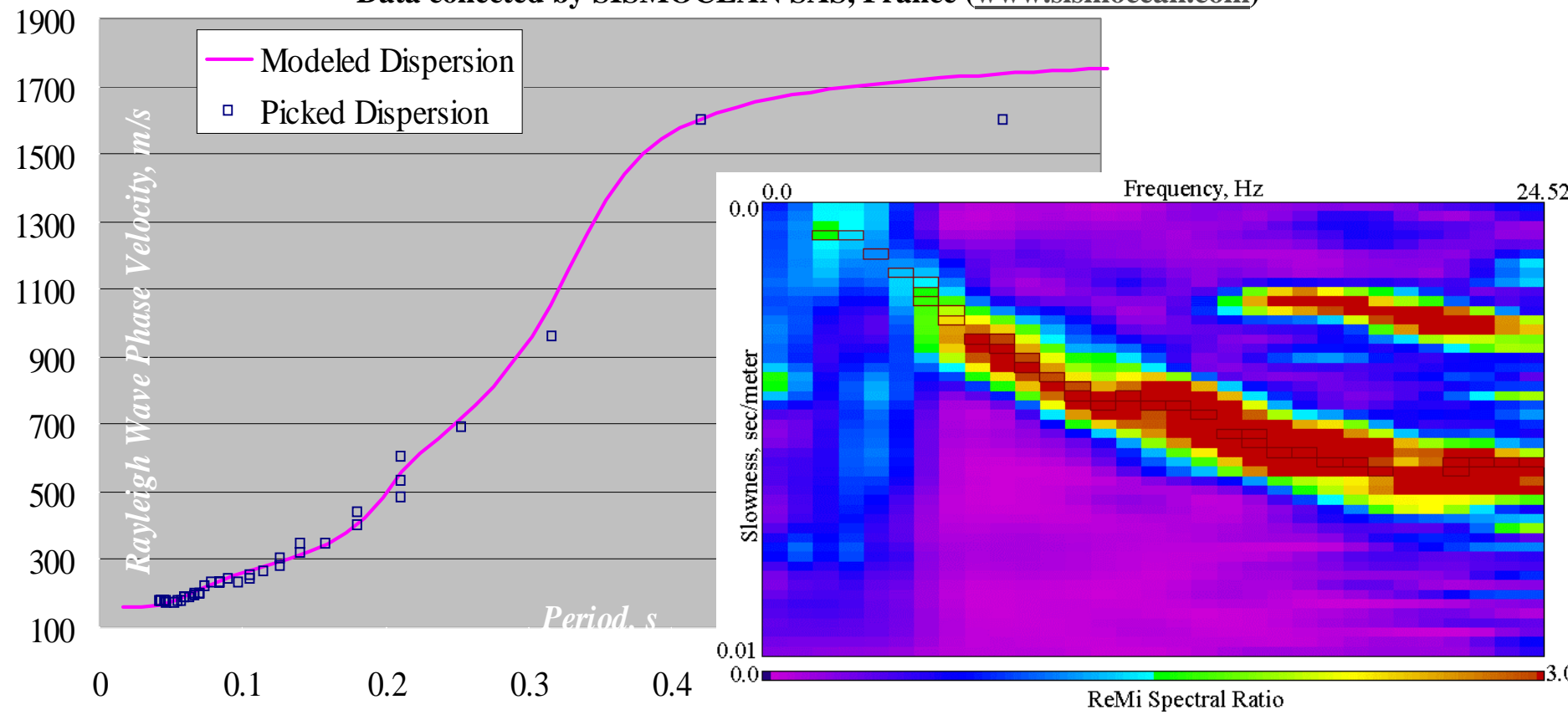
Case Study: Wickiup Dam, Deschutes National Forest, Oregon



Case Study: Loire Estuary, western France

Purpose: Soil classification for harbor extension

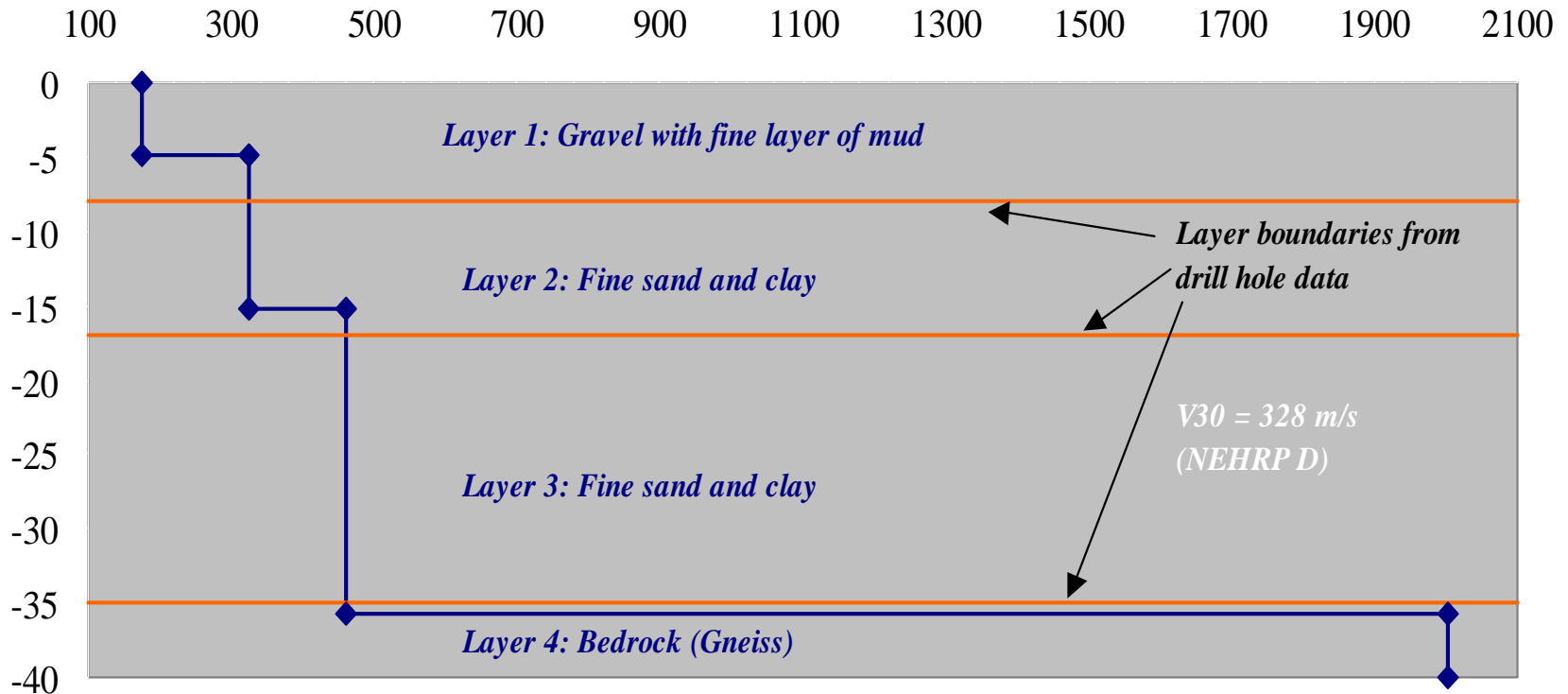
Data collected by SISMOCEAN SAS, France (www.sismocean.com)



•24, standard hydrophones, 5m spacing deployed along a linear array

•Source: 40 cu/in air gun. Hydrophone spread and air gun towed along seabed at 2 knots

Case Study: Loire Estuary, western France



The resulting ReMi S-wave velocity profile revealed boundaries that correlated well with logged cores from drill holes, and also provided the same soil classification standard as the drill holes.

SeisOpt[®] ReMi[™] Market Applicability

- ReMi V_s profiles can be used for:
 - *Earthquake site response*
 - *Liquefaction analysis*
 - *Mapping the subsurface and estimating the strength of subsurface material*
 - *Complementing seismic refraction analysis in areas characterized by near-surface velocity reversals*
 - *Finding buried cultural features, such as dumps and fill material in submerged structures*
 - *Determining soil classification for offshore projects*

Conclusion: SeisOpt[®] ReMiTM

- **Compares well with previously used 1-D shear wave measurement techniques: Economic, accurate and reliable**
 - *Correlates with SCPT measurements*
 - *Detects velocity reversals*
 - *Matches average velocities obtained using OYO logger*
 - *Greater depth of investigation compared to borehole and surface methods*
 - *Trends similar to velocity measurements from cross-hole*
 - *Data acquisition and analysis takes about 3 to 4 hours*
- **Determine shear strength of subsurface material**
 - *Concrete, water saturation material, buried fill material, etc.*
- **Save money in performing seismic site characterization studies**
 - *Minimizes number of boreholes required*
 - *No permitting required*
 - *Can be carried out in urban settings*
 - *Uses ambient noise as seismic energy source*
 - *Uses standard seismic refraction recording equipment*
- **Offshore application**
 - *Determine seismic soil classification standards for offshore projects*