EXTRACTING SITE CHARACTERISTICS AT DELANEY PARK GEOTECHNICAL ARRAY IN ANCHORAGE, ALASKA USING SEISMIC INTERFEROMETRY
Erol Kalkan (ekalkan@usgs.gov), Hasan S. Ulusoy, Fei Wang and Jon. P. B Fletcher

Abstract
Seismic interferometry, based on deconvolution of waveforms recorded at various borehole depths, is used to extract site properties including: 1. Predominant site frequencies, 2. Soil shear velocity profile, 3. Site amplification, 4. of a densely instrumented borehole array at Delaney Park in Anchorage, Alaska.
Waveforms used are from ten earthquakes having moment magnitudes between 4.5 and 5.4 at epicentral distances of 11 to 126 km. These waveforms were recorded by surface and six boreholes (up to 61 m depth) three-component sensors. Deconvolution of the waveforms at various depths with respect to the surface waveform provides upward (incident) and downward (reflected) travelling waves within soil layers. The travel times computed are agree rather well with the measurements at the site; the deconvolution predicts wave travel times within 15% of the measurements.

The Site
In 2003, USGS established a seven-level downhole array of three components as accelerometers at Delaney Park in downtown Anchorage.
The deepest downhole instrument is at a depth of 61 m. This array was installed to measure responses to ground shaking, and to provide input wave field to the nearby 20-story steel building.

Soil & Geology
Delaney Park (DPK) array consists of one surface and six borehole tri-axial accelerometers.

The geological section at the site consists of silty materials including outwash, bootlegger formation and till deposits in glacio-marine glaciolacustrine environment (Eley et al., 1993).
The bootlegger core foundation (20-30 m) is a soft formation thought to be responsible for much of the liquefaction phenomenon during the 1964 earthquake.

Wave-Deconvolution
The soil responses from six boreholes were deconvolved by the soil response measured at the surface.
The deconvolved wave at surface is a band-pass filtered delta function, because wave deconvolution decouples waveforms; with white noise added, yields a delta function.
The deconvolved waveforms at borehole 2 thru borehole 6 are superposition of upward and downward travelling waves for early times, while for later times, the waveforms are governed by site response that decays exponentially with time.
The deconvolved waveforms demonstrate a wave state of the borehole array as if the motion at the surface was given by a delta function.
For early times, this pulse travels downward in the soil column with a velocity equal to shear wave velocity of soil layers. At t = 0, the wave field is non-zero only at the surface.
The deconvolved waves are decoupled, site amplification shears wave velocity during each earthquake. The average shear wave velocities estimated from the ten earthquakes are practically identical with a maximum discrepancy of 1.7%.

Earthquake Data
Ten earthquakes with M between 4.5 and 5.4 were identified as DPK array since its deployment in 2003.

Site Amplification
Because deconvolved waveforms are decoupled, site amplification is computed directly by taking ratios of wave amplitudes at surface and the deepest borehole.

Soil Predominant Frequencies
The predominant frequency f1 of the upper 61 m of the soil is estimated from the shear wave velocities of the five individual layers.

Deconvolved Wave Amplitude
As shown in Figure 3, the predominant frequency of the soil is estimated from the shear wave velocity during each earthquake. The average shear wave velocity during each earthquake.

References

Average shear wave velocity of the upper 61 m of the soil is estimated from the shear wave velocities of the five individual layers.

Figure (left) shows the arrival time and travel distance of the upward and downward travelling waves. The negative times are due to the upward travelling waves, and the positive values are associated with downward travelling waves. A straight line is fitted to all data points to estimate an average shear wave velocity during each earthquake. The average shear wave velocities estimated from the ten earthquakes are practically identical with a maximum discrepancy of 1.7%.