Ultrasonic Surface Wave (USW)

Target of Investigation

Regarding concrete pavement, ultrasonic surface wave (USW) testing has the following applications:[1]

- Measuring modulus of elasticity of the concrete.[2]
- Estimating strength of concrete using the correlation between strength and modulus.[3]
- Indirectly assessing delamination, honeycombing, and debonding in the surface course material.[4]
- Assessing conditions of concrete for damage from various causes, including alkali–silica reactions, fires, freeze–thaw cycles, and other cracking processes.[5]

USWs can also be used to evaluate asphalt pavements and overlays if the mix is cold and stiff.[6]

Description

The USW technique is an offshoot of the spectral analysis of surface waves (SASW) method used in evaluating material properties (e.g., elastic moduli) in the area very near the surface. SASW uses surface-wave dispersion (i.e., velocity of propagation as a function of frequency and wavelength) in layered systems to obtain information about layer thickness and elastic moduli.[7] USW testing is identical to SASW testing except that the frequency range of interest is limited to a narrow high-frequency range in which the phase velocities of surface waves do not vary significantly with frequency. Using either the measured or assumed mass density and Poisson's ratio of the material, the phase velocity can be converted to the material modulus. A USW test consists of recording the response of the deck at two receiver locations from an impact on the surface of the deck. USW testing equipment is shown in figure 1.

Source: FHWA.

Figure 1. Photo. USW testing equipment.

This photo shows ultrasonic surface wave testing equipment, which consists of three vertical, cylindrical objects and one metal box, all attached to two large, rounded, horizontal connecting bars. The two cylindrical objects closest to the box are receivers. The third cylindrical object on the right end of the connecting bar is an impact source. Cables run from the metal box to each of the cylindrical objects.

Physical Principle

Surface waves are elastic waves that travel along the free surface of a material and, in most cases, constitute the predominant proportion of energy in comparison to body waves, such as compressive waves (P-waves) and shear waves (S-waves).(7) The arrival of the surface (Rayleigh) wave follows the arrival of the two body-wave components because the surface wave is slower (figure 2).

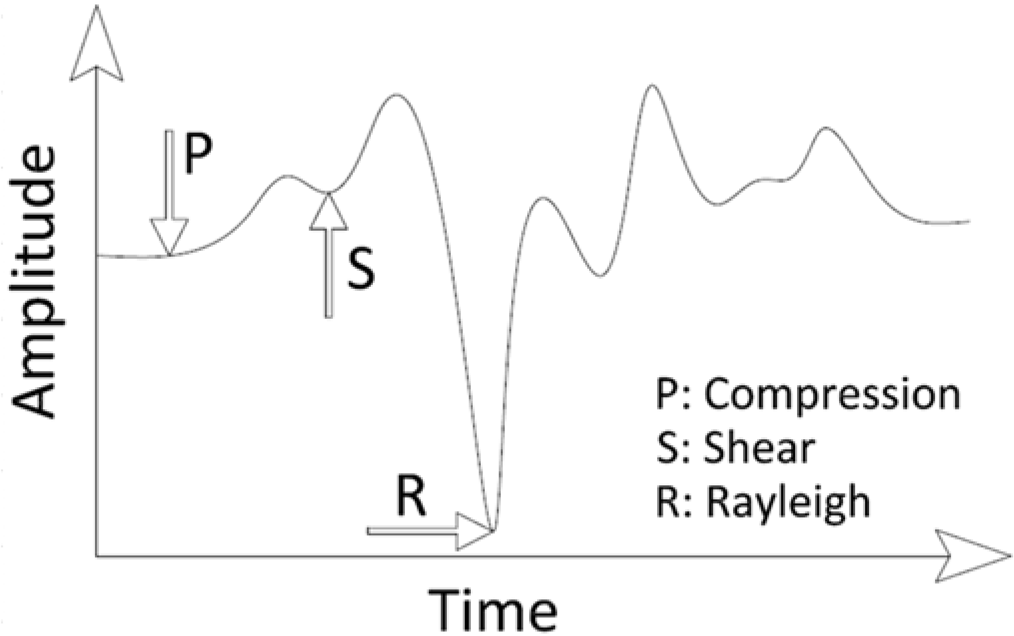
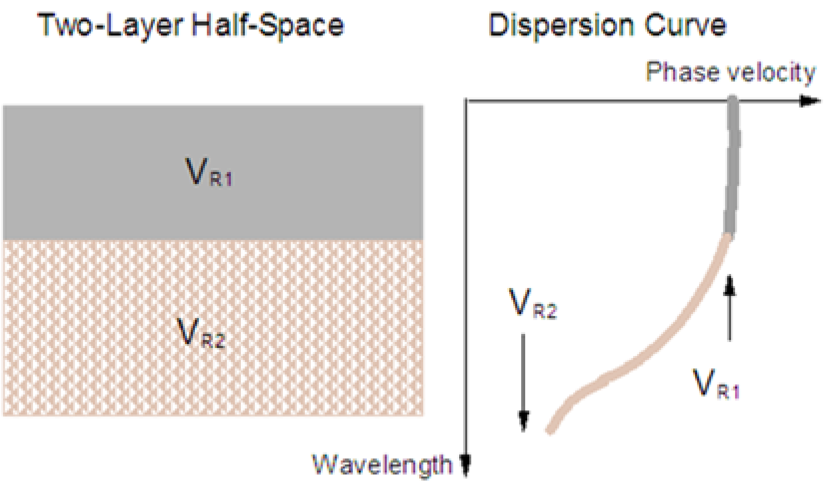


Figure 2. Graph. Typical time record obtained from USW testing.(7)

This graph is of a time record. The x-axis represents time, and the y-axis represents amplitude. The plotted record has three labeled points. Closest to the y-axis, with the shortest time measurement, is point P (compression wave arrival). The next labeled point is S (shear wave arrival). The amplitude of the shear wave is higher than that of the compression wave. The furthest labeled point, and thus with the longest time measurement, is R (surface or Rayleigh wave arrival). The surface wave has the highest absolute peak amplitude of the three waves.

Surface waves propagate radially from the impact source, forming a cylindrical front with a velocity dependent on the elastic properties of the medium. The waves propagating in a layered medium are dispersive; that is, waves of different wavelengths or frequencies travel with different velocities. Thus, information about the subsurface can be obtained by measuring the phase velocity versus frequency (dispersion curve) and backcalculating the dispersion curve to obtain the profile of the tested system (layer thickness and modulus).

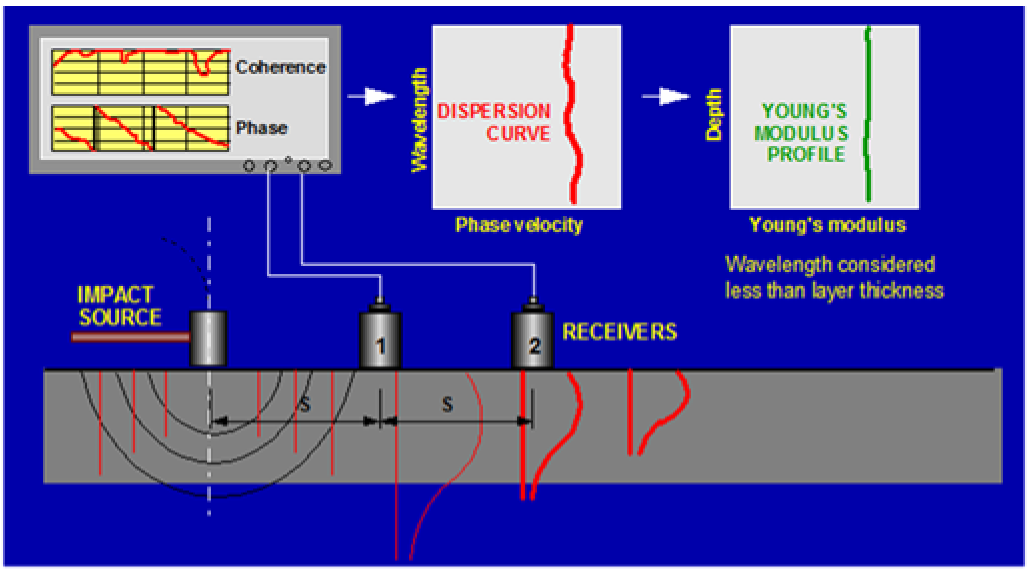
Surface-wave energy extends to a depth of approximately one wavelength. At wavelengths less than or equal to the thickness of the layer, the velocity of surface-wave propagation is more or less independent of wavelength (figure 3 and figure 4). Therefore, if the measurement is limited to wavelengths not exceeding the thickness of the surface course, the velocity of surface waves will be dependent only on the modulus of the surface course material. An average velocity is used for correlating to the material modulus. Significant variation in the phase velocity indicates the presence of delamination or another anomaly.(8)



© 2011 N. Gucunski, Rutgers University.VR1 and VR2: Rayleigh wave velocities in a two-layer half space.

Figure 3. Illustration. Phase velocity versus wavelength.(7)

This illustration has two components. On the left is a two-layer half space, which is a rectangle with the top layer labeled "V subscript R1" and the bottom layer labeled "V subscript R2." On the right is a plot of a dispersion curve. The x-axis is labeled "Phase velocity." The y-axis is labeled "Wavelength." The plotted line has two sections. The top part of the curve corresponds to V subscript R1 and descends vertically. The bottom part of the curve corresponds to V subscript R2 and curves downward to the left, indicating decreasing phase velocity and wavelength.



© 2011 N. Gucunski, Rutgers University.S: Distance between impactor and receiver.

Figure 4. Illustration. Evaluation of a layer modulus through USW testing.(7)

This illustration is a schematic of ultrasonic surface wave testing. At the bottom of the illustration is a surface with an impact source on the left and two receivers to the right. Signals from the receivers rise to a display that shows the outputs, coherence and phase. A dispersion curve with wavelength versus phase velocity is then plotted, which, in turn, produces a Young's modulus profile plot of depth versus Young's modulus. The Young's modulus profile is approximately a vertical line and is described as "Wavelength considered less than layer thickness."

Data Acquisition

The basic components of USW equipment include a source, at least one pair of receivers, and a portable computer with data acquisition software.(4) USW equipment enables both automatic and semiautomatic data collection and processing. Figure 5 shows an example of a simple USW device (a portable seismic property analyzer) with a solenoid-type impact source and two receivers (accelerometers). Once the device is placed on the ground, a series of impacts from the source is detected by the receiver pair and recorded on a portable computer.

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Source: FHWA.

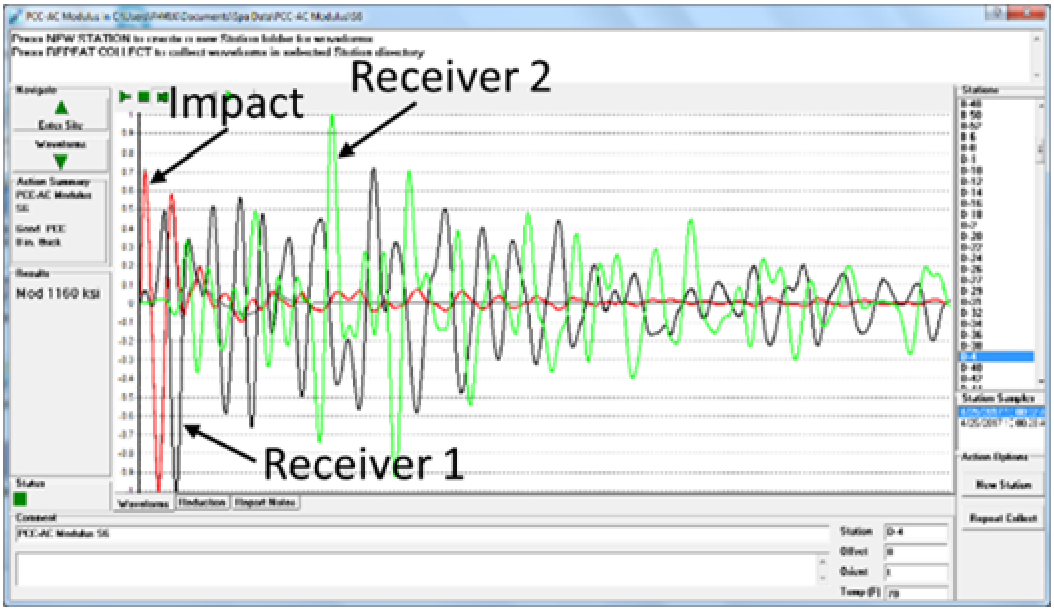
Figure 5. Photo. USW testing using a portable seismic property analyzer in a cart.

This photo shows a simple USW device (a portable seismic property analyzer) with a solenoid-type impact source and two receivers (accelerometers).">>Source: FHWA.

Figure 5. Photo. USW testing using a portable seismic property analyzer in a cart.

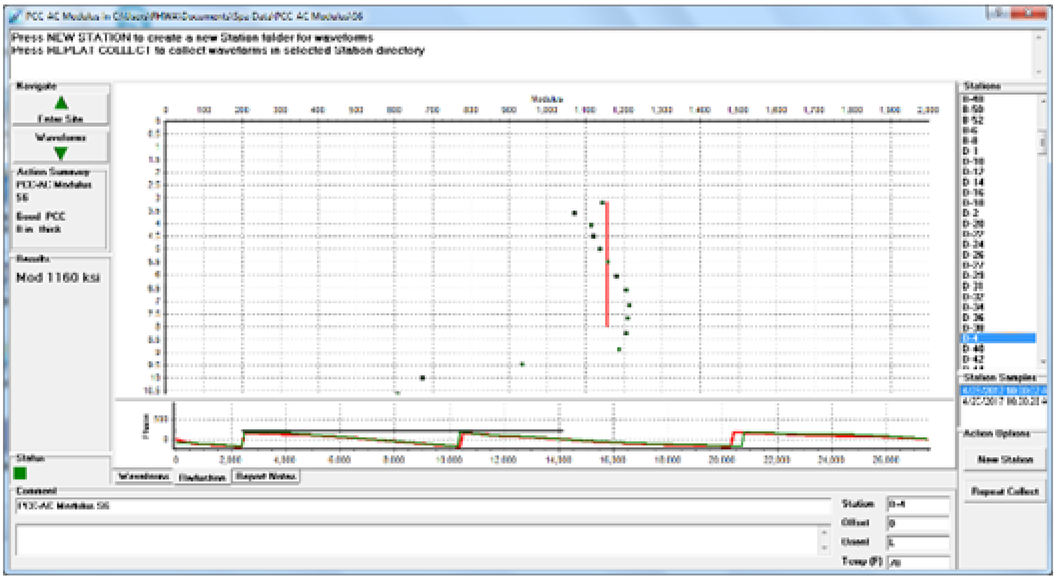
Data Processing

Compressional waves arrive at the receivers first and are followed by shear waves and then surface waves.[3] However, more than two-thirds of the energy in the wave train is in the surface waves, making them more easily recorded. Figure 3 and figure 4 illustrate the data-processing procedure of SASW testing. A dynamic signal analyzer is used to transform the receiver outputs from the time domain to the frequency domain. The coherence function and phase difference between the two receivers are acquired. The coherence function is a measure of the degree by which the signals are linearly correlated. The cross-power spectrum is used to obtain the relative phase shift between two signals (two-channel recorder). The received signals are processed, and a subsequent calculation scheme is used to calculate the modulus directly in the field (figure 6).



Source: FHWA.A. Raw data.

This screenshot shows raw data from the impactor and two receivers. Three curves represent time history data from the impact, receiver 1, and receiver 2.



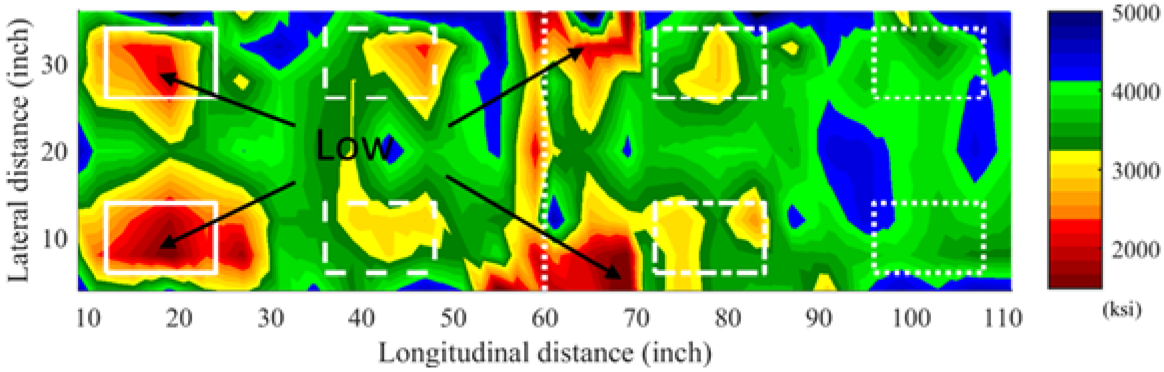
Source: FHWA.B. Processed data.

Figure 6. Screenshots. Raw and processed data during data collection.

This screenshot shows a display from the testing device's computer screen for processed data and contains two charts. The x-axis of the main chart is modulus in kilopounds per square inch, and the y-axis of the main chart is depth in inches. Dots represent the modulus at different depths, and a line represents the average of the modulus. The x-axis of the small chart is frequency, and the y-axis of the small chart is phase. Phase information for signals from the receivers is shown in the small chart at the bottom.

Data Interpretation

Data from USW testing are typically presented in terms of concrete modulus distribution (figure 7). A very low modulus often indicates low-quality material or the presence of delamination or cracking and does not necessarily represent the actual concrete modulus at the test location.



Source: FHWA.1 inch = 2.54 cm; 1 ksi = 6.9 mPa.

Figure 7. Contour map. Concrete modulus distribution from USW testing.

This contour map depicts concrete modulus distribution. The x-axis is labeled "Longitudinal distance" and ranges from 8 to 112 inches. The y-axis is labeled "Lateral distance" and ranges from 4 to 36 inches. To the right of the graph is the color scale of the modulus in kilopounds per square inch. The scale ranges from 1,500 to 5,000 kilopounds per square inch. The concrete modulus is mostly around 4,000 kilopounds per square inch. Four areas are indicated by arrows on the map; each of these has a low modulus, around 2,000 kilopounds per square inch.

Advantages

Advantages of USW testing include the following:

- Repeatability.
- Determination of modulus of material for appropriate design.

Limitations

Limitations of USW testing include the following:

- Slow data collection.
- Road and bridge closures necessary for surveying existing pavements.
- Expertise and training required for equipment setup and data collection, processing, and interpretation.
- Complicated backcalculation for multilayer systems.
- Limited ability to provide the degree of severity.
- Inability to measure pavement condition below the top of the discontinuity.[6]

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