Research on Comprehensive Exploration Technology of Underground Soil Karst Cave

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Abstract. Underground soil-karst caves are widely developed in China, especially in the southwestern region, and are relatively typical geological structures in limestone areas. It may cause adverse geological disasters such as landslides, ground fissures, ground collapses, mountain collapses, karst leaks, water loss, water inrush and mud out of mine pits, etc., which bring great hidden dangers to the survey and construction of foundation engineering. We analyze the mechanism of bad geological bodies for underground soil-karst caves, discuss the characteristics of several commonly used geophysical prospecting techniques for soil-karst cave exploration, such as high-density resistivity method, five-pole electric sounding method, and geological radar. Through the engineering examples, it is shown that the location and distribution of soil-karst caves can be effectively detected by using the above comprehensive exploration techniques, which take advantage of the differences in the electrical and magnetic properties of soil-karst caves.

1. Introduction

It is a difficult problem to find out the hidden karst caves in geotechnical engineering survey. At present, there is not a reliable method to investigate the hidden karst caves at home and abroad, which can only be used in comprehensive survey. The so-called comprehensive survey refers to the use of geological survey and mapping, drilling, geophysical exploration, in-situ testing and other means of exploration, to find out the geological environment, fully reveal the space location and shape of underground hidden holes. However, at present, most of the geophysical methods are used in a limited area by using one or several specific geophysical methods, but there is no specific karst engineering geological conditions for the application of multiple geophysical methods for comprehensive exploration. The stability of the site is taken as the basic principle of the engineering geological zoning of the karst site, among which “no karst area” and “karst undeveloped area” are easy to be divided, while “stable area of karst development site” and “unstable area of karst development site” are difficult to be divided [1,2]. At present, the evaluation of karst site is still in the stage of more experience than theory, more qualitative than quantitative. Therefore, it is necessary to reasonably combine the comprehensive geophysical method to carry out three-dimensional exploration of karst, solve some problems that can not be solved by common methods, so as to provide basic conditions for the scientific division of the stability of karst development site.

This paper mainly studies the application of high density resistivity method, ground penetrating radar, five-pole electric sounding and other geophysical exploration technology. According to the resistivity, magnetic susceptibility, wave velocity and other different geophysical characteristics of the earth cave, we investigate it to obtain the effective information of the distribution of underground media [3,5,6,7]. By the comprehensive use of various detection methods, they comprehensively and
accurately reflect the geological situation of the karst site, so that the design and construction are based on a solid and reliable basis, which ensures that the engineering design, construction and use are economic and reasonable, and avoid the adverse consequences of the design and construction caused by the inaccurate or even wrong survey results provided by a single survey method. We should give full play to the progressiveness and comprehensiveness of geophysical prospecting technology and the intuitive characteristics of drilling, and enable these characteristics to permeate and complement each other. Therefore all kinds of exploration methods can be effectively integrated together.

2. Formation mechanism of soil-karst cave
Soil-karst cave is the general designation of soil-karst cave and karst cave. Karst cave refers to the cave formed by the dissolution and erosion of groundwater in the soluble rock stratum, which is nearly horizontally expanded. Soil-karst cave refers to the cavity developed in the overlying soil layer of soluble rock. It is a special geological body formed by the potential erosion of groundwater which continues to expand upward after the formation of karst cave in the soluble rock layer to the overlying sand layer. The relationship between soil-karst cave and karst cave is very close, and it is often that there is a karst cave on the rock surface first. Under the action of groundwater undercutting, the continuous collapse of the underlying surface of the overlying soil layer results in the formation and expansion of soil-karst caves, and in serious cases, it can lead to the subsidence, cracking and collapse of the surface.

Karst caves can be divided into four categories, namely, empty cave, multi-layer cave, large cave (H > 3 m), filled Cave (full filled, half filled). The underground karst forms are mainly falling water cave (well), karst cave, underground river and natural bridge [5,6]. The formation of underground karst is due to the dissolution of water to rocks. Therefore, its formation conditions are: (1) there must be water-soluble and permeable rocks; (2) water is flowing and erosive among them.

According to the different buried depth, soil-karst caves can be divided into three types: ground water collapse, shallow buried soil-karst cave and deep buried soil-karst cave. Its formation is mainly caused by subduction. However, subsurface erosion refers to the dissolution and erosion of underground water in the soil, which can be divided into mechanical subduction and dissolution subduction. Karst morphology and soil-karst cave development are shown in Figure 1 and Figure 2.

![Figure 1. Karst morphology diagram](image1.png)  ![Figure 2. Schematic diagram of soil hole development](image2.png)

Both of them have the following engineering geological problems: (1) the strength of dissolution rock is greatly reduced. The dissolution of rock can make the rock have holes and loose structure, thus reducing the rock strength and increasing the permeability. (2) uneven fluctuation of bedrock surface. This results in the nonuniformity of the foundation. (3) the funnel affects the ground stability. (4) karst cave and soil-karst cave affect the stability of foundation.

3. Investigation method of soil karst cave
Due to the complexity and concealment of the distribution of karst caves in karst areas, the investigation purpose, investigation stage, investigation site and stratum should be considered
comprehensively. On the basis of investigation and research, engineering geological mapping and investigation, geophysical exploration, drilling, logging and other exploration methods are selected according to local conditions.

Geophysical exploration is called geophysical exploration for short. Its principle is to use the difference of physical properties of underground rock and soil to detect geological problems such as formation lithology and geological structure. There are obvious physical properties differences between the soil Karst Cave (cavity, half filling or full filling) and the surrounding rock, such as resistivity, wave velocity, wave impedance, density, magnetic susceptibility and heat dissipation rate, which are the prerequisite for the application of geophysical prospecting to the soil karst cave exploration [8]. The common geophysical methods used in the exploration of karst caves are high-density resistivity method, ground penetrating radar and five pole electric sounding method.

4. High density resistivity method
The high density resistivity method is a geophysical exploration method to solve the underground geological problems by observing and studying the distribution law of the artificial underground stable current field based on the difference of the conductivity of the geotechnical medium. It is the most effective resistivity method for cave exploration so far. It collects data through automatic switch, which has high efficiency and large amount of data collection. In the strong interference environment, it can effectively delineate the spatial location of the earth cave by detecting the target body with high signal-to-noise ratio.

This method mainly includes Wenner, Schlumberger, dipole-dipole method, Pole-Pole method and Pole-Dipole method. In general, the features of various devices are as follows (Xi, 2013): (1) different devices have different apparent resistivity response characteristics. Schlumberger device has the smallest abnormal amplitude, Wenner device is slightly larger, and dipole device has the largest abnormal amplitude. However, the abnormal shape measured by Schlumberger device is complex, and sometimes the low resistance anomaly appears above the high resistance hole. (2) when the concealed cavity is filled with water or soil, the Wenner device and the three pole device can achieve better detection effect. The Wenner device has good anti-interference performance, and there is a corresponding relationship between the abnormal position and the hole. The three pole device has large abnormal amplitude and narrow width.

When the karst cave is a cavity or filled with high resistivity objects, the high resistivity anomaly appears on the high-density resistivity profile; when the karst cave is filled with water, silt and other low resistivity objects, the low resistivity anomaly appears on the profile.

5. Ground penetrating radar
The GPR is a kind of electromagnetic method which uses the characteristics of electromagnetic wave propagation, absorption and reflection of geological body to deduce and explain the shape and buried depth of underground reflector. It uses one antenna to transmit high-frequency broadband electromagnetic wave, and another antenna to receive the reflected wave from the interface of underground medium. By observing the transmission path, reflection coefficient, phase, amplitude, frequency and other parameters of electromagnetic wave in the medium, as well as the received two-way travel time, amplitude and waveform data, we can infer that. The application of GPR method to the investigation of karst cave mainly makes use of the difference of the physical properties of the dielectric constant, conductivity and magnetoelectricity between the karst cave and the surrounding rock [4,9].

The radar pattern is the waveform record of pulse reflection wave. The positive and negative peaks of the waveforms are respectively represented by black and white, gray scale or color. Each measuring point on the measuring line records the waveforms in the vertical direction of the measuring line to form a radar profile. There are two states in the radar profile of the underground karst cave: (1) when the underground cave is filled with water or other low resistance objects, the resistivity of the cave area relative to the surrounding rock decreases, and the dielectric constant increases, so the reflected
electromagnetic wave velocity decreases correspondingly, which is shown as "depression area" in the GPR image. (2) When there is no filling in the underground cavity, the air conductivity is 0, the dielectric constant is 1, and the electromagnetic wave propagation speed is 0.3m/ns, which is much faster than the electromagnetic wave propagation speed of the surrounding medium. Therefore, the underground cavity is shown as a "convex area" in the geological radar image.

6. Five pole electric sounding method
The five pole electrical sounding method is a geophysical exploration method that is based on the difference of conductivity between the target body and the surrounding rock in the stratum, which reflects the characteristics of lithology change in different depths under the survey point. The apparent resistivity is measured point by point along the measuring line at the same measuring point. Through the analysis and interpretation of the field measured curve, it can reflect the vertical change of the stratum from shallow to deep. It is often used to solve geological problems such as detecting karst caves, underground rivers, tracing structural fracture zones and dividing contact zones of different lithology [10]. Its abnormal characteristics are similar to the high density resistance method. When the karst cave is empty or filled with high resistivity objects, the high resistivity anomaly appears on the profile of five pole electrical sounding method; when the karst cave is filled with low resistivity objects such as water and silt, the low resistivity anomaly appears on the profile.

Generally, various geophysical prospecting methods have conditions, limitations and multiple solutions, so it is necessary to choose the right geophysical prospecting methods reasonably according to different geological conditions, and compare them with the existing geological and drilling data, so as to get a good geological effect. We summarized the characteristics of the above three methods for the investigation of soil-karst cave, as shown in table 1.

| Methods                      | Characteristic                                                                                                                                 |
|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| **High density resistivity method** | It can acquire the apparent resistivity of underground rock and soil through a large number of data acquisition, which has the characteristics of intuitionistic, high efficiency, high resolution and high precision. However, the length of wiring in the survey is easily limited by the site, which affects the survey depth. |
| **GPR**                      | It can obtain the GPR profile intuitively and efficiently, with high detection accuracy and less limitation by the site, but it is easy to be affected by the surface gravel and groundwater. |
| **Five pole electric sounding method** | It can determine the location and depth of karst development zone. However, the accuracy is limited, and the survey is easily limited by the site. |

7. Project case analysis
In a power plant in Guizhou, the surface layer is silty clay with low resistivity, and the shallow part is mainly strongly weathered limestone and mudstone with higher resistivity, while the deep part is moderately weathered limestone with higher resistivity. There is a significant difference in electrical properties between the measured geological body and surrounding rock. In the process of karst exploration, we have used five pole electric sounding method, high-density electric method and geological radar method for comprehensive exploration, and achieved good exploration results.

According to the previous work data, the karst development in the plant area is strong, and there is a large karst cave in the south of the discovered karst cave. Based on the profile analysis of 11 survey lines by the above three geophysical methods, it is found that there is karst development in the borehole location where the karst cave is found. There is a span of about 16.5 m in the north-south direction, about 12 m in the east-west direction, a buried depth of 9.1 m in the top and 14.4 m in the bottom of the cave. The main forms are dissolution pores and karst caves, filled with silty clay and silty sand. In this case, on the section map of resistivity inversion by high-density electrical method, it
shows low resistance abnormality. Two small caves are also found in the west of the cave. In the center of the discovered caves, there are two small caves 15 meters and 22 meters away from the West. The North-South span of the cave at 15 m is about 5 m, the East-West span is about 4.5m, the buried depth of the cave top is 6.1m, and the buried depth of the cave bottom is 9.4 m. The North-South span of the cave at 22 m is about 3.5 m, the East-West span is about 4m, the buried depth of the cave top is 6.9 m, and the buried depth of the cave bottom is 11.2 m, both of which are mainly shown as dissolution pores and caves, filled with silty clay, silty sand and water. In the inversion of resistivity cross section by high density electrical method, it also shows low resistivity anomaly.

According to the obtained high-density resistivity profile (Figure 3), geological radar profile (Figure 4) and five pole electric sounding profile (Figure 5), three karst caves are found in total. The location and roof buried depth of the three karst caves obtained by the three geophysical methods are basically the same. The three karst caves are erosion pores and karst caves, filled with silty clay and silty sand. They are all low resistivity anomalies in electrical inversion section, and show convex curve characteristics in geological radar section. The high-density resistivity method mainly uses the electrical difference of the target body, and its application scenario is relatively wide, but the exploration depth is often limited. However, the five pole electrical sounding has a low requirement for topography, which can overcome the difficulty of layout survey lines, and it can realize depth detection, so as to supplement the high-density resistivity method. GPR has a high detection accuracy, which can overcome the problem of low accuracy of high-density electrical method and five pole electrical sounding, but it can not be used in the section with shallow groundwater level, and the exploration depth is shallow, so it needs electrical method to supplement. Therefore, these three methods complement each other, and our engineering examples also show that this comprehensive detection technology is effective for underground soil-karst caves.
8. Conclusion

(1) Engineering practice has proved that, according to different geological conditions reasonable selection of correct geophysical prospecting methods, and with the existing geological, drilling data for comparison, we can quickly and accurately identify the underground earth karst cave and other adverse geological distribution. However, any technology has its limitations and applicability. In order to effectively solve some complex conditions of the earth cave survey, we must use a variety of survey means to complement each other, mutual verification.

(2) The high-density resistivity method, five pole electric sounding method and geological radar method can effectively detect the location and distribution of karst caves by using the electrical and magnetic differences of karst caves, but each has its own advantages and disadvantages. The high-density resistivity method mainly uses the electrical difference of the target body, and its application scenario is relatively wide, but the exploration depth is often limited. However, the five pole electrical sounding has a low requirement for topography, which can overcome the difficulty of layout survey lines, and it can realize depth detection to supplement the high-density resistivity method. GPR has a high detection accuracy, which can overcome the problem of low accuracy of high-density electrical method and five pole electrical sounding, but it cannot be used in the section with shallow groundwater level, and the exploration depth is shallow so it needs electrical method to supplement.

(3) According to local conditions, one or more methods of engineering geological surveying and mapping, investigation, geophysical exploration, drilling, etc. are selected for exploration, especially the proper selection and reasonable combination of geophysical methods, which can achieve the effect of economy, time saving and high accuracy.

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