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Detecting the Weathering Structure of Shallow Geology via for Ground-Penetrating Radar

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Abstract: Taiwan exhibits very complicated features(Figure 1). Under the subtropical climate of high temperatures and moisture, the weathering reactions are both powerful and fast. The result, after weathering is the formation of regolith which often accumulates at hills, tablelands and slopes, and which can easily induce engineering problems such as slides and collapse during the rainy season. At present, the engineering industry often adopts methods such as shallow seismic reflection survey and drilling sample to investigate the properties and depth of regolith profiles. The drawback is that it not only damages the structure of the existing ground, but the sampling range is also limited, cost is higher and operation speed is slower. For shallow seismic reflection survey, on the other hand, scattered energy of reflection waves and slow speed of weathering, have entailed a poor resolution of stacked profile and the impossibility of accurate reading.
In order to seek an accurate, fast, economic and non-destructive method that can thoroughly investigate weathering and characteristics of underground geology, an attempt has been made to adopt GPR for detecting underground weathering of shallow layer. The experiment is done in mountainous area of Houlong Township, Miaoli County; the rock type of stratum is Shangshan sand rock of Pleistocene Toukoshan Formation. The research results indicate that there is an obvious reflection surface of electromagnetic waves, where the GPR can easily and accurately read out underground weathering. The result verifies that the method is not only accurate, fast and capable of reducing the high cost of seismic survey and drilling, but can also act as reference for regolith surveys for future industry.

Keywords: Ground penetrating radar (GPR); shallow seismic reflection survey; weathering reaction; slide; collapse.

1. Introduction

Taiwan's subtropical climate high temperatures and moisture, so the weathering reactions are powerful and fast. The results, after weathering, form into regolith which often accumulates at hills, tablelands and slopes, and which can easily induce engineering problems, such as slides and collapse during the rainy season. At present, the engineering industry often adopts methods such as shallow seismic reflection survey and drilling sample to investigate the properties and depth of regolith section. The drawback is that it not

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only damages the structure of existing ground, but the sampling range is also limited, cost is higher and operation speed is slower. For shallow seismic reflection survey, on the other hand, due to scattered energy of reflection waves and slow speed of stress traveling in weathering structures, it has resulted in poor resolution of stacked section and impossibility of accurate reading.

At present, the technology of non-destructive testing has shown obvious advances and the scope of applications has also expanded. Since the use of radio waves to test the thickness of ice layers, the technology of using electromagnetic waves as a survey tool continuously advances, and the method of GPR has been extensively used by academic and engineering industries for various aspects of research and applications. For example, Daniels et al. (1988) used GPR to detect ground soil stratum, and discovered that the decline of the radar wave in soil substantially relates to the conductivity of the soil itself. In 1990, GPR started to be used extensively in geotechnical engineering, which includes investigation of objects buried underground, investigations of soil or layer structure, as well as the detection of the depth of underground water levels and change of water content.

Since 1990 till now, GPR has become more mature due to advancing technology. The modifications of hardware equipment, extensive application of computer technology on testing method and data processing have boosted the detecting ability of GPR. In addition, the designed instrument has become lighter, the performance more stable, with the testing speed and resolution also relatively enhanced. This has allowed detection of GPR to be more extensively applied in various fields of geotechnical engineering.

Through the characteristics of different structure between regolith and parent rock that differing in terms of electrical property, the objective of this study is using GPR to detect shallow regolith of reflection interface and to further determine thickness of regolith, which can be used as reference for applications of future engineering development.

2. Theory of gpr

The GPR applies the principle of wave reflection that generates 10MHz to 1500MHz of wave (radar wave) for nano-second (ns) duration, via a power discharge coil of several volts. The wave penetrates into the underground or building structures, with the incident wave reflected to the ground surface via underground stratum interface of different electromagnetism, whereby highly sensitive antenna will receive partial signals and automatically store them. The recording time is determined according to detecting target with minimum of 1 ns and maximum of 32767 ns. After general processes, such as compensation for Declined Amplitude and Filter, plus Special Processes, including Speed Analysis, Deconvolution and Migration, the data recorded generates a Travel time wave section and this is used to plot the profile of the underground stratum and detect artificial objects buried underground.

Figure 2 is the illustration for GPR detection; Tx represents the transmission antenna and Rx is the reception antenna. While moving along the ground surface, the GPR transmits waves to penetrate the stratum and reach interface below the ground surface. The reflected wave that is generated is picked up by reception antenna when returning to the ground surface, producing the image and shape of the interface illustrated in Figure 1

This experiment is performed on County Highway No.119 over a mountainous area of Houlong Township, Miaoli County, with a total test length of 160 m (shown in Figure 2). The rock property of stratum is Shangshan sand rock of Pleistocene Toukoshan Formation. The GPR equipments used were an SIR-3000 machine and 16-80MHz antenna(shown in Figure 3). The test mode applied the Common Depth Point (CDP) method (shown in Figure 4). For data processing: Distance Normalization adopted 200 trace lines per meter; Gain adopted five stages of parameters, namely 4.0, 34, 38, 41 and 41; and Filter adopted LP=85MHz and HP=5MHz.

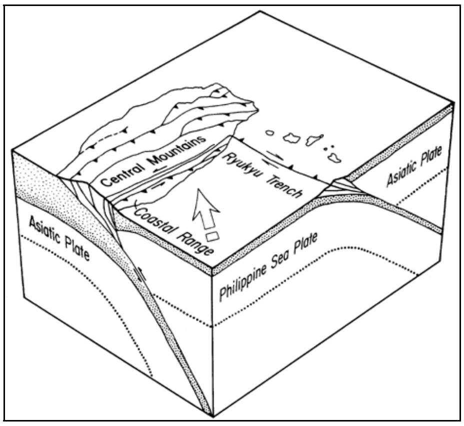

Figure 1. Taiwan by the Philippine Sea plate and Eurasian plate collision

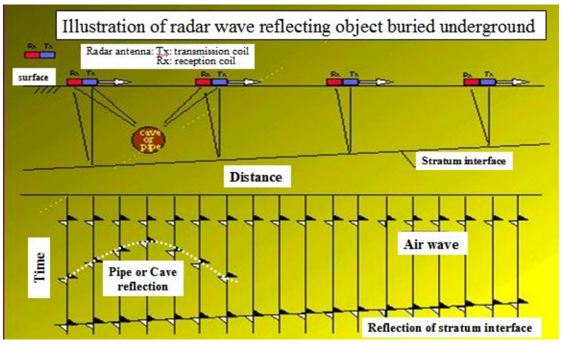

Figure 2. Illustration of survey with GPR

Figure 3. SIR-2 machine and 16-80MHz antenna

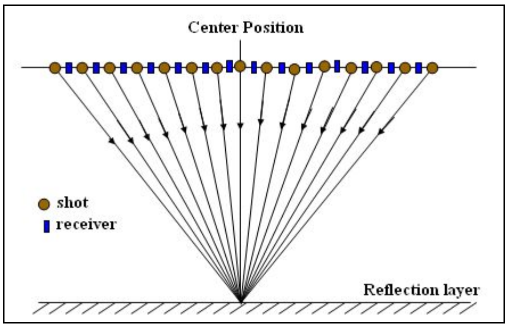

Figure 4. Common Depth Point method

3. Result analysis and discussion

The test area of this study consisted of 160 m along County Highway No.119 and formed a 2-D section of underground stratum structure. According to this stratum section, the reflection interface of the stratum structure can clearly be seen, whereby location and thickness of underground regolith can be estimated. The study by Kui-Tsung Lee (1996) pointed out that since there is an uneven composition of colluvial soil, which contains uneven particles of rubble and soil, most of the GPR reflections are scattered while the rocks are more intact. Hui-Lian Wang (1993) considered that attenuation of general medium with less speed is greater, thus the radar image is often shown as a narrow shaped strip with same direction; in other words, the wave shape becomes narrower, e.g. mud or soil containing water. The media such as sandy rock, limestone or rock-earth containing less water, with low declination and high wave speed on the other hand, show a wider wave shape. Figures 5 and 6 display the GPR section for distance on ground surface, at 0 m~20m and 20m~40m.

From the Figures, a clear surface of reflection can be observed at distances of 0 m~10 m from ground surface and underground depth of 10m, which shows different electrical properties of stratum above and below the reflection interface. At a distance of 10m~45m from ground surface, this reflection surface blurs gradually, which shows that property variance of material composed in the area is not large and is thus the area without obvious reflection contains evenly gradual change of the weathering level.

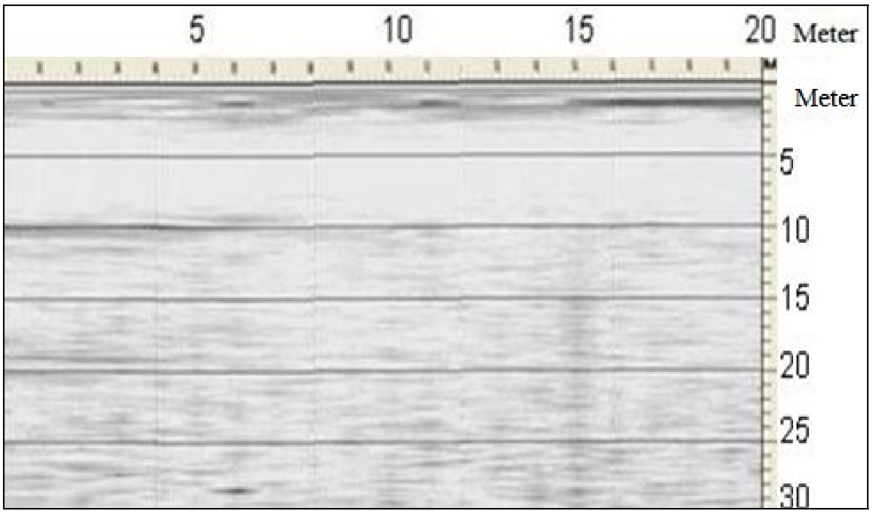

Figure 5. GPR Section at a distance of 0m~20m from ground surface

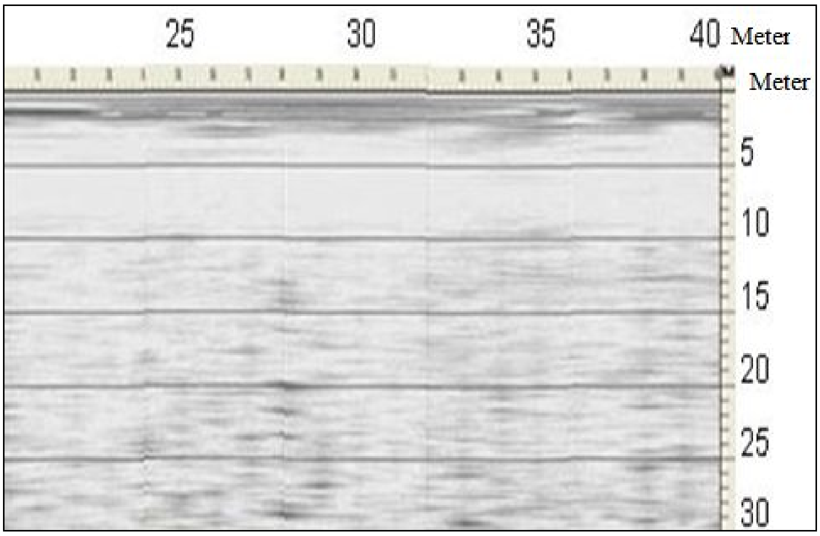

Figure 6. GPR Section at a distance of 20m~40m from ground surface

In Figure 7, with a distance of 45m~50m from ground surface, both depths of 8 m and 26m showed strong signal of reflection. The reflection surface of shallow layer is a weathering interface where great difference appears between the weathering levels above and below the interface. The reflection surface of the deep layer is the stratum interface with different rock property.

At a distance of 50m~74m from ground surface, the reflection surface of the shallow layer still continues to show at descended depth of approximately 11m (see Figures 7 & 8).

In Figure 9 with a distance of 75m~85m away from ground surface, the underground structure shows 2 very strong signals of reflection, which clearly divides the stratum into 3 layers. The area of 3 m~10m below ground surface is the shallow layer; the surface at a depth of 10 m below ground surface has very clear continuous image. The reflection signal is also very strong between 11m~17m below ground surface, which shows that the property of this layer differs a lot from the layers above and below it.

In Figures 9, 10, 11 and 12, the reflection surface of the shallow layer at 85m~157m from ground surface appears at depth of 10 m below ground surface. The reflection signal is not strong, indicating that underground materials of this area have even properties. At 129 m from ground surface, there is a clearer reflection signal between depths of 10m~15m under ground surface, which belongs to lighter degree of partial rock weathering. According to a study by Toshioka et al. (1995), the electromagnetic wave generates a reflection with a discontinuous surface. If the crack is full of water, the reflection wave will be very strong. It is determined that the strong signal of reflection in this area might be caused by rich content of underground water.

In Figure 12, the reflection surface at 157m~160m from ground surface is very obvious, but the deep section shows rather less reflection.

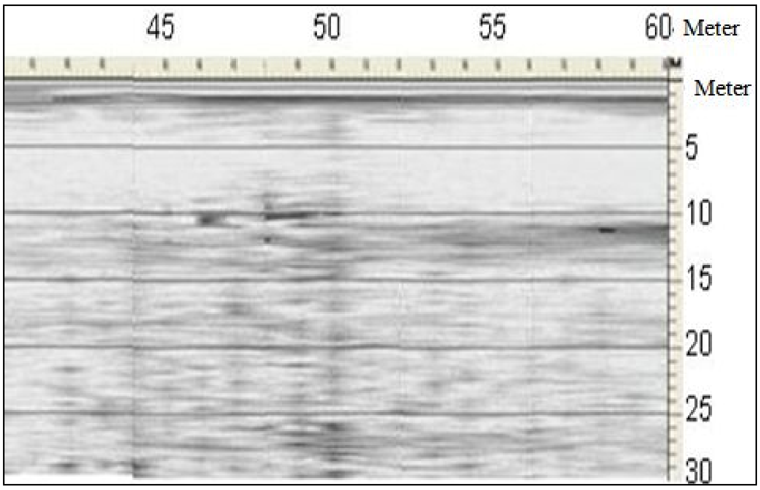

Figure 7. GPR Section at a distance of 40m~60m from ground surface

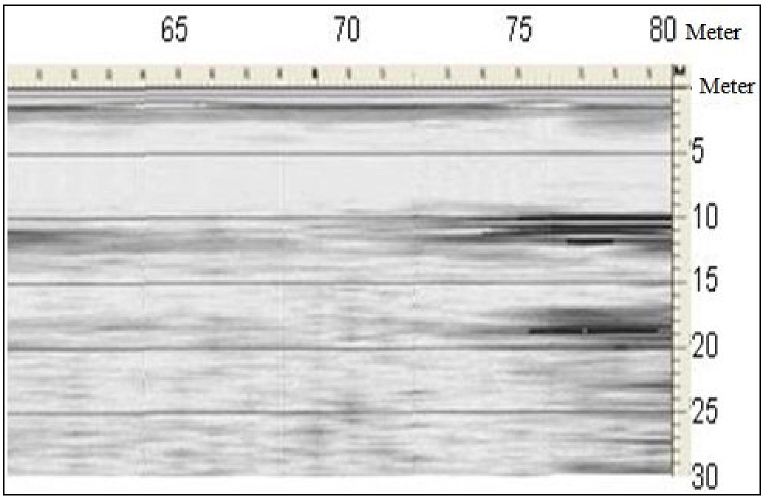

Figure 8. GPR Section at a distance of 60m~80m from ground surface

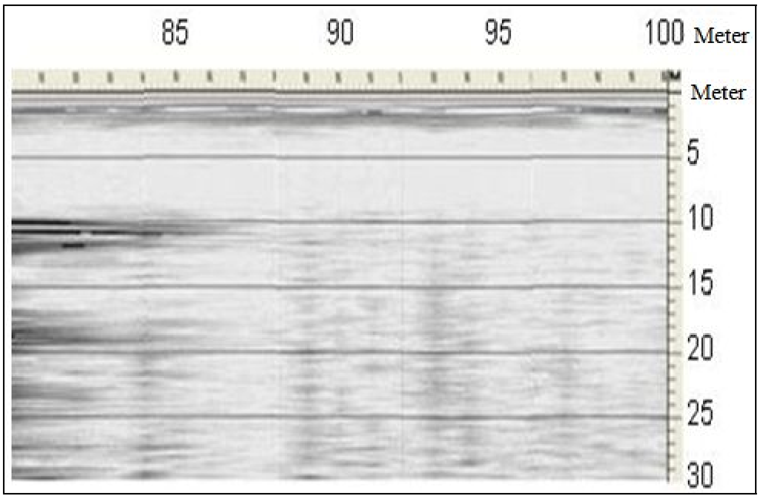

Figure 9. GPR Section at a distance of 80m~100m from ground surface

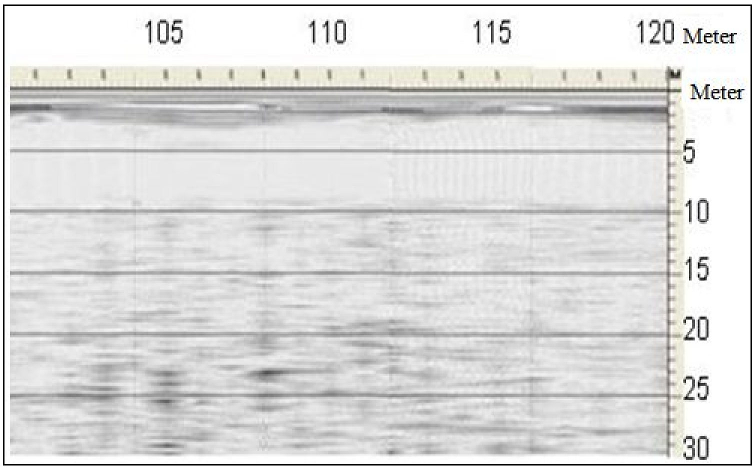

Figure 10. GPR Section at a distance of 100m~120m from ground surface

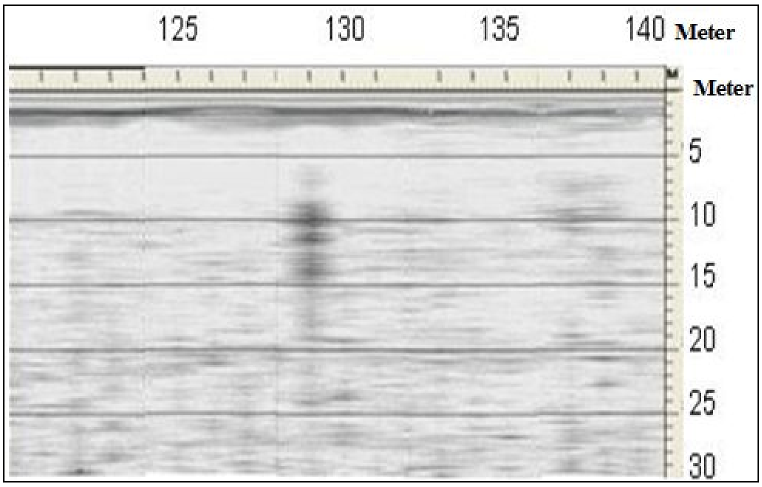

Figure 11. GPR Section at a distance of 120m~140m from ground surface

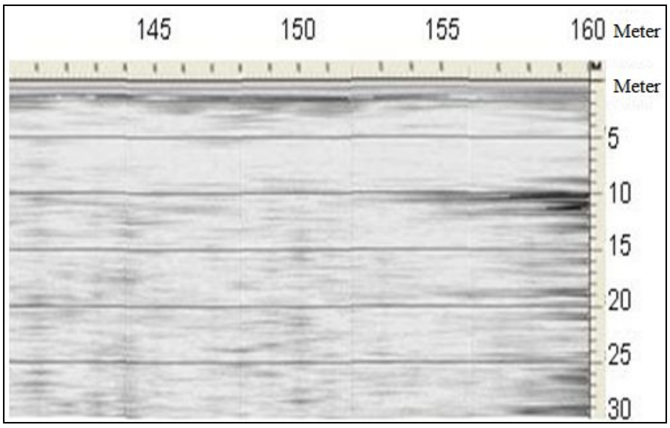

Figure 12. GPR Section at a distance of 140m~160m from ground surface

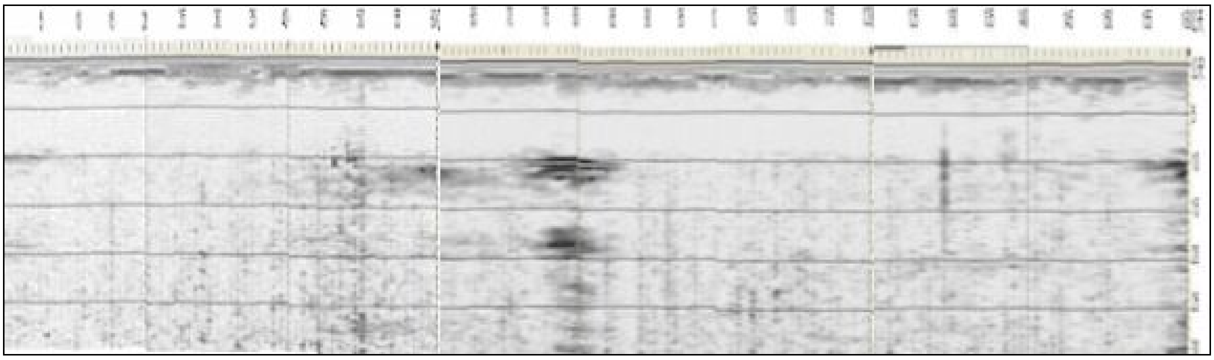

Figure 13. GPRSection of the entire test line

4. Conclusion

From the Section of this study in Figure 11, the reflection surface at approximately 10m below ground surface can be treated as the interface of regolith. The degree of weathering and thickness of rock under such ground surface differ due to the influence of many factors, and the interfacial magnitude (or depth) of such reflection surface shows a slight rise. However, there are strong signals of reflection at certain spots and this indicates obvious difference of stratum characteristics at that spot.

From this study, it can be seen that the spot at 25m underground still receives strong signal of reflection. This indicates the feasibility of detecting shallow geology for geotechnical engineering with GPR at lower frequency. As for the issue of fast deceleration of wave speed and incapability of deep penetration for GPR, further research is required.

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