Side Scattering Analysis (SSA)

Surface waves are known to be sensitive to the presence of near-surface anomalies such as near-vertical fractures and voids. A significant amount of surface wave energy impinging against them is transformed into scattered surface waves due to anomalies acting as new sources of surface waves (Figure 1). Therefore, MASW data collected for normal 2-D Vs mapping can also be used to detect possible subsurface anomalies existing off the survey line by using a processing scheme similar to conventional reflection processing. This process is called a side-scattering analysis (SSA) of surface waves. A brief explanation of the processing scheme follows.

When there is a void below a certain surface location (x_v, y_v), then a scattered surface wave component of f-Hz traveling with a phase velocity of C_f generated by impact of a source located at (x_s, y_s) will reach a receiver point (x_r, y_r) at time $\delta t(f)$ (Figure 2):

$$\delta t(f) = (L_1 + L_2)/C_f \tag{1}$$

with $L_1 = \sqrt{(x_s - x_v)^2 + (y_s - y_v)^2}$ and $L_2 = \sqrt{(x_r - x_v)^2 + (y_r - y_v)^2}$

Based on this travel-time relationship, to evaluate the relative probability of a surface point being the source of such scattering, a plane (x-y) grid is first established within which the detection of subsurface anomalies is sought (Figure 9). Then, each point (x_v, y_v) in the grid is assumed to be the source of scattering. The corresponding scattered wavefields are then collapsed to their origin in time by applying an appropriate phase shift and then all those collapsed waves are summed (stacked) together to yield an indicator $SSA(x_v, y_v)$:

$$SSA(x_v, y_v) = \left| \sum_{\text{traces}} \sum_{\text{frequencies}} e^{-j2\pi f \delta t(f)} R_{r,s}^{Norm}(jf) \right|, \tag{2}$$

where $R_{r,s}^{Norm}(jf)$ indicates the normalized Fourier transformation of seismic trace $r_s(t)$ recorded by the receiver at (x_r, y_r) when seismic source was located at (x_s, y_s). *SSA* is proportional to the intensity of scattering, therefore qualitatively the existence probability of an anomaly. Therefore, when these values of SSAs calculated at all the grid points are displayed through a simple 2-D format, actual points of scattering will show peaks or troughs depending on whether there is a 180° phase shift at the time of scattering or not, respectively (Figure 3). In the modeling illustration in Figure 10, the 180° phase shift was assumed. Phase velocities (C_f's) of a dispersion curve representative of the area are used in the calculation of $\delta t(f)$. The depth range sensitive to this analysis is assumed to be half the range of wavelengths defined by the representative dispersion curve. For example, if the reference curve has phase velocities changing from 1000 m/sec at the lowest frequency of 20 Hz to 100 m/sec at the highest frequency of 100 Hz, then corresponding wavelengths change from 50 m to 1 m and the sensitive depth range of the SSA analysis becomes 25 m – 0.5 m.

The sensitive depth range of the SSA method is expected to be about half the wavelengths used during processing and the minimum sensitive dimension (in diameter) of the anomaly is expected to be about 10% of its depth of existence. For example, if the reference curve had wavelengths of 4-20 m, then a depth (z) of 2-10 m is sensitive for those anomalies larger than 0.2 m existing at z = 2 m, 0.5 m existing at z = 5 m, and so on.

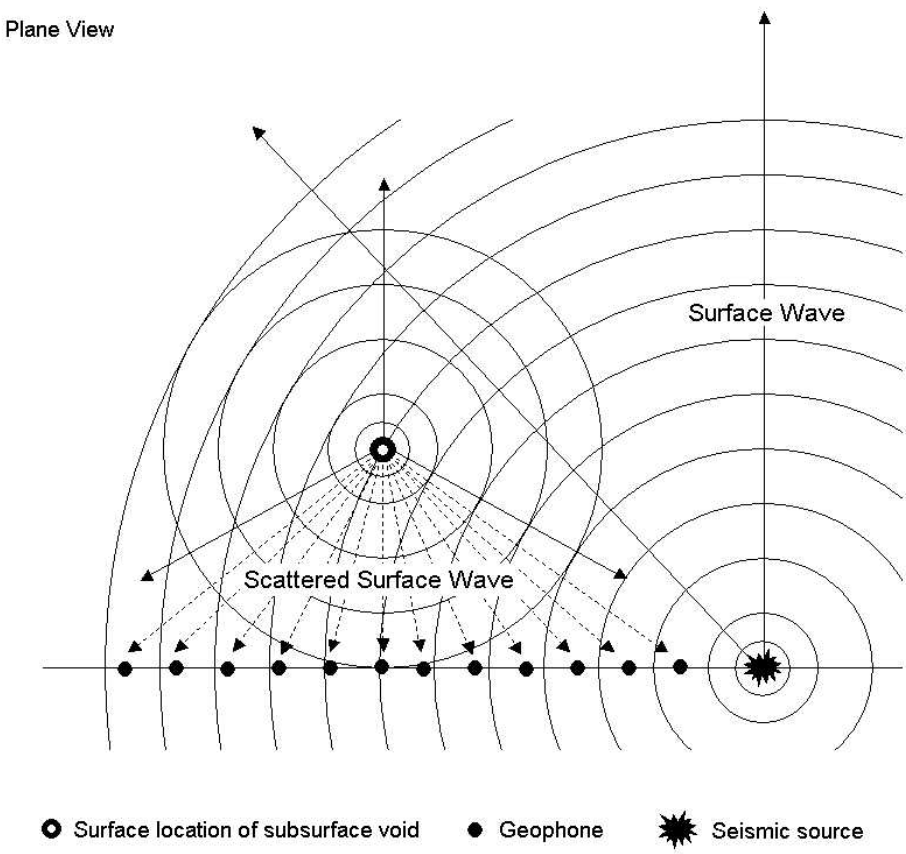

Figure 1. A plane-view schematic illustrating the scattered surface wavegeneration that can be set off by a near-surface anomaly like a void.

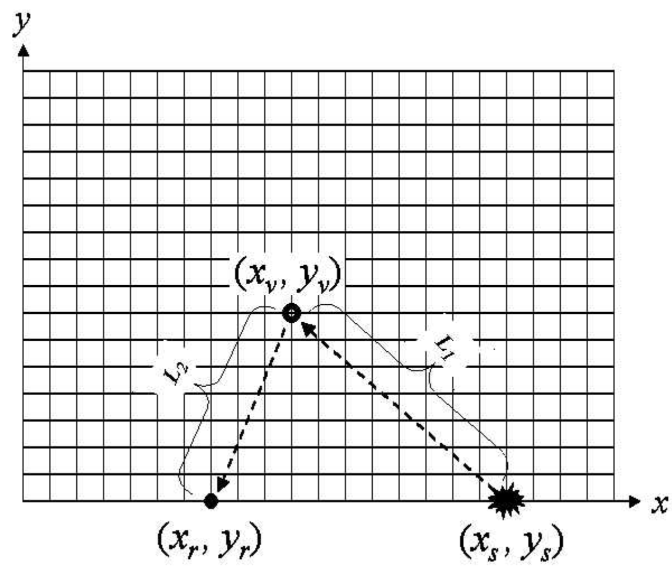

Figure 2. A fictitious grid net is used during the SSA processing in witch each point (x_v, y_v) in the net is assumed as a possible scattering source of surface waves generated by a source at (x_s, y_s). Then, a receiver at (x_r, y_r) can record such scattered waves.

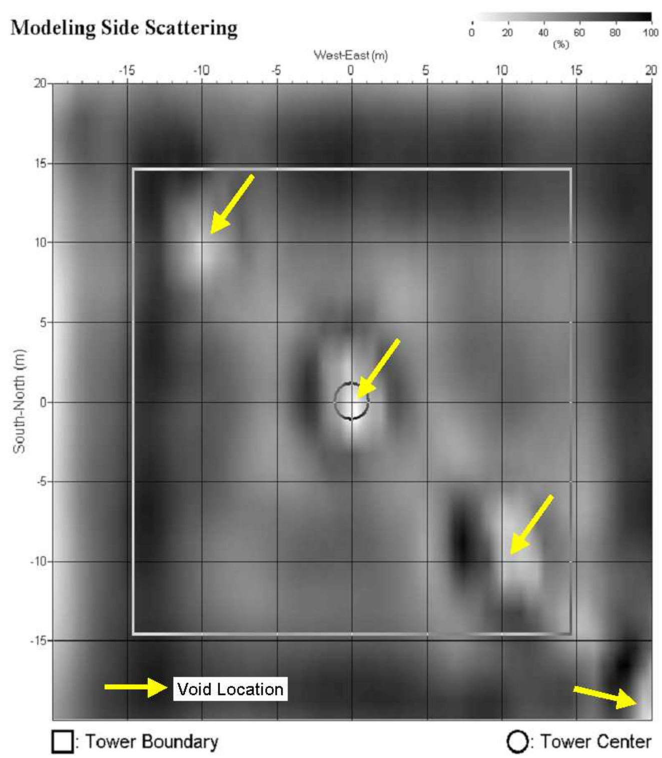

Figure 3. An SSA map from a modeling. Four (4) voids were modeled below the marked surface points with a spherical diameter (D) and a depth (Z) of (D=1m,Z=1m), (D=2m,Z=2m), (D=2m, Z=3m), and (D=1m, Z=3m) from top to bottom.