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A Research on Road and Bridge Detection Based on Test Detection Technology

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Abstract: The existence of karst cave at the bottom of bored piles has a great impact on projects under construction and the surrounding buildings. Since bored piles require slurry wall protection, the current geophysical exploration method cannot effectively detect the karst cave at the bottom of the piles in the slurry. Combined with the characteristics of stress wave propagation, the sonar detection method is proposed. JL sonar detector can realize the transmission and acquisition of on-site sonar signals. This method makes full use of the mud conditions of bored cast-in-place piles, and the development of karst caves can be tracked and detected within 10 meters at the pile bottom during the drilling process. It has several advantages, including low cost, high speed, and high precision. This paper verifies the application of sonar detection technology in practical engineering through specific engineering cases. The research results put forward a new solution for cave exploration in karst areas, especially in liquid environment.

Keywords: Karst; Cave detection; Sonar detection; Application research

1. Introduction

In Guangxi, Yunnan, Guizhou, and Hunan, karst is prevalent, and many projects have to address underground karst problems. In karst developed areas, since the selection of foundation treatment is not limited by stratum changes, there is no need for connection and pile cutting, which saves steel and reduces noise. It is suitable for large-scale projects, safe construction, and would not induce pumping-related land settlement [1]. However, in actual practice, it is difficult to determine whether there are karst caves, weak interlayer, and other adverse geological bodies at the bottom of the pile in many karst areas, especially in large-diameter engineering piles, through one hole construction measurement. In addition to construction survey, geophysical prospecting is usually used to confirm whether there are adverse geological bodies at the bottom of mountains. At present, the commonly used geophysical methods include seismic method, high-density electrical method, and ground penetrating radar method. Numerous geophysical methods cannot perform to their full potential because of the limited detection surface at the bottom of the pile hole. If it is placed directly on the ground, the detection depth and accuracy are insufficient to satisfy work requirements [2]. The sonar detection easily achieves the detection standard of 3 times the diameter of the bottom of the pile with a depth of not less than 5 meters.

2. The detection principle of the pile bottom karst cave sonar detection method

2.1. Sonar detection principle

The pile bottom karst cave sonar detection method refers to the use of sonar detection equipment to emit sonar elastic waves at the pile bottom. When the sonar encounters adverse geological bodies, such as faults, karst caves, dissolution fissures, and weak interlayer, within a certain range of the pile base, it will generate sonar echo, receive the echo, and analyze the adverse geological body at the pile bottom according to the characteristics of the echo. It is an underwater geophysical method for detecting adverse geological bodies [3]. Its principle block diagram is shown in **Figure 1**.

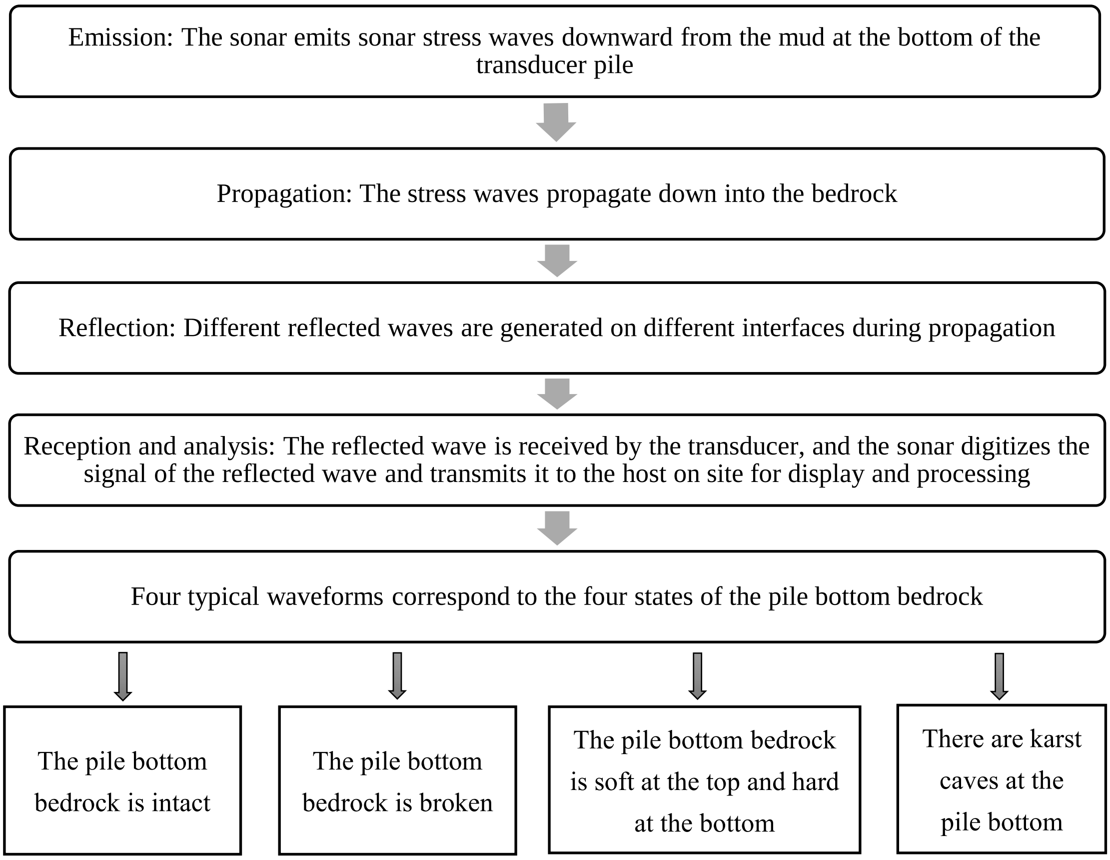

Figure 1. Schematic block diagram of the pile bottom karst cave sonar detection method

2.2. Purpose of the pile bottom karst cave detector

JL-SONAR (B) pile bottom karst cave detector can be used to detect faults, karst, weak interlayer, and fracture zone, as well as evaluate the integrity of the bearing stratum of the rock socketed pile foundation. It is an effective method to solve the following two problems: difficult karst detection and high detection cost of the surrounding rocks at the base of the pile foundation. According to the code for geotechnical engineering investigation, when large-diameter rock socketed piles are used in the construction investigation stage, special pile foundation investigations shall be carried out to determine the pile position. The investigation points shall be arranged pile by pile, and the exploration depth shall not be less than 3 times of the pile diameter below the pile bottom and not less than 5 meters.

At present, in engineering, the one pile one hole or the one pile multi hole drilling method is generally used for pile position survey. One pile one hole drilling often omits the karst near the hole. The survey cost of one pile multi hole drilling is high, and the construction period is long. For some manual hole digging piles, geophysical detection methods can be used, such as geological radar and seismic methods, because their inspectors can reach the pile bottom. However, at present, most of the pile holes are from rotary drilling or impact drilling, and they are full of slurry; hence, it is impossible to reach the pile bottom for detection, resulting in the difficulty in solving the karst cave issue at the pile bottom [4]. The pile bottom karst cave sonar detection method has obvious technical and economic advantages. It is easily interpreted and has high precision, obvious anomaly, strong resolution, short construction period, less investment in instruments and equipment, as well as low detection cost [5-7].

2.3. Main parameters of the instrument

The main parameters are as follows:

(1) two groups of high-power high-frequency underwater super magnetic synchronous sources;
(2) high precision A/D data acquisition;
(3) two synchronous acquisitions of three channels;
(4) three underwater acoustic high-frequency geophones matched with the source;
(5) detection depth of 0 to 20 meters;
(6) detection accuracy ≥ 5 centimeters;
(7) military grade components, and 16 GB solid-state electronic disk memory;
(8) color display, 10 inch 800 × 640 LCD, and controlled by capacitive touch screen;
(9) supplied by 12V DC battery power;
(10) host volume is 400 × 300 × 180 mm, with a weight of 7 kilograms;
(11) probe volume is 450 mm in diameter and 260 mm high, with a weight of 13.5 kilograms and specific gravity with water density of 3.0;
(12) a standard configuration of cable rack of 80 meters [2].

2.4. Detection method and operation steps

2.4.1. Precautions before test

(1) The sediment at the bottom of the hole is ≤ 30 cm (approximate value), and the accurate sediment thickness is recorded (the measured depth can be compared with the vertical depth of the cable line on site) for later analysis.
(2) The water depth at the bottom of the hole shall be ≥ 3 m (water shall be added to the dry hole to submerge the transducer), and the accurate water depth on site shall be recorded for later analysis.
(3) When the amplitude of the test signal at the bottom of the hole is ≥ 50mV (when the gain is 50 times), the signal of each channel is normal; otherwise, it is an invalid signal, and the cause shall be determined on site as soon as possible.
(4) It is necessary to gauge the conditions of rock entry, geology, and lithology at the bottom of the hole, as well as combine the data analysis with the previous exploration data as much as possible.
(5) Before detection, the pile hole shall be cleaned as much as possible, the slag forming thickness shall not exceed 30 cm, and the water immersion sensor with sufficient depth shall be ensured to realize better coupling with the pile bottom to obtain effective acquisition signals.
(6) If the amplitude of the wave train signal is found to be too small (less than 10 mV) and the direct signal at the top does not present a regular set of three oblique lines, this indicates that no effective signal has been collected, and it is best to improve the detection conditions and then re-detect.

2.4.2. Operation steps

(1) Placing the probe

The hole bracket is used to place the sonar probe at the bottom of the pile through the communication cable, and it is connected with the host computer on site through the communication cable. When there is no mud or water at the bottom of the manually excavated pile, 10-20 cm of water needs to be injected to ensure that the sonar transmitter and sonar sensor of the probe will be in contact with the water, and then the stress wave can be coupled with the interface at the bottom of the pile.

(2) Probe leveling
The host computer on site uses the three-dimensional compass in the probe to read the attitude of the sonar probe at the pile bottom and the orientation of each sonar receiving sensor through the communication cable, so as to ensure that the sonar transmitted from the transducer can be almost perpendicular to the pile bottom.

(3) Pile bottom detection
After the sonar probe is placed, the on-site host controls the sonar transmitting driving module and sonar transmitter to transmit sonar stress waves through the communication cable as well as the sonar signal processing module to receive sonar signal. It also transmits the received sonar digital data to the on-site host through the single chip microcomputer communication port for display and processing.

(4) Multi-angle detection
After detecting the current detection data, the sonar-transmitting transducer can be rotated in a certain direction together with the receiving sensor, and then steps (2) and (3) are repeated twice to obtain three groups of signals in 12 directions.

(5) Software analysis
By using the PBCA program of the cave sonar detector at the pile bottom, all the detected sonar signals are arranged according to the orientation of the sonar sensors, and a stress wave profile of the detected sonar is generated for comprehensive processing and analysis. The karst cave is developed within 10 meters of the pile bottom, which meets the specification [8]. It is necessary to make sure that the pile diameter is three times of the pile bottom and there is no karst cave or soft rock within a range of no less than 5 meters.

3. Case analysis

3.1. A project in Yunnan

Yunnan is one of the typical karst landform development areas. The road section that the highway project passes through fluctuates greatly and crosses different regional geomorphic units. According to the genetic types and morphological characteristics, the line profile landform can be divided into three types: erosion accumulation landform, low denudation middle mountainous landform, and low structural dissolution middle mountainous landform. Among them, the stratum with low degree of structural dissolution in middle mountainous landform is mainly composed of a variety of limestones of Permian Maokou formation, and the structural development along the line is affected by structural stress. The rock joints and fissures near the structural belt are extremely developed, and the rock mass is broken, which not only provides a broad space for groundwater discharge and storage, but also favorable conditions for karst development. The terrain of Yunnan expressway project crosses rivers and valleys, with many low-lying terrains and large-scale bridges. The foundation structure of the lower pier and abutment is mainly bored pile foundation, [9]. Therefore, there is a strong demand for detecting the development of karst cave in the surrounding rocks at the pile bottom.

Figure 2 shows that the detection waveform data frequency of Yunnan Jiantou Guangna expressway is high; the waveform is regular, and the attenuation is normal. The stratum at the bottom of the column is completely enclosed.

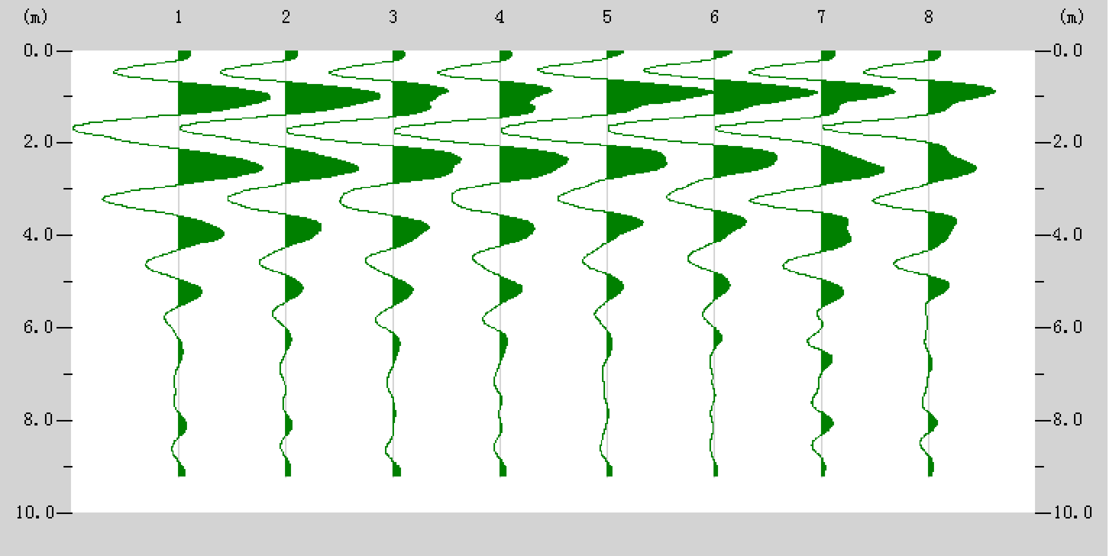

Figure 2. Yunnan Jiantou Guangna high-speed test data

Figure 3 shows that the frequency of the detection waveform data is high (or low), the waveform is irregular, the attenuation is abnormal, there are strong random reflection signs, and the surrounding rock stratum at the bottom of the pile is broken.

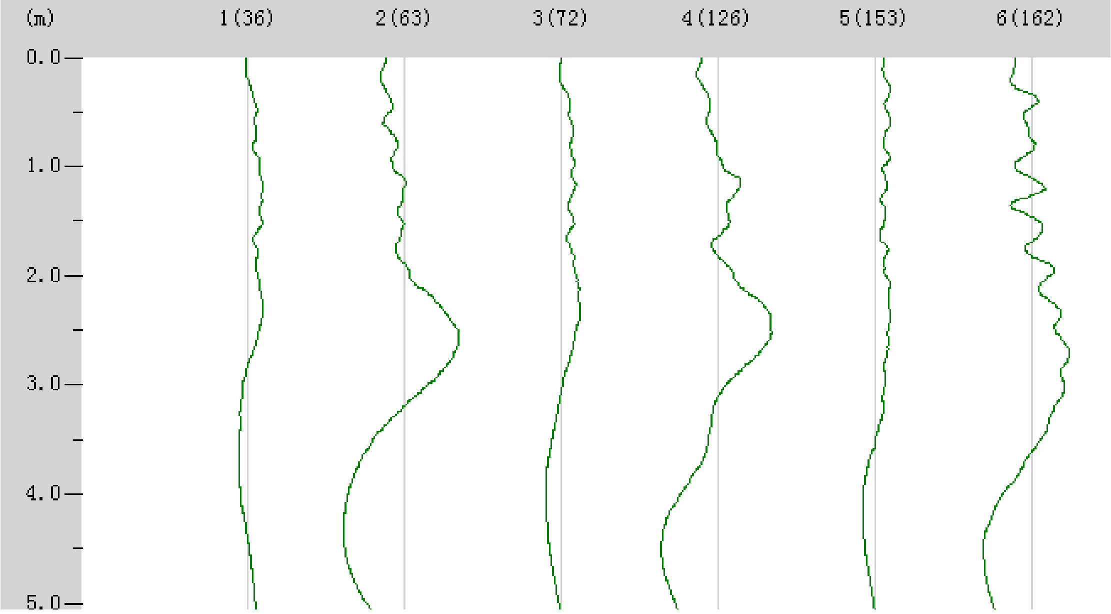

Figure 3. Test data of Yunnan Academy of Construction Sciences

Figure 4 shows that the karst caves (filled with mud or not filled) in the surrounding rocks of the pile bottom have low frequency waveform data, with irregular waveform and abnormal attenuation. They also appear to have strong low-frequency reflection signals and strong coaxial reflection waveform.

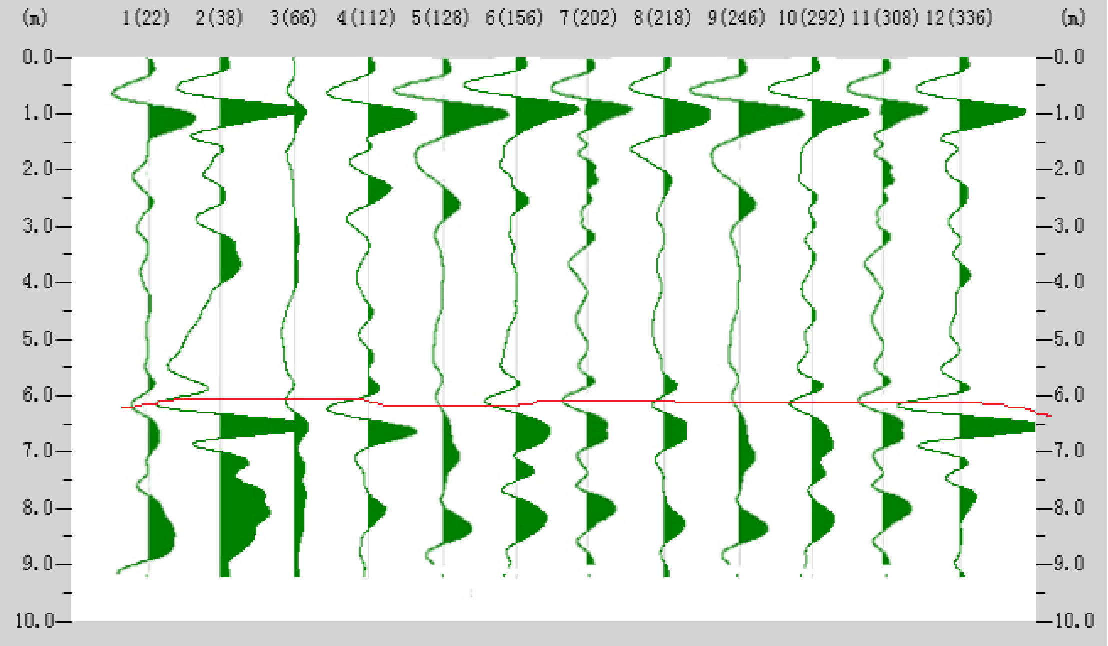

Figure 4. Test data of Yunnan Academy of Construction Sciences (5.8 m karst cave)

3.2. A project in Guizhou

Karst landforms in Guizhou are widely distributed and developed in a large area. Its highway route mainly passes through valley erosion landform areas, tectonic erosion low mountains, and low mountain landform areas. Under the influence of lithology, the karst in the carbonate rock distribution area of the line area is very developed, forming ridge and plateau karst mountains. The unfavorable geological phenomena in the line bridge area include karst, karst steep rock, and others. Therefore, it is necessary to check the bedrock integrity of the pile foundation base at the lower part of each bridge to determine the development of karst caves in the bearing stratum at the pile end of each pile hole. It is necessary to determine whether there are any adverse geological phenomena, such as karst caves, within the depth range of three times the pile diameter and no less than 5 meters below the pile bottom [10,11].

The detection results of this project are shown in **Figure 5**. As can be seen from the detection data, the pile foundation waveform has basic rules and normal attenuation, and weak high-frequency reflection signals appear in the local range of 1.8 to 2.5 meters below the elevation of the pile bottom. Based on this, it is determined that local cracks develop in the surrounding rocks 1.8 to 2.5 meters below the pile foundation, and no karst cave can be found within 8 meters below the elevation of the pile bottom.

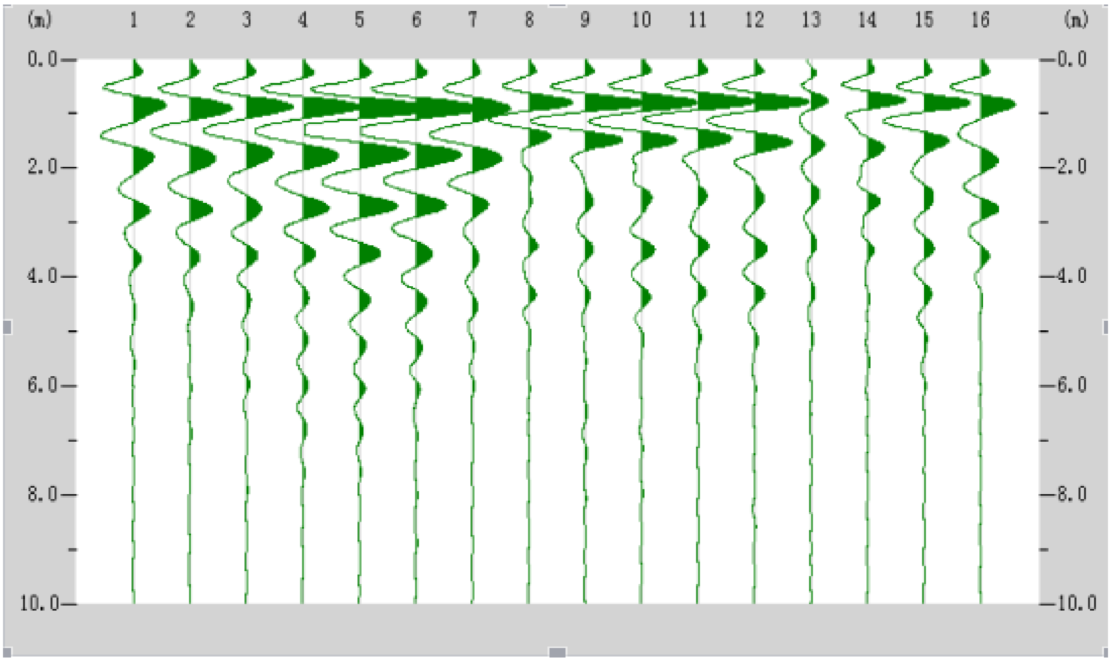

Figure 5. High-speed test data of Guizhou Bridge Meishi

The detection results of this project are shown in **Figure 6**. As can be seen from the detection data, the waveform data of sonar at the pile bottom of the pile foundation has low frequency, irregular waveform, and abnormal attenuation. Strong abnormal reflection signals and coaxial reflection signals appear at 1.8 to 3.0 meters below the elevation of the pile bottom. Therefore, it is determined that the suspected karst cave developed 1.8 to 3.0 meters below the elevation of the pile bottom. It is recommended to deepen the pile foundation and retest after penetrating the karst cave.

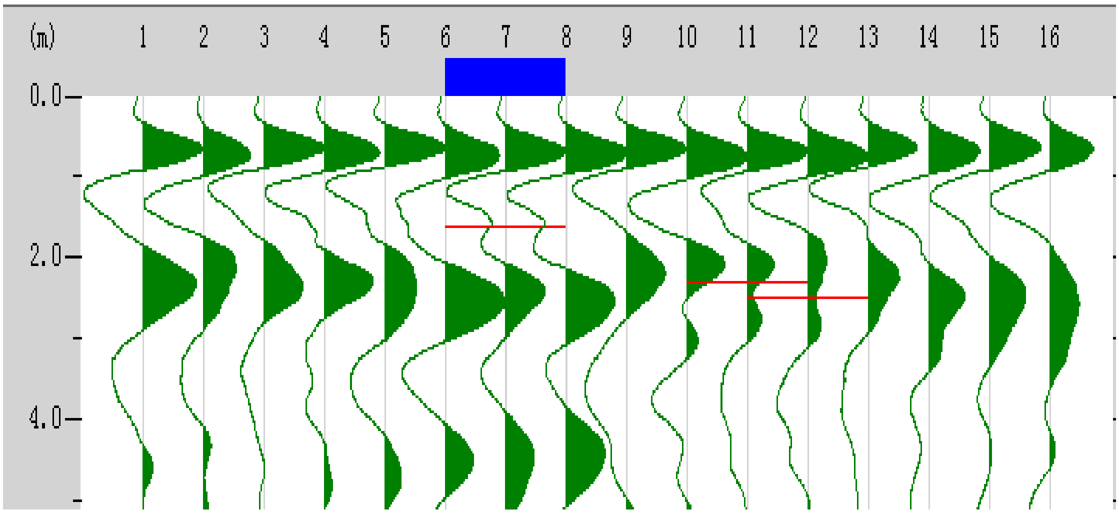

Figure 6. Test data of Guizhou Hongxin Chuangda

As can be seen from the detection data in **Figure 7**, the pile foundation waveform has basic rules and normal attenuation, and weak high-frequency reflection signals appear in the local range of 0.8 to 1.5 meters below the elevation of the pile bottom. Based on this, it is determined that the surrounding rocks at 0.8 to 1.5 meters from the pile bottom of the pile foundation have developed fissures, and the surrounding rocks are broken. It is recommended to go all the way to the bedrock, as there are no karst caves found within 8 meters below the elevation of the pile bottom.

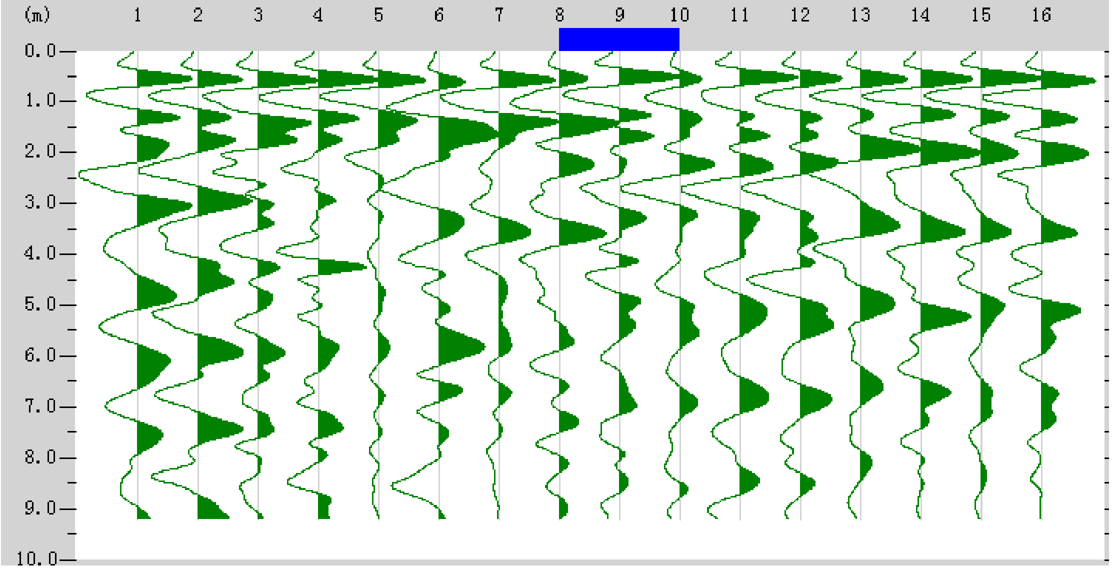

Figure 7. Guiyang Huangdao Expressway data of CCCC Second Highway Engineering Co., Ltd.

4. Advantages of the pile bottom karst cave sonar detection method

Through the research and application of the sonar detection method for karst caves at the bottom of bored piles, the advantages of this method in karst cave detection at the bottom of bored piles are as follows:

(1) sonar technology makes good use of mud, a material whose acoustic impedance is closer to the bedrock, as the coupling medium, which effectively reduces the acoustic impedance difference between different media at the top and bottom, so as to improve the acoustic coupling rate and ensure the smooth transmission of sound waves the bedrock at the pile bottom; the existence of mud has caused technical obstacles to other exploration methods; sonar detection skillfully turns the disadvantage of mud environment into an advantage;

(2) the detection results are not affected by the filling in the tunnel; whether there is filling in the tunnel or not, the wave impedance of air, water, clay, and other materials in the tunnel is much smaller than that of bedrock at the top of the tunnel; therefore, the superposition phase of the reflected waves will be opposite to that of incident waves, and the consistency of the test signal is very strong;

(3) the accuracy of cave detection is high, in which the minimum size of caves that can be detected is 10 cm; the resolution of acoustic detection increases with acoustic frequency, but in the process of acoustic propagation, the high-frequency part will decay before the low-frequency part; the source frequency band developed in this paper is 200-8000 Hz and the power is 10 kW; while transmitting high-frequency sound waves, the wide-band high-power source effectively protects the high-frequency signal and improves the resolution of the waveform;

(4) the detection does not depend on advanced drilling; it is a fast non-destructive detection method, which can complete the general inspection of each pile; in addition, the time for on-site detection of a pile is less than 10 minutes; with the progress of hole formation, the karst cave at the bottom of the pile can be tracked and detected at any time; this offers convenience and operability to the quality detection of bedrock at the pile bottom, thus popularizing the technology [12-15].

5. Conclusion

Through the exploration and practice of the pile bottom karst cave sonar detection method, it is found that the sonar detection method has better adaptability compared to other conventional geophysical methods when applied to the detection of karst caves at the bottom of bored piles. The acoustic impedance of mud is close to that of bedrock, and the use of mud as a coupling medium can effectively reduce the difference of acoustic impedance between the upper and lower media, making it easier for sound waves to transmit to the bedrock at the pile bottom. Sonar detection skillfully turns the disadvantage of mud, an environment where other geophysical methods cannot play a role, into its own advantage, and solves certain problems, including the low recognition rate of karst cave detection and the incapacity of applying traditional geophysical methods in the construction environment of cast-in-place pile bottom. In terms of accuracy, this detection method can detect caves within a diameter of at least 10 cm. At the same time, there are other problems that require urgent attention. In order to increase the resolution, higher sound frequency is required. In addition, high-frequency sound waves will decay before low-frequency sound waves. If the acoustic emission frequency range is too small or the transmitted signal energy is insufficient, some high-frequency signals will be lost and the resolution will be reduced. The sonar detector used in this paper has a source band of 200 to 8,000 Hz. When transmitting high-frequency sound waves, it can effectively prevent the attenuation of high-frequency signals and improve the resolution of waveforms.

Disclosure statement

The authors declare no conflict of interest.

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