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A Study on the Technologies for Detecting Underground Water Level and Processing Image

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Abstract: Under the massive compression forces from three major tectonic plates (Fig. 1), the geotectonic structure of Taiwan is characterized more by tall steep mountains than by flat lands. For this reason, underground water often flows directly from rivers into the sea, rather than being collected by reservoirs, a feature which contributes to the meager underground water resource. Furthermore, since most flatlands are formed by loose alluvium, and free underground water nearer the surface often rises during the rainy season, while the stratum in mountainous areas are commonly characterized by discontinuity (plane) and broken rock soil, this makings for a relatively complex underground water path. In terms of underground water site investigations, the drilling method commonly adopted is both labor intensive and material consumptive.

The aim of this study was to investigate the feasibility of detecting underground water level by using GPR (Ground-Penetrating Radar). A vacant land adjacent to the playground of an elementary school in Miaoli City was used as the experimental site, and tested with the SIR-2 mainframe and 80MHz antenna developed by GSSI (USA), according to the CDP seismic method. From the data compiled and images generated thereby, this study found the underground water level approximately between 11m to 16m underground. Thus, GPR has proven to be an effective detection method for underground water level, and can serve as reference for future applications.

Keywords: Ground-Penetrating Radar (GPR); Underground Water; Common Depth Point (CDP); Tectonic.

1. Introduction

The conventional underground water survey method is regarded as "Destructive Surveying" (e.g. monitoring wells, drilling and excavation) that often consumes excessive manpower resources and yet cannot accurately establish a network of underground water levels. All destructive surveying methods mentioned above provide specific suitability and constraint, but lack speedy convenience and low price if consideration is given to practicality, efficiency and economy. When solving specific types of underground water surveys, the selection of an effective and economical technique is significant in regard to results and efficiency of the survey. Therefore, it is necessary to develop a survey method with which to improve the testing

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technique with greater accuracy and precision.

The characteristic of GPR (Ground-Penetrating Radar) is that the transmitting antenna pointing towards the ground constantly transmits radar wave of 10~2500 MHz in very rapid velocity (speed of light in a vacuum environment). When a certain interface or object changes the conductivity or dielectric constant under the electromagnetic characteristic, a partial radar wave is reflected to the ground surface (Figure 2). The image is then displayed on the screen and, after processing, the signal can be plotted into a Distance-Time diagram which can be used to determine the position of abnormal underground electromagnetic waves as well as to estimate the relevant stratum interface.

The SIR-2 System (Figure 3) manufactured by GSSI (Geophysical Survey System, Inc.) (USA) was used as the instrument for the study, and study site (Figure 4) is located on vacant land to the right side of the playground at Wenshan Elementary School in Miaoli City. The test mode was similar to a reflective vibration test on CDP and the earth quality on site was mainly that of wet soil. The total length of test line was 100 m. With the skill of data processing, results were determined after the test and it was found that the GPR could accurately survey the underground water level, which verified the feasibility and practicality of surveying underground water with GPR.

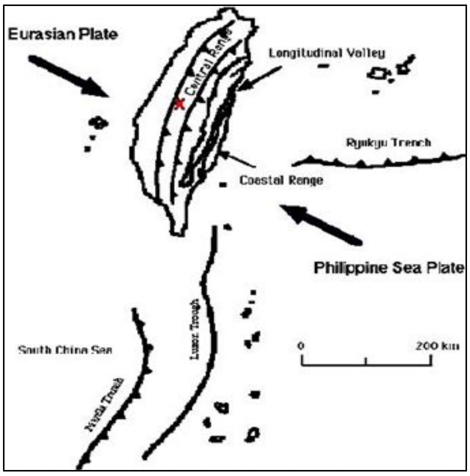

Figure 1. Land structure of Taiwan squeezed by 3 tectonic plates

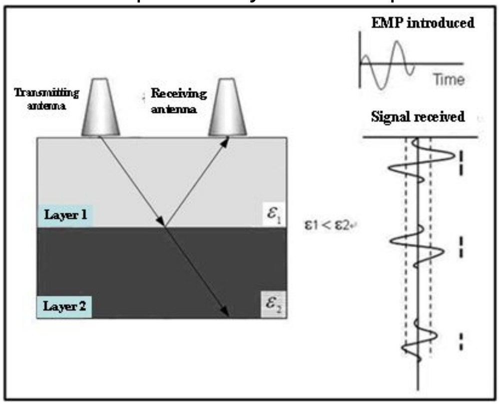

Figure 2. Principles of GPR image

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

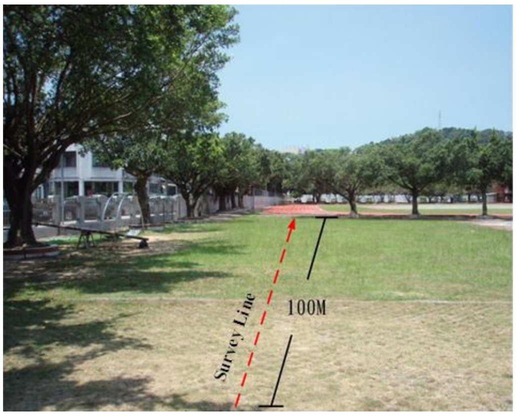

Figure 4.Test line on site

2. Literature Review

From the mid 60's to the early 70's, the military development in the USA established a significant initiation of GPR, and it was extensively applied for gauging the thickness of ice layers, mining, underground water level, soil interface, underground cavities, faults and layer texture. After the 1980's, a technical breakthrough was achieved in regard to GPR software and hardware; as a result the technology on resolution, test depth, data processing and analysis improved significantly. The fields of application expanded from the conventional geotechnical and mine surveys to such disparate fields as archaeology and pollution.

Regarding engineering applications of underground water surveys, many domestic and foreign experts and scholars have made studies to certain limited depths. Tronicke (1999)[1] established an underground water contour map on sandy land with the application of GPR and ground resistance in order to define the hydrological changes of an island. Nakashima (2001)[3] achieved more than 10m of depth in underground water surveying with GPR via improvement to the signal and noise ratio. In the study by Sato and Lu (2002)[2], GPR provided an effective technique for monitoring the changing underground water levels. Travassos and Menezesb (2004)[4] broke through the GPR applicability boundaries and carried out underground water survey in crystal land. Topp et al. (1980)[5] proposed the relationship between water content in soil ($\theta\nu$) and the dielectric constant to derive the characteristics of electromagnetic wave of non-saturated soil layer. Shih and Doolittle (1984)[6] noted that the reflection coefficient and height of the edge for capillary tube must be considered when surveying underground water levels with GPR.

Liang (1990)[7] noted that due to the difference between dielectric constants of water and soil, a reflection wave would be generated when the electromagnetic wave of GPR comes in contact with an underground water surface. Hence GPR could be used to test underground water level. In the study by Beres and Haeni (1991)[8], the underground water surface could be detected more easily in sandy soil layer than in clay layer. In the study by Yang and Liao (1994)[9], the results indicated that GPR would produce an even interface against underground water. Chou (1994)[10] were able to successfully monitor the shallow underground water for tide changes and seawater infiltration at a coastal region. The test result obtained by Lee (1996)[11] revealed promising effects from using GPR for detecting the underground water level and water content in mud rock. Daniels (1994)[12], Dominic (1995)[13] and Benson (1993)[14] concluded that the stratum of underground water level is formed by coarse materials.

3. Principles of CDP with GPR

3.1 Principles of CDP

The CDP (Common Depth Point, Mayne, 1956) method is a concept originating from the reflective seismic test that not only monitors the reflective layer more closely, but also distinguishes between the signal and noise, which further improves the creditability of the section (as shown in Figure 5). Since the lateral distance and travel time of a CDP signal differs, the data of speed for transmitting electromagnetic wave within the stratum was provided. A sectional diagram was plotted with the line passing various CDP's and the section represented the basic distribution of the underground stratum.

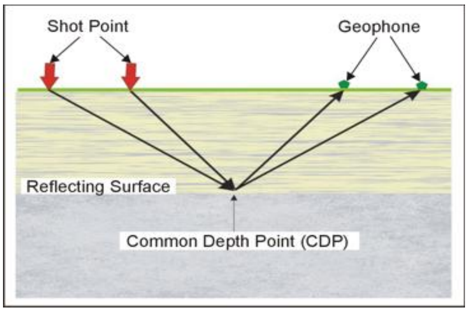

Figure 5: Principle of CDP test

According to the relationship between travel time and speed, the converted depth of the reflected signal can be obtained and shown in the vertical axis of the following GPR imaging graphs.

3.2 Data collection with GPR

In order to effectively and rapidly detect the target, as well as shortening the time and enhancing the quality, the GPR test must incorporate adequate settings, and the factors considered are referred to as the survey-process (as shown in Figure 6).

The influence of factors such as method of GPR recording, selection of monitoring system, type of underground interface and characteristics of wave transmission would generate differences between data and geotechnical space. In addition, diagrammatic distortion often occurs in the GPR wave records due to the noise, so it was difficult to analyze the status; therefore, data processing was used to assist the diagrammatic interpretation. During data processing, however, although the signal must be expressed as much as possible, excessive expression that generates false images must be prevented since it would cause misinterpretation (as shown in Figure 7).

4. Data Processing and Analytical Interpreation

(1) Use the data processing software "RADAN" to load original data and set every mark at intervals of 1m for a total length of 100m. The section of underground water level can be identified basically from the signal image (as shown in Figure 8). With the continuous connection of crests in the Wiggle diagram (Figure 9), the underground water level can be identified; however, many noises still existed.

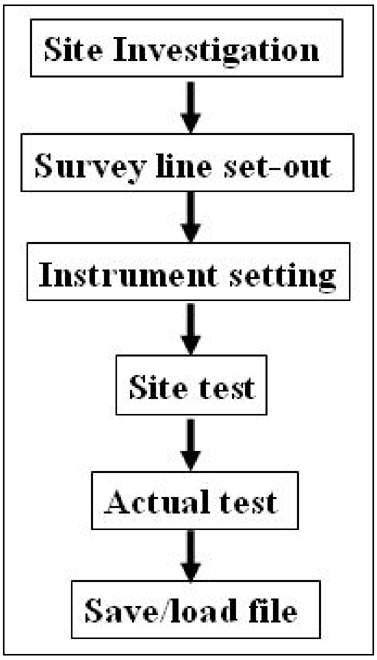

Figure 6: Flow Chart of Survey-Process

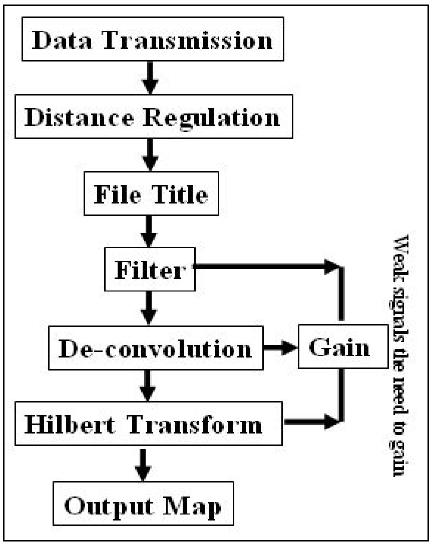

Figure 7: Flow Chart of Data-Process

(2) Due to the use of an 80MHz antenna, the frequency of reflection signal for site data must be lower than 80MHz. The filter is set at the range of 27MHz for high pass filter and 160MHz for low pass filter to eliminate unnecessary noise. After filtering, the energy was reduced and the sectional image

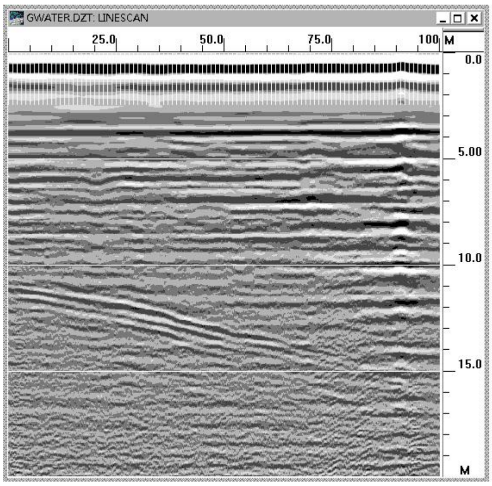

Figure 8: Original diagram after regulation

weakened (Figure 10), with the noise of the crest reduced significantly in the Wiggle diagram (Figure 11).

(3) De-convolution was used to eliminate he continuous fluctuation series of complex reflection which occurred when the radar wave was in contact with the interface. After elimination of complex reflection (Figure 12), the section of underground water level became relatively obvious. In Figure 13, the crest of the complex reflection in Wiggle diagram reset to a smoother state.

(5) The process of Hilbert transform displayed the status of underground water level distribution in the stratum (as shown in Figure 16). The process simultaneously enhances the images of the strips for the whole depth range.

(6) Software was used to overlay the diagram and Wiggle diagram for clearer demonstration of trend for the section of underground water level and continuity of Wiggle crests (as shown in Figure 17~20)

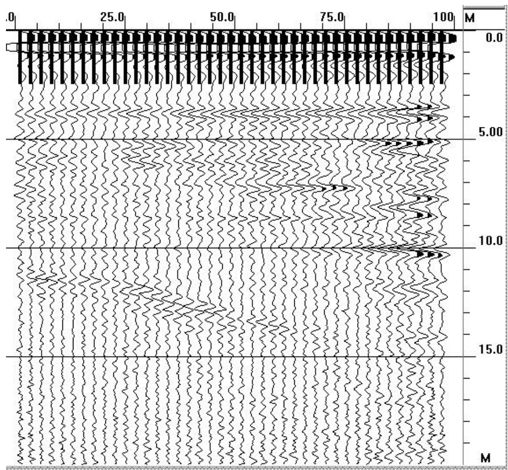

Figure 9: Original Wiggle diagram after

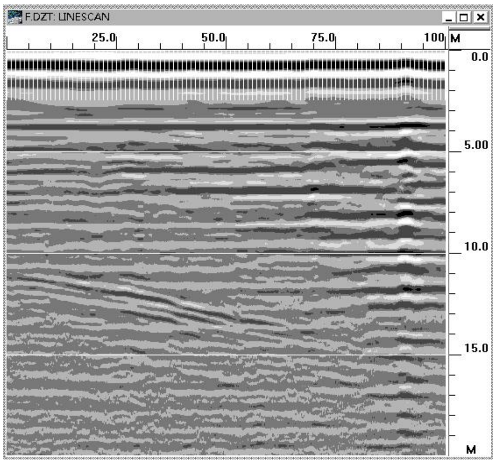

Figure 10: Diagram after filtering

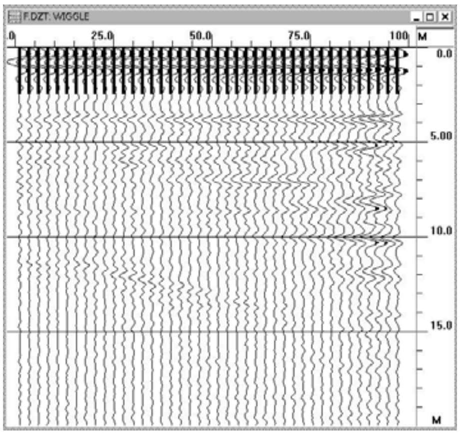

Figure 11: Wiggle diagram after filtering

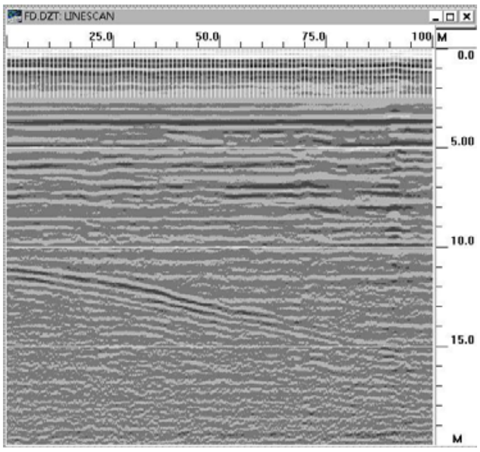

Figure 12: Diagram after de-convolution

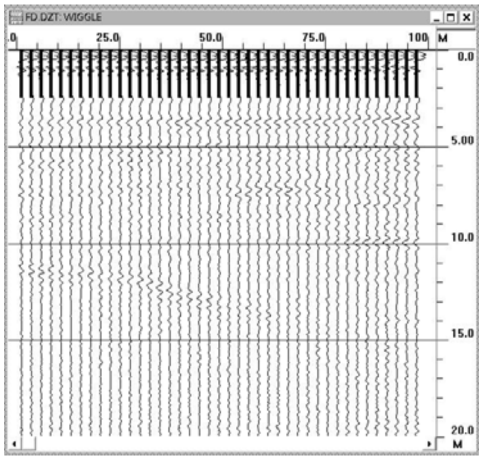

Figure 13: Wiggle diagram after de-convolution

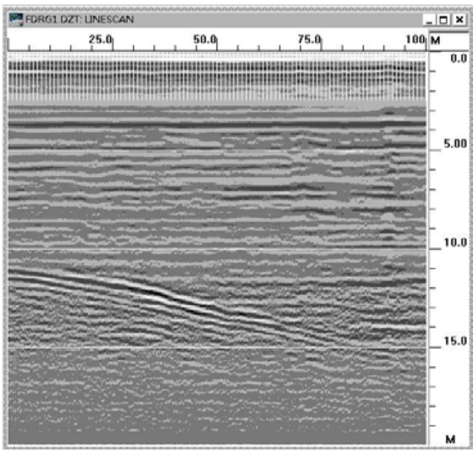

Figure 14: Diagram after gain

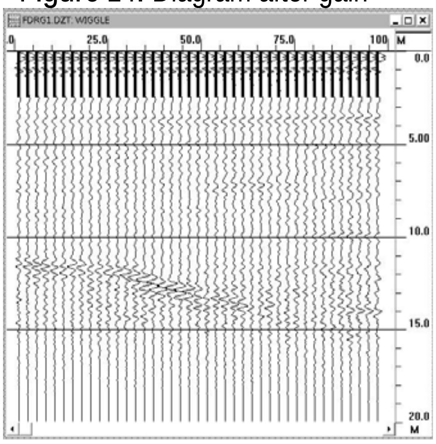

Figure 15: Wiggle diagram after gain

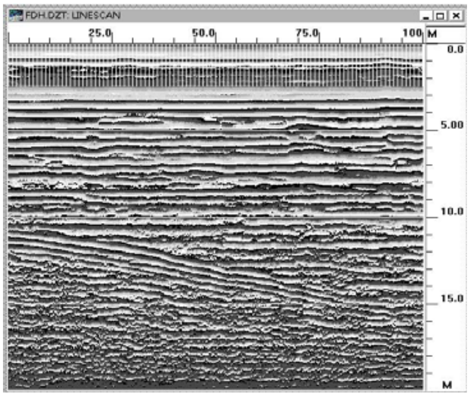

Figure 16: Diagram after Hilbert transform

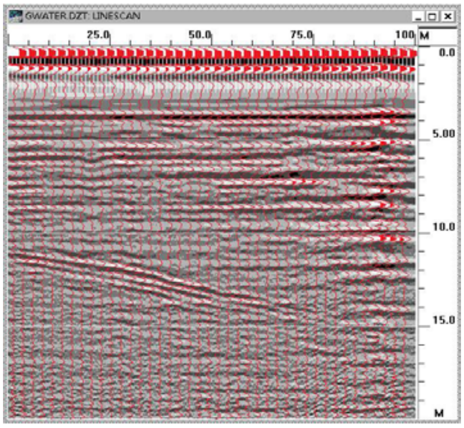

Figure 17: Overlaid demonstration of original diagram and Wiggle diagram after regulation

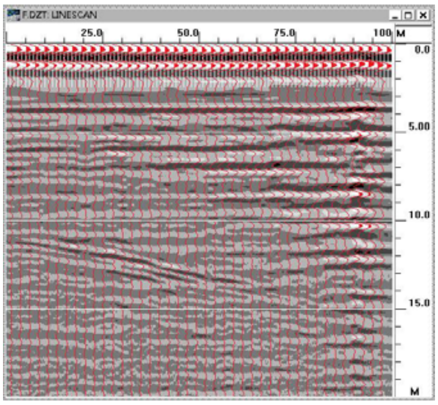

Figure 18: Overlaid demonstration of original diagram and Wiggle diagram after filtering

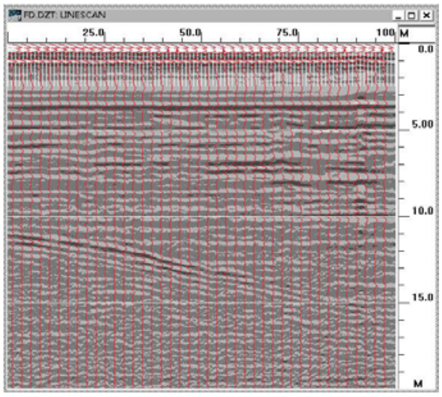

Figure 19: Overlaid demonstration of diagram and Wiggle diagram after de-convolution

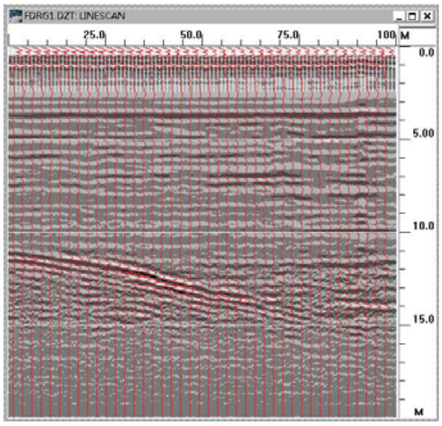

Figure 20: Overlaid demonstration of diagram and Wiggle diagram after de-convolution

5. Conclusions

Due to numerous uncertain factors during GPR testing on site, some unknown noises appear in the image and the post-process (e.g. regulation, filter, de-convolution or gain) before interpretation will assist in the correct identification of images. After re-processing and analytical interpretation of the data, the following conclusions were derived:

The underground water was found to extend from a south-east to north-west orientation, which approximately extended from 8m to 15m.

In situ, a ditch is located near the north-west end of the test line and the common water level of the school building is found in the drilling report used for school construction. According to the information, it was confirmed that the water level has a downward-sloping in the south-east to north-west direction at the depth about 11-16 meters.

(1) The fast, high-resolution and non-destructive characteristics of GPR have proven to be very useful for contemporary geotechnical engineering application.

(2) The diagrammatic characteristics and skill of signal identification could be used as reference for future studies.

(3) Although there have been many cases of successful GPR application and continuous improvement of technology (e.g. development of 3D image, image processing) incorporated with other non-destructive test methods, there is still vast room for development for theoretical and actual future applications; therefore, interested researchers are advised to continue with active development in this direction.

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