CROSSHOLE SEISMIC TOMOGRAPHY (CST): AN EXAMPLE OF AN EFFECTIVE USAGE OF THE METHOD FOR ENGINEERING APPLICATIONS
Method variations

A – parallel testing;
B – tomographic testing;
C – tomographic testing with addition of data from sources and receivers located on surface.
Equipment for parallel testing

A – high voltage cable line with a set of borehole sources for P- and SV-waves excitation (SPARKER and GEOS-H respectively);

B – a set of replaceable borehole receivers with cable line: clamping 3C-geophone probe ATG-14 and a hydrophone module.
Parallel testing data (distance 4 m)

A – summed seismogram (Z-component) for S-wave testing – the phase reversal of first arrivals is obtained by generating SV+ and SV- polarizations of the signal;

B – summed seismogram (H-component) for P-wave testing;

C and D – vertical distribution of S- and P- waves velocities respectively in the crosswell space.
Energy source **Jack-2500HP** and **JackPad** remote control

Borehole source **Pulse**

Borehole hydrophone array **WellStreamer**
Example of field data for CST on P-waves, obtained with usage of sparker and hydrophone receiver array: above – CSP seismic gathers for 2 shot points; below – amplitude spectra of signal and noise recorded before arrival of the wave.
Examples of CST application

Work window of ZondST2d program. On the left it is shown the coincidence of observed and calculated hodographs, on the right – reconstructed velocity model with seismic ray tracing. On the right side of limestone base, a sinkhole is allocated; on the left side the decrease in velocity is probably associated with decompression zone.
Examples of CST application

Drilling results:
Upper (blue) layer – sand and loams.
Medium (green) layer – heavily leached limestones, completely destroyed in places.
Lower layer – clays.

On CST section it is clearly seen that limestones layer is strongly destroyed – one can see the heterogeneous structure, sometimes merging with the background. Average velocities of about 2000 m/s also indicate a strong degree of destruction.
Examples of CST application
Examples of CST application

Layout of boreholes arrangement on the surface topography

Agreement between observed and calculated hodographs and the ray coverage of the model
Examples of CST application
Amplitude tomography
- Equipment: borehole sparker **Pulse** and 24-channel hydrophone array **WellStreamer**
- Seismic gathers were obtained with a time difference of 1.5 weeks.
- In the interim of presented seismic gathers the source had been working for about 240 000 shots.
Multiwave CST

Sparker Pulse

3C probe
An example of negative result when working with a 3C clamping receiver and omnidirectional sparker Pulse.
Equipment for CST on S-waves

Directional pattern of borehole sources GEOS-V and SHock in sounding plane (P- and S-waves)

Directional characteristic of a Z-directional force type source in an infinite homogeneous isotropic space

Directional characteristics of a X-directional force type source in an infinite homogeneous isotropic space.
Multilevel 3C- probe **GStreamer**

- Range of boreholes diameters: 76 – 140 mm
- Amount of modules in array: 1 - 8 (3 – 24 ch.)
- Compensation coupled geophones
- Remote snapping of springs
- Operations without plummet in borehole
- Clamping force: 1:7 ~ 1:11
- Diameter of the probe: 60 mm
Examples of **non-oriented data** \((Z / X / Y)\) from "right" and "left" blows.
Examples of the data of **non-oriented X component**
from "right" and "left" blows
Examples of the data of **non-oriented Y** component from "right" and "left" blows
An illustration of the process of orienting the seismic record in XY plane in RadExPro software. Visualization of the probe path is shown on the left. Right part illustrates seismic records for non-oriented (X’ and Y’) and oriented (X and Y) components.

Summed seismogram for oriented Y component after subtraction of “right” and “left” blows.
Orientation of seismic gathers

P-wave picking on oriented X-component

S-wave picking on oriented Y-component
An example of boreholes design that were used during operations at the proposed location of nuclear power plant.

The lower part of borehole is cemented, the upper part is covered with sand (after removing the casing).

Example of multiwave CST application

Layout of boreholes arrangement

Excitation of pressure and shear waves was carried out in well 5, receiving was carried out in wells 1–4.
Example of multiwave CST application

Distribution of $V_p$ (left), $V_s$ (center) and $V_p/V_s$ ratio (right) between wells 1-3-5
Example of CST application

Distribution of Young’s modulus (left), shear modulus (center) and Poison’s ratio (right) between wells
Typical CST seismic gathers on P-waves contain a lot of information besides first break times. Data processing can be carried out not only by velocity tomography.
Crosshole seismic tomography (CST) method allows to obtain a detailed distribution of pressure (P-) and shear (S-) wave velocities in the crosswell space over the entire depth of study. Using this data, one can proceed to the spatial distribution of such parameters as the shear modulus, Young's modulus, Poisson's ratio, which are directly used in the design of structures.

Data of such detail and reliability cannot be obtained using other methods, especially if the studied medium is located under the foundations of existing structures, as well as in other cases when operation from the surface is either impossible or very constrained.

CST method has no alternatives in the search for sinkholes at great depths, fractured zones and other anomalies associated with changes in the physical and mechanical properties of the rock mass leading to an appearance of local velocity anomalies of P- or S- waves.

At the moment, a full hardware and software complex is available for the solution of the most challenging tasks arising in industry with usage of CST method.
Designs, manufactures, supports and supplies Equipment & Software for geophysical surveys:

- Seismic
- Geoelectric & Electromagnetic
- Magnetic
- Gamma radiation detection

Advanced options:
- Rentals
- Field demonstrations
- Test surveys
- Projects startup
- Training courses

Saint Petersburg (Russia)
office@geodevice.ru
+7 812 748-18-82

Almaty (Kazakhstan)
office@geodevice.kz
+7 705 575-46-76

Saint-Maximin-la-Sainte-Baume (France)
office@geodevice.fr
+33 66 992-12-96

Calgary (Canada)
contact@brendvik.com
+1 403 464-66-07