Research on Transient Rayleigh Wave Method and Its Application in Slope Engineering

1. Test principle

Based on the theory of elasticity, when the ground is struck and vibrated, Rayleigh waves (also known as R-waves) exist near the ground surface. R-waves propagate in all directions, accounting for 67% of the total vibration energy, which results in a relatively slow attenuation in the propagation direction (proportional to the square root of the distance R). Moreover, surface waves have a lower frequency, larger period, and stronger wave amplitude energy. Therefore, these characteristics are conducive to data collection and analysis. The higher signal-to-noise ratio creates favorable conditions for improving the precision of the survey.

Based on the principle of Rayleigh wave propagation (Figures 1 and 2), a measurement line is laid out on the ground along the direction of wave propagation. With a certain channel spacing ΔX, N+1 detectors are placed. An instantaneous impact force is exerted on the ground at the excitation point, generating Rayleigh waves within a certain frequency range. These waves propagate forward in a pulse form, causing vibrations in the media near the surface layer. The N detectors receive the vibration signals, and the surface wave collection instrument collects and saves the records.

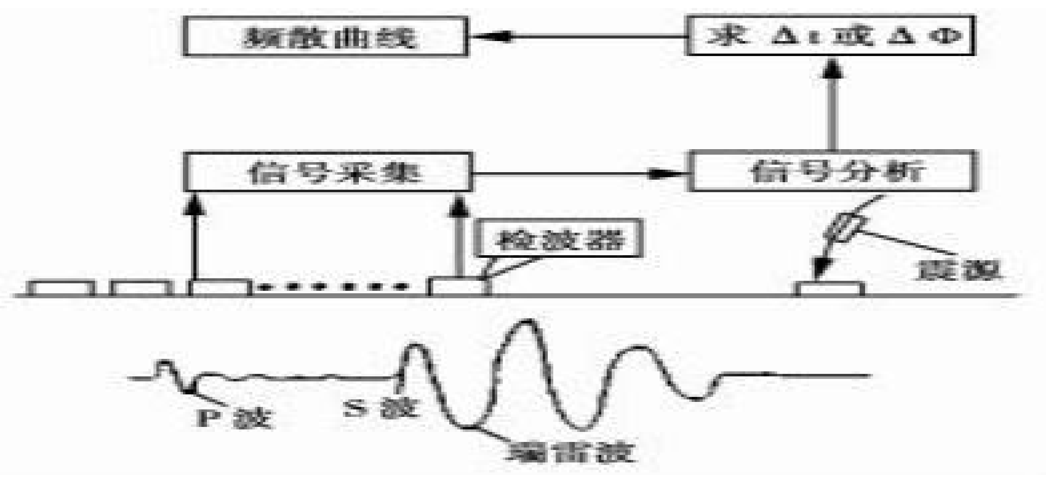

Fig.1 Diagram of principle of transient Rayleigh wave testing

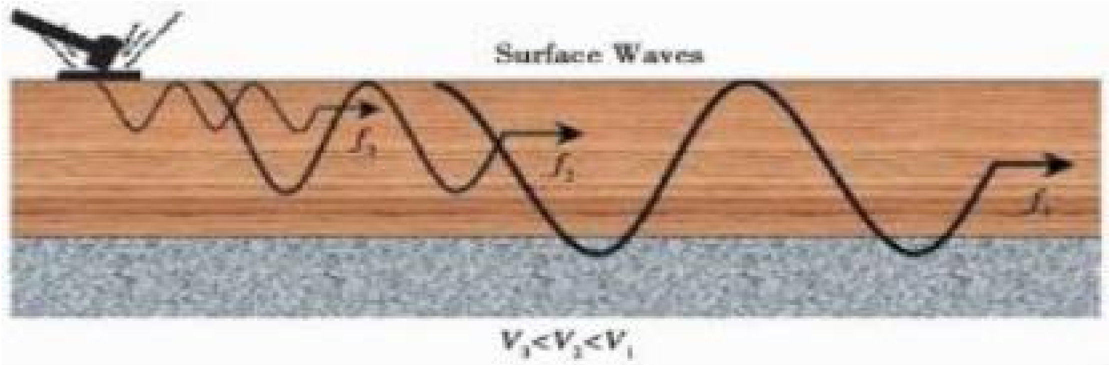

Fig 2 Graph of propagation of different frequency Rayleigh wave

After multiple low-frequency detectors receive the pulse-like vibration signals, the data is collected and subjected to spectral analysis. From this, the R-waves of various frequencies are separated and their corresponding VR values are determined, leading to the plotting of the surface wave dispersion curve. Using the Rayleigh wave dispersion curve obtained and through the half-wavelength method, the corresponding depth is determined, achieving the goal of testing the transverse wave speed of layered media at different depths. This, in turn, aids in the analysis and evaluation of the geotechnical stability conditions of the slope. At the same time, through coherent analysis of the shear wave (S-wave) derived from the dispersion curve, various rock mechanical parameters of the slope layered medium and the uniformity and adhesion between layers can be calculated. In a layered spatially elastic medium, the elastic properties of each layer differ, giving Rayleigh waves their dispersive nature. The propagation speed of a single-wavelength (or single-frequency) component of the surface wave is referred to as the phase speed of that wavelength (or frequency). The difference in phase speeds of different frequencies is termed dispersion. Given the approximate relationship between VR and Vs, the Rayleigh surface wave speed is close to the shear wave speed. The effective depth corresponding to this wave speed is between half to one-third of the Rayleigh wave wavelength (most domestic and foreign studies currently use half the wavelength as the effective propagation depth of the Rayleigh surface wave). Therefore, the wave speed and depth of each layer can be inferred from the dispersion curve. Additionally, the Rayleigh wave speed VR is approximately equal to the shear wave speed Vs, so the Rayleigh wave dispersion curve can also be directly analyzed to delineate stratification.

2. Engineering Application

In actual engineering, an appropriate field collection method is chosen to obtain the best Rayleigh surface wave raw records. Through meticulous data processing, the wave speed point Rayleigh wave dispersion curve is acquired, thereby obtaining the propagation speed VR of the Rayleigh wave.

2.1 Project Overview

A certain slope engineering project is located near the new railway station in District, Fuzhou (Figure 3). The terrain is an eroded foothill slope with a steep landscape. Most of the bedrock is exposed, with a small amount of vegetation and Quaternary sediments distributed in some valleys. The presence of cobblestones on the mountain suggests that this location was once a riverbed or bank, later elevated by crustal movements. The mountains mostly stretch from northwest to southeast, with significant elevation changes. Mountain peaks are about 150 meters above sea level, with slopes ranging from 20° to 50° . The geological rock type in the survey area is mainly medium-weathered granite, with some layers containing large quartz veins. The rock color is primarily bluish-grey and grey, with a few in light yellow. Surface rock weathering is severe, with well-developed joints and fissures. Layered sliding is evident, and large spherical weathering traces can be seen at the mountain top, with large boulders indicating significant weathering – all of which are detrimental to slope stability.

2.2 Field Data Collection

For this field data collection, we set up a total of five measurement lines. These lines were oriented perpendicular to the general direction of the slope, with a spacing of approximately 100m. The excitation of the surface waves was achieved by vertically striking a steel plate with a large hammer. We utilized a bidirectional multi-channel (6 channels, 12 channels, or 24 channels) observation system (as shown in Figure 4). The WZG-24A seismograph was used for data collection, with a channel spacing of 1m, an offset distance of 2m, a sampling interval of 0.5 ms, 1024 sampling points per channel, and a single detector recording length of 512.0 ms. The receiving sensors employed 4Hz vertical seismic detectors.For fixed-point reflection wave collection, we used 6 channels with an offset distance of 0.2m, and the receiving sensors were 38Hz vertical seismic detectors.

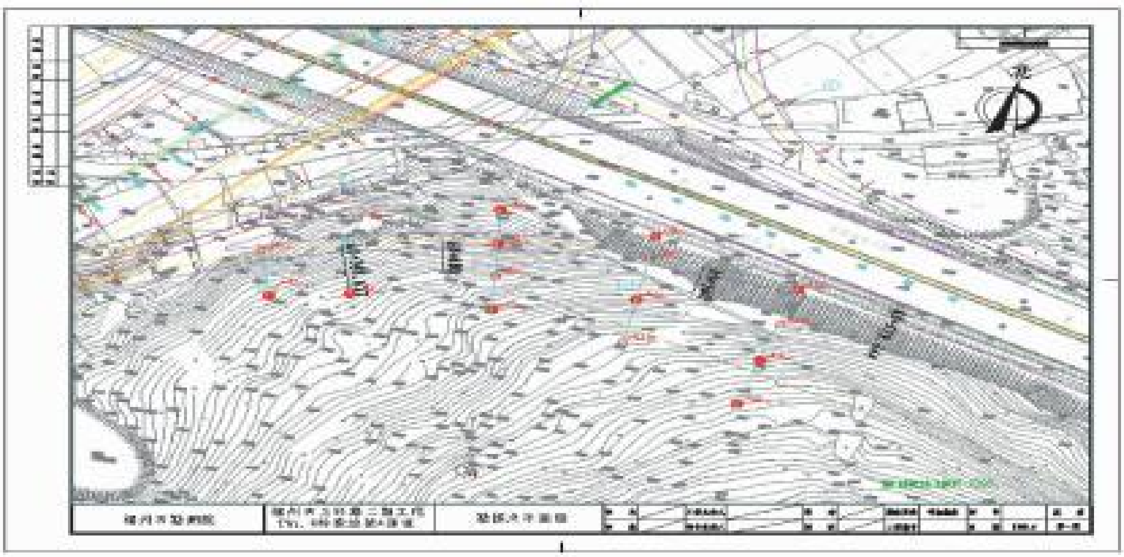

Fig 3 Arrangement diagram of slope Line

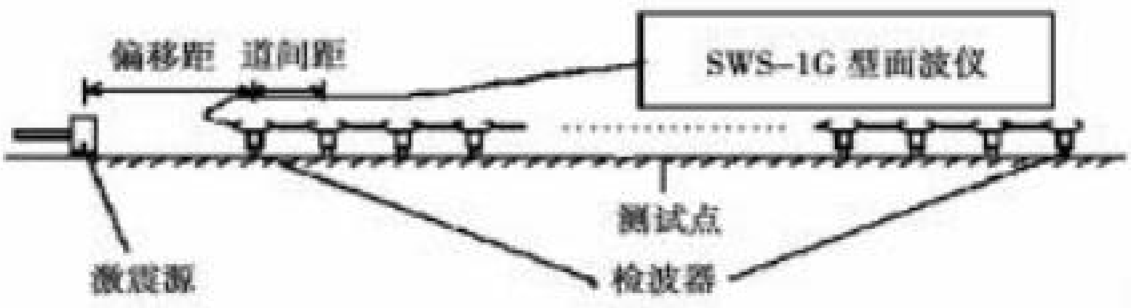

Fig 4 Diagram of transient Rayleigh wave testing

Once the excitation is complete, the detectors receive the ground vibration signals. The quality of the collected data is then checked. If satisfactory, the data is saved, and the excitation process is repeated two more times to save additional data. The detectors are then arranged in the opposite direction, and the excitation source is moved to the same offset distance on the other side. Excitation is performed three times, and the recordings are saved. Once the operations for one measurement line are completed, the above steps are repeated for the other lines.

3.3 Data Processing and Interpretation

3.3.1 Extraction and Interpretation of Surface Wave Dispersion Curves

During indoor processing, the surface wave data is first imported. A suitable time-space window is chosen for the fundamental surface wave to conduct a two-dimensional frequency analysis. In the f-K domain, energy groups of the fundamental surface wave are selected and picked up to obtain the dispersion curve (Figure 5).

This figure reflects the general relationship between the depth of the detected rock layer and the velocity of the surface wave. When the medium is uniform, the speed of the surface wave increases with increasing depth. When different media are encountered, the dispersion curve will present a "Z" shape at their boundary, which can be used for geological stratification. At a depth of 7.5 m, a "Z" shape change appears, dividing the first layer from 0 to 7.5 m as moderately weathered granite. The second layer, from 7.5 m to 22.0 m, is slightly weathered granite, and the third layer, below 22.0 m, is unweathered granite.

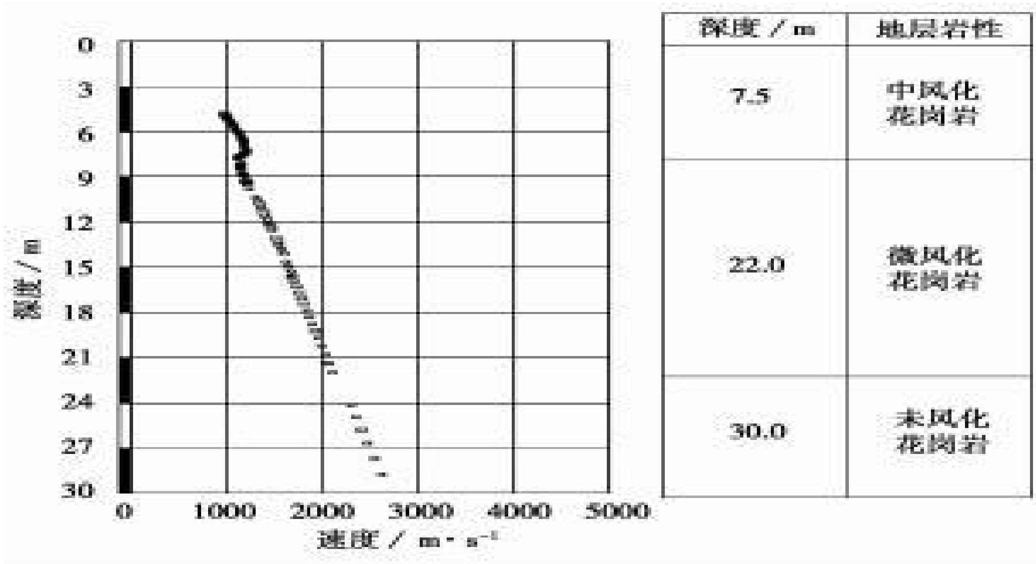

Fig 5 Diagram of frequency disperse curve

and geological layering

3.3.2 Utilization of the Surface Wave Dispersion Curve

The surface wave dispersion curve is used to generate a velocity imaging color cross-section, and a geological cross-section map is drawn based on this. The surface wave velocity contour map for one of the survey lines is shown in Figure 6, and the subsurface geological profile is shown in Figure 7.

Through the surface wave testing method and seismic reflection wave testing method, the subsurface geological layers were analyzed and compared. The distribution and geological properties of the strata in the survey area were basically ascertained. The surface layer is moderately weathered granite, which basically covers the entire survey area. Its bottom interface is generally distributed at a depth of 0 to 6 m. In some local areas, there is a strongly weathered granite layer, but its distribution area in the survey area is relatively small. The slightly weathered granite layer exists throughout the entire area, with a thickness of about 15 m.

In summary, the overlay in the survey area is relatively stable, with the surface rock being relatively intact and the deep rock having good integrity.

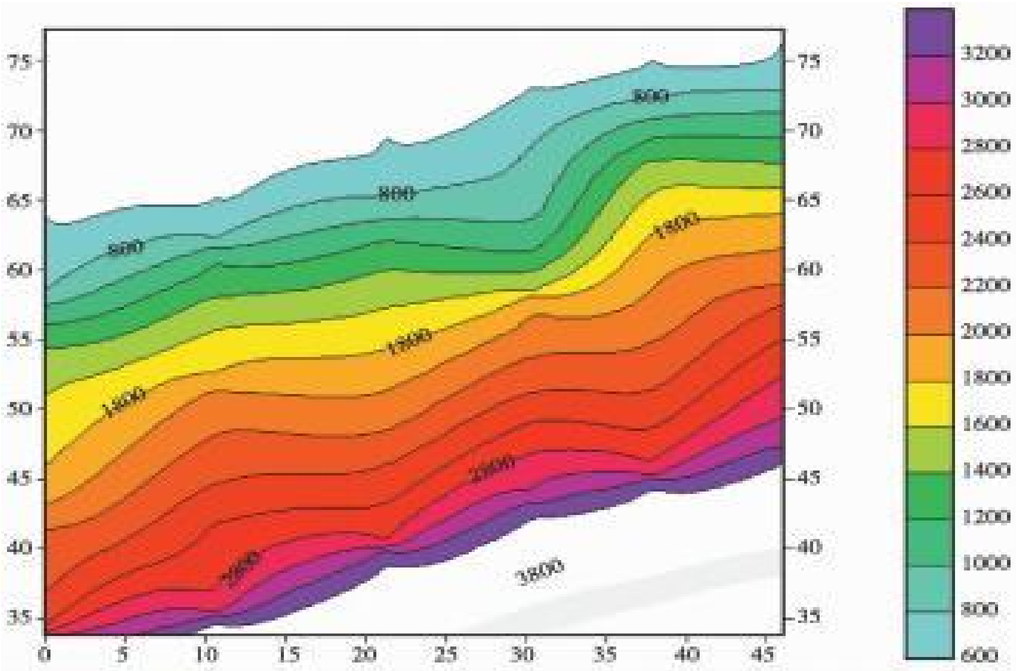

Fig 6 Isopleth of surface wave velocity

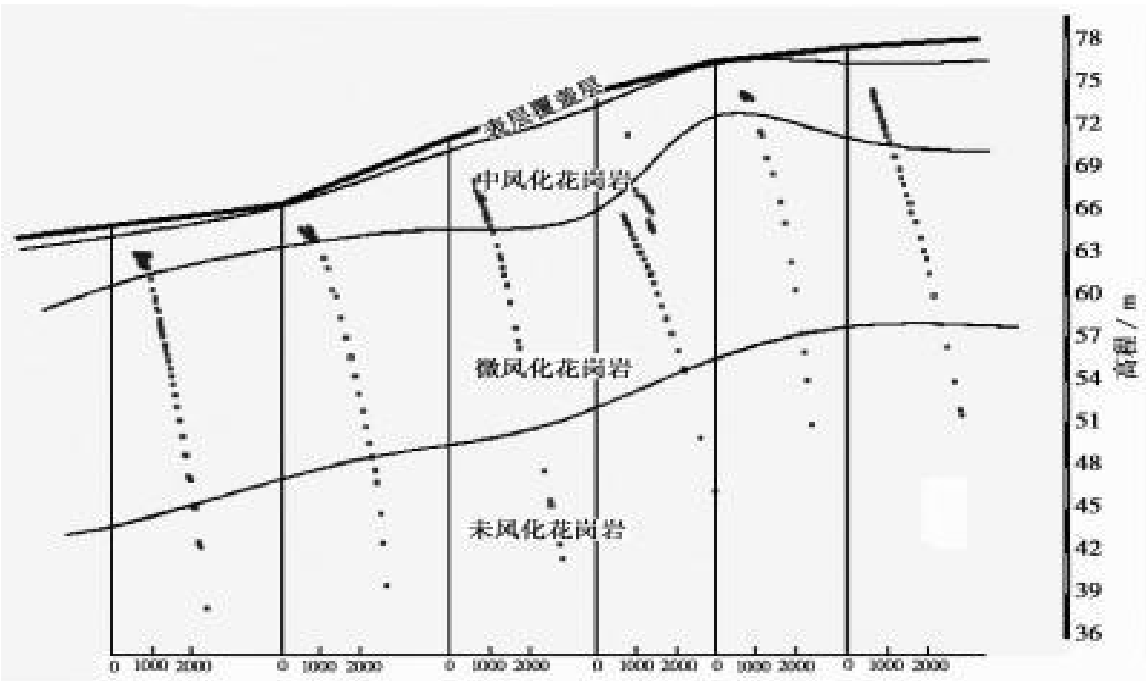

Fig 7 Geological profile diagram

4 Conclusion

The engineering examples demonstrate that the multi-channel transient surface wave method can detect the distribution and properties of stratified media in slope engineering. This provides a basis for stratification of rock media in slopes and for identifying potential sliding surfaces of the slope. However, from the processed data, we also identified some issues. Due to various operational and recording errors, there is room to improve accuracy. Furthermore, due to limitations in frequency and energy, the detection depth is confined to a certain range. This calls for more in-depth research on our part.