Application of CORS in Landslide Monitoring

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Abstract. Global Navigation Satellite System (GNSS) can provide continuous and high-precision absolute displacement information and therefore has been an important technical means of landslide surface displacement monitoring. When GNSS is used for landslide monitoring, a reference station is usually set for a monitoring landslide (referred to as "one reference station for one landslide "). Through the method of short baseline relative positioning, high-precision monitoring is realized by eliminating the atmospheric propagation error with strong spatial correlation. However, this application mode has problems such as high monitoring cost, low data reuse of reference station, and heavy dependence on the single reference station for the calculation results of monitoring stations, which limit the large-scale promotion and application of GNSS in landslide monitoring. Aiming at the above problems, this study took Liujiafen Landslide in Moxian County, Sichuan Province as a case to study the application of Continuously Operating Reference Stations (CORS) and Virtual Reference Station (VRS) issued by Natural Resource system in landslide monitoring to optimize the existing application mode of "one reference station for one landslide ". In this study, the evaluation of the quality of VRS data, the calculation accuracy of static base line, and the comparative analysis of the calculation results between virtual and physical reference stations were carried out to demonstrate the applicability of CORS in landslide monitoring. According to the results: (1) The data quality of the selected virtual reference station was good; (2) The calculation accuracy of the baseline composed of virtual reference station and monitoring station was basically equal to that of the baseline composed of physical reference station and monitoring station. In view of the regional differences in the construction density and quality of CORS reference stations, and the relationship between atmospheric propagation correction model and topographic relief, it is suggested that the application should be decided after comprehensive evaluation based on the actual distribution of reference stations and specific environmental conditions.

1. Introduction

Landslide monitoring and timely release of early warning information is the most direct and effective means to avoid casualties and reduce economic losses, and it is also one of the important work to solve the core problem of "when the hidden landslide may occur" [1,2]. The surface displacement of the landslide is usually monitored to study the movement state of the landslide. As a space-based radio navigation and positioning system [3] that has remarkable advantages such as global ground coverage, real-time, all-weather, three-dimensional coordinates with millimetre level positioning accuracy and easy automation, GNSS (Global Navigation Satellite System) has been widely used in landslide monitoring [4-6]. It has become one of the important technical means to obtain the absolute displacement of landslide surface. In practical application, a GNSS reference station is usually set for a monitoring landslide, which is referred to as "one reference station for one landslide " layout mode
For the specific layout of monitoring equipment, the monitoring stations should be set up according to the transverse and longitudinal sections or in the obvious deformation sections, and the reference stations should be set up at the stable place outside the landslide, with open and good satellite search conditions, no high-voltage line, substation and other electromagnetic interference sources. However, the layout mode "one reference station for one landslide" has the following problems: firstly, the frequent layout of reference stations leads to a waste of resources and funds, resulting in high layout cost; Secondly, the data of the reference station is only used for the equipment at one monitoring landslide, so the reuse rate of the reference station is low and not fully utilized; Thirdly, the results of the monitoring station depend heavily on the stability and baseline quality of a single reference station, so the reliability is poor; Fourthly, it is difficult to select the location of the reference station. Most of the landslides are located in poor stability areas, so it is difficult to ensure the stability of the reference station itself. In addition, the field observation environment is bad, so it is difficult to choose the ideal location of the reference station. According to the data released by the Ministry of Natural Resources, there are about 286000 potential geological disaster sites in China [8], and the layout mode of "one reference station for one landslide" cannot meet the needs of large-scale deployment of geological disaster monitoring and early warning in the future. In order to optimize the layout mode of "one reference station for one landslide", based on the real-time observation data of natural resources system CORS (Continuously Operating Reference Stations) [9], application experiment of Virtual Reference Station (VRS) technology in landslide monitoring was carried out in Liujiafen Landslide, Fengyi Town, Maoxian County, Sichuan Province, which is currently being monitored by universal GNSS.

2. VRS technology

Virtual Reference Station (VRS) technology was first proposed and applied by Trimble Terrasat in 2001[10]. It is a widely used network RTK (real-time dynamic) service scheme. The principle is to establish a virtual reference station near the mobile station (landslide monitoring station), and then the data center can model the troposphere delay, ionospheric delay and other spatial propagation path related errors of the virtual reference station by using at least 3 physical reference stations around the mobile station and real-time observation data, and calculate the observed value of the virtual reference station. The system is sent to the terminal of mobile station according to the standard RTCM[11] format to realize the real-time cm level solution accuracy. At the same time, it can also store the observation data of virtual reference station for post calculation, and then obtain the precision of the post millimetre level solution.

After VRS technology was put forward, many experts and scholars at home and abroad have carried out in-depth research on it, and successfully realized commercial application and industrialization [12-15].

3. Case study of CORS application in geological disaster monitoring

3.1. Study area and data

Liujiafen Landslide, located in group 3, Huilong village, Fengyi Town, Maoxian County, Sichuan Province, was selected for the case study. The landslide is 80 m long, 140 m wide and 10 m thick with a slope of 30° and volume of $10 \times 10^4$ m$^3$. It is a rock landslide. The lithology of sliding bed and sliding body are phyllite, which mainly threatens 28 families in the gathering area. The shortest illumination time of the landslide is 6h (hours) in four seasons, and the mobile 4G signal is strong. There are no large buildings, large area of water, high power and wire emission source nearby. According to the field survey, two sets of GNSS displacement monitoring stations are arranged along the main section line of the landslide, as shown in Figure 1.
According to the distribution of satellite navigation and positioning reference stations constructed by the national Natural Resources system, three physical reference stations with an average station spacing of 49km are selected around Liujiafen Landslide monitoring point for reference station networking calculation and virtual reference station observation data generation. The information of each reference station is shown in Table 1, and the relative positions of the three reference stations are shown in Figure 2.

**Table 1. Information of provincial reference stations around Liujiafen Landslide**

| No. | Reference station location | Receiver type | Antenna type | Antenna height (m) |
|-----|---------------------------|---------------|--------------|-------------------|
| 1   | Maoxian, Sichuan          | TRIMBLE NETR9 | TRM59900.00 SCIS | 0.110             |
| 2   | Mianzhu, Sichuan          | TRIMBLE NETR3 | TRM57971.00 NONE | 0.111             |
| 3   | Beichuan, Sichuan         | TRIMBLE NETR3 | TRM57971.00 NONE | 0.113             |

Based on the real-time observation data stream of three provincial reference stations, a small reference station network is established to calculate the data, and the observation data of virtual reference station is generated according to the real-time output mode in the area near the monitoring landslide.
3.2. Design of monitoring experiment

This experiment demonstrates the applicability of CORS in landslide monitoring from three aspects: the quality of virtual reference service, the accuracy of static baseline solution, and the comparison with the accuracy of physical reference station. The experimental scheme is divided into three steps, as shown in Figure 3.

(1) Data generation of virtual reference station and data collection of monitoring station: using the observation data of three reference stations around the monitoring point from November 1 to 7, 2020 (annual accumulation day 306-312), a virtual reference station, FYVR, is generated near the Liujiafen landslide monitoring point. The data sampling rate is 1Hz, and the total time of single day data is 24 hours; At the same time, the observation data of the Day of Year corresponding to the physical reference station FYJZ set near the landslide monitoring point are collected.

(2) Quality assessment of the observation data of virtual reference station and monitoring station: Using TEQC (Translation, Editing and Quality Checking) software developed by UNAVCO facility, the quality assessment of 312 days of FYVR observation data of virtual reference station is carried out (one time period is one hour). GNSS observation data quality evaluation adopts three commonly used quality evaluation indexes, which are data integrity rate $\geq 85\%$ and multipath effect error MP1 and MP2 less than 0.5m. The data integrity rate reflects the integrity of the received satellite signal by the percentage of the actual observation epoch and the theoretical observation epoch; MP1 and MP2 respectively reflect the influence of multipath effect on the first and second frequencies of the observed signal. The smaller the value of MP1 and MP2, the stronger the anti-multipath effect ability of the receiver.

(3) Baseline solution and analysis: Using Trimble TBC (Trimble Business Center) commercial GNSS data processing software, version 5.0.2, the physical reference station FYJZ and the virtual reference station FYVR are combined with two monitoring stations 02 (GP) and 03 (GP) respectively to form a baseline. The static baseline solution and accuracy evaluation are carried out. The data observation period is 306-312 days per year.
3.3. Analysis of experimental results

3.3.1. Quality evaluation of observation data. The results show that the average value of the data integrity of FYVR is 86%, the optimal 97%, and the worst 73%; The MP1 and MP2 values of the multi-path effect of the observation data of the virtual reference station are lower than 0.5m in all periods. It can be seen that the data quality of virtual reference station is good. This is related to the quality of observation data of the surrounding CORS station.

3.3.2. Accuracy analysis of baseline calculation.

(1) FYVR-02 (GP) virtual baseline solution: there are 150 effective observation periods in 7 days, and the average length of baseline solution is 369.296m. According to the statistics, the standard deviations of the solution results in X, Y and Z directions of the baseline are $0 \pm 5mm \pm 18mm$ and $12mm$. According to the analysis of 150 valid periods of baseline, the difference between the change of X and the average value is basically within 1cm. Since Y and Z direction is highly correlated with elevation direction, the difference between the change of Y and average value is within 2cm, Z is within 3cm, and more than 3cm in some periods. The specific changes are shown in Figure 4.

(2) FYVR-03 (GP) virtual baseline solution: there are 150 effective observation periods within 7 days, and the average length of baseline solution is 339.482m. According to the statistics, the standard deviations of X, Y and Z directions of the baseline were $0 \pm 5mm \pm 18mm$ and $11mm$. According to the analysis of 150 valid periods of baseline, the difference between the change of X and the average value is basically within 1cm. Since Y and Z direction is highly correlated with elevation direction, the difference between the change of Y and average value is within 2cm, Z is within 3cm, and it is close to 3cm in some periods. The specific changes are shown in Figure 5.

(3) FYJZ-02 (GP) physical baseline solution: there are 160 effective observation periods in 7 days, and the average length of baseline solution is 3469.795m. According to statistics, the standard deviations of solution results in X, Y and Z directions of baseline are $3mm \pm 12mm$ and $12mm$. Based on the analysis of 160 valid periods of baseline, it is found that in the X direction, the difference between the change of X and the average value is basically within 1cm. Y and Z have a great correlation with the elevation direction, so the difference between
them and the average value is large, which is basically within 2cm. The specific changes are shown in Figure 6.

(4) FYJZ-03 (GP) physical baseline solution: there are 160 effective observation periods in 7 days of baseline, and the average length of baseline solution is 3411.157 meters. According to statistics, the standard deviations of solution results in X, Y and Z directions of baseline are ±6mm, ±17mm and ±18mm. Based on the analysis of 160 valid periods of baseline, it is found that in the X direction, the difference between the change of X and the average value is basically within 1cm. Y and Z have a great correlation with the elevation direction, so the difference between them and the average value is large, which is basically within 3cm. The specific changes are shown in Figure 7.

The differences between the three directions and the mean value of the virtual baseline and the physical baseline are shown in Table 2.

| Baseline                   | Δ X(mm) | Δ Y(mm) | Δ Z(mm) |
|----------------------------|---------|---------|---------|
| FYVR-02(GP) virtual baseline | ±5      | ±18     | ±12     |
| FYJZ-02(GP) physical baseline | ±3      | ±12     | ±12     |
| FYVR-03(GP) virtual baseline | ±5      | ±18     | ±11     |
| FYJZ-03(GP) physical baseline | ±6      | ±17     | ±18     |

In summary, compared with the two virtual baselines, the results of the two physical baselines do not show absolute advantage in the effective observation period. This may be because the construction standard of Liujiafen Landslide reference station is lower than that of the three selected CORS stations, and the observation environment is not as good as CORS stations. It can be seen that the baseline resolution accuracy composed of virtual reference station and monitoring station is basically equivalent to that composed of physical reference station and monitoring station.

4. Conclusion

In view of the problems existing in the traditional GNSS application mode of "one reference station for one landslide", this study takes Liujiafen Landslide in Fengyi Town, Maokian County, Sichuan Province as a case to carry out the application experiment of CORS in landslide monitoring. The results showed that: (1) The data of virtual reference station have good quality; (2) The accuracy of baseline solution composed of virtual reference station and monitoring station is basically equivalent
to that composed of physical reference station and monitoring station. Due to the regional differences in the construction density and quality of CORS reference station network, and the relationship between atmospheric propagation correction model and topographic relief, it should be used after comprehensive evaluation according to the distribution of reference stations and specific environmental conditions.

**Funding Agents**

1. Research and development and demonstration of big data monitoring and warning platform for landslide and collapse award number(s): 2019YFC1509605
2. Research on the technology of acquiring and integrating multi-source data of sudden geological disaster award number(s): 2018YFC1505502
3. Research and development of object-oriented photogrammetry by UAV (Unmanned Aerial Vehicle) and rapid deployment monitoring and early warning equipment on high-steep slope award number(s): 2019YFC1509604
4. Landslide monitoring technology and intelligent early warning demonstration award number(s): DD20211364

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