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ACCURATE EXPLORATION OF KARST GEOLOGY BASED ON THE LAND SONAR METHOD

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ABSTRACT: Karst has a high degree of uncertainty in the actual development process, mainly affected by geological topographic, high-voltage line interference, the depth of exploration and other factors. The geophysical methods of exploration commonly used have difficulty in detecting the size and the location of the caverns accurately and the drilling method are limited due to the economic reasons if performed extensively. The land sonar method is a minimal seismic-extractive elastic wave reflection method. Due to its automatically exciting features and receiving ultra-wideband reflected waves, it has been an effective method for exploring karst geology. It has natural advantages in probing karst caves and can detect the karst caves with accurate exploration with a diameter of ≥ 0.5m. By comparing the results of drilling, wall imaging and high-density electrical methods, we can verify the accuracy of this method.

Keywords: The land sonar method; Karst; Precise exploration

1. INTRODUCTION

Karst is a kind of bad geology, in general term of the geomorphological morphology and hydrogeological phenomena, formed by the solute rock under the long-term chemical and physical action of flowing water. The Karst development zone is not only very harmful to the construction of bridges, tunnels, etc., but also there are always danger of leakage, hole collapse or even collapse at any time during the construction. It has great uncertainty in its actual development process, thus increases the difficulty of geological exploration greatly. Due to the topographic geological factors, high-voltage line interference and higher depth of detection, it is difficult to achieve accuracy in the detection of the size and the location of caves by common geophysical methods.

The high-density electrical method can be implemented in a wide scope, with low cost and good range. Wang Xiqian [1] et al. detected the quaternary soil caves, karst, fault development and other hazard geological bodies in the area by using the high-density electrical method and taking a highway crossing karst development zone in a certain section as an example. The results show that the anomalous area shown on the resistivity section map is consistent with the actual disaster geological body.

Higihara [2] of Japan adopted high-density electrical exploration and soil temperature probe of 1m depth as a comprehensive geophysical method to investigate the levee leakage damage caused by the influence of seasonal rainfall and typhoon No. 6. Under the condition of the unknown geological structure of the dam and multiple leakage points, the leakage cause was found out and the treatment scheme was determined.

Wang Jianjun[3]et al. took the medium-sized reservoir in Luxi County of Yunnan Province as an example, and explored the laws of karst development and the trend of underground dark rivers in the reservoir area by using high-density electrical methods to provide a basis for reinforcement of the reservoir. However, due to the low detection precision of the high-density electrical method, it is impossible to implemented fine detection, and the high-voltage wire is greatly affected.

The geological radar method has a good precision for shallow karst exploration, Li Renhai et al. Li Renhai [4] introduced the working principle and method of geological radar in karst geology, analyzed propagation characteristics and curve characteristics of radar wave in karst area, and explored the application of geological radar in karst geological exploration in combination with engineering examples

XiaTian[5-6] from the University of Vermont in America proposed the use of 2-D entropy analysis to narrow down the data scope to the interested regions, which can considerably reduce computational cost for more sophisticated data post-processin, and then use joint time-frequency analysis of short-time Fourier transform for singular region position detection and refinement. The proposed method has been tested in different laboratories, and the analysis results show good consistency with physical characteristics.

According to the actual application of geological radar method in karst areas, Zhong Lingyun [7] comprehensively analyzed the signal characteristics of different karst forms in radar profiles. As the resolution of the geological radar decreases with the increase of depth and is affected by the surrounding rock and soil environment, especially the overlying clay layer with high water content has a rapid conductivity decay, so the application effect in deep karst exploration is relatively poor. The Drilling method can accurately determine the geological conditions of the focal points, but the large-scale intensive drilling work is limited by economic benefits.

Land sonar method is an effective method for exploring karst geology. For karst caves with a diameter of more than 0.5m, accurate exploration can be achieved, and the method has low cost, high efficiency and abundant information. In recent years, land sonar method has been successfully applied to karst exploration, solitary rock exploration, tunnel advance geological prediction and other fields. In 1914, Reginald A. Fessenden applied for a patent of "Methods and Instruments for Hydroacoustic Orientation". The same year Ludger Mintrop designed a seismograph in Germany. In 1919, Mintrop applied for a German patent for "Methods for Detecting Rock Structures", putting forward Artificial (explosive) shock and receiving elastic waves for exploration. In 1920, John William Evans and Willis B. Whitney applied for the British patent "Methods and Improvements for Detecting Internal Characteristics of the Crust" and proposed the seismic reflection method. As a new technical method for the reflection of elastic waves, land sonar method was proposed by Zhong Shihang [8-11], a researcher of China Academy of Railway Sciences. Many technological innovations filled the technological gap in the exploration field inside and outside China. In 2010, the technical achievements of the Chinese society of rock mechanics and engineering were evaluated with strict specifications. In the shallow exploration field (0-200m), unprecedented application effects have been achieved, satisfying the requirements of anti-conventional interference, fine exploration and accurate positioning in urban geophysical exploration.

2. METHOD INTRODUCTION

2.1 Features and Advantages of The Land Sonar Method

The full name of the land sonar method is the “minimum seismo-removable ultra-wideband elastic wave reflection single point continuous profile method”. It is characterized by:

(1) The land sonar method is a nearly zero-seismic-remove elastic wave reflection method that can avoid direct wave, refracted wave, and surface wave interferences. Since the incident wave and reflected wave are almost perpendicular to each other, there is no converted wave. Not only the waveform received is simple, but also the energy of the reflected wave is greatly increased. With a 4-pound hammer, the reflected wave can be obtained with a depth of more than 150 m.

(2) There is no fixed detector at work, which improves the on-site collection efficiency.

(3) Due to its automatically exciting and receiving ultra-wideband reflected waves from 10 Hz~4000 Hz, so we can fully use the spectrum features.

In exploring caves, the advantages of land sonar are still the following:

a. Zero-seismic-remote reflection method, the reflection event of limited size objects such as caverns is hyperbolic, easy to identify (Figure 1,2);

b. The best reflection frequency for the 0.5~3m diameter cavern and the uneven river top is 1000～3000Hz, this is the best frequency band used by the land sonar.

c. When working in rugged mountainous areas and mountainous terrain, the impact of the terrain is small, which is suitable for areas with rough terrain, high elevation, and complex terrain.

2.2 Features and Advantages of The Land Sonar Method

Since the land sonar method adopted an ultra-wideband acquisition system when the data is processed by band-pass filtering, the filter frequency band is above 200-500 Hz, and the bandwidth is usually above 200 Hz. Therefore, the reflected waves are all in an ultrashort aftershock state. Generally, the reflected wave of a reflecting surface has only one period. When performing numerical simulation, both the incident wave and reflected wave are only one cycle, the staggered grid is staggered with high-order finite difference and the geological model is the upper and lower caves.

The model size is 150m×50m, the bottom layer (gray) speed is 3500m/s, the karst (white) speed is 3000m/s, the frequency is 550Hz, the sampling interval is 0.05ms, and the sampling length is 40ms. The first hole is buried 25m deep, and the height and width of the cave are 3m. The second cave is buried at a depth of 30m and the height and width of the cave are 3m respectively. The two caves are 2m above and below. The specific geological model and numerical simulation time profile are shown in Fig.1 and Fig.2 respectively. In Fig.2 the characteristic map of the upper and lower double holes can be clearly seen - the

obvious upper and lower hyperbola.

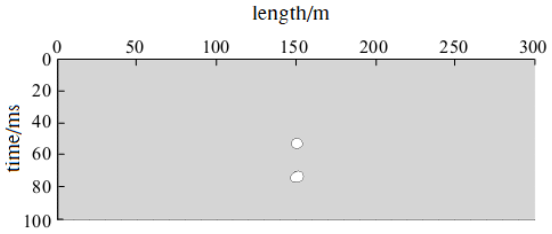


Fig.1 Upper and lower double-hole geological model

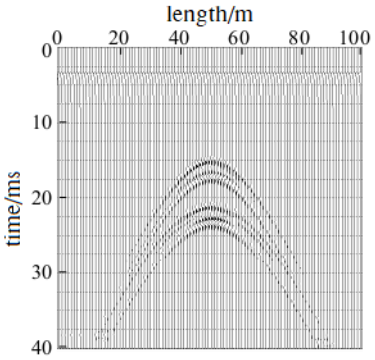


Fig.2 Numerical simulation of the upper and lower double holes

3. KARST GEOLOGY EXPLORATION OF HONGHE BRIDGE

3.1 Project Overview

The Honghe Bridge is a key control project on the Jianshui-Yuanyang Expressway. It adopts a suspension bridge design with a total length of 1,364 meters and the main span of 736 meters. The bridge site is mainly distributed with limestone, slate and conglomerate, and covered with a thick clay layer (5-20m). The limestone body at the Jianshui side is affected by the F13 Lani fault. The fracture zone is widely developed and the karst is extremely developed. Therefore, it is difficult to find a reliable pile-supporting base for the pile piers. At the same time, the position of the main pier also determines the position of the bridge axis, affecting the approach of the route of the two banks. Therefore, the purpose of this exploration is to select the location of suspension bridge piers in the extremely developed karst area.

The survey area is within K67+483~K67+583 of Jianshui-Yuanyang Expressway, the mountain stretches, the terraces are widely distributed, the step height difference is large, the moisture content in soil is high, and there are high-voltage lines passing over site location, which highly increased the difficulty to the on-site geophysical exploration.

Ten (viz. 1-10) horizontal lines are arranged along the east-west direction of the highway by using the land sonar method, as shown in Fig.3. The measuring line distance is 10m, the measuring point distance is 2m, and the main control points of the measuring network and the measuring line are determined by GPS. Geological exploration is mainly carried out on the caverns, cracks, and fracture zones within the range of the survey area. The depth of exploration is 0-100m below the surface, and the distribution and scale of caverns and soil caves ≥ 0.5m are explored.

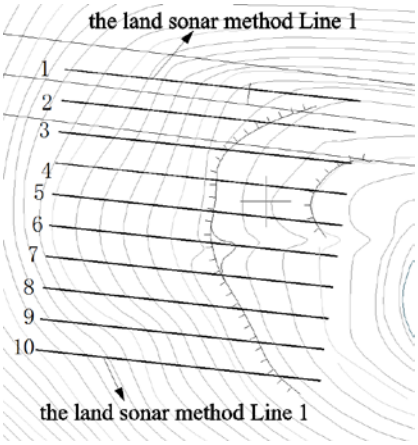


Fig.3 Land sonar method line layout

Set the sampling rate and sampling points according to the work requirements. The sampling rate is 50000 times per second and the sampling length is 6000 points. Two detectors are collected at the same time.



Fig.4 Field work photos

3.2 Exploration Results

Combined with the results of forwarding analysis of the terrestrial sonar feature map, the hyperbolic curve is found in the processed image. According to the geological characteristics of the cavity, the velocity of the elastic wave is sharply reduced when passing through the cavity, so the color is expressed as a hyperbolic hyperbola, as

shown in the Fig.5.

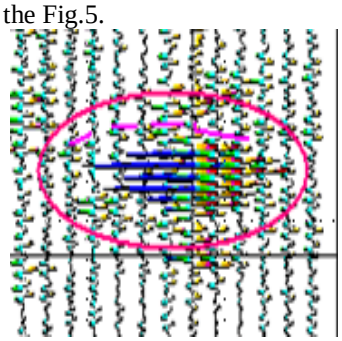


Fig.5-hole feature map

Here the characteristic curves are found in the whole graph, and finally obtain the geological layout of a certain line, as shown in Fig.6. The results of ten lines of land sonar are counted, and the void distribution of each line is calculated. Finally, the spatial distribution and scale of the holes are obtained, as shown in Fig.6 to Fig.8.

Based on the detect results, the following conclusions are drawn:

(1) The depth of bedrock ranged from 1.47 to 19.48 m, with large local differences and uneven bedrock surfaces.

(2) A total of 406 caverns were explored from the bedrock surface up to the depth of 100m, and there were a total of 5 numbers of caverns above the bedrock surface.

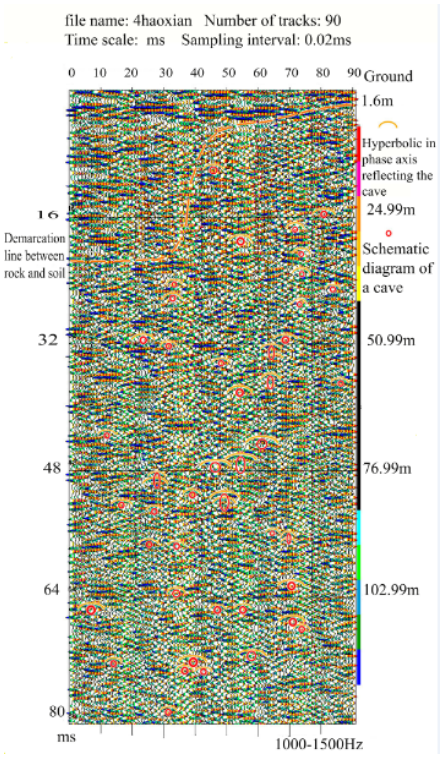


Fig.6 Time map of the land sonar time of the 4th line

(3) Within the survey area, there are many caves in the range of lines 3～7 and line 9, which belong to the karst development area. Among them, there are 37 caves in line 3, 48 in line 4, 74 in line 5, 44 in line 6, 40 in line 7, 52 in line 9, and there are almost 295 caverns in these six survey lines, accounting for 72.7% of the total caverns.

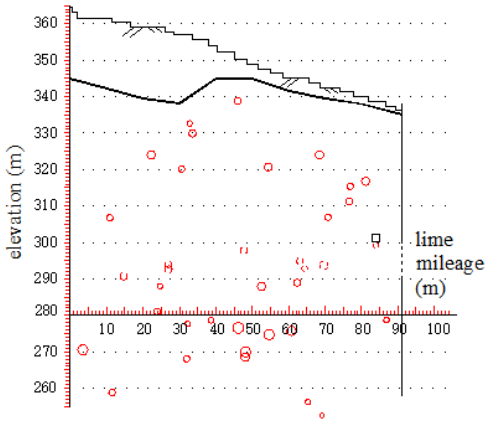


Fig. 7 Line 4

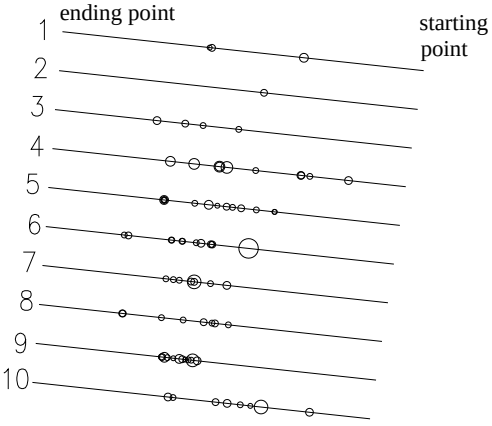


Fig.8 60-80m cave distribution

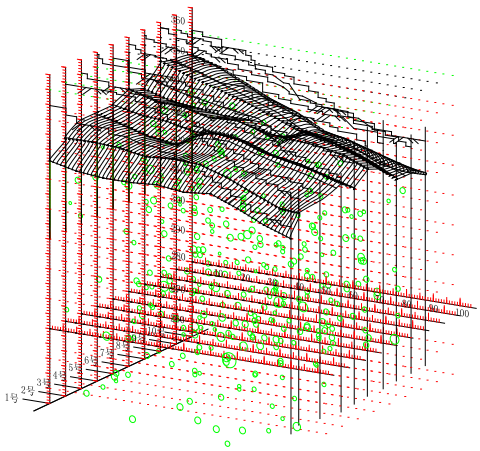


Fig.9 3D map of the void distribution

From line 1 to line 3 have relatively few karst caves within the horizontal distance of 50 ~ 90m, and the depth of 20 ~ 80m, indicating a more

homogeneous formation. Whereas from the lines 1 to 7 has relatively few karst caves within the horizontal distance from 75 to 90 m and the depth from 40 to 80 m, indicating that strata the stratum is relatively uniform. These two areas can be used as the location for suspension bridge piers.

4. COMPARATIVE VERIFICATION

On-site drilling verification of the terrestrial sonar method, a total of 20 holes, distributed around the line, as shown in Fig.10. Take the BCZK No. 27 drill hole as an example. The hole is drilled on the No. 4 line, which is 30m away from the zero points of the top of the slope.

The drilling results are shown in Figure 10. Within a range of 50m from the ground to the underground, 0-24m is the soil layer, and below 24m is the rock formation. Among them, the soil layer is inconsistent with the upper and lower rock layers at 27-30m, 31-34m, 38-40m. It is judged that the argillaceous cave is filled, and the results of the scale and location of the caves in the land sonar in Fig. 6 are basically consistent.

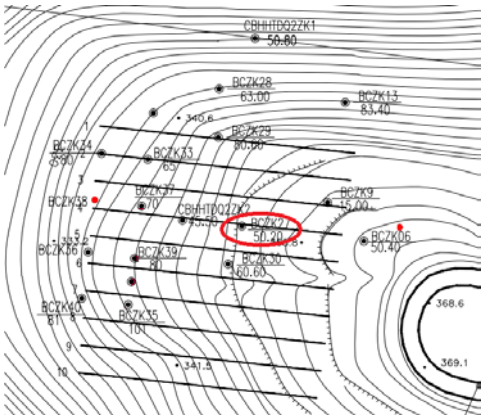


Fig. 10 Drilling map



a) 0.0-5.0m drilling reveals geological conditions



b) 20.0-25.0m drilling reveals geological conditions



c) 25.0-30.0m drilling reveals geological conditions



d) 30.0-35.0m drilling reveals geological conditions

In order to further verify the condition of the hole wall, images were made on the surrounding hole wall of the drill hole at the later stage to restore the real appearance of karst geology, as shown in Fig.12.



e) 38.2-41.4m drilling reveals geological conditions

Fig.11 BCZK 27 drilling results



Fig.12 BCZK27 hole wall imaging

The location of the main pier is finally determined in combination with the high-density electrical method, as shown in Fig.13.

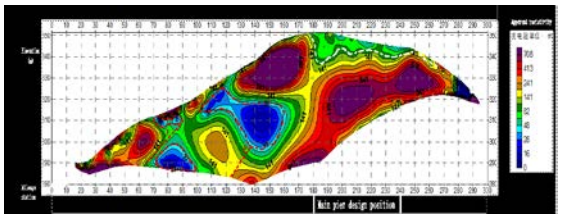


Fig.13 Combined with a high-density electrical method to confirm the main pier range

5. CONCLUSIONS

The Karst region has a high degree of uncertainty in the actual development process and affected by the topographic, geology, high-voltage line interference, the depth of exploration and other factors. The commonly used geophysical exploration methods are difficult to achieve accurate detection of the size and location of karst caves while drilling in a large range are not economically benefited.

The land sonar method is a minimal seismic-extractive elastic wave reflection method. Due to its automatically exciting and receiving ultra-wideband reflected waves, it is an effective method for exploring karst geology. It has natural advantages in probing karst caves.

The karst geology of the Honghe Bridge was investigated by using the land sonar method. The results showed that the land sonar method can accurately detect the caverns with a diameter of ≥0.5m. The accuracy of this method is demonstrated by the comparison of drilling, wall imaging, and high-density electrical methods.

As a new method of elastic wave reflection, the land sonar method fills the technological gap in the shallow exploration field in the field of geological exploration in both inside and outside China. It has been widely used in karst exploration, urban geophysical exploration, early warning and forecasting, and engineering quality inspection, etc., and solved the problem of anti-conventional interference and fine exploration in the field of geophysical exploration.

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