Overview of Slope Monitoring Technology

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Abstract. The geological disaster caused by slope engineering has always been one of the most concerned issues in the society. In recent years, the rapid development of urbanization in China has caused relatively large changes in the geological environment, sometimes leading to landslides and mudslides, which pose a significant threat to human lives and properties. The monitoring technologies of slope deformation have been rapidly developed and played an increasingly important role in ensuring slope stability. This paper briefly introduces the conventional slope deformation monitoring technologies and their shortages. The latest development of slope deformation monitoring technologies is presented in detail, followed by analysis of the features of these technologies. Finally, some research suggestions are proposed for future development of slope deformation monitoring technologies.

1. Introduction
In the middle of the 20th century, due to the backward and limited level of science and technology, people generally used a simple macro-geological observation method to monitor the slope, that is, to determine the deformation characteristics of the surface and the anomaly of ground fissures by manual observation [1]. However, with the improvement of modern science and technology, there are more and more slope monitoring instruments and systems, which play an increasingly important role in quantitative monitoring of slope deformation.

With the rapid development of urbanization, road building and mining have increased the problem of slope. In the process of slope treatment, with the passage of time, the complexity of rock and soil mechanics inside the slope makes it impossible for us to find out the true mechanical effect inside the rock and soil body of the slope. By monitoring the deformation of the slope, the deformation mechanism of the slope can be fully understood and the slope supporting design can be optimized. This paper comprehensively summarizes and evaluates the research and application progress of slope deformation monitoring technology at home and abroad from the aspects of the principles, advantages and disadvantages of the new monitoring technology in recent years, and provides some suggestions for the development of slope deformation monitoring technology in the future [2].

2. Development History of Slope Monitoring Technology
Slope monitoring including construction safety monitoring, effect of treatment monitoring and dynamic long-term monitoring. The construction safety monitoring is to monitor every data in the construction period to guide construction. The effect of treatment monitoring is to test the effect of slope treatment design and construction, and to judge the stability of slope after treatment. The long-term monitoring of the slope will implement dynamic tracking on slope mass after the prevention and treatment engineering completed to realize the variation characteristics of stability of slope mass. The monitoring content should be considered in many aspects, as shown in Table 1[3].

Table1. Traditional slope monitoring technology and its shortages

Monitoring Content	Monitoring method	Monitoring Displacement	shortage
Surface deformation monitoring	Geodetic method, seam measurement method	Theodolite, distance gauge, level gauge, steel tape measure, vernier caliper, etc.	The efficiency of realtime monitoring of surface displacement anges is low, and optical instruments are affected by environment.
Deep deformation monitoring	Borehole slanting method	Drilling inclinometer, multi-point displac ement meter, etc.	Long monitoring cycle and high equipment and instrument costs.
Structural stress monitoring	Monitoring geotechnical stress	Rock mass stress meter, earth pressure box, convergence meter, microvariation instrument, etc.	Vulnerable to environmental impacts such as humidity, strong acid, strong alkali.and rust.
Environmental factors	groundwater level,pore water pressure.	Soil moisture meter, water level gauge, pore pressure gauge, rain gauge, etc.	Low degree of automation, single monitoring param-eters, high instrument cost.

3. New slope Deformation Monitoring Technology

In order to meet the requirements of modern slope engineering monitoring, the development direction of slope engineering at home and abroad has gradually reflected the following characteristics: automation, remote monitoring, wireless sensing, distributed and high precision. In recent years, a number of new types of slope deformation monitoring techniques and methods have emerged, which have effectively promoted the prevention and control of slopes.

3.1. Distributed Fiber Optic Strain Sensor (DFOSS)

This technology of optical fiber sensing is mainly to measure the environmental parameters by measuring some parameters such as intensity and phase-related changes in optical fiber transmission light. Distributed optical fiber sensing technology is one of the most promising technologies in optical fiber sensing technology, mainly because it has the characteristics of reusability and long transmission distance. In addition, it is also the development trend of optical fiber sensing and monitoring technology. As for landslide monitoring, the effect of using distributed optical fiber sensing technology is obvious. For example, in Beichuan County West Slope Landslide Group Monitoring and Hong Kong New Territories Luk Keng Road Roadside Slope Monitoring, some optical fiber monitoring results are analyzed, and the experience of optical fiber monitoring technology in slope field application is summarized [4].

3.2. "3s"Technology

Since the 20th century, the rapid development of global positioning system (GPS), remote sensing technology (RS), geographic information system (GIS) and other technologies has provided strong support for slope deformation monitoring. Compared with the traditional geodetic technology, this kind of technology has the advantages of high degree of automation, high positioning accuracy, short observation time, all-weather real-time monitoring of surface displacement, no need of mutual viewing between monitoring stations, and real-time processing of analytical data [5].

3.3. Close-Range Photogrammetry

It is a process to put the close-range camera in two different fixed points, then take photographs of the observation point within the scope of slope to form stereo image pair, and to measure photographs for each point's 3D coordinates in the spatial position of a moment. Advantages are easy to photograph, relaxed in field surveying, can measure several point at the same time. However, the station is limited by the terrain, and the workload is large, so the application is not very extensive.

3.4. Terrestrial Laser Scanning (TLS)
The ground laser scanning can directly obtain the high-precision, high-density spatial three-dimensional coordinates of the surface , that's point cloud data , without touching the object to be measured, and then processing it to constructing a high-precision, high-resolution three-dimensional digital model. Therefore, it is widely used in slope deformation monitoring. This paper introduced the ground 3D laser scanner in detail. It has the advantages of non - contact, fast data acquisition speed (50,000 points / second - hundreds of thousands of points / second), real - time, dynamic and dynamic, penetrability, high precision, high density, full automation (schneider, 2006), and can be combined with GPS and external digital cameras, overcoming the one-sidedness of traditional point deformation monitoring and obtaining complete point cloud data in the monitoring area. Through processing and analyzing the point cloud data, the deformation characteristics of the landslide surface can be obtained [6].

3.5. Acoustic Emission (AE)
It can deduce the morphological changes and inverse the failure mechanism of rock by the acoustic emission signals from the rock mass [7] compared with other methods, it has the advantages of low labor intensity and fewer human factors. And it has more obvious monitoring advantages at complex area and terrible weather. So it attracts more and more attention in recent years.

3.6. Time Domain Reflectometry (TDR)
TDR is called the time domain reflection test technology. The method has been used in 1930s in the case of the United States for the detection of communication cable, and then applied to the geological industry. TDR system has many advantages, such as low price, short detection time, and data providing fast and high security. The shortage is that it can not be inclined to monitor, it can determine the shear plane, but can not determine the direction of displacement [8].

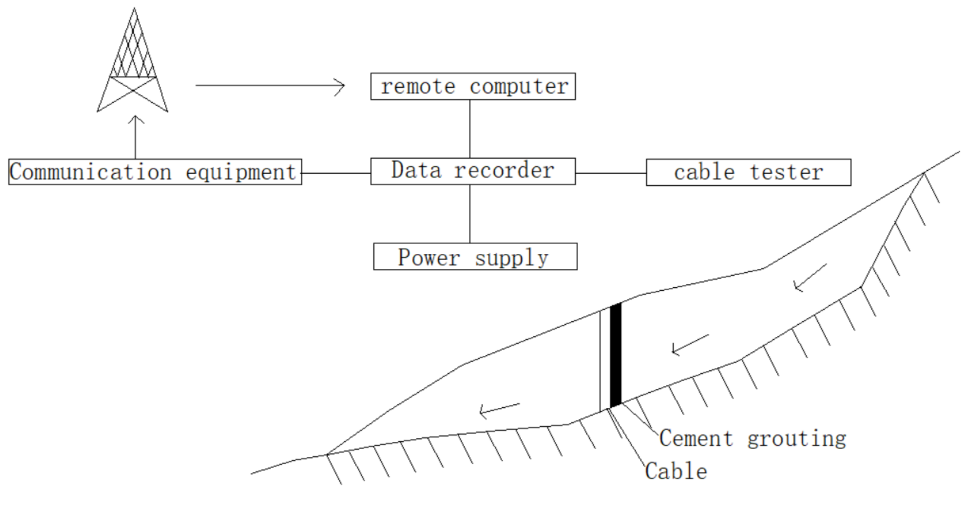

Figure1. TDR slope monitoring system (Tang et al. 2007)

3.7. Synthetic Aperture Radar (SAR)
Synthetic Aperture Radar (SAR) is a microwave sensor. Synthetic Aperture Radar Interferometry (InSAR) combines synthetic aperture radar imaging technology and interferometric measurement technology to accurately measure the spatial position of any point on the surface by means of imaging geometry and sensor system parameters. And minor changes, the main application areas include: Digital elevation model (DEM) acquisition, map mapping, ground extraction and monitoring of surface deformation such as landslides and land subsidence [9]. Chinese expert Fan Qingsong has been working on the study of using this technology to monitor surface deformation [10].

4. Problems in New Engineering Monitoring Technology

In the past ten years, the application of slope monitoring technology at home and abroad has made considerable progress in engineering. However, due to the immature state of the art, the complexity of geological rock and soil, and the uncertainty of the slope deformation mechanism, these technologies also have various problems in the application process of engineering practice. Mainly reflected in the following aspects:

1) Technical application and on-site construction are difficult and the technical cost is high. echniques that monitor well under laboratory conditions, when actually applied to engineering, may encounter difficulties such as difficult construction, complex field conditions, and sensor damage.

2) Limitation of monitoring conditions. Existing deformation monitoring techniques may only be suitable for monitoring under certain conditions. This technology cannot accurately monitor deformations.due to vegetation cover, small deformation of slopes, and slow deformation. This is one of the problems that TLS technology needs to solve in the future.

3) Slope monitoring data analysis and theoretical model research are insufficient. The current monitoring technology may interfere with external factors, so scientific data preprocessing, the maximum access to the hidden information of monitoring values becomes a key point in the analysis of monitoring results.

4) Monitoring technology is poorly integrated and coordinated. The new monitoring system developed on the existing basis is generally based on its own programming. When combined with other technologies, there will be problems such as data cannot be read or read incorrectly, and monitoring results cannot be visualized.

5. Conclusion

In summary, with the development of science and technology, various advanced monitoring equipment and communication technologies are applied to the monitoring of slopes, and the comprehensive utilization of various means can more effectively understand the actual situation and stability of the slope and improve the monitoring. Accuracy and ease of operation, and provide reliable information on safety and design. However, the application of slope deformation monitoring technology still has the disadvantages of low automation of equipment and insufficient intelligence of data acquisition and transmission. To this end, key research can be carried out in the following aspects: 1) Develop more economical slope monitoring instruments and equipment. 2) Strengthen the integration and coordination of comprehensive application monitoring technology methods. 3) Strengthen the research on slope monitoring data analysis and theoretical models.

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