Near-Surface Seismic Refraction Surveying Field Methods

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The seismic refraction method

- First major geophysical method applied to subsurface investigation of relatively deep oil-bearing geologic structures
- No longer the primary method in oil exploration, but has found use for near-surface, high-resolution subsurface investigation
- Common applications for civil engineering and environmental studies include depth-to-bedrock and groundwater investigations; also used for shallow fault and stratigraphic studies
- Main objective is to measure the time of the “first break”, that is, the time when a given geophone first moves in response to a seismic energy source. Simply stated, since time and relative distances of sources and geophones are known, the velocity of the subsurface can be calculated

Typical equipment

- Seismograph
  - 12 to 24 channels
- Sensors and spread cable
  - 8, 10, or 14 Hz vertical geophones
  - 2 to 5-m (5 to 20-ft) spread cable takeout interval
- Source
  - 10 to 20-pound sledgehammer with hammer switch, trigger cable, and striker plate

Geometrics seismographs

Laptop controller for
ES-3000 or Geode

ES-3000

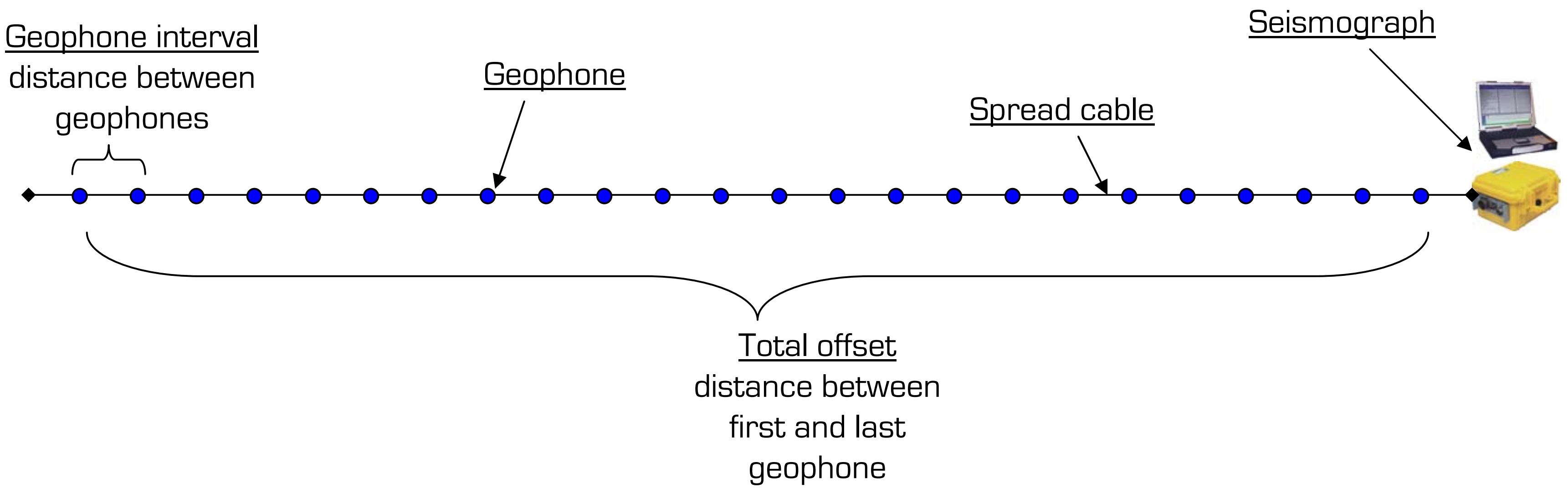
Geode

StrataVisor NZ
(PC built-in)

SmartSeis ST
(PC built-in)

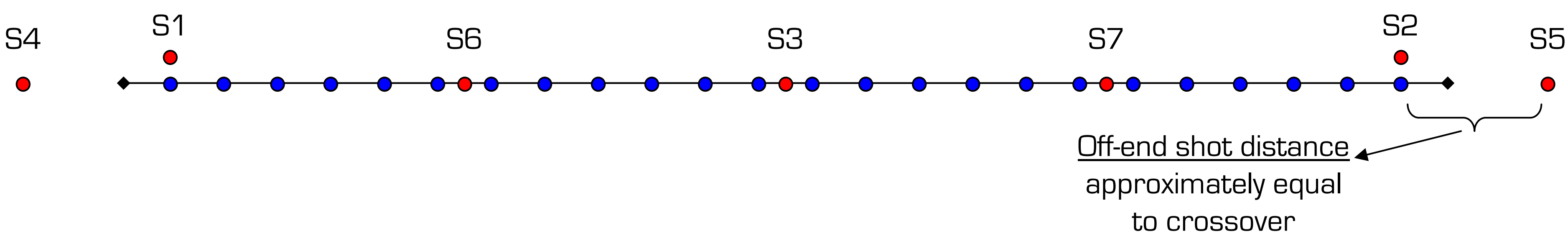
Survey geometry – sensors

- Geophones are distributed in a line, signals are transmitted to the seismograph by a spread cable.
- The total offset should be 3 to 5 times the depth of interest. However, this should be balanced against the number of channels available and the required horizontal resolution. If too few channels are used to span a large total offset, the horizontal resolution will suffer.



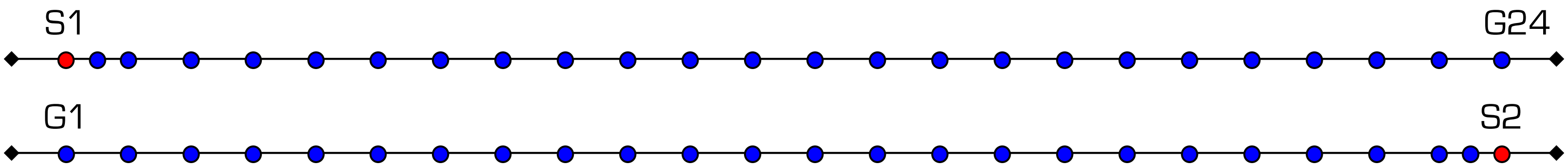
Survey geometry – sources

- At a minimum, there should be two shots (S1, S2) located at either end of the line. Common practice is to position the shots offset from the line at a right angle by about one-half the geophone interval. The goal is to position the shot so it is not too close to a geophone, but also not off-end. For true comparison of reciprocal times for delay times analysis, end shots should not be positioned off-end.
- It is best practice to also have one center shot (S3)
- Once the crossover distance(s) is identified, that distance should be measured off the ends of the line and shots located (S4, S5). Off-end shots allow you to use all the geophones to sample the refractor.
- Depending on the survey objective, quarter shots (S6, S7) in the interior of the spread and more distant off-end shots may be desired.

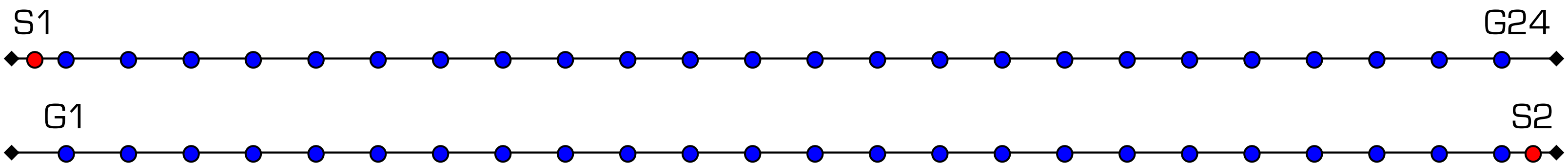


Survey geometry – sources (cont.)

- Instead of a perpendicular offset for the end shots, the end geophone can be moved inward by one-half an interval and the shot positioned on the end.



- For S1, the geophone on the right end has normal spacing, and for S2, the geophone on the left end has been returned to the normal spacing.
- This method allows the most accurate analysis of reciprocal times because the shots are exactly located on the ends of the line. In theory, the time it takes for energy to travel from S1 to G24 and from S2 to G1 should be identical.
- If end shots were located off-end (below), the travel paths would be different.



Survey geometry – coordinates

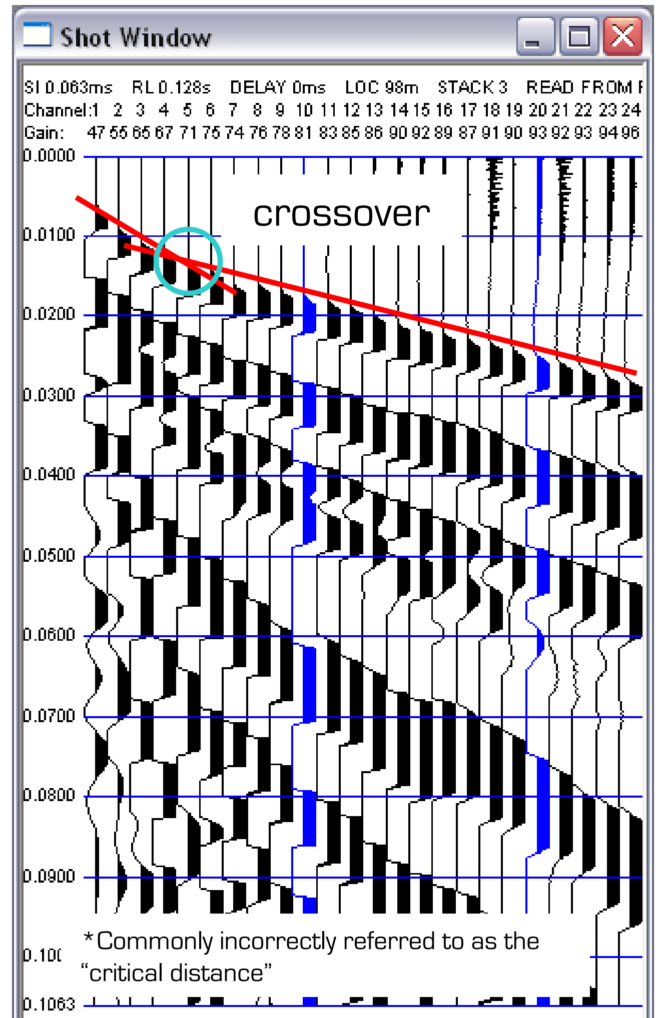
- At a minimum, relative x, y spacing is required
  - Easiest to save to the file header at time of acquisition, but can also be assigned in data analysis software
  - Set y equal to zero, and vary x values only (or vice versa)
  - Some deviation from a line can be tolerated, minimize deviation to 5% or less of the line length
- If there is any vertical relief on the line, the elevations should be surveyed
  - Elevations only need be relative, unless referenced elevations are desired
  - Z values are not saved in file header, but are easily input into data analysis software

Typical recording parameters

- Sample interval: 0.125 to 0.25 ms (over-sampling is fine)
- Record length: 0.25 to 0.5 s (should be long enough to capture distant arrivals)
- Stacking: as needed to increase signal to noise ratio, 5 to 10 times
- Delay: -10 ms allows the first break on the near geophones to be more easily viewed
- Acquisition filters: acquisition filters are NOT recommended because effect is irreversible; should be carefully applied to filter signal you are certain you will never want such as 60 Hz power line noise
- Preamp gains: highest setting
- Display gains: fixed gain (same gain over time for a given trace, but variable from trace to trace; traces far from the source will need a higher gain setting than those that are near)

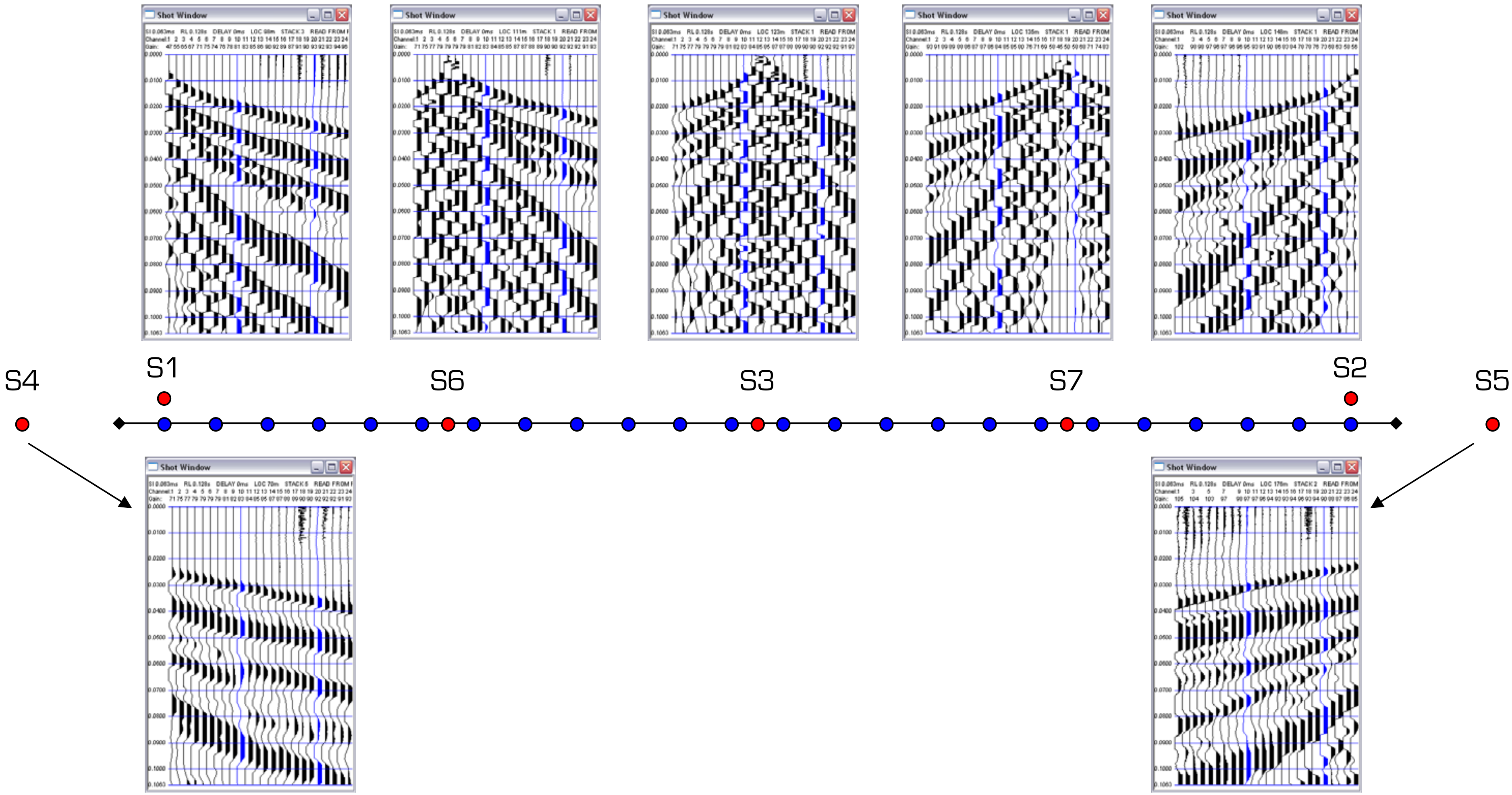
Analysis of the first end shot

- Analyze waveform file of the first end shot
  - What is the data quality? There is little pre-first break noise, the first breaks are obvious. Quality is excellent.
  - How many refractions are there? One break in slope indicates one refraction (two-layers).
  - What is the crossover distance*? Break in slope is 5 traces in. Five multiplied by a geophone interval of 2m equals 10m.



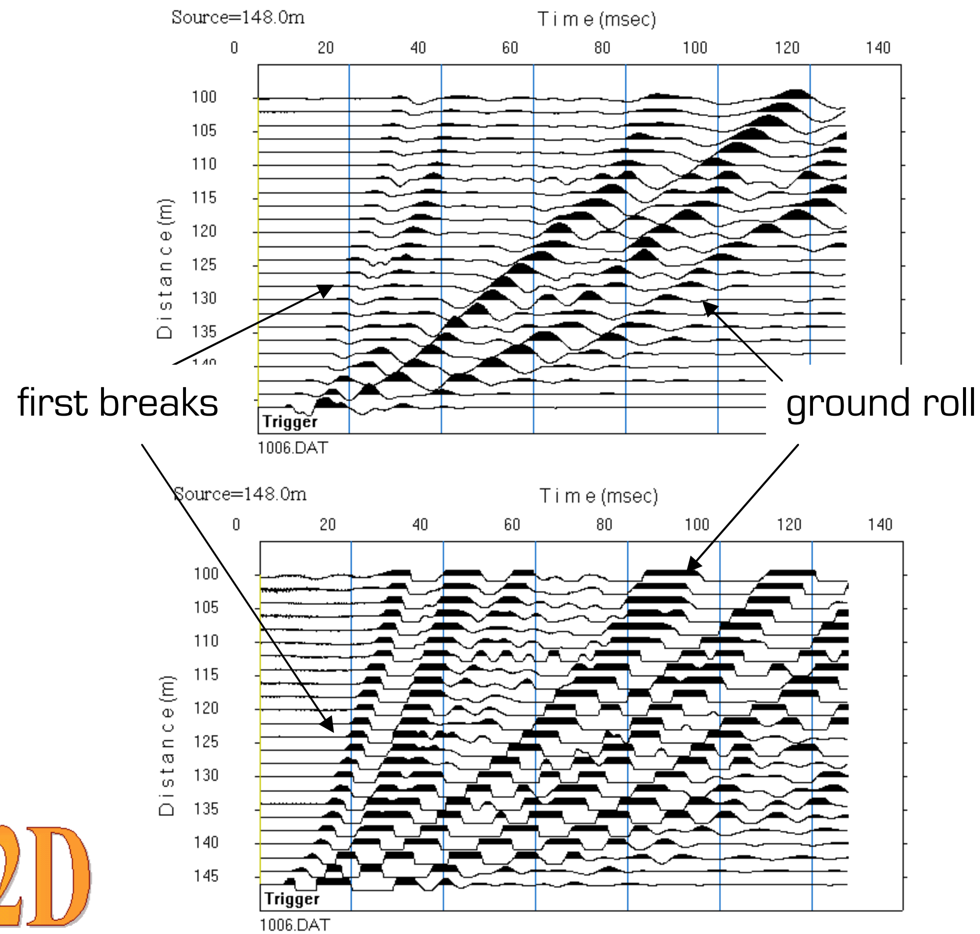
*Commonly incorrectly referred to as the "critical distance"

Complete dataset



Picking first breaks

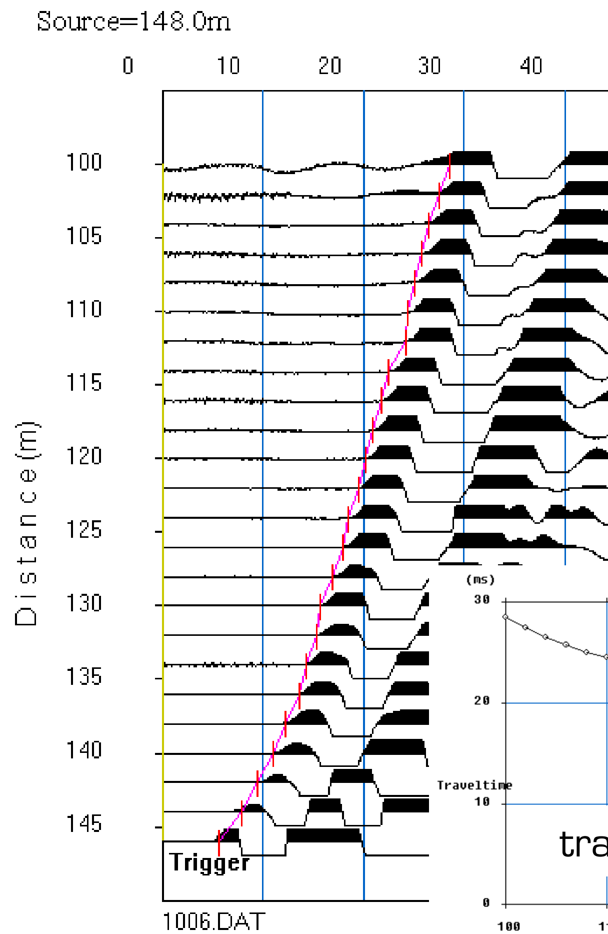
- Set the display gains so the first breaks are clearly visible
  - Ground roll has a relatively large amplitude and can be misidentified as the first arrival if the display gains are not high enough
  - Use display clipping so the traces do not overlap when the gain is set very high



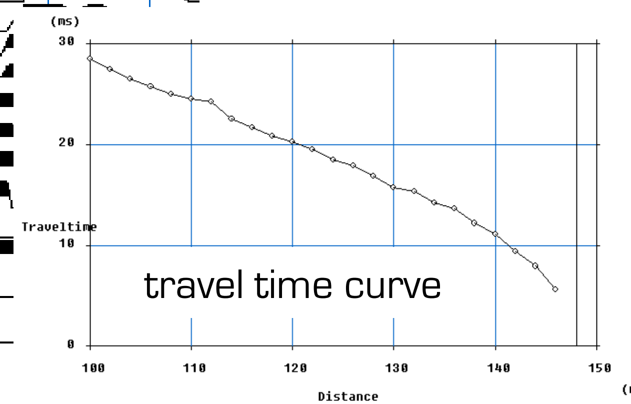
SeisImager/2D

Picking first breaks (cont.)

- Consistently pick the same event from trace to trace and from shot record to shot record
  - Adjust gains as needed during picking to optimize display
- Output data consists of a travel time (T) for each geophone location (X), data used to plot travel time curve

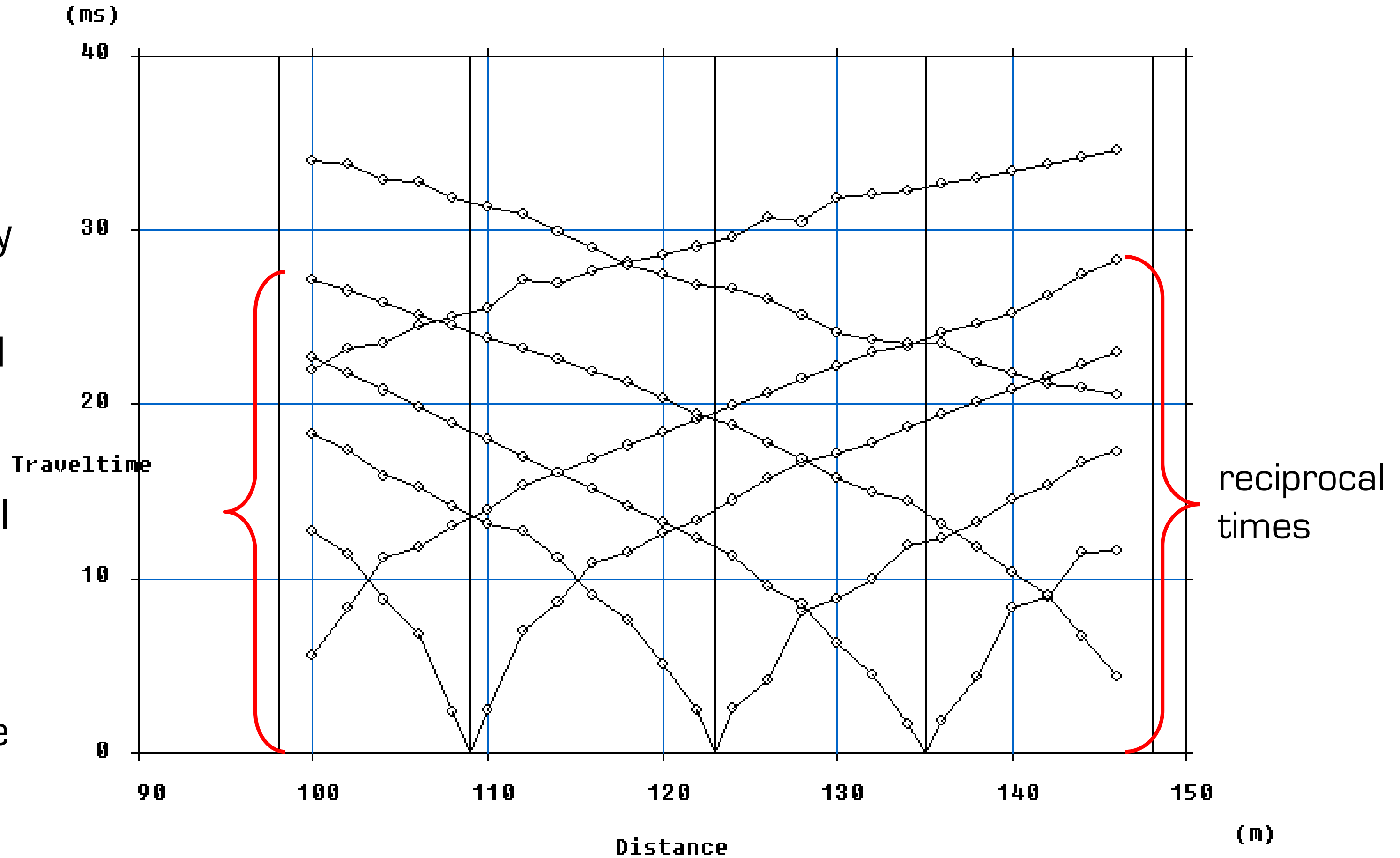


X (m)	T (ms)
100.000000	28.510254
102.000000	27.456757
104.000000	26.500004
106.000000	25.750004
108.000000	25.020546
110.000000	24.493797
112.000000	24.250004
114.000000	22.562502
116.000000	21.687502
118.000000	20.812502
120.000000	20.250002
122.000000	19.489689
124.000000	18.436192
126.000000	17.909443
128.000000	16.855947
130.000000	15.687502
132.000000	15.375002
134.000000	14.250002
136.000000	13.625002
138.000000	12.181055
140.000000	11.127559
142.000000	9.437501
144.000000	7.937239
146.000000	5.596701



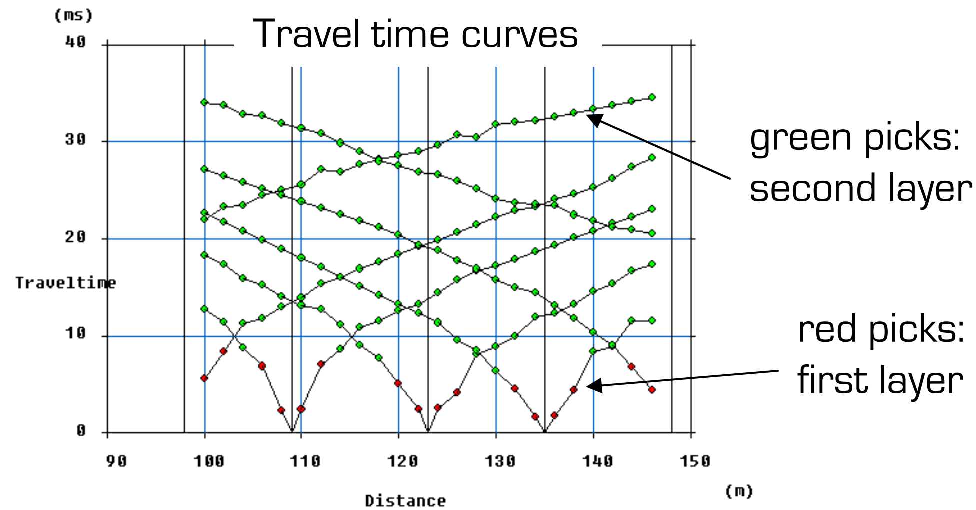
Complete set of picks

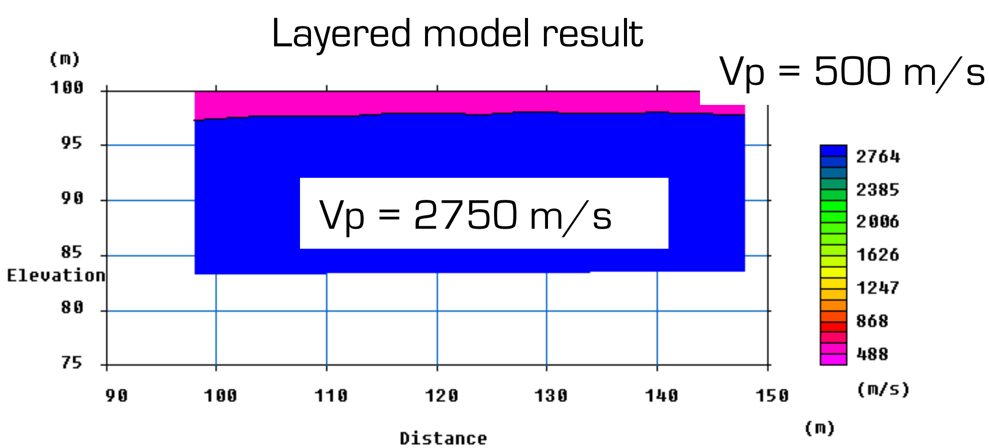
- Reciprocal times are about equal (good quality check)
- The forward and reverse shots are symmetrical about the center indicating there is little or no dip on refractor



Complete analysis process

- Pick first breaks
- Select analysis method
  - Time-term inversion gives a quick solution for 2 to 3-layer cases with evident breaks in slope
- Assign layers
- Input elevations (if applicable)
- Run inversion
- Compare calculated to observed data
- Final layered model result





Additional topics

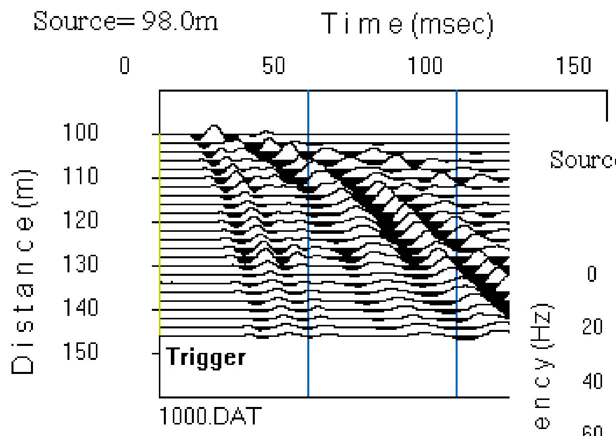
- Multiple spreads for long survey lines
  - Set up available channels/geophones at desired interval for the first spread
  - Locate and take shot points as if entire line is instrumented with geophones
  - Move geophones to next spread
  - Reoccupy the same shot points
  - Repeat process until entire line has been covered by spreads
  - Append together shot records from each spread by common shot point in SeisImager/2D refraction data analysis software
- Use of horizontal geophones for shear-wave refraction surveys
  - Records of polarized shear waves can be displayed together in SeisImager/2D to allow picking of the first break

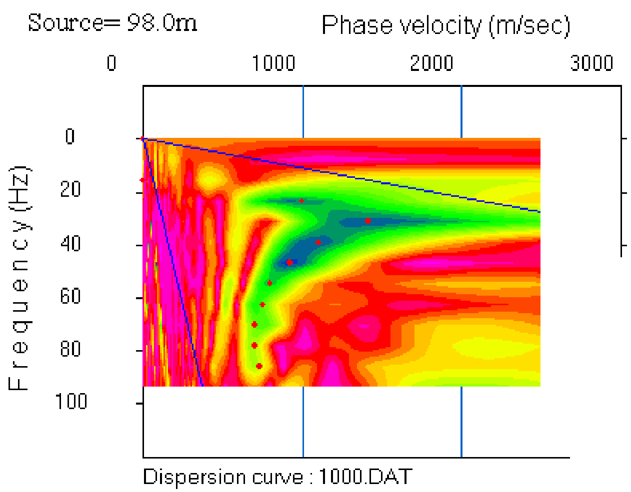
Additional topics (cont.)

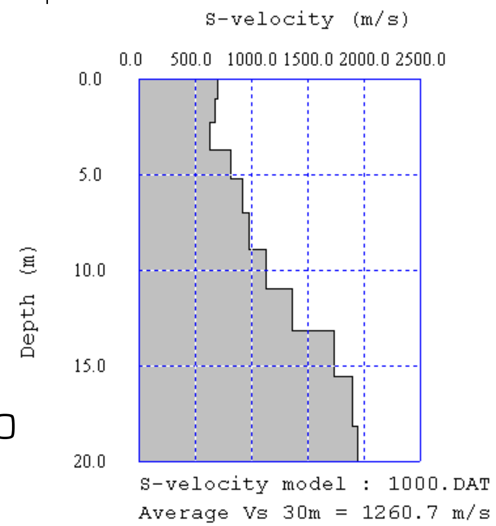
- Other methods offered by SeisImager/2D, require high data redundancy
  - Reciprocal method for detailed analysis of travel time curves, calculate delay times manually (vs. Time-term inversion where delay times are calculated automatically)
  - Tomographic method for gradational velocity increases with depth, strong horizontal velocity variation, and extreme topography
- SeisImager/SW-1D available for surface wave data analysis for IBC Vs100/Vs30 site classification
  - Calculates dispersion curve from surface waves and outputs 1D curve of shear wave velocity with depth
  - For both active and passive (microtremor) sources
- SeisImager/SW-2D available for surface wave data analysis for 2D cross-sectional imaging of Vs

Surface wave data analysis

SeisImager/SW







<u>Surface wave analysis of refraction shot record S2</u>

Use of 4.5 Hz geophones and a longer record length of 1 to 2 s would have provided more surface wave data, but still some information can be gleaned from this refraction record. Not surprisingly, the calculated Vs30 is about one-half of the second layer Vp determined through refraction.

References and recommended reading

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