KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 2002-32

SURFACE WAVE IMAGING TO DETECT TUNNELS

by

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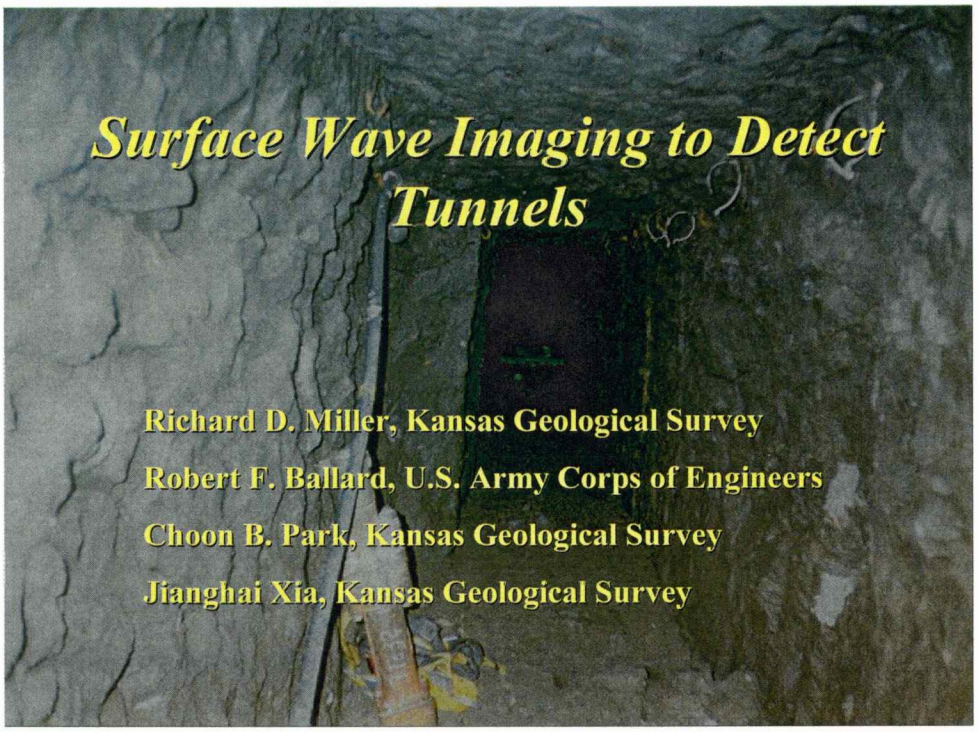
Presentation given by R.D. Miller to the
American Geophysical Union 2002 Spring Meeting
Washington, D.C.
May 28, 2002

KGS Open-file Report 2002-32



Unauthorized Entry

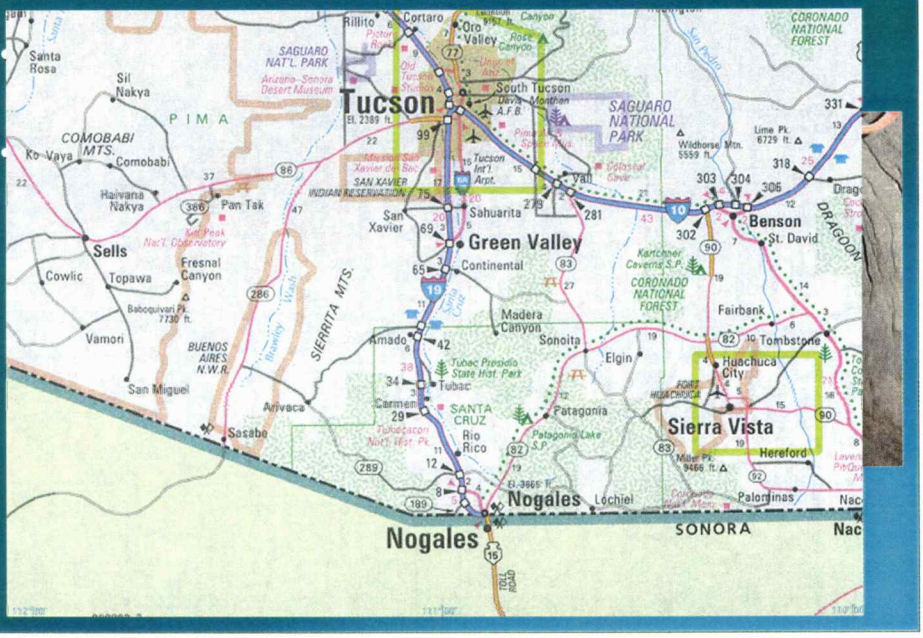
- Air
- Sea
  - Surface
  - Underwater
- Land
  - Over ground
  - **Underground**

Tunnels for Terrorism?

- Delivery system
- Staging, storage, housing
- Moving operatives across borders
  - Country
  - Facilities

Focus Areas: Southwest US-Mexico Border

Nogales, Arizona



Douglas, Arizona

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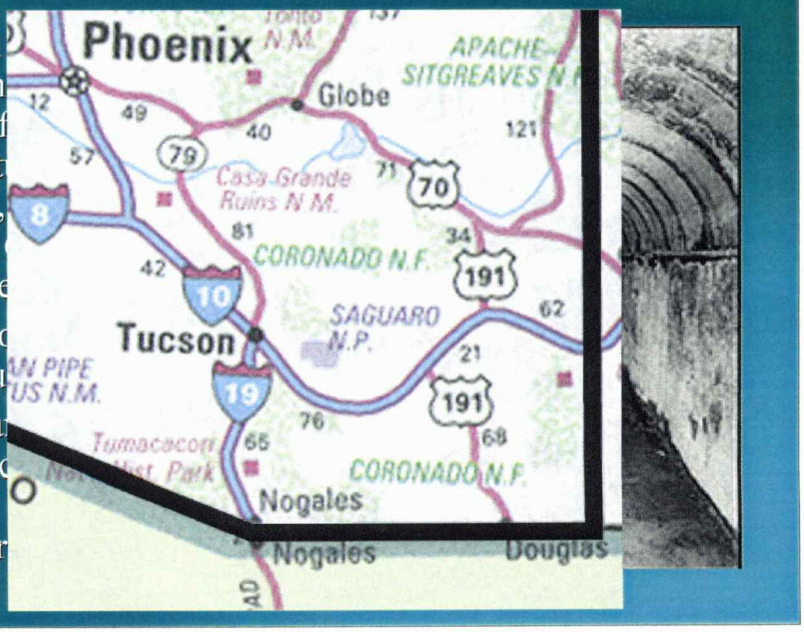
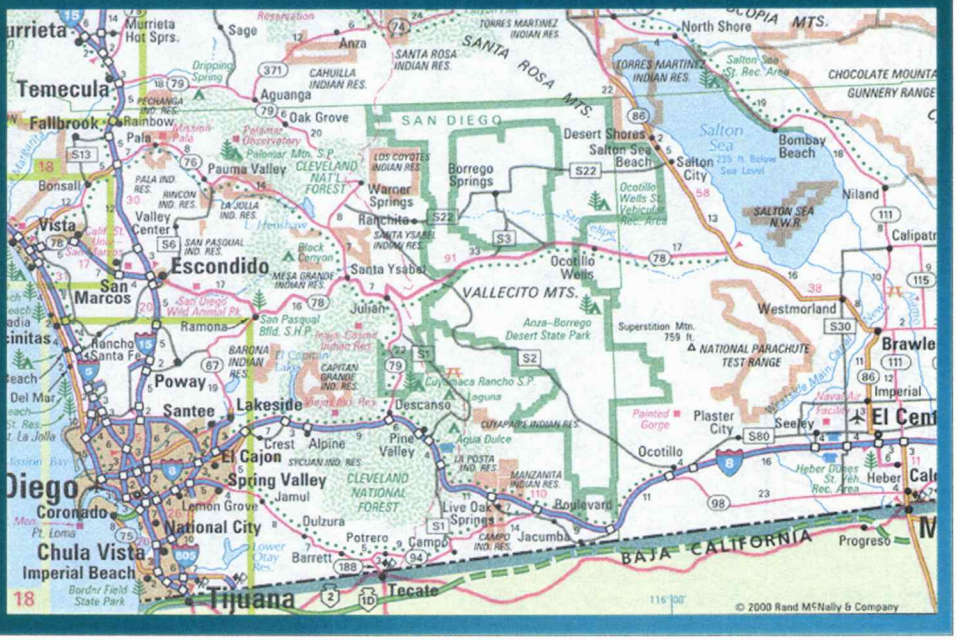
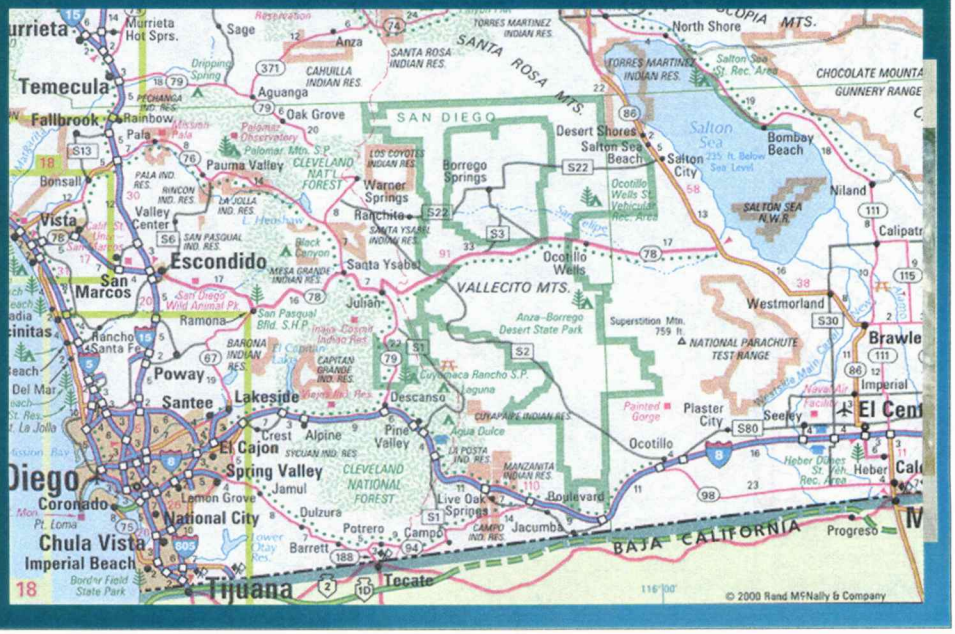


Tecate, California



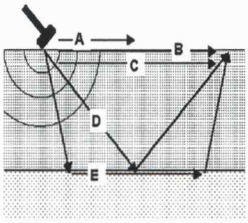
Otay Mesa, California



LAX Bombing Attempt

- December 1999, Ahmed Ressam apprehended with 130 lbs of explosive chemicals and four timing devices.
- Routine search after crossing from Canada into US on a ferry.
- Possible discharge methods: suitcase bomb, strap to fuel tanker, car bomb, etc.

Surface Waves: Travels in the Half-Space

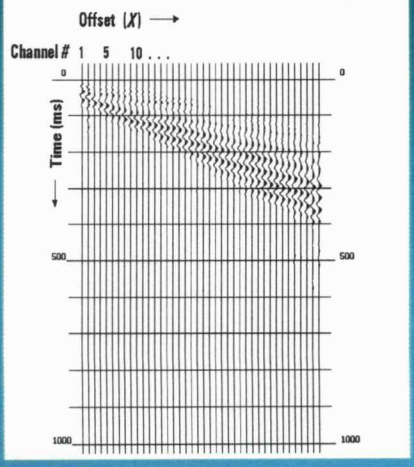


BODY WAVE

A: Air Wave
B: Direct Wave
D: Reflected Wave
E: Refracted Wave

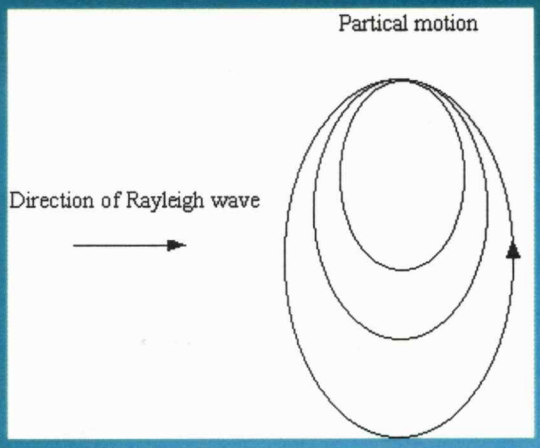
SURFACE WAVE

C: Ground Roll

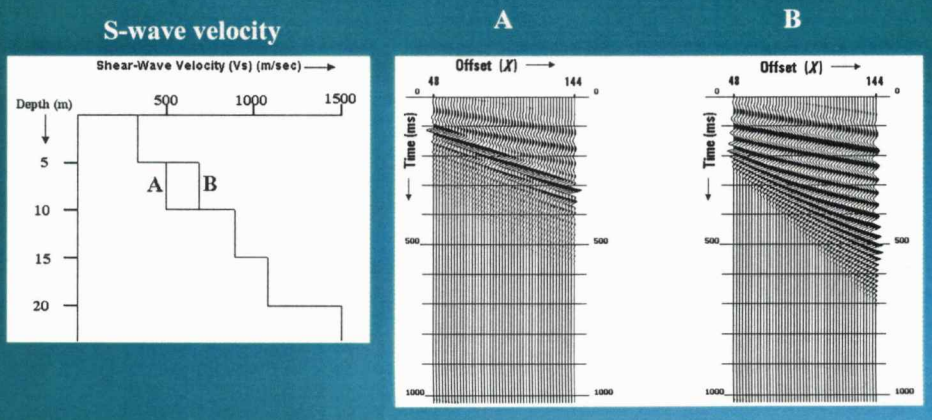


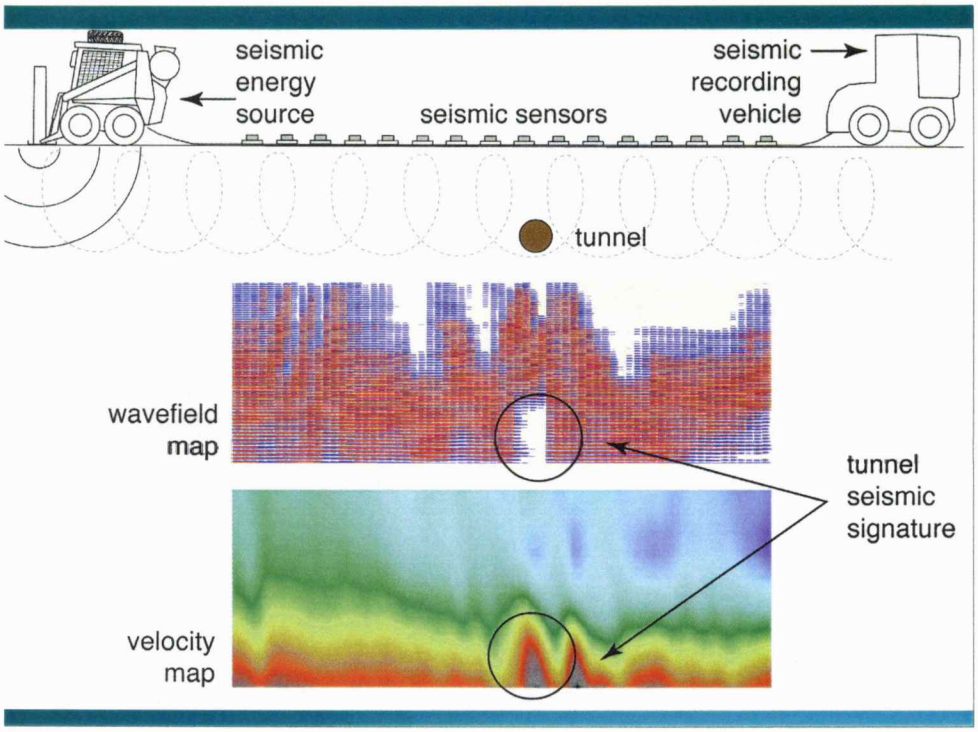
Rayleigh Wave Characteristics

- Penetration depth is about one wavelength, sampling depth about 1/2 wavelength.
- Longer wavelengths "see" deeper than shorter wavelengths
- Rayleigh wave velocity is generally about 0.92Vs for a homogeneous half-space.
- Retrograde elliptical



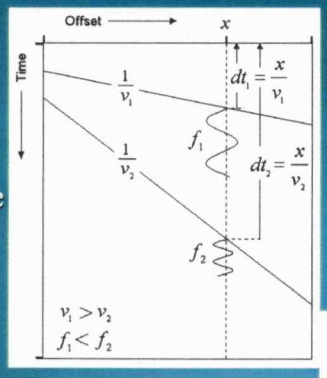
Model Response for 200 m/sec Change in Interval Velocity

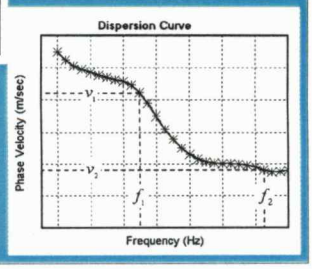




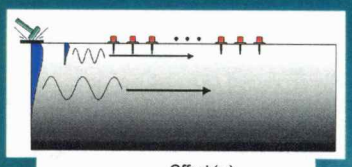
Frequency-Variant Linear Move Out (FV-LMO) Correction

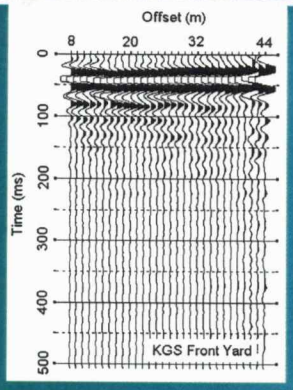
- Offset (x) compensation – frequency (f) dependent (due to dispersion)
- Compensation by phase shift – phase velocity from dispersion curve
- All forward propagation compressed to be flat, whereas all backward scattering remains fanned and sloped backward.



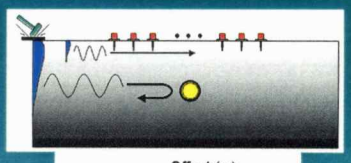


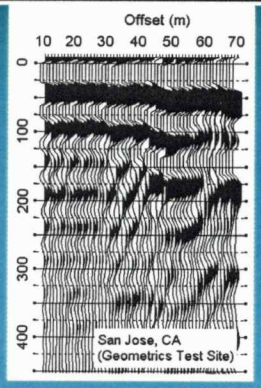
No Void





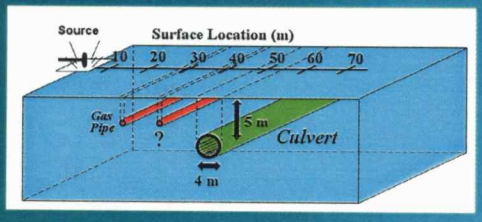
Void



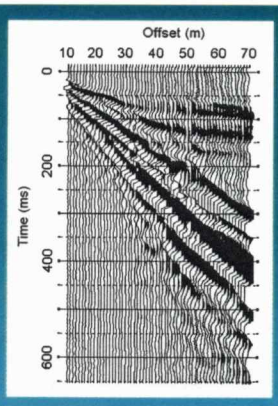


*** Shot gathers after Frequency-Variant Linear Move Out (FV-LMO) correction applied**

Detecting Voids (Storm Culvert) San Jose, CA

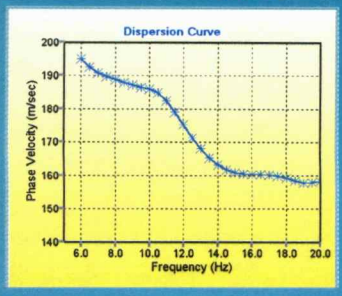


- Hammer, 4.5 Hz geophones, 0.6 m station interval

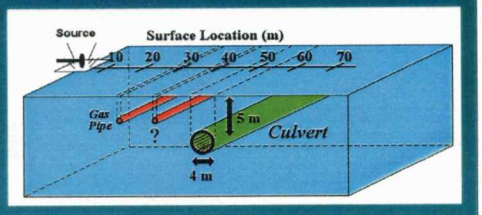


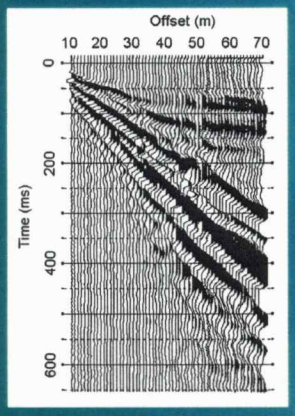
60 channel shot gather

Dispersion Curve

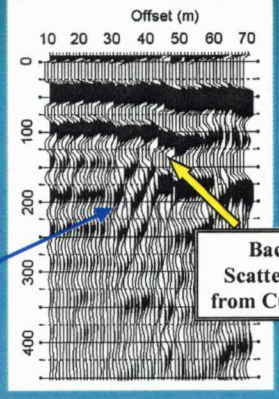


Frequency-Variant Linear Move Out (FV-LMO) Correction





FV-LMO Correction



Frequency = 15 Hz
Phase Velocity = 160 m/sec
Wavelength= 11 m
Approx. Depth = 5.5 m

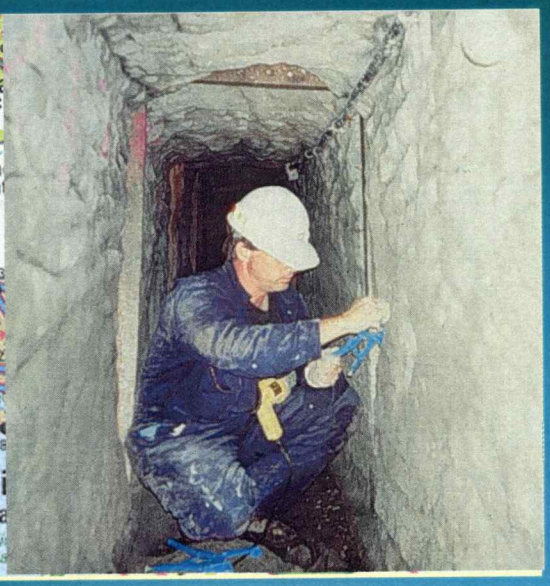
Back Scattering from Culvert

Searching for the Known Tunnel Beneath US-Mexico Border at Otay Mesa, California

- FV-LMO Correction Method
- Vs Inversion Method
- Common-Offset Gather

Otay Mesa Tunnel Site

- > 1200 ft long
  - Cement lined < 40 ft deep
  - Lighting, ventilation, and cart
  - 35 ft deep to max of 65 ft deep
  - 3 ½' x 3 ½'
- Discovered: northern end of the tunnel drilled when it was 100' short of warehouse



Tunnel Orientation and Site

- Warehouse was target destination
- Cement cap on drill hole that intersected the tunnel <150 ft short of immergence location
- Two profiles: one to establish background & one across tunnel

Acquisition Geometry & Equipment

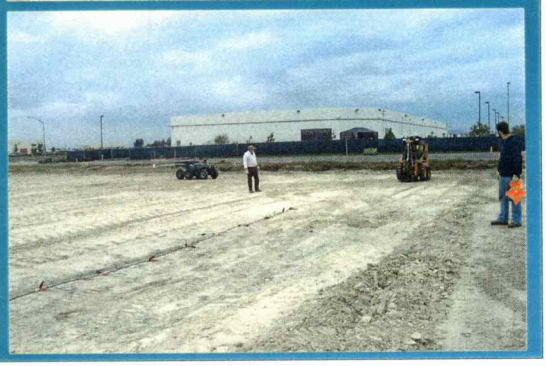
- Seismograph
  - 60 channel Geometrics Strataview (240 used for dual testing)
  - 12V power for all systems
  - Impulse or vibroseis
  - 24 bit A/D

Acquisition Geometry & Equipment

- Source
  - Accelerated weight drop
  - Broadband, but low frequencies critical for depth of penetration
  - Repatability

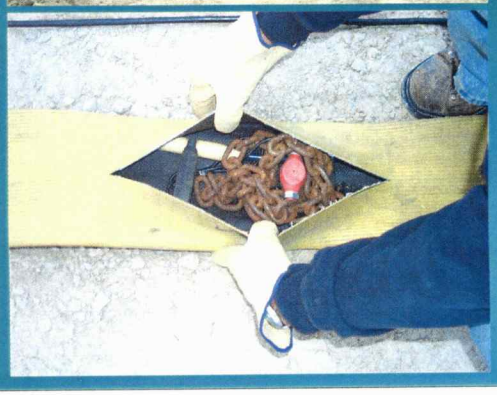
Acquisition Geometry & Equipment

- Spread geometry
  - 1.22 m receiver spacing
  - Comparison of conventional and streamer
  - 2.5 m to 120 m offsets used
  - Source 2.5 m offset

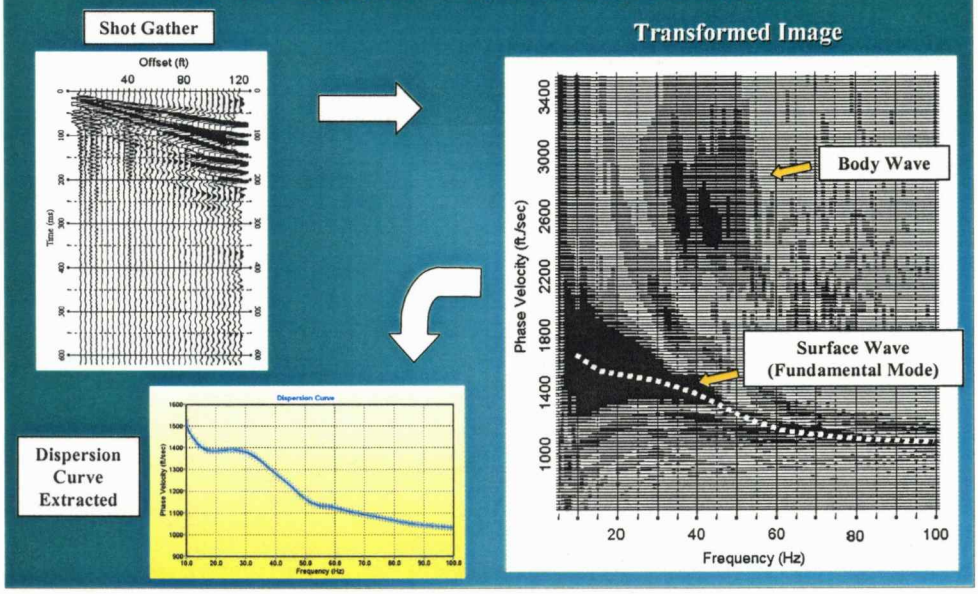


Acquisition Geometry & Equipment

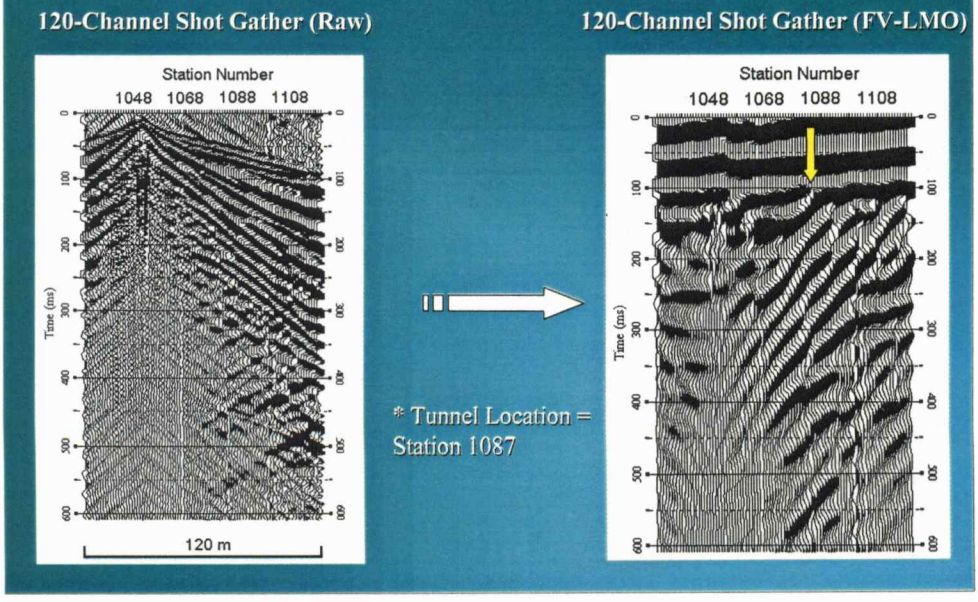
- Receivers
  - Single Geospace GS-11, 4.5 Hz
  - Land streamer: steel skid, geophone screwed to skid plate, chain used to weight the skid, source drags streamer
  - Seismograph connects opposite to source
  - Conventional spike plants



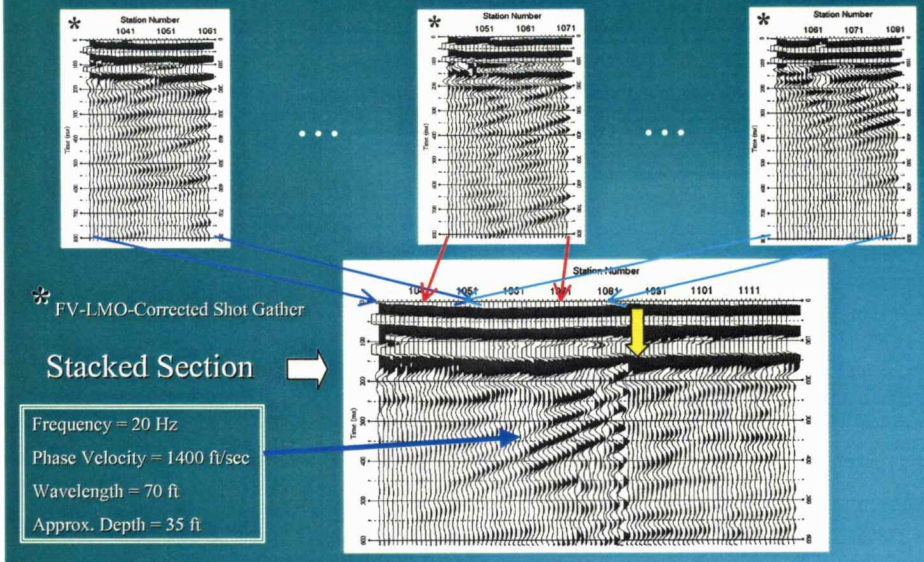
Imaging Dispersion Curve by Wavefield Transformation



FV-LMO Correction



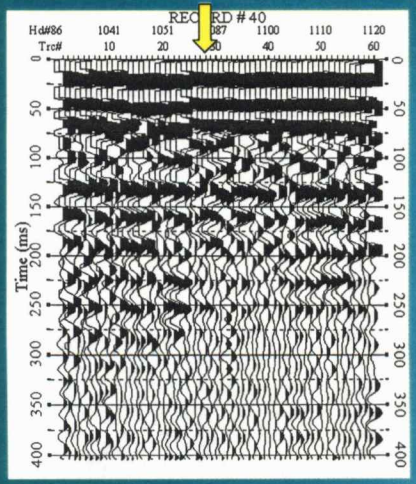
Stack FV-LMO-Corrected Shot Gathers



Common-Offset Display

- Hyperbola (Diffraction)? Or Two-Linear Slopes (Back Scattering)?

#40



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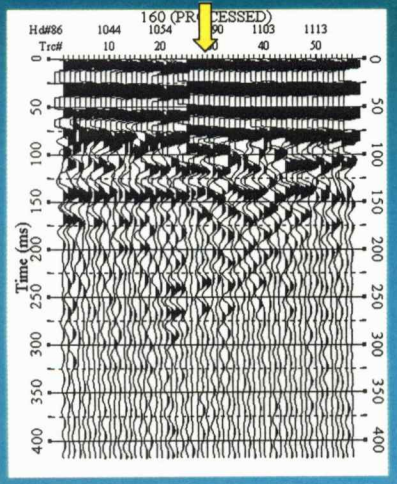
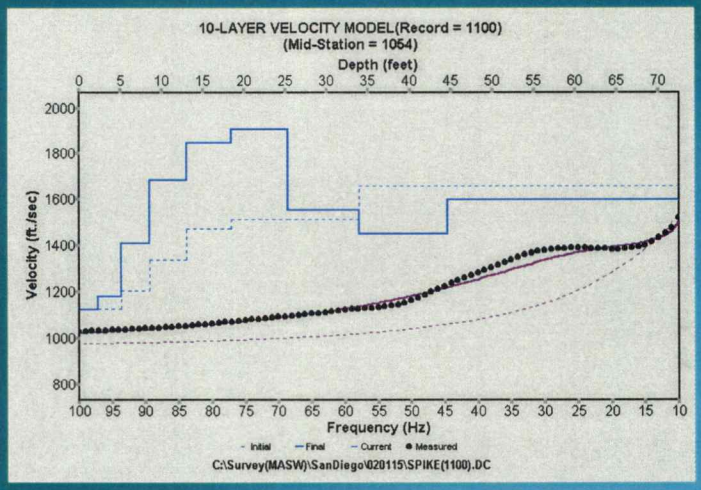
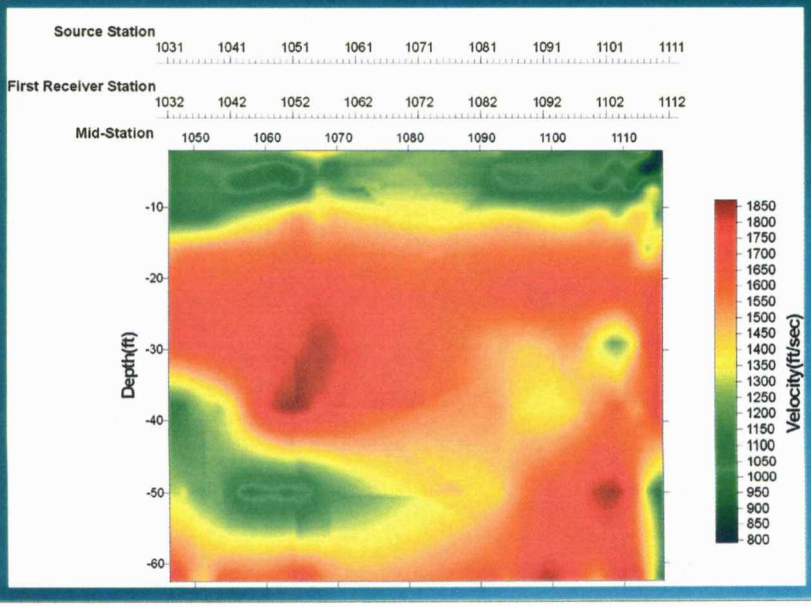


S-Velocity (Vs) Inversion

(Example of a 1-D Profile)



2-D Vs Mapping



Conclusions/Findings

- Abrupt changes in material characteristics such as those resulting from tunnels disturbs surface wave propagation in a predictable and detectable fashion.
- Surface wave data can be acquired rapidly, processed without highly technical staff, and interpreted based on either changes with time or uniquely as anomalous near-surface material.