Application of Data Visualization in Data Analysis of Inclinometer Hole

Yang Jie¹, Xu Xiaoyan¹*, Zhang Pengli² and Wang Jiaming²

¹Institute of Water Resources and hydro-electric Engineering, Xi’an University of Technology, Xi’an, China
²Hanjiang-to-Weihe River Valley Water Diversion Project Construction Co., Ltd., Xi’an, China

*Corresponding author: 1200412037@stu.xaut.edu.cn

Abstract. The deformation measurement data of the bank slope survey hole is one of the typical physical quantities characterizing the safety state of the bank slope. The measurement results of the inclinometer hole are two-way horizontal displacements perpendicular to each other at different depths, and the traditional two-dimensional analysis diagram can't show the vectorization of the horizontal displacement of the inclinometer hole well, neither highlighting the change of displacement with time nor showing the direction of displacement. In this paper, the measuring principle of inclinometer hole is introduced firstly, and then the monitoring data of several inclinometer holes on the back bank slope of an arch dam is taken as an example to visualize, and the advantages and disadvantages of traditional two-dimensional analysis chart, three-dimensional process analysis chart and spatial displacement analysis chart in visualizing the measuring results of inclinometer hole are compared and analysed. It has certain reference significance for the analysis of the monitoring results of inclinometer holes.

1. Introduction

Different from general monitoring instruments, the measurement results of inclinometer holes are two-way horizontal displacements perpendicular to each other at different depths. The measurement results at each moment of the same inclinometer hole are a function of depth, and this function changes with time. When evaluating the deformation of inclinometer hole, it is necessary to consider not only the change of horizontal displacement with depth, It is also necessary to consider the change of the whole deformation of the inclinometer hole with time, that is, it is necessary to analyze a set of data with depth and time as independent variables. In the actual measurement, the measurement time interval is generally long and uneven, so the monitoring results of inclinometer holes have the characteristics of fewer data and poor continuity with time. At the same time, due to the difficulty of installation. It is impossible to arrange more inclinometer holes on the steep bank slope behind the dam. Therefore, the results of inclinometer monitoring have the characteristics of poor continuity with spatial variation.

The traditional processing method of monitoring results of inclinometer hole is to establish a coordinate system with depth and displacement as axes, and draw the joint displacement line of multiple measurement results on the established coordinate system, such as literature [1]-[6] have adopted this kind of analysis method. Due to the data characteristics of the inclinometer hole, this traditional visual processing method has the disadvantages of low efficiency and poor analysis effect. In terms of visualization of inclinometer data, Gu Chuan[7] made two-dimensional fitting of foundation pit
inclinometer results and expressed them in the form of color three-dimensional surface, which achieved good display effect; Li Xiang[8] used mathematical software Maple to fit the deep horizontal displacement of the side wall of the excavation foundation pit, it is convenient to grasp the deformation of the side wall of the foundation pit more intuitively as a whole; Meng Yongdong[9] analyzed the spatial distribution characteristics of the deep deformation monitoring data field, studied the deformation and failure mode of the accumulation body, and reasonably analyzed the deformation of the accumulation body on the left bank of Xiluodu Hydropower Station on Jinsha River.

Although the traditional visual processing method of the monitoring results of the inclinometer hole has certain reference value, it is difficult to show the displacement change law and direction of a single inclinometer hole with time, and it is more difficult to reflect the overall deformation of the monitored area, and it is difficult to combine with other monitoring methods to reflect the operational behavior of the dam site area. Therefore, in order to reflect the change of horizontal displacement of the bank slope more reasonably and comprehensively evaluate the horizontal displacement of the monitoring area from the spatial and temporal perspectives, it is necessary to use appropriate data visualization processing technology to comprehensively evaluate.

In this paper, the monitoring data of slope inclinometer hole behind an arch dam is taken as an example, and the data visualization processing is realized by using the drawing program written by MATLAB. By comparing the processing results, the advantages and disadvantages of various methods are analyzed, which provides a new visual idea and method for the displacement analysis of inclinometer holes, and has certain application and reference significance.

2. Principle of inclinometer hole

Inclinometer hole has four main components: (1) inclinometer probe (detector); (2) Data acquisition system; (3) transmission cable; (4) inclinometer with built-in guide groove. The inclinometer hole is first buried in the soil of the bank slope, and the bottom of the pipe is generally embedded in the relatively stable stratum for 3~5m, and the surrounding of the pipe wall is filled with backfill, as shown in Figure 1. See fig. 2 for the measuring principle of inclinometer[4].

The displacement variation of each measured depth is:

\[
\Delta d_i = \sqrt{\Delta A_i^2 + \Delta B_i^2} \times K
\]  

(1)
\[ S = \sum_{i=1}^{n} \Delta d_i \]  

(2)

where \( k \) is the conversion coefficient of the instrument; \( \Delta A \) is the deformation in direction \( a \); \( \Delta B \) is the deformation in the \( b \) direction; \( \Delta d \) is the horizontal displacement at a certain depth of the inclinometer hole; \( S \) is cumulative displacement. During the monitoring design, many inclinometer holes are usually arranged on the bank slope, and the long-term observation of each inclinometer hole can fully reflect the characteristics of bank slope deformation in the dam site area.

3. Layout of inclinometer holes on the bank slope of a reservoir

The water retaining structure of a reservoir is RCC (Roller Compacted Concrete) hyperbolic arch dam, with the maximum dam height of 98.5m, crest elevation of 884.00m, crest width of 8m and bottom width of 31.0m. A total of 6 inclinometer holes are arranged on the bank slopes on both banks downstream of the dam, as shown in Figure 3, in which IN1, IN2 and IN3 are arranged on the left bank and IN4, IN5 and IN6 are arranged on the right bank. Because the monitoring system has been built for a short time, Therefore, by the end of 2020, a total of 12 horizontal displacements of the inclinometer hole were measured, including 1 measurement in 2017 (December 20) and 3 measurements in 2018 (May 31, October 31, December 12). It was measured 4 times in 2019 (March 12, May 24, September 20, November 23) and 4 times in 2020 (March 18, July 31, September 26, December 15) See table 1 for the orifice position of each inclinometer hole. For the convenience of data processing, see Table 2 for the minimum values of \( X \), \( Y \) and \( Z \) coordinates of each inclinometer hole minus the coordinates of each inclinometer hole in three directions:

![Figure 3. Layout of inclinometer holes behind a reservoir dam.](image)

Table 1. Original coordinates of each inclinometer hole and minimum values of coordinates in each.

| Monitoring area                  | Inclinometer hole number | X coordinate (m) | Y coordinate (m) | Z buried elevation (m) |
|----------------------------------|--------------------------|------------------|------------------|------------------------|
| Downstream slope on left bank    | IN1                      | 3763792.503      | 36628956.64      | 867.181                |
|                                  | IN2                      | 3763812.034      | 36628973.77      | 848.924                |
|                                  | IN3                      | 3763825.593      | 36628996.76      | 823.528                |
| Downstream slope of right bank   | IN4                      | 3763975.281      | 36629069.31      | 872.867                |
|                                  | IN5                      | 3763951.629      | 36629063.8       | 860.324                |
|                                  | IN6                      | 3763934.996      | 36629058.56      | 841.227                |
| minimum value                    |                          | 3763792.503      | 36628956.64      | 823.528                |
Table 2. Coordinates of each inclinometer hole after transformation.

| Monitoring area                  | Inclinometer hole number | X coordinate (m) | Y coordinate (m) | Embedded elevation (m) |
|----------------------------------|--------------------------|------------------|------------------|-----------------------|
| Downstream slope on left bank    | IN1                      | 0                | 0                | 43.653                |
|                                  | IN2                      | 19.5314          | 17.1294          | 25.396                |
|                                  | IN3                      | 33.0895          | 40.1193          | 0                     |
| Downstream slope of right bank   | IN4                      | 182.778          | 112.6746         | 49.339                |
|                                  | IN5                      | 159.1259         | 107.1591         | 36.796                |
|                                  | IN6                      | 142.4927         | 101.9182         | 17.699                |

4. Data processing and visual presentation of inclinometer hole

4.1. Two-dimensional analysis chart

The measurement result of inclinometer hole is horizontal displacement in A and B directions at each depth on a certain day, but normally, the combined displacement is used directly in the analysis, and then the displacement direction at each depth is analyzed in combination with the horizontal displacement in A and B directions. Different from the general monitoring instruments, due to the data characteristics of the inclinometer hole, when the traditional visualization method draws the horizontal displacement "hydrograph" of the inclinometer hole, and it is necessary to draw the joint displacement line of multiple measurements in the same figure. Now, take IN3 inclinometer hole as an example to draw a two-dimensional analysis diagram, as shown in Figure 4. This kind of analysis diagram takes depth and displacement as axes, and the variable "time" can only be expressed by different colors or marks, so it is difficult to directly observe the displacement change of a inclinometer hole with time from this kind of diagram. It is also difficult to visually show the displacement direction of the inclinometer hole.

![Figure 4. 2D analysis diagram of horizontal displacement of IN3 inclinometer hole.](image)

4.2. Two-dimensional analysis chart

It can be seen from Section 3.1 that it is necessary to draw a three-dimensional analysis diagram with depth, displacement and time as variables when analyzing the horizontal displacement of a single inclinometer hole. Through the MATLAB drawing program, all previous measurements and displacements are connected according to the monitoring sequence with time as the axis, and the three-dimensional process analysis diagram is drawn. Different time intervals can be expressed by the distance on the time axis. Taking IN3 inclinometer hole as an example, draw a 3D analysis diagram with depth, displacement and time as variables, as shown in Figure 5. At the same time, the displacement variation of each depth during two adjacent measurements is also very important. The increment of each depth in each measurement can be obtained by subtracting the corresponding depth displacement from each
measurement result. Taking IN3 inclinometer hole as an example, See fig. 6 for the incremental analysis chart before each measurement.

Figure 5. Three-dimensional analysis diagram of horizontal displacement of IN3 inclinometer hole.

Figure 6. Three-dimensional analysis diagram of horizontal displacement increment of IN3 inclinometer hole.

4.3. Spatial Displacement Analysis Diagram
The above analysis method can well obtain the combined displacement change of a single inclinometer hole, but it is difficult to directly analyze the horizontal displacement direction of the inclinometer hole, and it is also difficult to reflect the whole displacement change of the monitoring area. By drawing the displacement vector diagram of each depth of a single inclinometer hole, the direction and magnitude of horizontal displacement can be directly reflected. Taking the survey results of IN1~IN3 inclinometer holes on December 20th, 2017 as an example, the spatial displacement vector diagram of inclinometer holes is drawn. Mark the displacement with color, with red indicating larger displacement and blue indicating smaller displacement. See Figure 7 (a), (b) and (c) for the drawing results. For the monitoring area where the installation density of inclinometer holes is small and the terrain is complex, the spatial fitting effect of displacement directly is poor. In order to analyze the overall displacement change of the monitoring area, the horizontal displacement change of all inclinometer holes in the downstream slope of the left bank of the dam can be obtained by simple transformation using the coordinates established in Table 2, as shown in Figure 8.

Figure 7. Horizontal displacement vector diagram of IN1 ~ IN3 inclinometer holes.
Figure 8. Spatial displacement analysis diagram of each inclinometer hole on the downstream slope of the left bank of the dam.

It can be seen from Figure 8 that the displacement of the downstream slope on the left bank of the dam is unevenly distributed along the space when measured on December 20, 2017, and the displacement decreases as the elevation decreases and the distance from the riverbed decreases. The upper part (IN1) of the left bank abutment mainly moves downstream and left bank, and the shallow layer mainly moves downstream and the deep layer mainly moves to the left bank. The middle part (IN2) is mainly displaced to the downstream river channel. However, the bottom of the bank slope (IN3) is displaced towards the upstream dam body, so it can be roughly judged that the downstream slope on the left bank of the dam is twisted with somewhere between IN2 and IN3 as the axis.

The spatial displacement analysis diagram directly reflects the horizontal displacement of three inclinometer holes on the downstream slope of the left bank of the dam, and can clearly express the direction and relative size of horizontal displacement. Compared with the three-dimensional process analysis chart, its outstanding advantage is that it can show the spatial distribution of horizontal displacement in the monitoring area. Display of horizontal displacement of monitoring area with time.

It is necessary to draw a plurality of horizontal displacement spatial distribution maps at the minimum time interval through linear interpolation, and finally synthesize a dynamic video to observe the continuous deformation of the inclined hole in the monitoring area more intuitively and clearly.

However, it is difficult to quantify the displacement directly in the spatial displacement analysis diagram. It can only show the relative displacement trend of different parts in the monitoring area.

5. Conclusion

In this paper, firstly, the measuring principle of inclinometer holes is expounded, and then based on the measured data of several inclinometer holes on the back-bank slope of an arch dam, the data visualization processing is carried out. The advantages and disadvantages of traditional two-dimensional analysis chart, self-defined three-dimensional process analysis chart and spatial displacement analysis chart in the data analysis of inclinometer holes are compared, and the following conclusions are obtained:

1) Two-dimensional analysis diagram needs to draw multiple horizontal displacement lines on one diagram, and the change of horizontal displacement with time needs to be expressed by line type or mark; At the same time, for the convenience of analysis, the number of measurements drawn in each graph is limited, resulting in a graph showing only a few measurement results. Therefore, each two-dimensional analysis graph has less information. It is impossible to visually show the change of horizontal displacement of the inclinometer hole with time, and it is also impossible to show the horizontal displacement direction at each depth of the inclinometer hole.

2) Three-dimensional process analysis diagram adds time axis on the basis of two-dimensional analysis diagram, and visualizes the measurement results in three-dimensional form, which can more intuitively show the change of horizontal displacement at each depth of a single inclinometer hole with time; However, the three-dimensional process analysis diagram cannot express the displacement direction of the inclinometer hole. Therefore, it is still necessary to use the measured displacement data.
in A and B directions to judge the overall displacement of the monitoring area, which leads to the lack of intuitive analysis.

3) The spatial displacement analysis diagram can directly show the horizontal displacement direction of a single inclinometer hole. After simple coordinate transformation, the measurement results of multiple inclinometer holes can be drawn in the same three-dimensional diagram to show the spatial distribution of horizontal displacement in the monitoring area; A plurality of spatial displacement analysis graphs with fixed time steps can be obtained by linear interpolation. The spatial distribution of horizontal displacement in the monitoring area and its variation with time are displayed through the synthesized video. However, the spatial displacement analysis chart can only show the relative horizontal displacement of each inclinometer hole in the monitoring area by color, and cannot directly and accurately quantify the displacement.

With the aid of data visualization method, it can effectively improve the analysis efficiency and the accuracy of analysis conclusions. Choose different visualization methods according to different analysis requirements, or comprehensively analyze the measurement results of inclinometer holes by combining the advantages of different methods. It has certain application and reference significance for the analysis of the measurement results of slope inclinometer holes.

Acknowledgement
This work was supported in part by the Joint funds of natural science fundamental research program of Shaanxi province of China and the Hanjiang-to-Weihe river valley water diversion project under Grant 2019JLM-55.

References
[1] G Bièvre, Crouzet C. Multi-proxy analysis of boreholes in remolded Quaternary paraglacial deposits (Avignonet landslide, French Western Alps) - ScienceDirect[J]. Engineering Geology, 2021.
[2] Zhang Dade, Wang Chungui, Fang Li. Failure analysis of soft soil foundation reinforced by plastic drainage board [J]. Journal of Geotechnical Engineering, 2020, 42(11): 2034-2039.
[3] Stolecki L, Grzebyk W. The velocity of roof deflection as an indicator of underground workings stability – Case study from polish deep copper mines [J]. International Journal of Rock Mechanics and Mining Sciences, 143.
[4] Cai Qing’e, Zhao Dong, Xia Wangmin. Analysis of monitoring data of landslide deep displacement [J]. Journal of Disaster Science, 2018, 33(S1): 156-160.
[5] Su D, Zhang P, Dougherty H, et al. Longwall mining, shale gas production, and underground miner safety and health [J]. International Journal of Mining Science and Technology, 2021.
[6] Song H, Pei H, Zhu H. Monitoring of tunnel excavation based on the fiber Bragg grating sensing technology [J]. Measurement, 2020, 169:108334.
[7] Gu Chuan, Pan Guorong. 2D fitting and 3D display of foundation pit survey results [J]. Railway Survey, 2005(06): 4-6.
[8] Li Xiang, Zhou Dongdong. Plane fitting calculation and spatial display of deep horizontal displacement of foundation pit sidewall [J]. Construction Technology, 2014, 43(S2): 10-12.
[9] Meng Yongdong, Fan Fangtao, Xu Weiya, Wang Renkun, Cai Dewen. Visual analysis of deep deformation monitoring in Baitieba accumulation area of Xiluodu [J]. Journal of Three Gorges University (Natural Science Edition), 2013, 35(04): 5-11.