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Study on the Cause Analysis and Trend Prediction of Typical Landslide Disasters in Pukou District

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Abstract: This paper takes the typical soil-rock binary structure landslide on the east side of the middle section of Yanshan Avenue in Pukou District as the research object. Through field investigation, geological surveying and mapping, Lidar scanning, drilling, rainfall and deformation monitoring data analysis and other means, the basic characteristics of the landslide and the factors affecting the stability of the landslide are analyzed. It is found that the expansibility of kaolin and the floating support force of temporary confined water are one of the factors affecting the stability of the slope. Through real-time monitoring to explore the relationship between rainfall and surface horizontal displacement and vertical displacement, it is found that the surface deformation is greatly affected by the season. When the rainfall is large, the impact of temporary confined water has a large time lag. The faster the speed to reach the saturated state, the shorter the lag time, and vice versa. On this basis, the relationship model between landslide and rainfall is established, and the development trend of landslide is predicted.

Keywords: Soil-rock binary structure; Landslide; Failure mode; Rainfall; Trend prediction.

1. Introduction

Landslide geological disaster is a common natural disaster that poses a huge threat to human life, property and the environment. In recent years, with the continuous growth of population and economy, human destruction of the natural environment has become more and more serious, resulting in the increasing frequency and scale of landslides. Between 2021 and 2023, China has experienced multiple landslide disasters, causing significant economic losses. The causes of landslides are multifaceted, mainly including the influence of geological conditions, climate environment, hydrology and water conservancy, land use and other factors. Among them, human activities have a particularly obvious impact on landslide occurrence. For example, the acceleration of urbanization, large-scale land use change, engineering construction and other activities may lead to the change of the original geological environment, thereby increasing the probability of landslides. Therefore, how to control and prevent landslide disasters and reduce their impact on humans and the environment has become one of the important scientific research topics today.

This paper will discuss and analyze the causes and development trend of landslides. Firstly, through the study of the causes of landslide disasters, the impact of different factors on landslide occurrence is discussed, and corresponding prevention and control strategies are proposed. Secondly, the trend of the current landslide development is predicted, and the scale and frequency of future landslides are discussed, and corresponding early warning and countermeasures are proposed. In recent years, the rainfall in Pukou District is not stable [1-3], increasing from 1091mm in 2014 to 1768mm in 2015, and suddenly to 1807.7mm in 2016.Moreover, summer rainstorms occur frequently, with monthly rainfall reaching 661.5mm in June 2015 and 477.3mm in July 2016.Therefore, there are many rainfall-induced landslides in Pukou and its surrounding areas, such as Fangshan, Niushoushan, and Youzishan in Jiangning [4-6].

In 2015, due to the heavy rain, a typical landslide in Pukou District developed cracks on the basis of existing anti-slide piles, with obvious shear outlets. Through real-time monitoring data, the entire gentle slope area in front of the mountain is still in an intermittent creep state. According to the analysis, the reason for the resurrection of the landslide is frequent rainfall.

At present, the landslide has not caused casualties. For the overburden landslide with a gentle slope and poor stability in Pukou District, many scholars have conducted research. Zhong Yinqian [7] et al. believe that 90% of landslides are related to rainfall. Liu Guoen [8] et al. analyzed the deformation characteristics of the landslide body, the formation mechanism and external forces of the landslide in Pukou District, and proposed relative preventive measures. Yan Xiaoying [9] et al. concluded through numerical simulation and theoretical analysis that the landslide in Pukou District is a rainfall-type landslide, and the failure mode is the floating support force and seepage force generated synchronously with rainfall. Chang Jing [10] concluded through survey results that the sliding surface is mainly located in the kaolin layer that contacts the permeable layer and the impermeable layer, and the sliding surface is broken line type. Yu Liangchen [11] analyzed the formation process of temporary confined water in the landslide under the condition of continuous rainfall through numerical simulation, and analyzed the impact of the formation of temporary confined water. In this paper, through the field survey means of UAV aerial photography, crack measurement, slope displacement monitoring and other methods, combined with the previous survey results, the basic characteristics, boundary conditions, factors affecting the stability of the landslide and the sliding mode of the landslide are analyzed. Taking the landslide HP2 as the research object, real-time monitoring data processing is carried out.

2. Analysis of Basic Landslides

The typical landslide in the project area is located at the eastern end of Laoshan Mountain in Pukou District.

Influenced by the fault control in Pukou District, a set of Tertiary sand layers were deposited on the northwest slope of Pukou District. In the 1970s, there were large-scale mining activities in the area, and a large amount of artificial filling was filled, which increased the load of the slope and changed the circulation conditions of groundwater. After 2000, due to the shortage of land resources, the foot of the slope was gradually used. In the process of land use, unreasonable slope cutting caused the slope to slide many times, and many houses on the foot of the slope and the slope were destroyed, causing a large property loss and many people were threatened by landslides. The northern slope of Pukou District has long been a landslide disaster prone area. There are six large-scale landslides in the northern slope of Pukou District, forming a landslide group, which is numbered HP1-HP6. The specific distribution is shown in Figure 1.

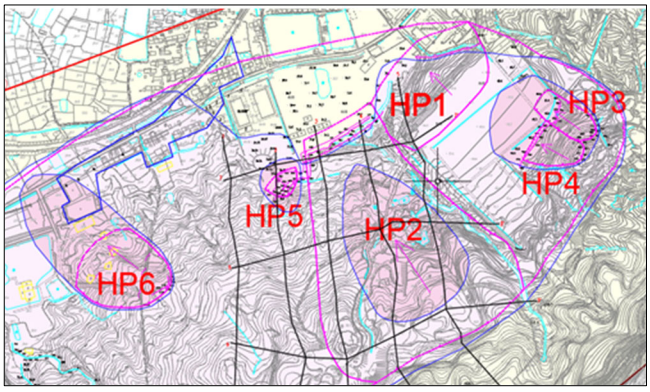

Figure 1. Landslide distribution map of the north slope of Pukou District

In 2011, the local government carried out staged treatment, and the landslide has become stable.The geological disaster area of HP2 landslide is located at the northern foot of Laoshan Mountain.The aerial photograph of the landslide is shown in Figure 1.Due to the heavy rain in 2015, the HP2 landslide has a resurrection trend, and the landslide has deformed. There are great potential geological disasters in this area. The landslide body is still in the creep stage, and the landslide body has cracks and obvious shear exits. The schematic diagram of the landslide danger is shown in Figure 2.

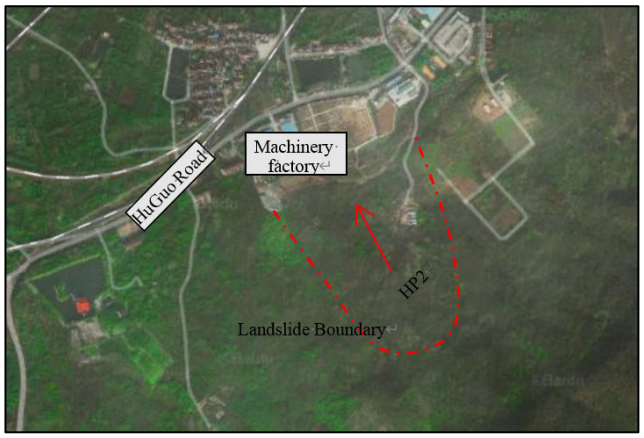

Figure 2 Schematic diagram of partial landslide hazards

After preliminary investigation and demonstration, there are potential landslide geological disasters with a width of 300m and a length of about 200m. It is estimated that the potential landslide volume is about 60,000 cubic meters, and the landslide scale belongs to small landslides. The landslide has caused obvious deformation in the local area of the built anti-slide piles, and the walls and slope protection at the shear exit have obvious cracks (as shown in Figure 3, Figure 4).The lower edge of the main sliding direction of the sliding body is threatened by about 60 households, houses and several nearby enterprises. Therefore, the HP2 landslide will pose a serious threat to people's life and property safety.

Figure 3. Tension cracks at the trailing edge of landslides

Figure 4. The fence damaged by the landslide shear exit

The landslide section is mainly composed of the Xiashu formation silty clay. The stratification and physical properties of the soil in this section are shown in Table 1. Within the exploration depth range, the first layer is recently artificially filled soil with complex composition, containing more gravel, poor soil quality and large thickness, new time, soft structure, and poor stability; the second layer is residual slope accumulation soil with poor engineering geological properties, medium compressibility, medium and low strength, and extremely unstable distribution, which is not suitable for the supporting layer of retaining wall foundation; the third layer of soil has good engineering geological properties, medium and low compressibility, medium and high strength, and weak swelling potential, among which the strength of the 3-2 layer of soil drops sharply when water is added, and the

water stability is poor; the fourth layer of gravel layer is locally distributed, medium and high strength; the fifth layer of soil is low compressibility, high strength soil layer. The stratigraphic structure of the landslide area is shown in Figure 5.

Table 1. Physical property indexes of soil (mean value)

Number	Name	w	γ	e	W_L	W_p	I_p	I_L
		%	KN/m^3	—	%	%	—	—
1	filling soil	27.5	18.6	0.828	38.3	22.0	16.3	0.50
2-1	Powdery clay	26.8	19.0	0.796	39.4	22.0	17.4	0.26
2-2	Powdery clay	27.9	19.5	0.728	34.7	18.4	16.3	0.47
3-1	Clay	24.6	19.2	0.756	43.9	23.6	20.4	0.06
3-2	kaolin clay	24.7	19.3	0.745	43.8	24.4	19.3	0.03
4	gravel sand	14.4	19.1	0.594				
4—A	Powdery clay	19.3	19.5	0.640	36.7	21.4	15.3	-0.14
5-1	Clay	21.6	19.6	0.680	43.7	23.7	20.0	-0.12

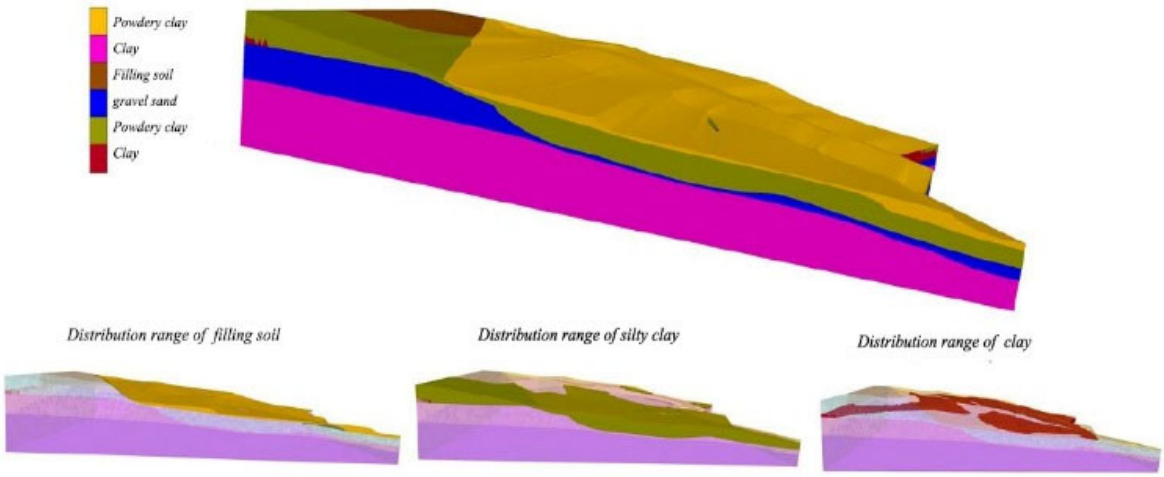

Figure 5. Schematic Diagram of Landslide Stratum Structur

The three layers of soil and the 5-1 layer of soil in the survey area have certain swelling and shrinkage, among which the 3-2 layer is kaolin clay with a free swelling rate of 46.7%, and the 5-1 layer of soil has a free swelling rate of 44.3%, which is a weak swelling potential soil. The swelling deformation is large when dry and wet alternately, and the strength decreases greatly after long-term saturation, and the water stability is poor. In addition, according to the survey data of various expansive soil slopes, the natural stable slope foot of expansive soil is small, generally 3-20o, and the vast majority is less than 14o, which may increase the possibility of landslides. From the stratum situation revealed by this field investigation and survey, it can be seen that filling is the main constituent material of the landslide, and the sliding surface is basically located in the 3-2 layer of kaolin clay.The 4-layer gravel layer is sandwiched between the 3-layer and 5-1 layer of clay. When heavy rain falls frequently, the permeability coefficient of the 3-layer and 5-layer clay layer is small, which is quite different from that of the 4-layer gravel layer. The gravel layer will temporarily store a large amount of rainwater and cannot be excreted. The 3-layer and 5-layer clay layer can be used as a water barrier relative to the gravel layer, which will eventually cause the gravel layer to be saturated for a long time after the rainstorm. When the layer is saturated, the groundwater has a certain bearing capacity.

Therefore, it is preliminarily estimated that there are two reasons for the landslide activity: first, the infiltration of rainwater significantly reduces the physical and mechanical parameters of the soil, thus reducing the stability of the slope. Under the action of external forces such as water seepage, the slope cannot maintain its stability and eventually slides.Second, the 3-layer and 5-layer clay layer swells due to water absorption, causing the stratum to rise, and the 4-layer groundwater with bearing water quality under saturated state floats and supports the overlying stratum, which destroys the stability of the slope and eventually leads to the sliding of the slope. In order to effectively avoid unnecessary damage caused by geological disasters in this area, the following measures have been taken:

(1) Evacuate all residents in the residential buildings near the slope for three rows;set up a security cordon to prohibit personnel from entering.

(2) Conduct real-time monitoring of the top of the built anti-slide piles and the landslide body, and report the displacement data of the landslide body and the anti-slide piles every day.

3. Analysis of Landslide Monitoring Point Data

In order to better understand the specific situation of the typical landslide in Pukou District, eight monitoring points are set on the slope of Pukou District, named J1-J8. The setting position is shown in Figure 6.

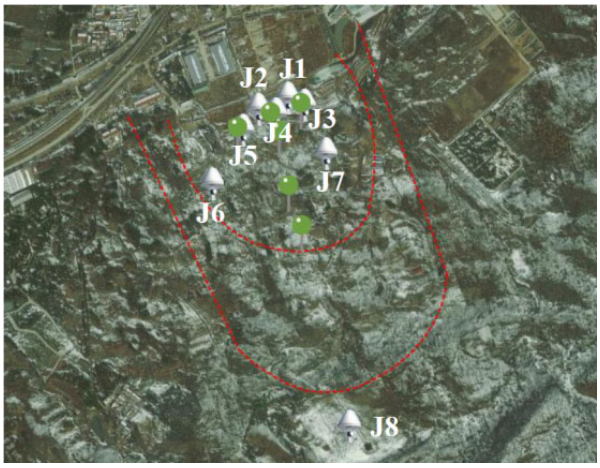

Figure 6. Landslide monitoring point layout

The monitoring time of the eight monitoring points in Pukou District is from July 14, 2017 to February 1, 2021. In order to better represent the horizontal deformation of the monitoring body, two axes A and B are set. The setting position of axes A and B is shown in Figure 8. The direction of axis B is parallel to the long axis direction of the disaster-hit object, and the direction close to the monitoring body is positive, and the direction away from the monitoring body is negative. The direction of axis A is perpendicular to the long axis direction of the disaster-hit object, and the direction away from the disaster-hit object is positive, and the direction close to the disaster-hit object is negative.

Through statistics of the monitoring data, the cumulative vertical displacement map of the monitoring points is obtained (as shown in Figure 7). The monitoring vertical displacement is actually the settlement value of the monitoring body, with vertical downward as positive and vertical upward as negative. According to the monitoring data statistics, as of February 1, 2021, J1 and J2 are subsidence, with the cumulative settlement values of 54.2mm and 159.7mm respectively.J3, J4, J5, J6, J7 and J8 are all uplifted, with the cumulative uplift values of 159.3mm, 94.0mm, 112.9mm, 68.8mm, 115.4mm and 5.8mm respectively. Thus, it can be seen that most of the monitoring points are in a overall uplift state. The data fluctuate in June to August each year. Due to the large amount of rainfall, the rainwater cannot be discharged in time, which makes the expansion of the kaolin layer push the upper layer and the floating support force of the gravel layer reach the peak. At this time, the curve appears a trough, and the slope body has an overall uplift. With the passage of time, the groundwater gradually discharges, the support force gradually decreases, and the vertical displacement returns to the value before rainfall, and the curve rises. The vertical displacement tends to be stable in March 2020, without further expansion trend.

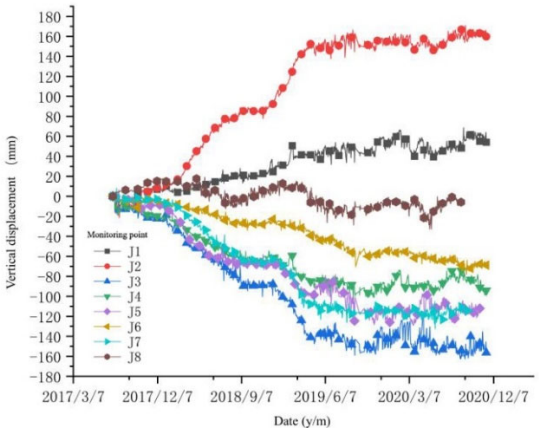

Figure 7 Cumulative vertical displacement map of monitoring points

In order to further discover the impact of rainfall on vertical displacement, the timeliness of the impact of kaolin expansion and temporary confined water on the vertical displacement of the slope after rainfall is explored. Draw the comparison chart of the uplift value and rainfall of J3-J8 (J1 and J2 are excluded due to the final result of real-time monitoring for subsidence), as shown in Figure 10-Figure 12.The span is three years from July 2017 to August 2020, and the rainfall is measured in units of months. To reduce the contingency and represent the overall situation of each month, the monthly uplift value is the average of the daily uplift value. To better highlight the relationship between the uplift value and rainfall, the Y axis is selected as being greater than 0 for uplift and less than 0 for subsidence. Since the vertical displacement of the monitoring points in each month is an independent sample, the law can be found by observing the time node when the uplift value is greater than 0.

By analyzing Figure 8-Figure 10, it can be found that although the changes in the degree of rainfall received by each monitoring point are not the same, such as the sensitivity of monitoring points J7 and J8 to rainfall is higher than that of monitoring points J3-J6, the changes are basically the same. When the monthly rainfall is at a low level, the overall trend of the monitoring points is basically settlement. But when the monthly rainfall increases, it can be found that the influencing factors of rainfall on the slope have changed, and the dominant influence is the reduction of the mechanical properties of the soil layer caused by rainwater infiltration, which becomes the influence of the swelling of expansive soil and the floating support force of temporary confined water. The latter has a large time lag, with a lag time of half a month to one and a half months. The reason for this phenomenon is that rainwater infiltrates into the 3-2 layer of kaolin soil, which expands when absorbing water, resulting in a part of rainwater staying in the kaolin soil layer. With the increase of rainfall, rainwater enters the gravel layer. When the gravel layer reaches saturation, it will generate temporary confined water, which exerts floating support on the overlying soil layer. It can be seen that when the rainfall is large but does not reach a certain value, the thrust of expansive soil is dominant. When the rainfall is large and the fourth layer of gravel reaches saturation, the floating support of temporary confined water and the thrust of expansive soil work together. Therefore, the reasoning lag time depends on the speed of the gravel layer reaching saturation. The faster the speed of saturation, the shorter the lag time, and vice versa. When the rainfall is low for a long time, the temporary confined water

in the gravel layer is discharged through runoff, and the 3-2 clay layer expands and gradually becomes constricted. As a result, the value of vertical displacement gradually decreases, and the amount of sedimentation gradually increases until the next rainy season.

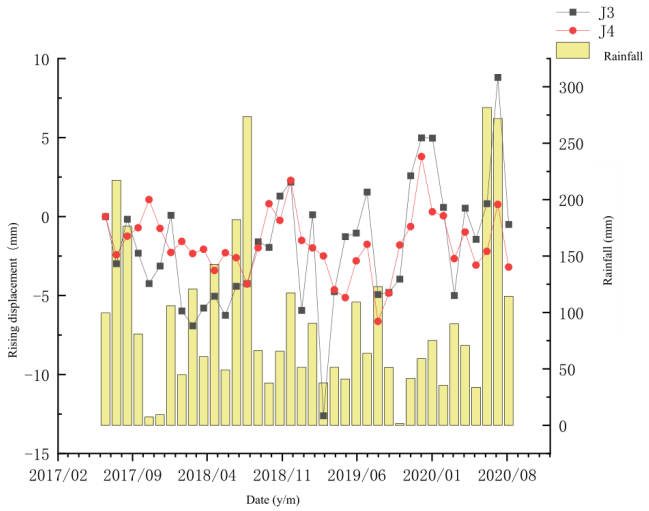

Figure 8. Comparison of vertical displacement and rainfall amount of monitoring points J3 and J4

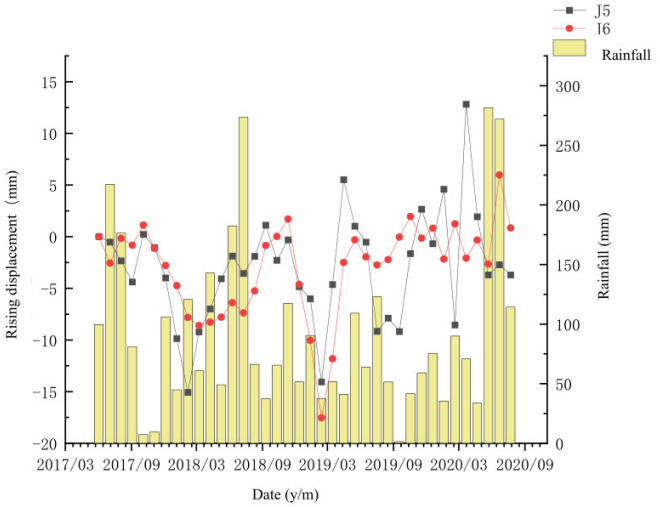

Figure 9. Comparison of vertical displacement map and rainfall of J5 and J6 monitoring points

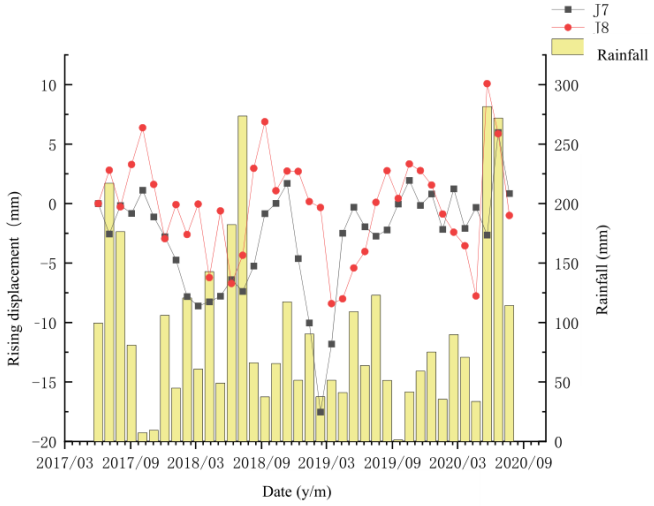

Figure 10. Comparison of vertical displacement map and rainfall of J7 and J8 monitoring points

The horizontal displacement data of the monitoring points were statistically analyzed, and the cumulative displacement maps of Axis A and Axis B were generated.(Fig.11-Fig.12) The analysis of the cumulative displacement of Axis A revealed that J1-J8 moved towards the negative direction of Axis A, close to the disaster-affected objects, with a maximum displacement of -883.8mm;the analysis of the cumulative displacement of Axis B revealed that J1-J8 moved towards the positive direction of Axis B, away from the disaster-affected objects, with a maximum displacement of 404mm.The overall landslide had a large displacement, but it has basically tended to be stable.Through the curve, it was found that the horizontal displacement was greatly affected by seasonality. In August 2018, the cumulative displacement increased, and the cumulative rate reached the maximum value. However, according to the statistics of the National Bureau of Statistics, in 2018 and 2019, the rainfall was 1267mm and 721mm respectively, and in August 2018, the rainfall reached 273.6mm. Therefore, it was guessed that due to the large rainfall, the kaolin soil layer expanded, causing the horizontal displacement of the layer in the direction of A and B to increase, and the horizontal displacement value increased continuously. The data tended to be stable in early 2020.There was a small fluctuation in June 2020, because the rainfall from June to July 2020 was above 270mm, similar to that in August 2018. The sudden increase in horizontal displacement caused by the rainfall in 2018 can demonstrate the effectiveness of the treatment, which effectively controls the horizontal displacement of the slope.

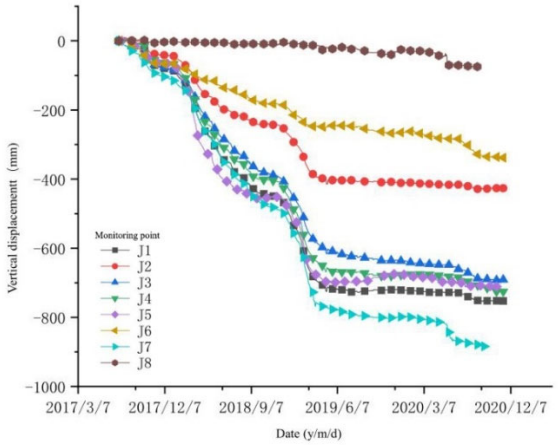

Figure 11 Landslide vertical displacement-time curve

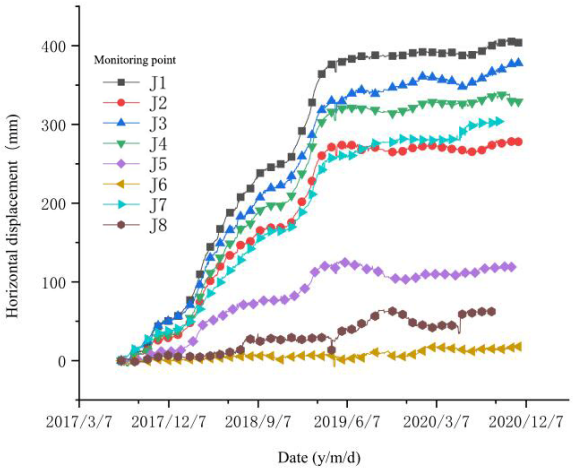

Figure 12 Landslide horizontal displacement-time curve

4. Conclusion

In the geological disaster investigation and treatment, this paper analyzes the basic characteristics of the HP2 landslide in Pukou District and the factors affecting the stability of the landslide, and explores the relationship between time and vertical and horizontal displacement through real-time monitoring. It also explores the relationship between rainfall and vertical displacement, and draws the following conclusions:

(1) There are two reasons for the landslide activity: First, the rainwater infiltration causes the soil physical and mechanical parameters to be greatly reduced, which reduces the stability of the slope. Under the action of external forces such as water seepage, the slope cannot maintain its stability and eventually slides. Second, the 3-layer kaolin layer and 5-layer clay layer swell due to water absorption, and the gravel layer in the saturated state, the groundwater with the property of bearing water has the floating support force on the overlying strata, which destroys the stability of the slope and eventually leads to the sliding of the slope.

(2) The vertical displacement is greatly affected by the season. When the monthly rainfall increases, it can be found that the influencing factors of rainfall on the slope have changed. The dominant factor is the rainwater infiltration, which leads to the reduction of the mechanical properties of the soil layer, and becomes the influence of the expansion of the expansive soil and the floating support force of the temporary bearing water. The latter has a larger time lag, and the lag time depends on the speed at which the gravel layer reaches the saturated state. The faster the speed reaches the saturated state, the shorter the lag time, and vice versa.

(3) The horizontal displacement is also greatly affected by the season. Due to the large rainfall, the kaolin layer expands, causing the layer to have a large horizontal displacement in A and B, and the horizontal displacement value increases continuously.

References

[1] National Bureau of Statistics. 2016 China Statistical Yearbook [M]. Beijing: China Statistics Press, 2015.

[2] National Bureau of Statistics. 2016 China Statistical Yearbook [M]. Beijing: China Statistics Press, 2016.

[3] National Bureau of Statistics. 2017 China Statistical Yearbook [M]. Beijing: China Statistics Press, 2017.

[4] Yan Changhong, Xu Baotan, Wu Chengyu, et al. Stratigraphy and Stability Analysis of the Frontal Mild Slope in Ningzhen Area [J]. Journal of Engineering Geology, 2019, 27(1):48-54.

[5] Yan X Y, Xu B T, Zhang L P, et al. Mechanism analysis of a landslide in highly weathered volcanic rocks of Niushoushan Hill in Nanjing[J]. Environmental Earth sciences, 2019, 78(24).

[6] Yu Liangchen, Yan Changhong, Guo Shulan, et al. Analysis of the sliding mechanism of Youzishan in Nanjing affected by temporary confined water[J]. Hydrogeology and Engineering Geology, 2020,47(1):133-141.

[7] Zhong Yinqian. Relationship between landslides and rainfall and their prediction[J]. Chinese Journal of Geological Hazards and Control, 1998(04):82-87.

[8] Liu Guoen, Dai Bing, Sui Zhaoxian. Causes and prevention measures of landslides in Pukou District, Nanjing, Jiangsu Province[J]. Jiangsu Geology, 2007(04):319-322.

[9] Yan Xiaoying, Yan Changhong, Tan Jinzhong, Wu Chengyu, Guo Shulan, Xu Chenghua, Wang Zhenxiang, Shi Wei. Reanalysis of the reactivation mechanism of a hillside gentle slope landslide in Pukou District, Nanjing[J]. Geological Review,2020,66(06):1626-1636. DOI:10.16509/j.georeview.2020.06.014.

[10] Chang Jing. Analysis of influencing factors and stability evaluation of the northeastern slope landslide in Pukou District, Nanjing[D]. Shandong University of Science and Technology, 2019. DOI:10.27275/d.cnki.gsdku.2019.001062.

[11] Yu Liangchen. Simulation analysis of a hillside gentle slope landslide in Nanjing under the action of temporary confined water[D]. Nanjing University, 2020. DOI:10.27235/d.cnki.gnjiu.2020.000707.