# Multichannel Analysis of Surface Waves (MASW)

In the last 50 years, surface wave surveying has been developed to determine 1D profiles of the shear wave velocity ($V_S$), and hence ground stiffness, with depth to about 30 m below the ground. The first surface wave method developed was the Continuous Surface Wave (CSW) technique, which uses a single transmitter that generates a continuous vibration signal with two or more receivers. Surface wave surveying using an impulsive source with two receivers was then developed (the Spectral Analysis of Surface Waves, or SASW, method). This was further extended to the use of multiple receivers (multi-channel). With the associated development of more complete and complex processing techniques, this approach became known as Multichannel Analysis of Surface Waves (MASW), which has been popular with geotechnical engineers from about 2000.

## Principles of operation

There are several types of seismic wave, the most important of which are body waves (which travel through the Earth) and surface waves (which travel along it's surface). There are two types of body wave: compressional waves (P-waves), which have particle motion in the direction of travel, and shear waves (S-waves), which have particle motion perpendicular to the direction of travel. The shear wave velocity is related to the stiffness of the medium through which the waves travel. Hence, surface wave surveying is a useful tool for determination of variation in ground stiffness with depth.

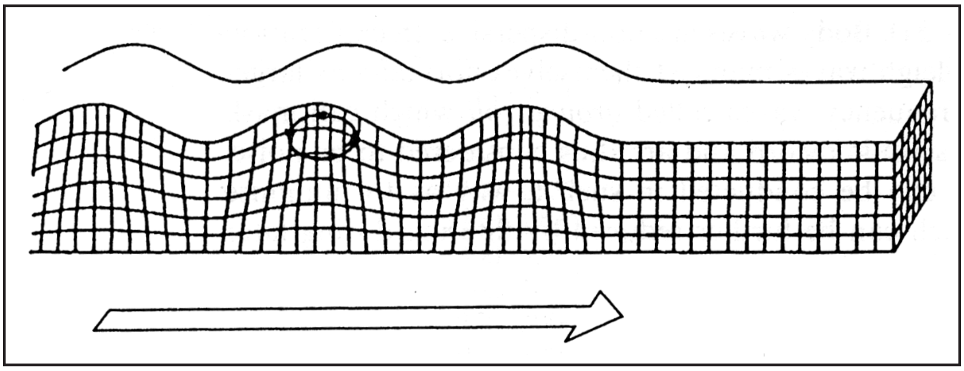


**Figure 1**: Rayleigh wave particle motion (from Bolt, 1982).

In a homogenous earth, Rayleigh waves would not be dispersive. In a two-layer earth, Rayleigh waves become dispersive when their wavelengths are in the range of 1 to 30 times the thickness of the top layer. Generally, longer wavelengths penetrate to greater depths and are more sensitive to the elastic properties of deeper layers while shorter wavelengths are sensitive to the elastic properties of shallow layers. Each surface wave of a particular wavelength possesses a particular phase velocity, which is why the surface waves disperse. However, a series of different frequency Rayleigh waves can possess the same apparent phase velocity. The lowest velocity for a given frequency is called the *fundamental mode* velocity; the next highest velocity for that frequency is called the *second mode velocity*, and so on. The Rayleigh wave phase velocity of a layered earth is a function of frequency, S-wave velocity ($V_S$), P-wave velocity ($V_P$), and the density and thickness of the layers. The desired frequency range for surface wave studies is 1-30 Hz. Rayleigh waves travel approximately 5% slower than S-waves.

## Processing and interpretation

In SASW processing, a 1D dispersion curve is calculated through Fourier transformation of the data. This curve is likely to include the influence of higher modes as well as other types of waves, a problem which requires considerable processing to ameliorate. However, in MASW surveying the use of many receivers (multichannel surveying) allows the transformation of the data into frequency-wavenumber or frequency-phase velocity space to form a dispersion image. This allows identification and separation of modes. Figure 2 shows a typical MASW dispersion image. The fundamental mode has been picked, but higher modes (overtones) can also be seen clearly.

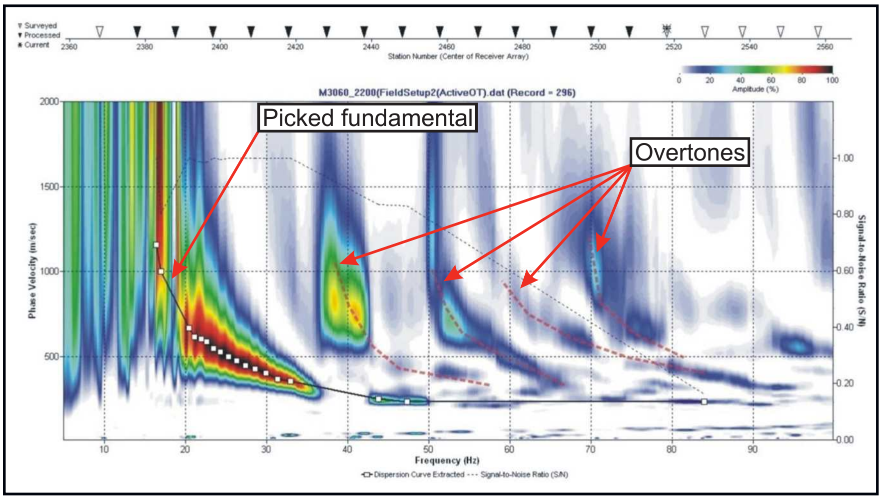
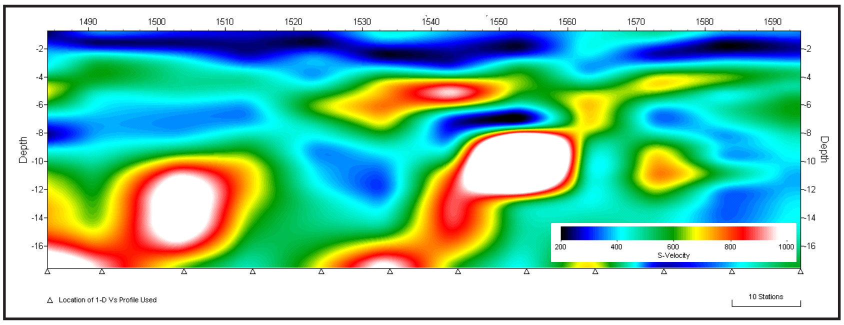



**Figure 2**: A dispersion image displayed in SurfSeis software (Kansas Geological Survey). Pre-processing to improve data interpretability has been carried out. The fundamental mode has been picked manually. Multiple overtones are also clearly identifiable.

Inversion is used to obtain the 1D $V_s$ structure from the dispersion data. Commonly, this is done by attempting to match a synthetic fundamental mode dispersion curve to the curve picked from the data. An initial $V_s$ model is constructed, automatically or manually, from which a synthetic dispersion curve is generated. The initial $V_s$ model is then iteratively adjusted to improve the fit between the two curves. Inversion is focused around matching dispersion curves rather than $V_s$ profiles because changes in Rayleigh wave velocity are not directly proportional to changes in $V_s$ (non-linearity).

Commonly, multiple MASW tests are conducted along a line and processed to give multiple 1D $V_s$ profiles. These profiles are then displayed as a 1.5D section, so called to distinguish them from sections produced using full 2D inversion (Figure 3). Less commonly, higher modes may also be picked and included in the inversion. Theoretically, this provides more accurate results, but it also introduces more variables to the inversion process and can degrade the solution.

**Figure 3**: A 1.5D $V_s$ section displayed in SurfSeis software. Component 1D sections were produced by gradient-based, iterative inversion of manually picked fundamental dispersion curves.




Inversion based on picked dispersion curves will only produce accurate results where modes are correctly identified; however, modes are often mixed, or misidentified due to a weak fundamental. Direct inversion of the dispersion image data is a more rigorous method that bypasses the mode picking stage entirely, but is more computationally intensive than the usual approach and should be reserved for areas of complex geology where the risk of mode misidentification is higher. Whichever inversion method is used, subsequent conversion from a $V_s$ profile, section or volume to $G_{max}$ is comparatively straightforward, using Poisson's Ratio and the bulk density of the soil or rock.

Because MASW inversion is both non-unique (*i.e.* the observed dispersion could be produced by a number of $V_s$ models) and very non-linear, MASW processing must be carried out by a trained operative who can select the most appropriate inversion method and parameters to obtain a geologically realistic solution. An extended discussion of the MASW method is given by Reynolds (2011).

## References

Bolt, B. A. 1982. *Inside the Earth*. San Francisco: W. H. Freeman.

Reynolds, J.M. 2011. *An Introduction to Applied and Environmental Geophysics*. John Wiley & Sons Ltd, Chichester, 2nd ed., 712 pp.