The Application of BeiDou Navigation Satellite System in Slope Displacement Monitoring

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Abstract. The stability monitoring of high slope engineering is extremely important. In this paper, BeiDou Navigation Satellite System (BDS)is applied to the displacement monitoring of slope engineering in Dazhou Hospital Area of West China Hospital in Sichuan Province. The installation method of BDS under the slope frame beam support has been discussed in detail. The BDS has the real-time, remote automatic monitoring and SMS early warning function for slope surface displacement monitoring by the web data platform; at the same time, the advantages of BDS compared with traditional monitoring methods bas been analyzed; the observation data can be well satisfied to the accuracy requirements of slope deformation monitoring, the reliability of BDS was be verified. The slope monitoring technology would be significant improved and perfected by the relevant results.

Keywords: Slope engineering; BDS; Monitoring station; Reference station.

1 Introduction

The people's lives and property safety were always threatened by the collapse of high and steep slopes[1]. Which is necessary to monitor the displacement of slopes for getting its stability in-time. The total station or dumpy level was used to monitor manually by laying deformation monitoring points on the slopes[2][3], this method was slow in efficiency and cannot suitable for severe weather and emergencies especially; so traditional monitoring methods can no longer meet the needs of engineering slope monitoring, and people has been looking for efficient landslide monitoring methods; Xiong Ch[4] studied the automatic slope monitoring system of intelligent total station, which is composed of intelligent total station, machine room and power supply facilities, reducing the workload of manual on-site measurement and realizing automatic monitoring. However, total station equipment is expensive, and the measurement accuracy is greatly affected by the weather. Qi E combined a large amount of practical experience in geotechnical engineering monitoring to elaborate on the working principles and characteristics of three main automatic monitoring systems, and objectively pointed out the shortcomings of automatic monitoring systems[5].

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With the development of science and technology, China has made remarkable achievements in the field of satellite positioning. The BDS contains 30 positioning satellites. The positioning technology based on BDS is widely used in various fields. The application of BDS in slope monitoring has greatly enriched deformation monitoring means[6][7]. Compared with traditional optical monitoring methods, BDS monitoring can efficiently achieve all-weather fully automated monitoring, strong applicability and controllable cost. Civil use of BDS is also a national grand strategy requirement. In this paper, the BDS is applied to the deformation monitoring of the slope, from the selection of instruments and equipment, the installation mode of monitoring points, the acquisition frequency and other technical details, the automatic high-precision monitoring of the slope has been realized, and some valuable experience has been obtained.

2 Overview of BDS

The monitoring of BDS is based on pseudo range difference and phase difference technology; by placing the BDS transceivers at the location of the monitoring point to form a monitoring station, using relative positioning method, the station coordinates are obtained by intersecting the monitoring station, reference station, and multiple satellites in space. The position calibration is performed between the monitoring station and the reference station[8].

Set the coordinates of the monitoring station as x, y, z; the satellite coordinates are xi, yi, zi

$$R=\sqrt{(x-x_i)^2+(y-y_i)^2+(z-z_i)^2} \tag{1}$$

In the formula, R is the geometric distance between the satellite and the monitoring station, and i is the satellite number; in equation (1) above, there are only three unknowns of the monitoring station coordinates x y z, and the position coordinates of the monitoring station can be calculated by receiving four satellite signals simultaneously.

In order to improve monitoring accuracy, one or more BDS receivers are placed at fixed points as reference stations. The reference station synchronously receives satellite signals and calculates the position of the reference point. At the same time, the reference station sends real-time data such as reference station coordinates, carrier phase observations, and pseudo range observations to the monitoring station. Based on the above information, the monitoring station can calculate the vector position relationship with the reference station, Accurate monitoring station center coordinates can be obtained through geometric decomposition operations.

3 Engineering Overview

Dazhou hospital area of west China hospital is located in lotus lake area of Dazhou city. It is a typical mountain landform in Sichuan province. The stratum in the site is mainly composed of the upper quaternary overburden and the lower thin thick Jurassic middle upper formation (J2s) silty mudstone, sandstone and siltstone. The bedrock is produced in interbedded layers of unequal thickness. The surface artificial fill is mainly composed of sandstone, silty mudstone rubble and construction waste. Some cohesive soil, in which skeleton particles account for about 50%~70%, is backfilled when the plant area is built. The backfilling period is about 3 years, and the self weight consolidation settlement has basically been completed. This layer is mainly distributed near the south side and southwest corner of the factory area, with a significant variation in thickness. The drilling revealed a thickness of 2.10-16.00 meters; in addition, an ancient river channel was discovered during the survey; the excavation volume of the project is huge, forming an artificial slope with a maximum height of 53.0m. The upper part of the slope is supported by anchor (cable) rods and frame beams, while the lower part is supported by anchor piles and sheet walls. The typical section of slope support is shown in Figure 1. The hospital building is only 20m away from the anti slip pile. In order to cope with sudden situations such as landslides and minimize social impact, monitoring the stability of the slope is of great significance.

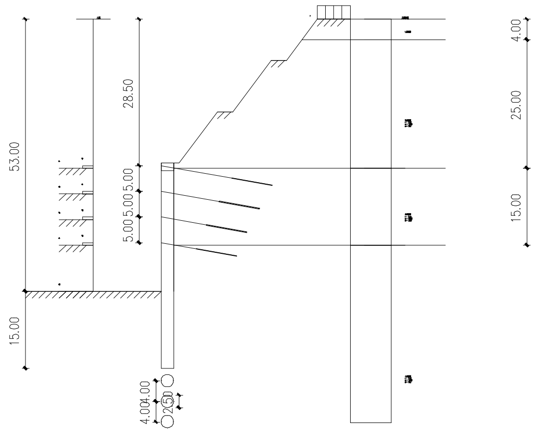

Fig. 1. Cross Section of Slope(Unit: meters)

4 Deformation monitoring

The slope stability monitoring of Dazhou hospital of west China hospital in Sichuan includes the construction period and the operation period. In order to meet the requirements of all-weather real-time online monitoring of the slope, the BDS is used to monitor the slope surface displacement; a total of 4 vertical sections are arranged, and BDS monitoring stations are respectively arranged at the top of the slope, the secondary platform, the crown beam surface of the anti slide pile and other locations on each section. The accuracy of monitoring station calculation is negatively correlated with the distance between the monitoring station and the reference station. In order to improve observation accuracy, a reference station is installed at a location that is visible, close, and stable to all monitoring stations.

4.1 Power supply system

The monitoring station of BDS consists of a base head and a power supply system. The power supply system includes solar panels, solar controllers and batteries, as shown in figure 2 (a). During field monitoring, continuous power supply to the monitoring station is a prerequisite for reliable monitoring. Through research, it has been found that the power consumption of most monitoring stations is between 6w and 10w, with a DC power supply voltage of 12V and a power supply current of 0.5A to 0.9A. The required battery capacity is calculated based on the maximum power while considering losses. The power consumption for uninterrupted operation 24 hours a day is 24Ah, ensuring the stable operation of the monitoring station during three consecutive days of cloudy and rainy weather. It is recommended to use a battery capacity of no less than 60Ah, and to choose a solar panel power of 150W to 200W to match it, The specific situation can be determined based on the climate of the project location and the duration of sunlight exposure at the monitoring station location.

The reference station adopts a mains power supply method, and in order to prevent accidents such as tripping, the reference station is equipped with an uninterruptible power supply UPS system. As shown in Figure 2 (b).

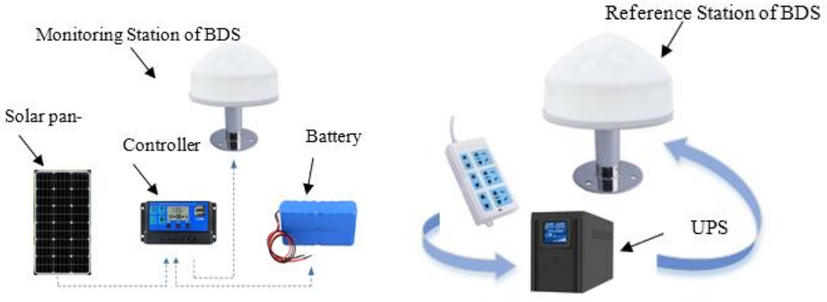

Fig. (a) Monitoring Station of BDS Figure (b) Reference Station of BDS

Fig. 2. Composition of BDS Monitoring Station and Reference Station

4.2 Installation of monitoring stations/reference stations

The core components of the BDS are highly integrated monitoring station base heads and reference station base heads. The base heads are small in size, with built-in DTU and 4G chips, which can realize data acquisition, data transmission and other functions; the static monitoring accuracy of the monitoring station is ± 2.5mm+1ppm. The terrain of the slope engineering is steep, and the top of the slope is adjacent to the initial landform. The installation of monitoring equipment should make use of the slope structure as much as possible. The solar panels should be placed on the longitudinal beam of the frame beam, and the monitoring station should be fixed on the surface of the beam. The benchmark station should be installed upright, stable, and deformed in coordination with the frame beam, as shown in figure 3 (a). The reference station is installed on a column foundation with an unobstructed elevation angle of 45 ° or above, as shown in figure 3 (b), which is visible from the slope monitoring station.

Fig.(a) Installation diagram of on-site monitoring station

Fig. (b) Installation diagram of on-site reference station

Fig. 3. Composition of BDS Monitoring Station and Reference Station

4.3 Data Analysis

Figure 4 (a) and figure 4 (b) show two sets of monitoring data of BDS at different locations on the same section, the x, y and z correspond to station center coordinates e, n, u, that is, plane displacement x, y and settlement z; according to the continuous monitoring data within three months, it can be seen that the plane displacement fluctuates within a millimeter range, with a maximum fluctuation range of 4mm. The same monitoring section shows irregular changes in data from different monitoring stations, indicating that the slope deformation is very small and basically in a stable state, which is consistent with the on-site slope inspection situation. The elevation shows a slow sinking trend in mid to late May, which may be related to the excavation of the soil outside the anti slip pile at the bottom of the slope. The sinking amount is about 5mm, which is within the allowable range of slope deformation; in general, the application of BDS to slope surface displacement monitoring is ideal, and good monitoring results have been achieved.

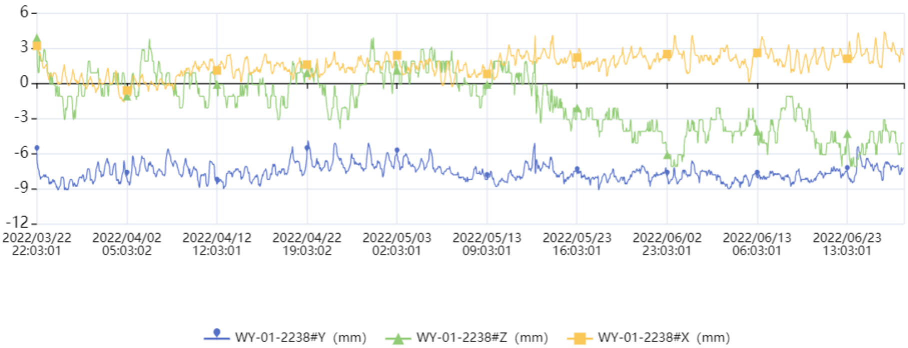

Fig. (a) Time varying displacement curve of monitoring station WY-01

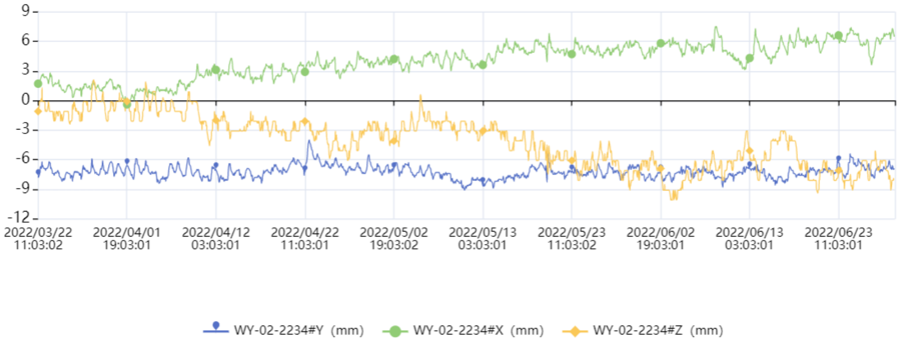

Fig. (b) Time varying displacement curve of monitoring station WY-02

Fig. 4. Displacement Monitoring Results of BDS at WY-01 and WY-02 Points

The standard requires a deformation rate warning value of 2mm/d for slope monitoring. Currently, the nominal accuracy of most universal BDS positioning receivers on the market is ± 2.5mm+1ppm, and the cost is controllable within the project. Higher precision imported motherboard receivers can achieve sub millimeter level accuracy, but the corresponding cost is also high. Practical application has proven that the accuracy of the universal BDS positioning receiver meets the requirements of slope observation, and the effect is significant; the reason for the analysis is that the slope monitoring adopts the relative positioning method, which pays more attention to the changes in two observation values. The accuracy of the receiver refers to the difference between the observation values and the absolute position. For the relative positioning method, the more attention is paid to precision, that is, the consistency of the measurement results under the same conditions. The higher the precision, the more accurate the measurement results of the relative positioning method, and the higher the proportion of equipment system error in random error, The achievement of good slope monitoring results is closely related to the precision of the instruments; therefore, taking into account cost considerations, instrument selection can refer to two indicators: accuracy (precision) and precision. In addition, the monitoring frequency can be increased. The monitoring frequency required by the specification during the slope construction period is 1 time/d. The BDS can be used for real-time monitoring, and the sampling frequency is usually set to 1 time/h. High frequency monitoring can eliminate some data errors, and the slope stability can be evaluated through the curve trend of data deformation.

5 Conclusions

(1) The relative monitoring method is adopted for slope monitoring. The single precision (accuracy) index of the BDS is only for reference. Precision should be paid attention to when selecting instruments.

(2) In order to cope with rainy weather and ensure the continuity of monitoring data, the battery of the power supply system shall not be less than 60Ah, and the power of the solar panel shall not be less than 150W.

(3) Improving observation accuracy can be achieved by increasing monitoring frequency and setting up multiple reference stations.

(4) Through the application of BDS in the high slope monitoring project of Dazhou hospital of west China hospital in Sichuan, the deformation data fluctuates within the millimeter scale, and the monitoring results are stable and reliable, meeting the requirements for slope early warning values in the specification, and the relevant monitoring methods are worth popularizing.

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