Application of Inverted Vertical Line Method in Landslide Monitoring

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Abstract. The inverted vertical line method is generally used in dam monitoring. It relies on the relative displacement between the vertical wire and vertical coordinate instrument installed in the dam wall to monitor the deformation of the dam at different heights. In this study, the inverted vertical line method is applied to a landslide monitoring process. Firstly, a geological exploration well is excavated during geological supplementary exploration. A fixed point is embedded in the exploration well basement as a vertical reference. Secondly, a buoy is erected at the wellhead. Thirdly, vertical coordinate instruments are installed at the upper and lower sides of the predicted sliding surface to monitor the displacement of the rock mass. Finally, the sliding direction and displacement of the sliding body are determined by analyzing the monitoring data. Hence, real-time monitoring of the landslide deformation is possible through the field application of the aforementioned method. Furthermore, the reliability of the inverted vertical line method in landslide monitoring was verified by comparing the monitoring results obtained with that from an inclinometer.

Keywords: landslide monitoring, inverted vertical line method

1. Introduction

Deep displacement monitoring is a vital aspect of landslide monitoring. The landslide deformation can be monitored by a borehole inclinometer or multi-point displacement meter. In some cases, the landslide leads to tunnel damage \cite{1,2}. Therefore, geological exploration wells are excavated to investigate the geological conditions near the tunnel during geological supplementary exploration, to obtain the geological information, and to determine the causes of landslide \cite{3,4}.

The exploratory well depth for landslide exploration, which is up to 20 m or more, is mainly used to identify the structure of complex landslide with medium-sized and deep sliding surfaces. At the same time, the undisturbed soil samples of the sliding zone can be collected by exploratory wells to perform large-scale shear tests in the well. The exploratory wells can also be used as the water collecting well for the landslide treatment or the monitoring well of drainage and hydrogeological dynamic change. In comparison with a borehole inclinometer or multi-point displacement meter, a high-precision slope displacement is obtained when using an inverted plumb line to monitor landslide. Moreover, the use of an inverted plumb line provides room for direct observation of the failure of the rock mass and change of sliding surface from exploration wells. However, few studies have reported the use of exploratory wells to monitor landslide deformation.

The inverted plumb line is generally used to monitor the deformation of dams. In the present study, the inverted plumb line method is applied to landslide deformation monitoring for the first time. After determining the position of the landslide sliding surface, the vertical coordinate instruments are installed above and below the surface in the geological exploratory well. The deformation of the landslide could be obtained by the relative displacement at different heights.
2. Project overview
The case study for this project is a tunnel in Northwest China, which was damaged by landslide deformation. To study the mechanism of the landslide, geological exploration wells were excavated; the dimension of the geological exploration well is $2 \text{ m} \times 2 \text{ m} \times 80 \text{ m}$. Furthermore, the thickness of the protective wall is 0.3 m. After the exploration, the vertical coordinate instrument was installed in the exploration well to monitor the landslide deformation.

3. Installation and layout plan
The inverted vertical line method mainly comprises an inverted vertical line device, which includes an anchor block, high-strength wire, and buoy device; a vertical line coordinate instrument used mainly for data measurement; and an automatic device, which includes a data acquisition instrument and wireless module. Three sets of the inverted vertical lines are installed in the exploratory wells, which are located at the wellhead, above, and below the sliding surface. The schematic representation and physical diagrams of the inverted vertical line are shown in Figures 1 and 2.

![Figure 1. Schematic representation of the inverted vertical line.](image1)

![Figure 2. Pictorial representation of the inverted vertical line.](image2)

Installation steps of the inverted vertical line:
1. The specific position of the inverted vertical line at the entrance of the exploratory well was determined. A vertical line was drawn to determine the position of the anchor block;
2. A pothole, $0.3 \text{ m} \times 0.3 \text{ m} \times 0.8 \text{ m}$ in dimension, was dug at the bottom of the well;
3. The anchor block was then placed in the pothole;
4. Next, the concrete was set around the anchor block;
5. Afterward, the buoy was installed and steel wire was used to connect the buoy and anchor block. The position of the buoy support was then adjusted to keep the steel wire in vertical orientation;
6. Finally, the vertical coordinate instrument bracket was installed on the wall of the well to enable the steel wire to shift the middle position of the vertical coordinate instrument.

In the monitoring system, the anchor block is located below the sliding surface and is considered as a fixed point. The installation position of the vertical coordinate instrument is shown in Figure 3.
Figure 3. Schematic representation of the site layout of the vertical coordinate instrument.

The vertical coordinate instrument 1 is installed at the wellhead of the exploration well. The vertical coordinate instrument 1 has two functions. First, it can be verified with the vertical coordinate instrument 2 to monitor the displacement of the sliding rock mass, and second, it can be easily observed and checked at the wellhead. The vertical coordinate instrument 2 is installed above the sliding surface, and the vertical coordinate instrument 3 is installed under the sliding surface. The rock mass at the vertical coordinate instrument 3 is considered to be stable as the bedrock. Therefore, by monitoring the displacement differences between the three sets of equipment, the sliding condition of the sliding body can be obtained.

Before installing the vertical coordinate instrument, the fixed bracket was installed on the wall of the exploration well using bolts. The installation of the vertical coordinate instrument in the accurate position is extremely difficult to achieve due to the bad installation environment in the well. The design of the universal frame is adopted on the upper part of fixed support, as shown in Figure 4. Part \( a \) is fixed on the wall of the exploration well by a steel rod placed perpendicular to it, and part \( b \) is installed above part \( a \). In this way, by adjusting the position of part \( b \) relative to part \( a \) and the position of the instrument on part \( b \), the accurate position could be achieved.

Through the above configuration, the deformation in the \( X \) - and \( Y \)-direction can be monitored by the vertical coordinate instrument. After a monitoring period, it became clear that the method could stably monitor the landslide.

Figure 4. Design of the universal frame on the upper part of the fixed support.
To obtain the real-time monitoring of the landslide, using the automation monitoring equipment is necessary. Each vertical line coordinate system has an independent network address, and up to 32 vertical coordinate systems can be combined into a complete measurement network through the RS-485A data interface, as shown in Figure 4.

![Figure 4](image)

**Figure 5.** Schematic representation of the RS-485 network, which comprises multiple vertical line coordinate instruments.

When using the RS-485 network connection, a three-wire connection should be used, and all devices on the RS-485 network must be grounded. Except for the D+ and D− of the RS-485, the ground wires of all devices must be connected. Otherwise, the communication port may be damaged due to the system not sharing the ground.

4. **Data monitoring and verification**

Inclinometer boreholes were set up near the exploratory well. The monitoring equipment, which can be continuously monitored, is arranged in the borehole. At every 0.5 m, a monitoring point is located. After a monitoring period, from May 15 to June 15, the data of the inclinometer and vertical coordinate instrument at the same height were compared. The monitoring results are represented in Figure 6. The inclinometer data is the average value of the monitoring point data in this section. The inclinometer data of the vertical coordinate instrument is the average value of the relative deformation values of the vertical coordinate instruments 1 and 2, relative to the vertical coordinate instrument 3.

As observed, the monitoring data of the two monitoring methods have high consistency, and the magnitude of deformation for both methods is closely related. Thus, this is an indication that the landslide undergoes a small deformation and is continuously and slowly deformed. The two monitoring devices are located in different positions within a certain distance as such the data obtained would be different. Moreover, because the monitoring time is short and the precision of the two monitoring devices are different, the change in the landslide monitoring data is very small.

![Figure 6](image)

**Figure 6.** The monitoring data of the inclinometer and vertical coordinate instrument.

5. **Conclusions**

Through the above discussion, the following conclusions can be drawn in this study:

(1) The inverted vertical line method can be applied in landslide monitoring.
(2) Through the installation method introduced in this study, the vertical coordinate instrument can be installed in a geological exploration well with good effect. Moreover, through the application of the automatic data acquisition system and wireless module, the continuous monitoring of landslide deformation could be actualized.

(3) In comparison with the inclinometer data of the borehole near the exploration well, the inverted vertical line method can effectively monitor the deformation of the landslide. Furthermore, the monitoring data of the two methods have high consistency. However, the monitoring effect needs to be verified in future long-term monitoring.

Reference

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