

Applications

- ✓ *Stratigraphic mapping*
- ✓ *Estimation of depth to bedrock including landfill base location*
- ✓ *Soil stiffness and ground improvement verification*
- ✓ *In-situ ground stiffness for geotechnical and civil engineering projects*

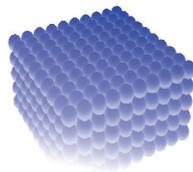
Basic Theory

Surface waves allow the measurement of the variation in soil stiffness with depth. A Surface wave (Rayleigh wave) has the property that ground motion reduces exponentially with depth. By recording Rayleigh waves of different frequencies, and therefore wavelengths, the properties of the subsurface can be determined at different depths.

The characteristic velocity of the surface waves can be determined by measuring the signals received at a series of geophones. The data collected can be processed to produce values of maximum shear modulus (G_{max}) at different depths.

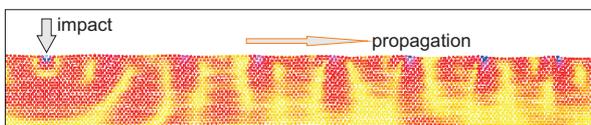
A stiffness profile can be generated for each adjacent pair of geophones. Profiles can be combined to produce cross-sectional images of the properties of the subsurface. Similarly, a number of adjacent cross-sections can be combined to produce a 3D image.

IMPROVED INTERPRETATION THROUGH MODELLING

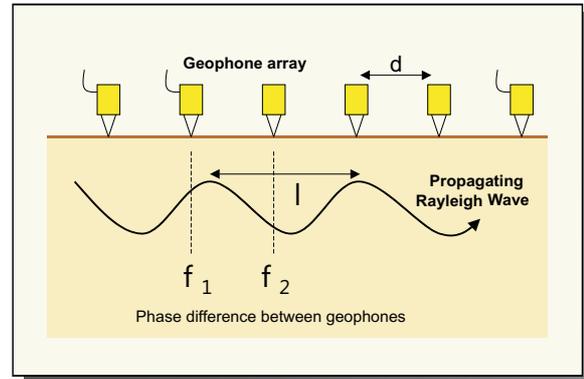


RSK's experts have developed unique forward modelling software to aid interpretation of surface wave data. The implementation of this advanced technique provides significant improvements in the delineation and location of major boundaries in the subsurface, and also the accurate determination of ground stiffness variations with depth.

The software is an implementation of our GeoDEM3D discrete element code. The advantages of this numerical scheme over traditional finite difference or finite element schemes is its ability to accurately model the motion of the ground surface, cope with large contrasts in elastic properties, and include voids, disaggregated zones, delamination and fractures.



Numerical model of Rayleigh waves propagating through the ground. Colours indicate displacement



Data Acquisition

Two different methods of acquisition are available for the collection of surface wave data.

The Surface Wave Ground Stiffness (**SWGS**) system operates with either an active source (from vibration or hammer blow) or by utilising the seismic noise already present. This allows the technique to be used in active and noisy sites that would be unsuitable for other geophysical investigation techniques.

The Continuous Surface Wave (**CSW**) system employs a frequency controlled vibrator and geophones. The vibrator generates a Rayleigh wave at a specific frequency, within a range of stepped harmonic frequencies between 5 - 700 Hz. By collecting data over a range of frequencies, the effective depth of investigation can be varied.

Recorded data are analysed to determine the wavelength of each frequency present within the data, and also the velocity at which that frequency propagates. In processing the data as a first approximation the velocities from each profile can be assigned to depths equal to one third of the wavelength. More robust ground models are then typically modelled as a stack of homogeneous linear elastic layers, and the parameters to be determined in refining the ground models are the layer thicknesses and shear wave velocities.

Good continuous depth coverage relies on the ability to record suitable amounts of energy at all frequencies within the range of interest. It is not necessarily the case that these ground vibrations will be present, and long recording times may be necessary to capture reliable signals that can be inverted and interpreted in terms of a useful ground model.

Data Examples

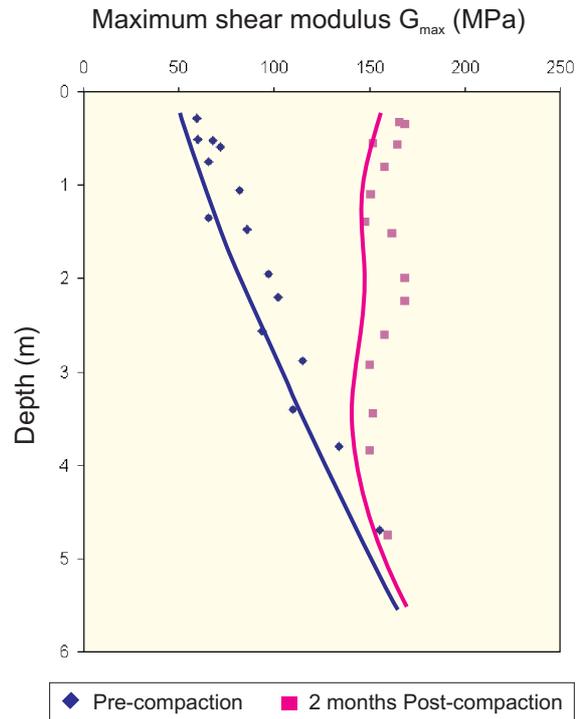
Ground improvement monitoring

A seismic surface wave ground stiffness profiling survey can determine the ground stiffness at depth.

In this example it was used to assess the change in stiffness after ground-improving compaction had been carried out prior to the construction of a road.

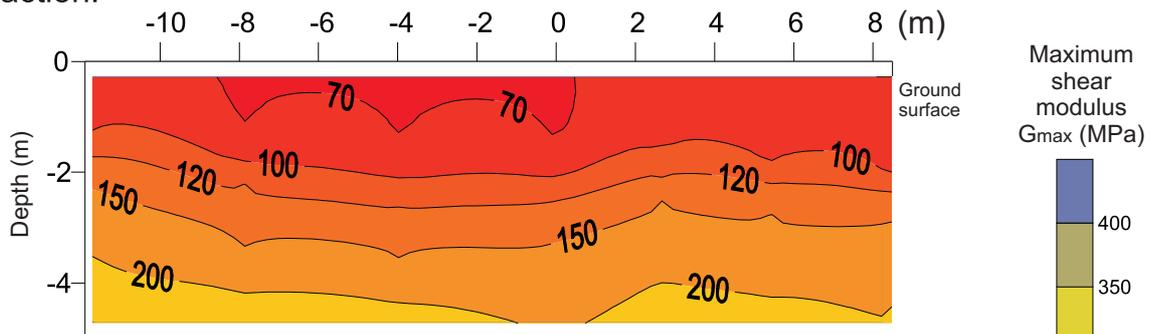
To the **right** is a graph displaying the maximum shear modulus of the ground versus depth. The results show a clear and measurable improvement after compaction.

The two diagrams **below** show a 2-dimensional stiffness profile from the same site, before and after ground improvement.



Surface wave testing can be carried out on soils of many types. No ground penetration is involved so stiffness values are not affected. This technique is a reliable means of measuring soil stiffness when other traditional methods (such as SPTs) may fail to produce results.

1 Pre-compaction:



2 Post-compaction:

