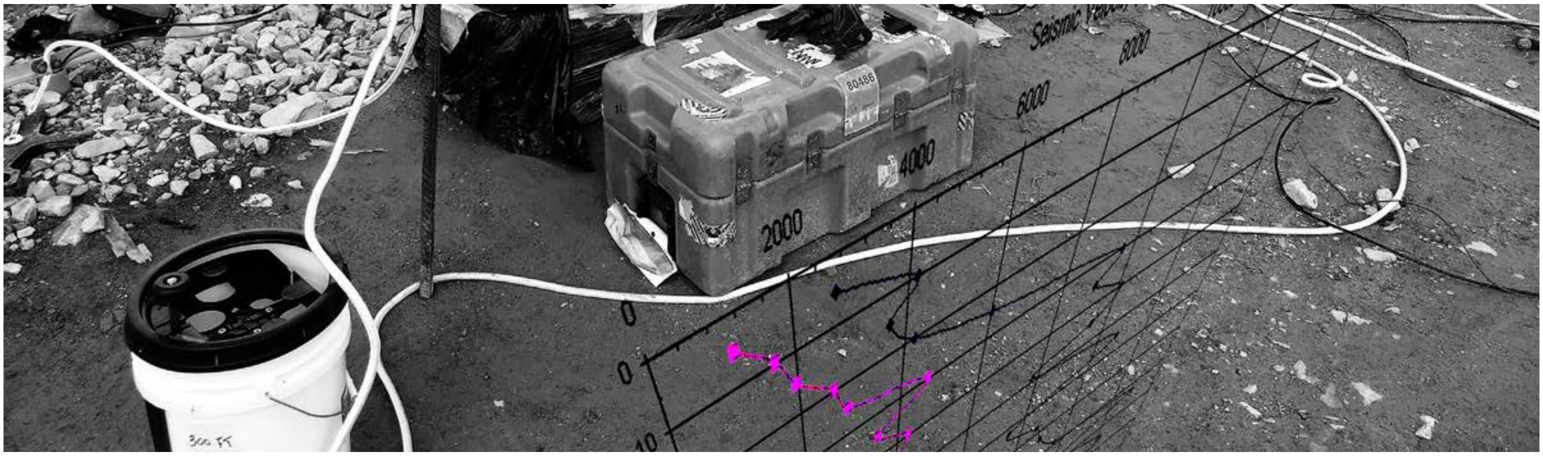
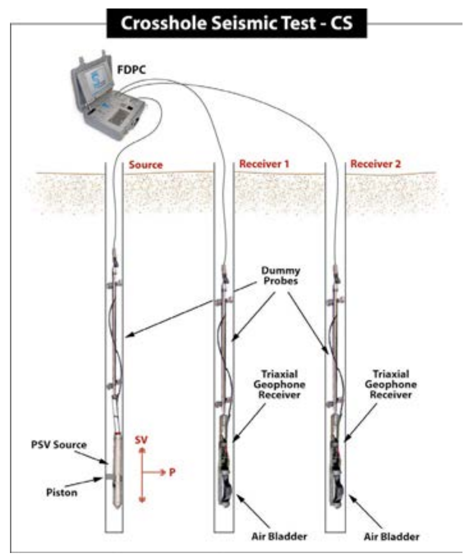
Olson ENGINEERING

CROSSHOLE & DOWNHOLE SEISMIC (CS/DS)

METHOD BRIEF

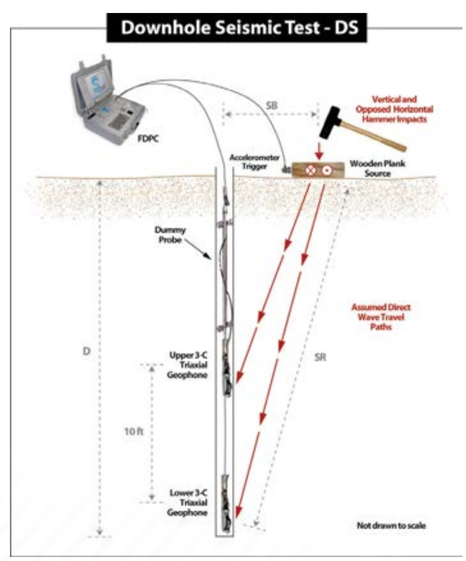


APPLICATION



Crosshole Seismic (CS) investigations are performed to provide information on dynamic soil and rock properties. This information is used for earthquake design analyses for structures, liquefaction potential studies, site development, and dynamic machine foundation design. The investigation determines shear and compressional wave depth versus velocity profiles. Other parameters, such as Poisson's ratios and moduli, can be easily determined from the measured shear and compressional wave velocities. In addition, material damping can be determined from CS tests. The CS method is a downhole method, used for the determination of soil and rock material properties. A source capable of generating shear and compressional waves is lowered into a borehole, and matching three component geophone receiver(s) are lowered to the same depth in one or two additional boreholes set at evenly spaced increments (typically 10 and 20 feet from the source borehole) in a line (see on right). The receivers are secured against the side of the borehole casing in order to allow detection of shear and compressional waves generated by the source.

Downhole Seismic (DS) investigations are similar to the CS method, but require only one borehole to provide shear and compressional velocity wave profiles. The DS method uses a plank source at the surface to generate shear and compressional waves. A pair of matching three component geophone receivers are lowered downhole spaced 5 to 10 feet apart to sense the P- and S-wave energy.



STANDARDS

The CS/DS method is performed in accordance with ASTM D4428-D4428M Standard Test Methods for Crosshole Seismic Testing. The CS method is an acceptable investigation method for obtaining soil classification ratings as required by IBC/UBC.

** See end of document for full references.*

FIELD INVESTIGATION

ACCESS

The CS method requires drilling two or three boreholes. The boreholes are typically 3-4 inches in diameter cased with 2.5-3 inch I.D. PVC pipe or 2.32 inch I.D. slope inclinometer casing, and grouted in accordance with ASTM Standards to ensure good transmission of the wave energy. The testing is simplified if inclinometer casing is used instead of normal PVC pipe. Typical distances between adjacent boreholes are on the order of 10 feet. A field setup for CS measurements is shown on the previous page. The receiver boreholes are drilled to the total investigation depth. For tests using the split spoon as a source, the source borehole is advanced during testing at intervals equal to the measurement intervals required (2-5 feet). If a source containing an impactor (that can be clamped to the borehole wall) is used, then the source borehole can be drilled to the total investigation depth prior to testing.

COLLECTION OF DATA

In a CS investigation, the source is lowered to the first desired test depth measurement depth and is incrementally advanced to the bottom of the borehole. One or two triaxial geophone receivers are incrementally lowered to the same depth in the other boreholes. Dummy inclinometer probes may be used to maintain correct receiver orientation throughout the investigation as shown in the schematic on the previous page; if PVC casing is used, orientation rods may be attached to the source and receiver. The source is triggered from the surface to generate shear and compressional wave energy at depth. In some instances where a split spoon is used as the source, an instrumented hammer strikes the rod to generate shear and compressional wave energy. The source borehole is incrementally advanced for the split spoon source. The vertical component of the receiver is used to capture the vertically polarized shear waves (SV). Both upward and downward polarized energy is generated for duplicity of data and to measure shear arrival effectively. The radial or tangential component senses the propagating compressional waves (P). An Olson Instruments Freedom Data PC with the CS/DS System is used to record the P-SV source input as well as the receiver outputs.


FDPC

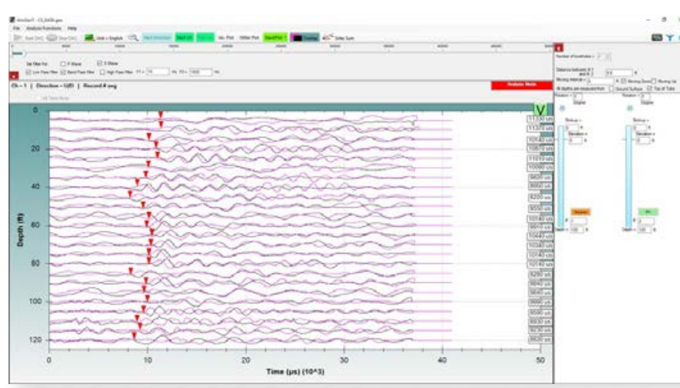
CS/DS System

In a DS investigation, the source is typically a hammer hitting a plank at the surface and requires only one borehole. The three component geophones are separated by 10 feet and lowered together downhole. The hammer source generates both shear and compressional wave energy, which are recorded by the geophones. The vertical component of the receiver is used to capture the vertically propagating compressional waves (P) and the radial transverse component senses the horizontally polarized shear wave (SH).

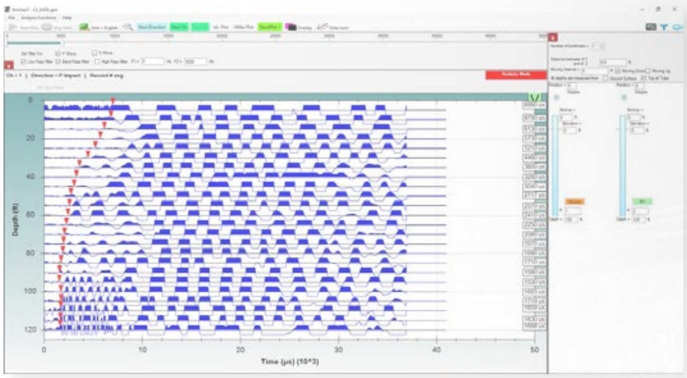
DATA REDUCTION

PROCESSING TECHNIQUES

Data processing is performed using Olson's software to pick arrival times of the source and separate receiver components. The figure below shows a screen shot of the upper 25 feet of a profile. The split in polarization, as indicated, allows shear wave arrival times to be picked. Pick times can then be exported into a standard spreadsheet to calculate velocities, moduli, and Poisson's ratios.

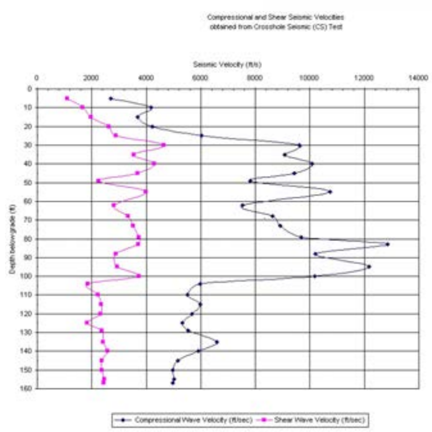


Screenshot of CS Data showing Overlap for Shear Wave Picking



Screenshot showing P-wave Picking (typical)

Once shear velocity is calculated, a graph can be generated to show the velocity profile. The chart below shows the sensitivity of the CS method in identifying layers of particular strata.



INTERPRETATION OF DATA

If one receiver borehole is used, the travel time from source to receiver is measured. This is referred to as direct travel time measurements. If two receiver boreholes are used, the travel time between the receivers can be measured. This is referred to as interval travel time measurements. The wave velocities at the test depth are calculated by dividing the travel distances by the measured travel time. The travel distances are determined after the verticality of the boreholes is evaluated (inclinometers are typically used). Note that interval travel times are normally more accurate than direct travel times, and thus the three-hole test configuration is preferred.

The Poisson's ratio, as well as shear and constrained moduli can be determined from the shear and compressional wave velocities using the following equations:

G = r VS2
M = r VP2
μ = [0.5 r (VP/VS)2 - 1] / [(VP/VS)2 - 1]

where G is the shear modulus, r is the mass density, VS is the shear wave velocity, M is the constrained modulus, VP is the compressional wave velocity, r is the mass density, and μ is Poisson's ratio.

EFFECTIVENESS

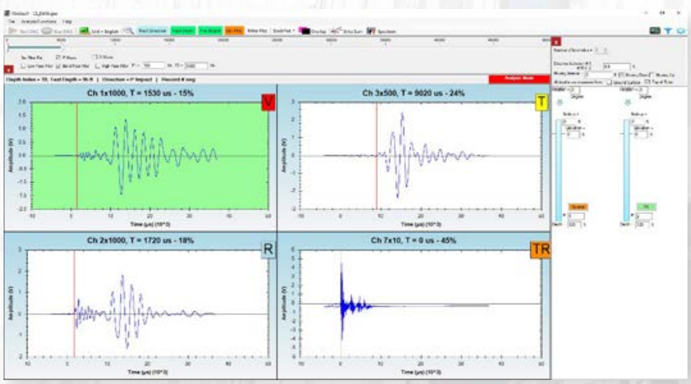
As compared to surface methods, the CS method is the most accurate method for determining material properties of rock and soil sites. Thin low-velocity layers lying between high-velocity layers can be detected with the method. Similarly, thin high velocity layers between low-velocity layers can be detected, which may not be possible with surface methods such as Spectral Analysis of Surface Waves (SASW) or Refraction Survey tests. Often, when boring logs indicate particular strata of rock and soil of interest, such as a shallow, high-velocity layer, the CS equipment can be set to that depth easily and the overall accuracy at a particular site can be improved. In addition, the accuracy and resolution of the CS method is constant for all test depths, whereas the accuracy and resolution of the surface methods decreases with depth. Olson Engineering has performed the CS and/or DS method in conjunction with SASW for comparison purposes and for repeatability of results. For CS investigations, two or preferably three boreholes are required to perform the test. In circumstances where two or three boreholes are not economical or where available space is limited, the DS method can be utilized with only one borehole. In rock site investigations, the boreholes may be uncased, but for most soil site investigations, the borehole should be cased (preferably with inclinometer casing) and grouted.

EXAMPLE RESULTS

CS METHOD – SOIL SITE TEST

To illustrate the concepts of the CS method, example results from CS tests on a soil site are presented below. The records shown are from CS measurements at a depth of 116 feet. The figure below shows a screenshot from an Olson Instruments

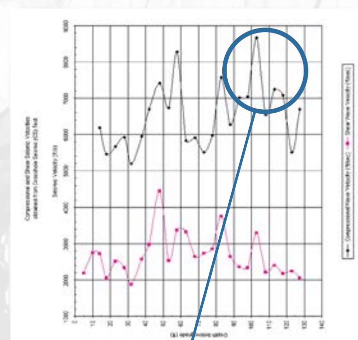
Freedom Data PC showing the aforementioned record. Channel 5 is the vertical component of the three-component geophone, which is measures the vertically polarized shear wave energy. Channels 6 and 7 are the radial and transverse components, respectively, and they measure the compressional wave energy. Typically, the radial component is aligned with the source and is thus used to measure the arrival of the compressional wave more accurately. Channel 8 is the trigger component from the P-SV source for timing.



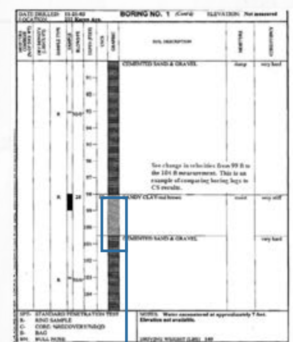
Screenshot from WINGEO-T showing typical waveform set

CS METHOD – SOIL SITE VELOCITY PROFILE

In determining a velocity profile, boring logs and calculated shear wave velocities are compared done to confirm subsurface conditions. The figures below show a CS velocity profile alongside a boring log from the same site. The example demonstrates the accuracy of the CS method in identifying a change in soil strata. The red circle on the plot shows the area where a velocity increase occurred; a similar change in soil strata is indicated at 100 ft., in the boring logs, as a change from sandy clays to cemented sands and gravels.



Velocity increase occurred



Change from sandy clays to cemented sands and gravel

REFERENCES

STANDARDS AND GOVERNMENTAL REPORTS

- ASTM D4428/D4428M-14, "Standard Test Methods for Crosshole Seismic Testing,"ASTM International.

Olson ENGINEERING

Metro Denver Corporate Office:
Olson Engineering Inc.
12401 W. 49th Ave.
Wheat Ridge, CO 80033
Phone: (303) 423-1212
Fax: (303) 423-6071

Metro Washington D.C. Office:
Olson Engineering Inc.
7529 Standish Place, Suite 102
Rockville, MD 20855
Phone: (240) 477-7738
Fax: (240) 801-9951

www.olsonengineering.com | www.olsoninstruments.com