The Application of Beidou High-Precision Positioning Technology in the Deformation Monitoring of Ship Locks

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Abstract. Accompanying the construction of inland navigation projects is the generation of high slopes, whose stability has always been an important safety issue of great concern during the process. The safety incidents involving high slope instability often cause huge economic losses and even casualties. Therefore, it is of particular importance to monitor high slopes, to identify safety hazards and to predict the occurrence of safety accidents in advance through the tendency of changing. Once the project is completed, effective monitoring is also essential during the operation of the locks in order to avoid safety accidents such as the collapse of ship locks and other main structures.

Based on the BeiDou high-precision positioning technology, this paper investigates the application of the automated displacement monitoring system in the construction and operation of navigation projects. The system mainly consists of sensor subsystem, data transmission subsystem, data processing and control subsystem as well as other auxiliary support subsystems. The system collects static satellite data from fiducial points and monitoring points, carries out baseline vector solution to realize millimeter-level displacement monitoring, and effectively monitors high slope displacement during construction according to the storage, management, query, statistics and analysis of the monitoring data, as well as timely detects abnormal situations about the displacement. When there is slope instability, early warning will be issued by grading so that measures could be implemented in advance to avoid safety accidents. When applied during the operation of ship locks, it can monitor the displacement of the lock chamber's main work persistently to ensure its normal operation.

This paper takes the construction site of certain ship lock project as the object and sets up 1 fiducial point and 10 monitoring points. The real-time displacement monitoring of the site's high slopes throughout the construction period is carried out, the main functions of the monitoring system are tested and the monitoring data and results are briefly analyzed. After the completion of the project, the monitoring system is applied during the operation of the ship lock and the deformation of the lock chamber is constantly monitored and analyzed.

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1 Background

Deformation monitoring is the periodic and repeated measurement of the observation points set on deformed bodies in order to determine the changes of their spatial location and the characteristics of their internal structure over time [1]. Throughout the construction and during the operation, the engineering structures should be continuously monitored in order to keep track of the deformation, identify problems in time and ensure their security.

The deformation monitoring of the lock includes the main work such as the lock head, the lock chamber [2], and the foundation pit [3]. The fill behind the lock chamber walls gradually increases in height during the construction, covering the original observation points. Therefore, they must be increased in height as well to enable continuous monitoring. Due to the phased construction of the lock chamber wall, its surrounding area is excavated and back filled every now and then, making it necessary to frequently change the monitoring route for settlement measurements and thus it would compromise the continuity and accuracy of the monitoring. What's more, the release of water within the lock chamber during the operation phase will affect the observation points during the construction phase, also creating difficulties for deformation monitoring.

Since its establishment, the BeiDou system has been widely used in various fields like navigation and positioning. Its advantages of high accuracy, high efficiency, all-weather service and no need for line of sight in static relative positioning have led many researchers to choose it over the conventional methods such as triangulation, trilateration and triangulateration. And it has brought fruitful results both in theory and practice. It is also increasingly widely used in the deformation monitoring of precision engineering.

Therefore, this paper carries out research on the automated displacement monitoring in the main work of ship locks based on the BeiDou high-precision positioning technology.

2 The Principle of BeiDou High-Precision Measurement

Four satellites are required in the BeiDou positioning technology. The distance from each of the two satellites to the user machine is the radius of two spheres intersecting at two points. Suppose the distances from the 4 satellites to the user machine are R1, R2, R3 and R4 respectively [4].

$$R_1 = c(t_r + dt_r - t_{s1}) = \sqrt{(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2} \tag{1}$$

$$R_2 = c(t_r + dt_r - t_{s2}) = \sqrt{(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2} \tag{2}$$

$$R_3 = c(t_r + dt_r - t_{s3}) = \sqrt{(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2} \quad (3)$$

$$R_2 = c(t_r + dt_r - t_{s4}) = \sqrt{(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2} \quad (4)$$

where xi, yi and zi are the coordinates of the i-th satellite; c is the speed of light; tr is the signal arrival time measured by the receiver; dtr is the clock bias between the receiver and the satellite; tsi is the signal emission time measured by the satellite.

Four unknowns can be solved with the above four equations to obtain the coordinates of the station. To improve the accuracy of the BeiDou measurement, RTK technology is used where one receiver is placed on the reference station while other receiver(s) on a carrier (called mobile station). Both the reference station and the mobile station receive signals from the same BeiDou satellite synchronously. The reference station sends the carrier phase measurement, pseudo-range measurement and the coordinates of the reference station to the mobile station in real time by radio transmission. The monitoring station starts the differential processing based on the simultaneously received data from the reference station and the BeiDou satellite to obtain the baseline vectors (Δx, Δy, Δz) of the reference station and the mobile station. The baseline vectors are combined with the reference station coordinates to obtain the WGS84 coordinates for each point of the mobile station. And finally, the plane coordinates x, y and the normal height h of each point of the mobile station are converted and obtained by coordinate transformation. The BeiDou displacement measuring system [5], based on the RTK principle, satellite positioning and post-processing of measured data, has certain lags in the post-processing of measured data due to the large amount of data. The BeiDou monitoring equipment requires its reference station to be located in a stable zone, generally on an unobstructed and steady bedrock. The layout of BeiDou monitoring equipment is shown in Fig. 1. The accuracy of static displacement measurement of the BeiDou monitoring equipment reaches the millimeter level [6].

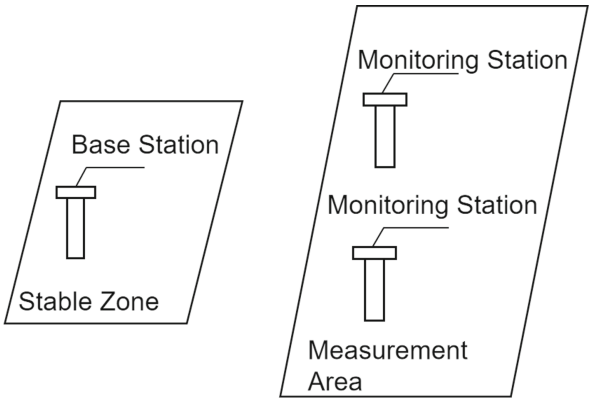

Fig. 1. Layout of the BeiDou monitoring equipment

3 Deformation Monitoring System for Ship Lock Projects Based on BeiDou High-Precision Positioning Technology

Through the equidistant deployment of professional BeiDou-based displacement monitoring system between the upper and lower lock heads on the lock chamber wall, coupled with the existent building deformation monitoring and early warning system platform for real-time displacement monitoring of stress points, the lock chamber monitoring and early warning demonstration system is built, which could allow dynamic monitoring on the displacement of the lock chamber, as well as store, manage, inquire, count and analyze the monitoring data. When the monitoring data reaches the threshold, the early warning system will be activated. Through the development of this project, we'll gradually improve and enrich the application scenarios of the BeiDou system on shipping hubs and water conservancy projects, providing technical support for lock chamber safety monitoring. The technical route is shown in Fig. 2.

The monitoring system consists of four main components, namely, the sensor subsystem, the data transmission subsystem, the data processing and control subsystem and the auxiliary support system.

Sensor subsystem: it is responsible for data acquisition. This is mainly a BeiDou receiver that monitors the horizontal displacement, vertical displacement and the rate of change of the lock chamber. What's more, the sensor subsystem can also be extended with strain gauges, rain gauges, video dome machines and other equipment.

Data transmission subsystem: it is responsible for transmitting the data collected by the sensor system to the monitoring centre server. Most of the sensors have built-in transmission modules, which can transmit data via 3G/4G/Lora/NB and other communication methods.

Data processing and control subsystem: it is the data processing and analysis centre of the whole monitoring system and the monitoring centre of the system. The monitoring centre server collects, processes, stores, analyzes, displays and alarms all kinds of sensor data in real time.

Auxiliary support system: it consists of equipment that assists in the normal operation of the entire monitoring system, including power supply, lightning protection, comprehensive wiring and off-site cabinets and other subsystems.

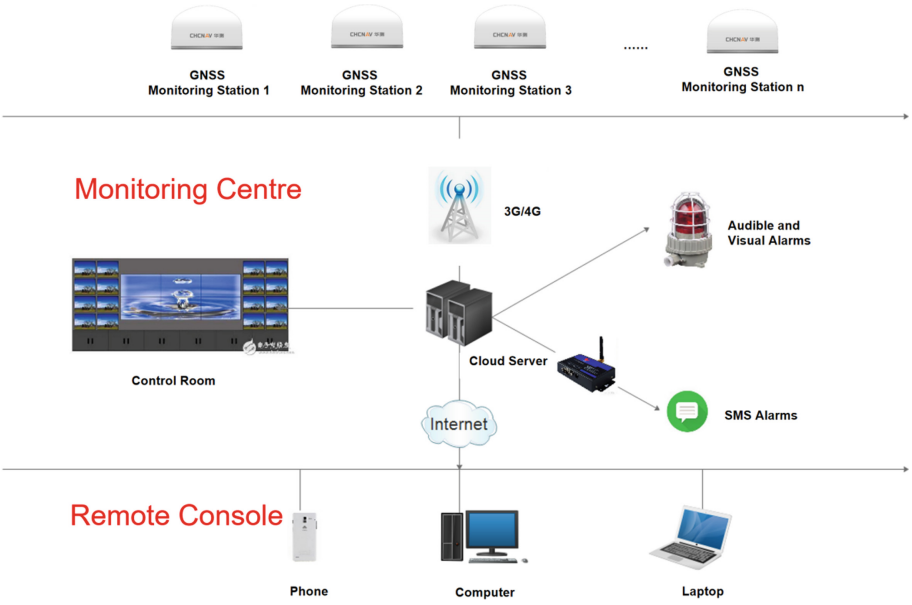

Fig. 2. Architectural diagram of the monitoring system

4 Application of Deformation Monitoring System for Ship Lock Projects Based on High Precision Positioning Technology

4.1 Introduction to the Project

The monitoring project is the second-line ship lock of Guigang Shipping Hub of Xijiang Main River, which is located in Xintang Town, Gangnan District, Guigang City, Guangxi. It aims to monitor the horizontal and vertical displacements and the rate of change of displacements of the lock chamber walls between the upper and lower lock heads of the second-line ship lock of Guigang Shipping Hub of Xijiang Main River. A BeiDou receiver was used to receive signals from BeiDou satellite system. And the differential between the reference station and the monitoring station will be used to calculate horizontal and vertical displacements. In the early phase of the project, system testing was carried out for slope monitoring during the construction. And it will eventually be deployed to the main body of the lock chamber.

4.2 Monitoring Points Layout

According to field situations and technical requirements, a total of 10 BeiDou monitoring stations were laid out on both sides of the lock chamber at equal intervals to monitor the overall deformation activities and changes on the surface of the force bearer on both sides of the lock chamber. Another BeiDou reference station was laid on the roof of the central building of the engine room, which is not affected by the

potential energy of the water level, to improve the accuracy of deformation monitoring. The points are shown in Fig. 3 and Fig. 4.

Fig. 3. Map of monitoring points on the top chamber wall

Fig. 4. Map of monitoring points on the lower chamber wall

4.3 Analysis of Monitoring Accuracy

During the test period, total station prisms were installed at the columns of 2 BeiDou monitoring points simultaneously. Comparing the BeiDou monitoring data with the total station monitoring data, it can be seen that the basic deformation trend shown by the 2 groups of data is the same. The comparison between the monitoring data from BD1 and BD2 equipment and that from total station equipment is shown in Fig. 5.

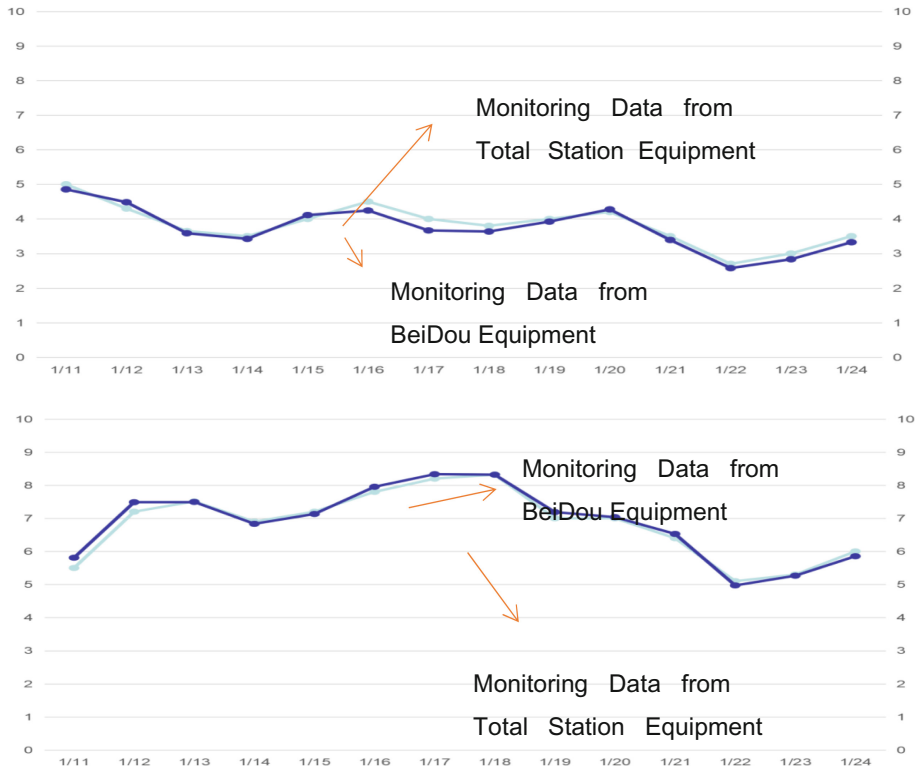

Fig. 5. Comparison of the monitoring data from BD1 and BD2 equipment and the total station equipment

As can be seen from Fig. 5, the deformation trends of the locks are basically the same, excluding the manual observation errors. In order to verify the usability of the BeiDou displacement monitoring, a hypothesis test was conducted on the two monitoring results of BD1 and BD2 [11]. The original hypothesis is that the two kinds of observation means, BeiDou monitoring and total station monitoring, have no significant effect on the displacement data. The results of the significance calculation are shown in Table 1.

As can be seen from Table 1, the ANOVA results for BD1 and BD2 were 0.8516 and 0.7487, both of which were greater than 0.05. Therefore, the original hypothesis was accepted as there was no significant difference between the observations of the two monitoring methods.

Table 1. Calculation results of significance

Significance analysis indicators	BD1		BD2	
	Inter-group	Intra-group	Inter-group	Intra-group
S 11. 53		14 329 0.10	92. 47	37 160. 40
f	1	44	1	42
F-value	11.0	325. 7	92. 47	884.70
P-value	0.851 6		0. 748 7	
F threshold value 4. 06			4. 07	

Note: S is the sum of squares of the sample data; f is the degree of freedom; F is the ratio of the sum of squares between groups to the mean square of the sum of squares of the error; P is the probability of the F value at the corresponding significant level.

5 Conclusion

This paper briefly outlines the technical method of applying BeiDou technology to monitor the deformation of ship locks, and successfully applies it to the displacement monitoring of the second-line of ship lock at Guigang Shipping Hub of Xijiang Main River. The conclusions are as follows:

1) It is feasible to apply the automated monitoring method of BeiDou monitoring equipment to monitoring ship lock projects, which has the advantages of being all-weather, unaffected by bad weather, continuous observation and high observation efficiency, compared with manual observation by means of total stations and so on.
2) BeiDou monitoring and total station monitoring data are in good agreement, and there is no significant difference between the data. The comparison with the data from total station monitoring verifies the reliability of BeiDou monitoring data, and basically removes the error of manual observation;
3) The extreme weather conditions of rainstorm and typhoon during the field test had little impact on the fully automated monitoring by BeiDou. Compared with the manual monitoring of total station, automated monitoring made by BeiDou featured stronger usability.
4) The monitoring system can be applied to the construction and operation of lock project, so it is meaningful to promote the application of such projects, and it can be extended to the monitoring of breasting dolphins at the same time after the completion of the lock project.

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