Experimental study on the refinement detection at the bottom of foundation pit used by GPR in the strong interference environment

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Abstract. Due to the refraction of the detection environment and conditions, the electromagnetic waves emitted by the ground penetrating radar are susceptible to interference from external factors. The received reflected waves often have the characteristics of "weak signals and strong interference", resulting in low sensitivity and low signal-to-noise in the collected data. Resolution tolerances cause difficulties in data interpretation. Based on the uniqueness characteristics of spectral response for the single medium, and the differences of energy intensity between effective signal and interference signal, the spectrum energy intensity analysis is introduced into signal processing in this article, the spectral response feature of different target mediums have been extract from the signal of radar reflected wave, the spectral energy strength about the underground target medium has been calculated, and the geological distribution feature of underground soil has been inversed according to three-dimensional reconstruction technology in further. It showed that this data processing method proposed in this article can remove interference and preserve effective signal which even weak and deep at the same time by the detection and application effect in the strong interference environment at the bottom of construction foundation pit, the interpretation accuracy of ground penetrating radar had improved and the purpose of refinement data processing had achieved.

1. Introduction
The geotechnical engineering investigation is very important during the construction of foundation pit engineering, it can provide the reliable data support for the design and construction of foundation pit engineering though accurate and strict geotechnical engineering investigation, and can ensure project construction safely and reliably. The conventional engineering investigation mainly uses geological survey, drilling, geotechnical test and other methods to find out the stratum structure of construction field, the physical and mechanical properties of each rock and soil layers, the type of underground water and the buried depth of groundwater, and whether adverse geological effect which interference site stability exist and its harm degree. But the investigation results often have locality and limitation with the characteristics of point and line, and these are unable to understand the overall situation of the region.

The ground penetrating radar is a kind of fast, successive and non-destructive electromagnetic detection technology, which has the feature of fast collection and high-resolution. It has been one of the most important technical means for geological investigation in construction [1,5]. Because multiplicity characteristics of collected signal analysis, these will lead to the uncertainty of abnormal interpretation. Especially for the GPR signal under the external strong interference environment which
are relatively deeper, weaker and contain more clutter [6], its abnormal information is difficult to visually reflect, and it can’t meet the need of fine geophysical prospecting about underground engineering. Therefore, the spectral energy strength analysis is applied and it provides a new way for GPR signal processing and fine interpretation [2].

The proposed building in the test and research site is a high-rise residence, with 14 floors above ground and 1 underground, a building height of 40.1m, and a buried depth of 3.7m below the ground. The foundation pit had excavated to the bottom and bored piles had been finished, under the strong interference conditions, GPR was used for the supplement investigation about the conditions of the basement at the bottom of foundation pit [4], in order to find out the geological conditions of basement and the deeper range, detect diseases such as loosening or voiding of the basement caused by the excavation of foundation pit [7], and verify the detection effect of GPR in the strong interference environment after using the new data processing method.

2. The detection of refinement with GPR at the bottom of foundation pit
GPR launches natural frequency electromagnetic waves through transmitting antenna into target medium in the form of high-frequency wide-band and short pulse, and the electromagnetic waves are reflected and received by the receiving antenna on the surface with the features changes of underground medium. The electromagnetic reflected waves can be as a synthesis result of electromagnetic polarized wave with the same frequency and the same direction transmitting formed from the different mediums and abnormal underground. The conventional GPR and combination antenna are used to collect radar reflected wave data and signal.

GR GPR was used and configured 100MHz low frequency shielded antenna in the field detection, 200ns was selected as time window and 1024 was selected as sampling number. Meanwhile, RTK was used to locate accurately for the starting and finishing points about measured profile. And then, the random point measurement had been done in the field.
3. The data processing of spectral energy

3.1. The data preprocessing
The data after editing will be done some pre-processing such as zero point offset, two-dimensional spectrum analysis and others by the conventional geological radar processing and analysis software.

3.2. The discrimination of target medium signal
The original signal by directly measured in superposition synthesis system and express different sine waves information and characteristics about frequency, amplitude and phase. Through the Inverse Fourier Transform, a frequency spectrum of non-periodic synthesis signal by collecting can be decomposed countless periodic signals with the continuous variation in time domain. Then the decomposed sampling signal will be identified and the signal of target medium will be determined according to the unique spectral response characteristics from different mediums [3], and then the unique frequency spectral line characteristics of target medium will be determined by the frequency response characteristics on the wave phase.

3.3. The separation of frequency response characteristic
According to the result calibrated by center frequency of GPR antenna, amplitude spectrum and frequency belt width of the standard reflected wave will be analyzed, and the main frequency response of electromagnetic waves polarization will be separated from different mediums.

3.4. The calculation of spectral energy strength
As for a single medium has unique frequency response. According to the main frequency response value and frequency response range of different mediums above separated, the spectrum strength of different mediums are integrated through the spectral density function $F(\omega)$ in respective bandwidths, and the total spectrum strength of target medium is the integration of spectral density function $F(\omega)$ in the whole bandwidth range. The spectral energy strength of target medium in frequency response spectral domain can be calculated.

$$K_n = \frac{\int_{\omega_1}^{\omega_2} F_n(\omega) d\omega}{\int_{0}^{\omega_2} F(\omega) d\omega}$$

In the formula, $K$ is the spectral energy strength of target medium, $n$ is different medium and $\omega_1$~$\omega_2$ is frequency response range of target medium.

![Figure 3. The uniqueness of frequency response character for a single medium.](image)

3.5. The drawing of image
According to the radar wave response parameters of different mediums were calibrated by the combination configuration of radar host and antenna. Applied data processing software of the spectral energy algorithm compiled by C++ language, the amplitude spectrum of standard reflected wave signal was analyzed in known window. The frequency responses of electromagnetic wave polarization
were separated from different target mediums. The spectral energy strength of target medium were obtained through calculating in the frequency response spectral domain. Combined with surveying point coordinates and spectral energy strength values of particle in the different time windows, the equivalent profile of spectral energy strength distribution about rock and soil layers drawn and obtained through kriging interpolation, in order to judge and identify the geological conditions about much deeper the bottom of foundation pit.

4. The analysis and interpretation of test effect

4.1. The comparison and analysis on the two-dimensional results

The L3-L4 profile which is done for conventional processing shows that the waveform is uniform in shallow and there are stronger reflection waves in local position, and infer that it is interferenced by bored pile at the bottom of foundation pit. In the middle depth of profile position, the waveform of local position is more unorganized, the event is leap and discontinuous, but the strength of reflection wave is much stronger, which is caused by the loose soil or disturbance. The reflection wave is weak in deer depth and there is no obvious abnormality.

The underground geological condition is very clear reflected by GPR image which is processing through the method of frequency spectral energy strength. The layer information of strata is obvious, uniform and compacting in shallow at the bottom of foundation pit. In the effect of the external strong interference, the reflected waves of GPR are more obvious in the middle and deeper depth position, and there are some discontinuous anomalies on the vertical, which is a comprehensive reflection of underground concrete bored piles and surrounding soil. There is no obvious geological abnormality body in the range of detection.

![Figure 4. The conventional processing image of GPR.](image)

![Figure 5. The two-dimensional image of spectral energy strength of GPR.](image)

4.2. The three-dimensional modeling and geological reconstruction

Through detecting with the manner of random point and accurate location in the field of the bottom of foundation pit, the detected area has been divided into a series of rectangular grid units, and physical parameters of target medium in the grid have been processed by homogenization and linearization. The detected target model has been reconstructed through three-dimensional modeling. Combined the point coordinate, elevation and the value of spectral energy strength for particle with different time window, the Voxler software and Kriging interpolation method have been used to inversed and reconstructed the three-dimensional shape and spatial distribution about underground strata, weathering degree, water areas and geological anomalous bodies.
4.3. The verification of detection results

According to the results of geotechnical engineering investigation in the field, there are five main layers and several sub shells in the range of 35.0m depth from the ground surface, the fist layer is artificial filled soil layer, the second layer is recently sedimentary layer, and the following are the general quaternary sedimentary layer with alluvial-diluvial, the Permian layer and carboniferous bedrock layer. Early excavation was more serious in the site and there were formed several pits which had backfilled, the backfill soil was much deeper and the foundation basement were mostly located above the backfilled soil, and there was no obviously adverse geological effects.

5. Conclusions

Based on the differences of frequency response from GPR signal about different mediums can pertinencely calibrate and identify the frequency response feature of the target medium, the effective information with the characteristics of target medium were extracted from the reflected wave with stronger interference. The better application effect has achieved through the practice of engineering, it
can improve the identify ability about the deep weak information and enhance the ability of anti-interference. The geological distribution characteristics of the underground soil at the bottom of the foundation pit were effectively inferred under the strong interference environment of the basement.

Field data collected by GPR is fast and high efficient, the measuring points are accurate located by RTK, the geological conditions of whole area have been known through reconstructing three-dimensional results, which can overcome the limitation in the manner of point and line to infer the whole condition by geotechnical engineering investigation.

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