THE APPLICATION OF GPR IN DETECTING THE FAST FEED SUPPORTING TOWER FOUNDATION

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Abstract: The Five-hundred-meter Aperture Spherical Telescope (FAST), which is a major national scientific project, is sited in Pingtang county of Guizhou province. The geologic structure of this location is complex and the engineering geology condition is rather severe. According to the construction plan of the FAST, six feed supporting towers will be built in a circumference of 600 meters in diameter, to function as the main load-bearing spots. In order to effectively evaluate the stability of the foundation towers and manage the engineering geology diseases, we study the Ground Penetrating Radar (GPR) samples from the FAST feed supporting tower foundation, and show that the geophysical exploration technique plays an important role in Karst foundation detection.

1. Introduction

Ground Penetrating Radar (GPR) is a high precision detection technique in engineering geophysics. Since it has great advantages on many aspects, such as easy to operate and fast to process, it has been a very popular and reliable technique that has been broadly applied in engineering. Since the 70's of the last century, there have been a lot of successful applications of the GPR in Archeological study, field exploration, road and railway route selection, engineering quality inspection, engineering disease diagnosis, tunnel exploration prediction and geological structure study during the last 40 years,

The Five-hundred-meter Aperture Spherical Telescope (FAST) is a major national scientific project, which will function as an international research center for astronomical studies. It is sited in a place called Dawodang in Pingtang county of Guizhou province. It is to the north-eastern Pingtang and about 85km away, and Dawodang is named after its geometric character of “U” shape in profile i.e. a marsh in the center which is surrounded by a closed group of hills (see Fig. 1). This area has a rather regular geometric shape like a wok with a diameter of about 550m at the height of 960m. The bottom area is quite flat with a diameter larger than 250m. The whole area is located in the transitive band from the Guizhou plateau to the hilly terrain in Guangxi province, where the northern part is higher than the south. There are five sizeable hills around the wok, among which the highest one is located at the northern-east side and labeled as Hill no. 1. Its altitude is 1104.10m with a height difference of 352.60m from the wok bottom. It scatters rich Carbonate in this area and the landforms are dominated by the Karst dissolution type. There are also mature Karst hills, terrains, depressions and sinkholes in this place. The rock structure appears to be monoclinic along north-north-east with an angle of 5-15 degrees without significant fractures crossing this area. There are residual slope red clay and ancient slump deposits in the low-lying land and nearby stratum. It contains thick limestone and dolomite of the Middle Triassic Liangshuijing Formation（T_{2L}）in the underlying bedrocks.

The FAST site is a Karst low-lying land with local mature Karst dissolutions. Its geologic structure is complex and the engineering geology condition is rather severe. According to the construction plan of the FAST, six feed supporting towers will function as the main load-bearing spots and to be built in a circumference of 600 meters in diameter and in equal separations at 1H-3H-5H-7H-9H-11H of a clock panel. The metal tower has a mast structure with a height of 90-100m, pressure upper limit of 5000KN, and the largest uplift force of 3500KN. Since the drilling probe is limited to expose the geologic structure information, it is necessary to apply the GPR detection to the foundation detection in association with the drilling method in order to effectively evaluate the stability of the foundation towers and manage the engineering geology diseases.

Figure 1: Real picture of the FAST site (left) and its 3-dimension schematic picture.

2 Methodology

2.1 Work method

Since the six feed supporting towers extend to a rather large field, the drilling detection can only cover limited areas. In order to have a better understanding of the structure of the bedrocks (complete or broken), Karst dissolution and growth, we shall apply the GPR to the exploration in additional to the drilling probe. It will allow us to make a global evaluation of the stability in the construction of the foundation towers.

Table 1: Dielectric constants for different media

Medium type	Dielectric constant (εr)
Quaternary covers	10.0～17.0
Complete limestone	6.0～8.0
Loose cement, broken bedrocks	10.0～15.0
Filled karst caves	12.0～20.0
Karst caves, empty caves	1.0

According to the in-site physical testing results, the dielectric constants for complete limestone, broken bedrocks, and Karsts are different (see Table 1). This is a geophysical prerequisite for the GPR detections. In another word, the GPR detection will be able to provide rather accurate information about the completeness or brokenness of the limestone around the foundation towers, Karsts and their growths, etc.

2.2 Theory

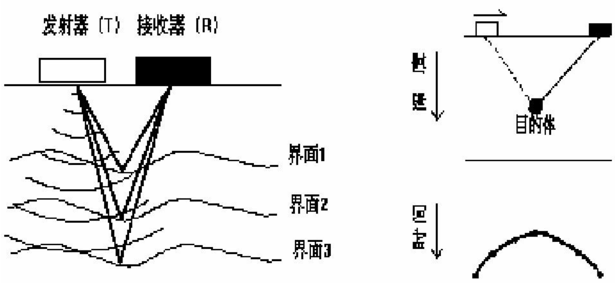

Figure 2: Schematic diagrams for the geological radar detection theory

GPR is a high-precision detecting method that is to probe the electromagnetic (EM) differences of the dielectric constants for different underground medium structures. By sending a beam of high-frequency EM waves in a form of broadband and short pulse through the transmitting antenna of the detecting radar into the ground (see Fig. 2), the velocity (V) of the EM waves when propagating in a medium will depend on the frequency ω of the EM waves, dielectric constant ε of the medium, permeability μ, and conductivity σ. When cross the interface of different media, a fraction of the EM waves will be reflected back to the surface, and then intercepted by the receiving antenna. The radar response recorder will record the time series of the reflected waves from the medium interfaces. By the radar analyzing software, the depth h(m) of the profile can be reconstructed by the two-way time difference △t(ns) of the reflected waves. A detailed analysis of the wave shapes, frequency spectra, and wave amplitudes will allow us to determine the location, size, and shape of an abnormal field, and extract information about the position, geometric form, and physical property of the underground geological structures. When the probing waves encounter hidden Karsts or jointed structures, the phase axis of the reflected waves in the radar depth profile will appear as a hyperbolic form. If a cave or sink is full of water or full of clay, the polarity of the reflected wave will be opposite.

EM waves can be reflected and transmitted by the interface of different impedances when they propagate through different media. The changes to the polarities and amplitudes will be determined by the properties of the media separated by the interface. The reflection coefficient, labeled by the polarity and magnitude, can be applied to describe the property of the reflected waves. For an incoming EM wave, the reflection coefficient of the electric field will be:

$$\frac{E1}{E2} = \frac{\sqrt{\varepsilon 1}\cos\theta 1 - \sqrt{\varepsilon 2}\cos\theta 2}{\sqrt{\varepsilon 1}\cos\theta 1 + \sqrt{\varepsilon 2}\cos\theta 2} \qquad (1)$$

where E1 (E2) denotes the electric field strength of the reflection (emission) waves; ε 1 (ε 2) is the dielectric constant of the medium; θ 1 and θ 2 are the incoming and refraction angles, respectively. When the EM waves travel from an optically sparse medium (larger ε and lower velocity) into an optically denser one (smaller ε and higher velocity), the reflection coefficient will be negative, i.e. the EM waves have opposite polarities. On the contrary, when the EM waves travel from an optically denser medium into an optically sparse one, the reflection coefficient will be positive, i.e. the waves have the same polarities. Generally, if there exist empty holes or defects between the concrete linings or wall rocks, or inside the wall rocks, the differences of reflection coefficients will produce strong reflection waves. Based on the analysis of the radar waves, for instance, the polarities of the radar waves, wave strengths, two-way time differences, etc, it is possible to achieve the determination of the position, structure, electric changes, and geometric forms of the target.

3 Work plan

3.1 We arrange the measurement as follows: along the circumference we separate it into 6 sectors at 1H～3H～5H～7H～9H～11H～1H as in a clock panel. For each sector we place 20 measurements labeled in clockwise and they keep 15m in distance. For each center of the foundation towers, we place one measurement. So, in total we have 126 measurements (see Fig. 3 for the field works).

Figure 3: Determine the detecting position. Figure 4: In-site measurement.

3.2 The GPR detection starts from the position of 1-3H+6m and proceeds anti-clockwise (see Fig. 4). Along the circumference of the feed supporting towers, the measurement covers 1912m on the profile (since the terrain is undulant significantly, the distance on the profile exceeds the circumference of the feed supporting towers. In general, the positioning error for each measurement is within 2m (see Fig. 5).

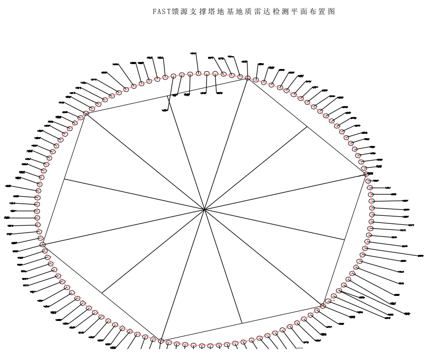

Figure 5: Layout for the geological radar detection system.

Figure 6: Signal emissions of the geological radar antenna.

Figure 7: Datum acquisition of the geological radar detection system.

The GPR detection system in this study is the advanced SIR20 detection radar from Geophysical Survey Systems Inc. USA. It carried a 100MHz high-frequency shielded antenna and takes data at a precision of 20cm by a continuous profile recording form.

4. Detection results and geological interpretations

4.1 Typical GPR detecting profiles

Along the circumference of the feed supporting towers, we obtain a circular profile from the GPR detection. The following three figures (Figs. 7-9) are typical GPR detecting profiles. As shown by these figures, boundary of the quaternary covers, loose cement and broken bedrocks, borders of cavern gaps and complete bedrocks can be clearly identified.

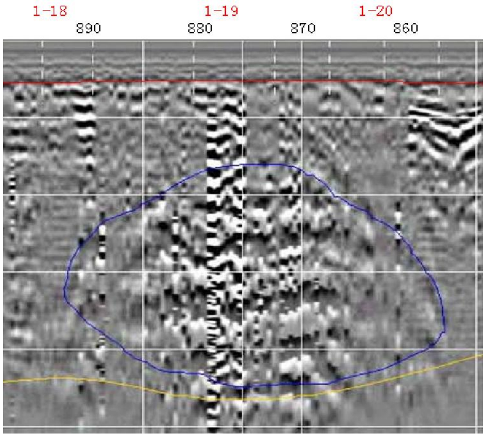

Figure 7: 1Hour 18-20 GPR detecting profile sample.

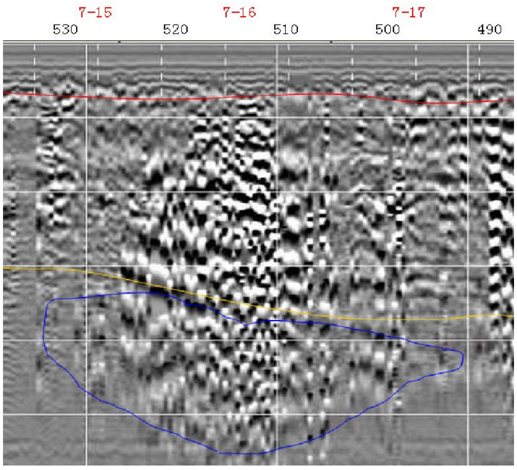

Figure 8: 7Hour 15-17 GPR detecting profile sample.

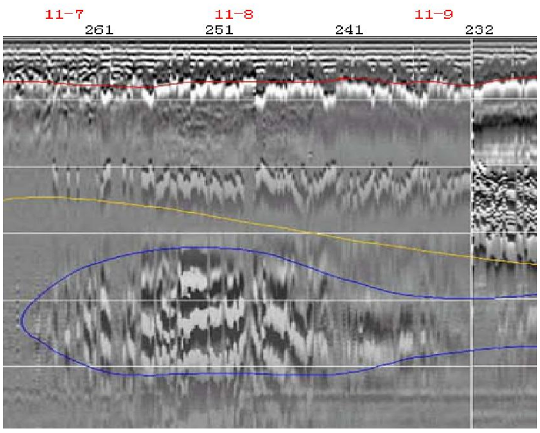

Figure 9: 11Hour 7-9 GPR detecting profile sample.

4.2 Geological interpretations

1) The red lines indicate the areas with the dielectric constant in a range of 14-17εr. We conclude that they are the boundaries of the quaternary covers. The yellow lines with the dielectric constant of 10-15εr correspond to the boundaries of weakly-cemented collapsed accumulations or broken bedrocks. The blue

lines indicate the areas with the dielectric constant in a range of 16-20εr which can be identified as the growth borders of the Karst dissolutions. It shows that the thickness of the loose covers is rather uneven ranging from 1 – 2.2m. The thickness of the weakly-cemented collapsed accumulations (partly weathered limestone) is about 0.2～12m, below which are boundaries of relatively strongly cemented collapsed accumulations or broken bedrocks.

4.3 Detection range

The detection range in diameter increases with the increasing depth by the high-frequency spherical EM wave's transmitting and receiving. In this exploration, the detection range is restricted within a depth of 16.5m because of the attenuation effects by the quaternary covers and loose cemented layers. In the transverse direction of a range of about 2.5m, any abnormal signals of the media will appear in the GPR profiles. Therefore, the GPR profiles provide the synthetic information about the geological structures in a band of 5m in width around the circumference of the feed supporting towers.

5. Engineering confirmations

In order to confirm the detection results, we carry out some field work to drill and dip up several areas which appear to possess abnormal geological structures. We find that our deductions based on the GPR detecting results are consistent with the real situation, namely, the size and depth of those places are in agreement with the GPR results. Part of those investigations is shown in Figs. 10-13.

1) The GPR detections find 8 sizeable growing Karsts. In the drilling test seven Karsts are confirmed except the one located in 1Hour 11-16. It was found to be a broken bedrock area instead of a Karst form. The accuracy of the GPR detections is about 87.5%.

2) At the 3Hour 2-3 and 11Hour 19-20 locations, the drilling test shows that they are Karsts, but the GPR detections suggest they were bands of broken bedrocks. The drilling eventually confirms 9 growing Karsts, among which seven were found by the GPR detections. The accuracy rate is about 77.7%.

3) Error analysis: The location of 1Hour 11-16 is mainly a band of broken bedrocks, while the GPR detections interpret it as a Karst area. In contrast, the sites of 3Hour 2-3 and 11Hour 19-20 are actually Karsts but they were interpreted by the GPR detections as broken bedrocks. The reason for these faults is because the dielectric constants in these three places are compatible. It actually shows that a precise calibration of the dielectric constants for different media is important for improving the GPR detection accuracies. Meanwhile, it is crucial to carry out in-site physical tests in a large engineering field in order to obtain more precise dielectric constants.

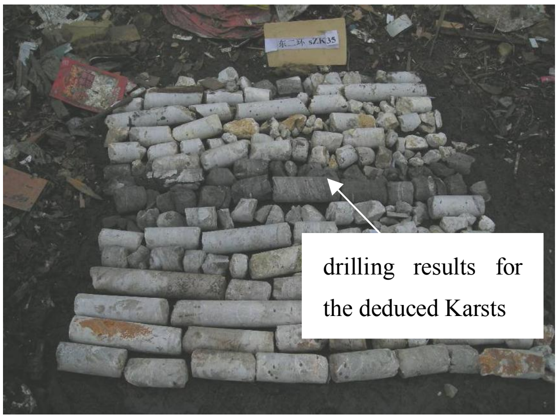

Figure 10: Drilling results for location 1Hour 18-20.

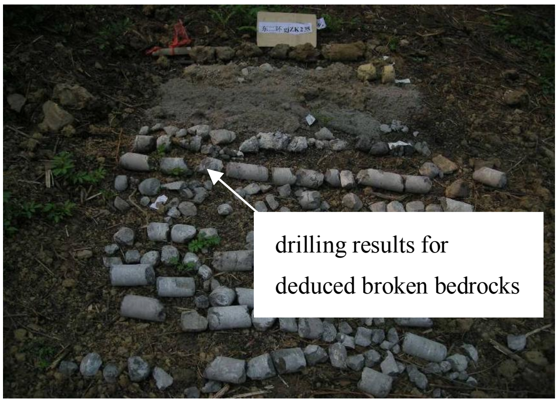

Figure 11: Drilling results for location 7Hour 15-17.

Figure 12: Drilling results for a deduced broken bedrock band.

Figure 13: Drilling results for a deduced Karst.

6 Conclusion

Using the GPR detection system, we succeed in gaining a clear view of the geological structures around the circumference of 600m in diameter where the six feed supporting towers for the FAST are to be built. The thickness of geological covers, loosely-cemented collapses, and boundaries between the broken bedrocks and complete limestone are measured. We shall carry out the drilling tests in field to cross check the GPR detection results. It allows us to make a global evaluation of the geological stability in the construction of the foundation towers. A combined application of these two methods turns out to be essential for providing accurate and reliable information for carrying out engineering works and managing the engineering geology diseases.

1) Our study shows that the GPR profiles can clearly distinguish the borders between the covering layer and underneath limestone, between the limestone Karst development areas and Karst dissolutions, and different

properties of the filling materials. It can provide an effective method for the engineering explorations in the Karst areas, and a reliable evaluation of the Karst bedrock stabilities.

2) It should be recognized that the GPR method is based on the EM theory of which the application will be affected by a lot of influential factors such as geological environment, media, EM properties of the target subject, facilities and even the experiences of the technicians. Therefore, one should start with simple cases to gain experiences on the identification of abnormal events, try to summarize and induce existing engineering cases, and learn to cross check the detecting results by different methods.

3) It is important to carry out in-site physical tests in a large engineering field in order to obtain more precise dielectric constants. This turns out to be crucial for improving the detection precision.

4) One should realize that the couplings between the GPR antenna and probes could be affected by the severe geological conditions, for instance the undulant terrains. Also, the detection efficiency could be affected by the loose cover layers and loosely-cemented collapsed accumulations due to their strong absorptive power to the EM waves.

In brief, with the progress on the physical detecting methods and development on the radar antennas and signal processing techniques, we expect that the GPR system will be more broadly applied to various fields in engineering constructions.

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