Research on intelligent monitoring technology of grouting based on dielectric characteristics

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Abstract. The electromagnetic characteristics of the grouting material can be changed to achieve the electrical difference with the surrounding rock, so as to meet the needs of grouting monitoring. The combination of this principle and the high-density resistivity method can be used to detect whether or not the grout is in the diffusion of an underground space, yet still cannot meet the expected grouting monitoring effect. To monitor the grouting process and detect the grouting effect more clearly, in the present study a theoretical method is proposed, and a high-precision distributed monitoring system based on high-density electrical method technology is independently developed to dynamically monitor the grouting process of non-dispersed materials. The system possesses a stronger ability to identify the resistivity difference of underground materials, and can be used to monitor the entire grouting process through networking technology. The system uploads the collected data to the server in real time through the Internet of Things module, then continuously inverts the uploaded data to obtain the real-time apparent resistivity section diagram. Next, through observation and analysis of the apparent resistivity section diagram and data, it detects the mud diffusion in the underground space. Through the analysis in this study, it is proven that the system can be used for grouting monitoring and that it meets the expected performance requirements.
1. Introduction

A strong grouting method can help avoid the problems of house collapse, landslide, leakage and deformation[1]. Since the turn of the 21st century, China has gradually paid greater attention to infrastructure construction, particularly in the construction of tunnels and underground projects. With its rapid development of grouting technology and construction technology, China has now become the country with the world’s largest infrastructure. As of 2019, the total mileage of China’s highway system reached 4.8465 million km, and that of expressways reached 142,600 km. Chinese has 40 cities that have opened city rail transit, with a total length of operation is 6,736.2 km, and a total ground line length of 4366.5 km. There are 65 urban rail transit projects in China involving underground pipe network, such as the Shenzhen Chunfeng tunnel. With the large-scale construction of infrastructure, geological disasters, such as ground collapse, mountain collapse, uneven ground settlement, groundwater drainage and destructive mine earthquake, have caused direct harm to railway and highway construction, water conservancy and power engineering facilities, industrial and civil buildings, ecological and hydrological environment and local residents’ lives and property[2]. As for how to effectively avoid these hazards, grouting technology is one of the most effective means, thus quickly and effectively monitoring the grouting process and ensuring the quality of grouting engineering are important technical issues involved in reducing geological disasters[3, 4].

At present, there are many geophysical monitoring methods for grouting effect, such as the borehole wave velocity logging method, Rayleigh wave method, transient electromagnetic method, high-density electrical method and magnetotelluric method (MT), yet there have been few studies on monitoring-based methods regarding the difference of grouting material properties and physical properties.

2. Experiment and monitoring system

1.1 Laboratory testing of grouting materials

In order to realize the rapid detection and monitoring of grouting, in this study the electrical difference between the grouting material and surrounding rock is applied for testing.

This study is divided into 16 proportions and 128 groups of experiments, in which the cement is 425 ordinary portland cement from the Chengdu Lafarge cement plant, the mineral additive is marble slag from the Ya'an Baoxing Second Light Industry Co., the steel fiber is 0.2 mm in diameter, 13 mm in length, 2,850 MPa in tensile strength, while the organic additives and other components are quite complex, and are not discussed here.

![Fig. 1 Experimental comparison of grouting materials](image)

From the experimental data, it can be seen that the electrical characteristics of grouting
materials with the same ratio change at different times. In addition, the overall resistivity becomes higher, and the resistivity of grouting materials with different ratios sometimes differ, and may be changed artificially. Combined with the electrical characteristics of grouting materials, and according to the geological conditions of geological disasters, the matching design of grouting materials can be carried out to meet the monitoring requirements.

1.2 Monitoring system design

According to the physical property experiment of grouting material and the principle of high-density electrical method monitoring system, the monitoring mechanism and hardware performance of the system are improved. The main system design principles include the following:

1) The entire grouting detection time should not be excessively long, as this requires manpower and material resources;
2) The process should be suitable for all kinds of construction sites with complex environments;
3) Safe operation, effective and reliable data acquisition and transmission must be ensured;
4) The ADC must have very high accuracy and resolution for resistivity change in the grouting area.

The system is combined with 32-bit high-precision ADC and networking technology to meet the performance requirements of the grouting monitoring equipment. After 3 hours, the time taken by each monitoring system to complete the resistivity data acquisition in the same area is shown in Fig. 2. It can be seen that the efficiency of grouting monitoring system is more than twice that of the WDJD-3 high-density electrical system, and slightly higher than that of the N2 electrical measurement system.

![Fig. 2 Proportion of system working time](image)

3. High-efficiency dynamic monitoring technology and system structure of grouting projects

The technology uses short distance wireless communication technology for networking, and applies 32-bit high-precision ADC to carry out the data acquisition. A distributed system which can support the rapid deployment and high-efficiency monitoring of the different working areas can realize fine monitoring for the entire grouting project. In order to deal with complex terrain, the system is equipped with a GPS elevation measurement function, which can more accurately collect the longitude, latitude and elevation data of each measurement point. In the following data analysis and processing, terrain correction can be performed in
real time, and thus more accurate and good monitoring effects can be obtained. In the field grouting construction, in order to achieve high grouting quality, combined with the comprehensive analysis of data collected by various sensors, timely adjustment of grouting speed and slurry concentration is the key to ensuring the smooth completion of the grouting project. The distributed monitoring system as a whole consists of four parts. The main function modules include a data transmission module, data acquisition module, GPS height measurement module and data analysis center platform. The system structure is shown in Fig. 3.

![System chart of grouting monitoring](image)

**Fig. 3** System chart of grouting monitoring

### 4. Application test

1. The grouting effect directly affects the safety of construction operation. The new distributed grouting monitoring system based on high-density electrical method technology can monitor a large range of grouting area in real time, and can be used to obtain the resistivity data of the area[5, 6]. In order to avoid error caused by external factors as much as possible, the resistivity data before and after karst grouting are measured after the measuring points have been marked. The apparent resistivity profile is shown in Fig. 4.

![Apparent resistivity profile in the karst area](image)

**Fig. 4** Apparent resistivity profile in the karst area
The results in Fig. 4 show that, because most of the karst landforms here are cavities or non-dense fillings, which exhibit high resistivity, before grouting there are three areas with large resistivity values. From the new distributed grouting monitoring system, the resistivity value of grouting area 1 is measured as (500 ≤ ρs ≤ 1,000). Then, after adjusting the proportion of grouting fluid, the slurry exhibits relatively low resistance. The 1’ resistivity of the area measured by the grouting monitoring system is (80 ≤ ρs ≤ 120). The results also show that the resistivity of the same area before and after grouting decreases significantly, thus indicating that the grouting has filled the area. By observing the distribution of resistivity in the grouting area 1’, it can be seen that the resistivity of the grouting location is significantly reduced, and the resistivity around it exhibits an upward trend, thus indicating that the slurry is still slowly spreading following karst grouting. The resistivity value of grouting area 2 measured by grouting monitoring system is (1,550 ≤ ρs ≤ 2,260). This area is the main grouting area, and the resistivity value here is significantly higher than that of the surrounding area. The average resistivity value of 2’ after grouting is (38 ≤ ρs ≤ 55). It can be seen that the main grouting area has been well filled with slurry, the surrounding crevices are also well filled, and the surrounding resistivity value is (500 ≤ ρs ≤ 2,260) to (38 ≤ ρs ≤ 80). The resistivity of zone 3 measured by the grouting monitoring system is (1,075 ≤ ρs ≤ 2,260). This area is the secondary key grouting area, and the 3’ resistivity of the area after grouting is (80 ≤ ρs ≤ 243), thereby indicating that the slurry in this area has been well filled. At the same time, it can be seen that the resistivity value near 3’ of the area is significantly decreased compared with that before grouting, thus indicating that the permeability of the slurry is good[7, 8].

(2) In the early morning of August 17, 2020, a landslide occurred in group 5, Quan'an village, Longquan Mountain, Eastern New Area of Chengdu, following continuous heavy rainfall. Six homes collapsed in the landslide. The length and width of the landslide were approximately 210 m and 180 m, respectively, the buried depth of the sliding surface of the landslide was approximately 35 m, and the volume was approximately 13.23 × 105 m³. The new distributed grouting monitoring system is used to collect resistivity data in the landslide area, and the apparent resistivity profile obtained after inversion of the measured resistivity data is shown in Fig. 5.
Due to the fact that the grouting area 4 is a landslide fracture zone fracture, which contains fracture water and serious mineralization, the area has relatively low resistance. The resistivity of the area measured by the grouting monitoring system is $(10 \leq \rho_s \leq 40)$. For this kind of geological structure, cement-based slurry is used for grouting, and the grouting material possesses high resistance to mineral water, thus the expected resistivity value of $4'$ after grouting should be larger. Following grouting area 4 in landslide area, the resistivity measured by the grouting monitoring system is $(330 \leq \rho_s \leq 900)$. The data show that the cement-based slurry filled the area, and that the resistivity around the grouting area $4'$ also increased significantly.

5. Validation of the grouting monitoring system data

In order to verify the validity of the new distributed grouting monitoring system data, after the monitoring points have been marked, the resistivity data before and after grouting obtained through the same point measurement as WDJD-3 high density electrical method system and N2 electrical method measurement system are as shown in Table 1.

### Table 1. Comparison of monitoring system data $\rho_s (\Omega \cdot m)$

| Data   | Grouting monitoring system | WDJD-3 high-density electrical method system | N2 electrical measurement system |
|--------|-----------------------------|---------------------------------------------|---------------------------------|
|        | Resistivity value before    | Resistivity value after                      | Resistivity value before        | Resistivity value after                      |
|        | grouting                    | grouting                                    | grouting                        | grouting                                    |
| Area   | $500 \leq \rho \leq 1000$  | $450 \leq \rho_s \leq 70$                   | $480 \leq \rho_s \leq 75$      |                                               |
| 1      | $s \leq 120$               | $\leq 850$                                  | $\leq 970$                     |                                               |
| Area   | $1550 \leq \rho_s \leq 2260$ | $1400 \leq \rho \leq 34$                  | $1590 \leq \rho_s \leq 40$    |                                               |
| 2      | $s \leq 55$                | $s \leq 2100$                               | $s \leq 2300$                  |                                               |
It can be seen from the pre-grouting resistivity values listed in Table 1 that the resistivity value of area 1 to be grouted, as measured by the grouting monitoring system, is \(500 \leq \rho_s \leq 900\). In addition, the resistivity value of the area as measured by the wdjd-3 high density electrical method system is \(450 \leq \rho_s \leq 850\), and that of the area as measured by N2 electrical method measurement system is \(480 \leq \rho_s \leq 970\). The results show that the resistivity of the three different high-density electrical instruments is close to that of the same region. Similarly, the three different high-density electrical meters are used to measure the area again after grouting, and the resistivity difference between them is only 20 Ω·m. Following repeated high density electrical detection in the other three areas, the difference of resistivity as measured by the grouting monitoring system and the other two systems is also controlled at 30 Ω·m.

The designed grouting monitoring system is compared with the WDJD-3 high-density electrical method system and N2 electrical method measurement system in the same area, both before and after grouting. The results show that the data measured by the grouting monitoring system is effective, and that the system exhibits good performance in the field.

6. Laboratory experiment methods and results

In order to verify the monitoring precision of the grouting monitoring system designed in this study, the system is a set of differential input channel short circuit, and the ADC sampling rate is set to 2.5 SPS. The results showed that the grouting monitoring system can achieve an effective bit rate of a 20-bit application. To contrast the grouting monitoring system and the monitoring efficiency of high density resistivity method system, an area of about 20 m2 was selected to carry out the electrical method data experiment in, and two instruments were chosen to apply the same A-M-N-B arrangement complete data acquisition device to. The results showed that the grouting monitoring system for monitoring the area of work time was superior to the traditional high-density electrical method system by around one third.

7. Monitoring system advantage

(1) The system uses Zigbee to network and remote control the acquisition equipment, and realizes safe, fast, automatic and real-time dynamic monitoring.

(2) Remote control technology is adopted to greatly reduce the risks to workers caused by the complex on-site environment. Operators can work at a distance of 200 m from the shore.

(3) The equipment adopts a modular design, wherein each sub-module has a small mass and fast connection. The mass of a single device is less than 6 kg, and can be carried by hand.

(4) The system is effectively connected with other sensing modules to obtain more effective on-site data, and can complete the grouting process in real time.

8. Conclusion

(1) Combined with the differences in the physical properties of grouting materials, the new distributed grouting monitoring system exhibits higher monitoring data accuracy and superior the resolution for resistivity of different underground geological characteristics.
It can effectively monitor grouting and invert grouting effects in combination with the physical properties of actual geological structure and the differences of physical properties of grouting materials, so as to guide production practice and engineering applications, as well as new ideas, methods and technologies.

(2) Apparent resistivity can be used as an important parameter by which to judge the grouting effect, and plays an important role in grouting monitoring. There are two main points in judging the effect of grouting: one is the change of apparent resistivity value in the corresponding area of apparent resistivity profile before and after grouting; and the other is whether the closed anomaly basically disappears or the scope shrinks, which can also result in changes to the opposite anomaly under the coordination of the electrical characteristics of grouting materials.

(3) The monitoring system has the characteristics of distribution, high precision, automatic processing, and simple and convenient operation, which allow it to effectively monitor the grouting in various complex environments. However, the system also has some limitations. For example, it is difficult to judge in the sections where the physical properties of the grouting area and surrounding rock show little change. Comprehensive analyses should be performed based on the quality control during grouting and the observation results of drilling verification.

9. References

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