Construction of risk assessment system of a typical foundation pit based on monitoring data

Yonghua Sha[1,2,a], Zhen Zhang[1,2,b] and Mingli Tang[1,2,c*]

[1] Zhejiang Guangchuan Engineering Consulting Co., LTD, Hangzhou, Zhejiang, 310020, China
[2]Zhejiang Water Conservancy and Hydropower Engineering Management Association, Hangzhou, Zhejiang, 310020, China

[a]shypaper402@163.com, [b]zhangzhen900201@126.com
[c*]tangmingli08@163.com

Abstract. Taking the foundation pit of a pumping station project in Wenzhou as the object, a risk assessment system was constructed by making full use of routine monitoring items and monitoring data, and the foundation pit construction safety was comprehensively judged by using this system. The research results showed that: (1) the introduction of correlation calculation and GRA to prioritize the monitoring items can reduce the subjectivity of the evaluation system and improve the reliability of the system; (2) Using the risk assessment system, the dynamic changes of the overall safety of the foundation pit could be effectively presented, which was of great significance for guiding the safe construction of the project.

Keywords: Foundation pit, Monitoring, Correlation degree analysis, Risk assessment.

1 Introduction

Safety monitoring is one of the essential components of foundation pit engineering. The timeliness and accuracy of monitoring can effectively prevent the risk of foundation pit constructiont. For the research of foundation pit monitoring and risk assessment, predecessors have done a lot of work.

Yangqing Xu developed a monitoring data processing system, which basically covered the monitoring means used in foundation pit monitoring, and improved the standardization and accuracy of monitoring[1]. Chengping Qu compared the deformation monitoring data of a project's deep foundation pit with the 3D model simulation data, and found the most significant factors affecting the retaining structure[2]. On the basis of the monitoring data, Weihua Li carried out a risk grade assessment of a subway foundation pit project. The results showed that the risk grade of the foundation pit was reduced from danger to safety after the effective measures were taken, indicating that the method was intuitive and reliable[3].

At present, foundation pit monitoring in water conservancy industry mainly refers to building foundation pit and dam monitoring. The conventional safety judgment method

P. Xiang et al. (eds.), *Proceedings of the 2023 5th International Conference on Hydraulic, Civil and Construction Engineering (HCCE 2023)*, Atlantis Highlights in Engineering 26,
https://doi.org/10.2991/978-94-6463-398-6_59

of foundation pit monitoring is to compare each monitoring item with the design or specification requirements one by one. When a certain monitoring index exceeds the limit, it will give an early warning and alarm. For the foundation pit with simple structure or few monitoring categories, conventional methods can meet the requirements. When the foundation pit reaches a certain scale, or the structure is complex and there are many monitoring categories, the conventional safety discrimination methods often have limitations[4]. There may be a situation that one or some monitoring items exceed the early warning value, but the other monitoring indicators are normal and the overall appearance of the foundation pit is good. At this time, we can't know whether the foundation pit is damaged or not.

On the basis of predecessors' research results and objective problems, this paper taken the foundation pit of a pumping station project in Wenzhou as the object, and comprehensively used the methods of correlation analysis, GRA[5] and scaling method to fuse and mine the monitoring data, and put forward a foundation pit risk assessment system based on the monitoring data, and used this system to comprehensively judge the foundation pit construction safety, with a view to improving the comprehensive judgment level of water conservancy foundation pit safety and providing reference for similar projects.

2 Project Overview

Bailonggang Pumping Station is located on the left bank of Bailonggang, Wenzhou City. The total designed drainage flow of the pumping station is 100 m^3/s. The main building is Grade 2 and the total installed capacity is 4. The pumping station is located on the soft foundation, and the silt layer is about 35 meters thick. The excavation area of the first-stage foundation pit is about 9978 m^2, and the maximum excavation depth is 11.3 meters. According to the requirements of the specification[6], the engineering foundation pit is classified as Grade I

In order to meet the needs of construction safety, a number of monitoring items are set up for the foundation pit of the pumping station. Monitoring items and controlling values are shown in table 1.

Table 1. Monitoring items and alert values

Labels	Monitoring items	Quantities	Cumulative values
V1	Deep horizontal displacement	7	30mm
V2	Horizontal displacements of crown beams	15	30mm
V3	Supporting axial force	24	6000kN
V4	Settlement of crown beams	11	30mm
V5	Settlement of columns	15	30mm
V6	Surrounding settlement	11	30mm
V7	Groundwater level	7	300mm/d

3 Risk Assessment of The Foundation Pit

3.1 Main evaluation indicators and correlation analysis

3.1.1. Analysis of the main evaluation index.

There were seven monitoring items in the foundation pit engineering of pumping station, and daily manual measurement and reading were carried out by using instruments and equipment such as the level, total stations and clinometer. Considering the variety of monitoring points and monitoring data, typical monitoring points are selected for each monitoring project. The corresponding observation date was from the first day to the 98th day. The specific data were not detailed here. The Spearman correlation method was used to analyze the original monitoring data.

After correlation calculation, the correlation coefficients between the pairwise of these seven monitoring items were in the range of 1.190 to 5.534. Combined with the actual situation, the groundwater level mainly fluctuated during the monitoring period and generally remained stable, while the other monitoring items all showed the characteristics of increasing with time, so the correlation coefficients were large. The correlation coefficient between deep horizontal displacement and other monitoring items was the largest, so it was selected as the main evaluation index. The other six monitoring items were designated as sub-evaluation indexes.

3.1.2. Correlation analysis of monitoring items.

Based on the main evaluation index analysis results, GRA method was used to analyze correlation degrees between each sub-evaluation indexes and the main evaluation index.

The time interval was the same as previously. In order to facilitate data analysis, monitoring data was processed without dimension[7]. The monitoring data of groundwater level showed fluctuation, so the method of averaging was adopted. The monitoring data of other items showed an increasing trend, so the normalized processing method was adopted. The formulas were as follows.

$$x_i'(k)=x_i(k)/x_1(k) \tag{1}$$

$$x_i'(k)=nx_i(k)/\left(\sum_{i=1}^{n}x_i(k)\right) \tag{2}$$

In (1) and (2), k represents the monitoring item, $x_i'(k)$ is the value after treatment, $x_i(k)$ is the initial value, $x_1(k)$ is the first value, n is the number of data in the specific monitoring item. Calculation results were showed in table 2.

Table 2. Summary of dimensionless values of evaluation indicators

Time	V1	V2	V3	V4	V5	V6	V7
1	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.00000
2	1.07170	1.07214	0.93716	1.00000	1.20482	1.00027	0.01031
3	1.13962	1.14317	0.87431	1.11000	0.53012	1.00055	0.02034
4	1.21132	1.00000	0.91921	1.22000	0.13253	1.00082	0.03065
5	1.28302	0.85683	0.96411	1.33500	0.80723	1.00082	0.04069
……	……	……	……	……	……	……	……
94	43.02264	4.88346	26.69119	4.39000	10.03614	1.09397	0.00000
95	43.52075	4.93896	26.72764	4.28000	10.44578	1.09379	0.00000
96	44.01887	4.99445	26.52505	4.16500	10.84337	1.09360	0.00000
97	44.52075	5.04994	26.91643	4.05500	11.24096	1.09342	0.27124
98	45.01887	5.12764	27.12275	3.94500	11.51807	1.09330	0.00000

The degree of correlation was reflected by the difference value. According to the following formula, the corresponding grey correlation coefficient could be obtained $\xi_{\mathrm{i}}(k)$.

$$\xi_{\mathrm{i}}(k) = (\Delta\min + \rho\Delta\max)/(\Delta x_i(k) + \rho\Delta\max) \tag{3}$$

In (3), △min and △max are the minimum and maximum absolute differences between the comparison sequence $x(k)$ and the reference sequence $x(0)$, $\triangle x_i(k)$ is the difference between the comparison sequence $x(k)$ and the reference sequence $x(0)$, ρ is the gray correlation resolution system with a value of 0.5.

The grey relational degree can well express the similarity between the general trend of reference sequence and the general trend of comparison sequence. *r(k)* is the grey correlation degree of $x(0)$ and $x(k)$, the formula was as follows.

$$r(k) = \frac{1}{n}\sum_{i=1}^{n}\xi_i(k), \quad k = 1, 2, ..., n \tag{4}$$

The higher the correlation between monitoring items, the greater the value of *r(k)*. The calculation results were showed in table 3.

Table 3. Calculation results of grey correlation degree

Items	V1~V1	V1~V2	V1~V3	V1~V4	V1~V5	V1~V6	V1~V7
Correlation degree	1	0.5849	0.6975	0.5845	0.5838	0.5794	0.5778
Rank	1	3	2	4	5	6	7

The monitoring items of this project were sorted according to the degree of correlation from large to small as follows: V1 > V3 > V2 > V4 > V5 > V6 > V7.

3.2 Weight distribution

According to the calculation results of correlation coefficient and grey correlation degree, V1 had the greatest impact on the overall risk of foundation pit, followed by V3. The correlation degree of V2, V4 and V5 was close to V1, and the overall risk impact on the foundation pit was equivalent. V6 had a weak impact on the overall risk of foundation pit, while V7 had the smallest impact. Based on the above judgments, the 1~9 scale method[8] was used to score seven indicators of foundation pit monitoring, so as to build the judgment matrix A, which was shown in table 4.

The element a_{ij} in matrix A represents the relative importance of i over j, and a_{ii} =1, a_{ij} =1/a_{ji}. If a_{ij} is greater than 1, it indicates that i is more important than j, the larger the value, the more significant the importance of i over j.

Table 4. Rating scale of relative importance and the judgment matrix

Indexes	V1	V3	V2	V4	V5	V6	V7	Judgment matrix
V1	1	3	5	5	5	7	9	$A=\begin{bmatrix} 1 & 3 & 5 & 5 & 5 & 7 & 9 \\ 1/3 & 1 & 3 & 3 & 3 & 5 & 7 \\ 1/5 & 1/3 & 1 & 1 & 1 & 3 & 5 \\ 1/5 & 1/3 & 1 & 1 & 1 & 3 & 5 \\ 1/5 & 1/3 & 1 & 1 & 1 & 3 & 5 \\ 1/7 & 1/5 & 1/3 & 1/3 & 1/3 & 1 & 3 \\ 1/9 & 1/7 & 1/5 & 1/5 & 1/5 & 1/3 & 1 \end{bmatrix}$
V3	1/3	1	3	3	3	5	7	
V2	1/5	1/3	1	1	1	3	5	
V4	1/5	1/3	1	1	1	3	5	
V5	1/5	1/3	1	1	1	3	5	
V6	1/7	1/5	1/3	1/3	1/3	1	3	
V7	1/9	1/7	1/5	1/5	1/5	1/3	1	

Maximum eigenvalue of judgment matrix $\lambda_{\max}$ was 7.256, consistency index CI was 0.043, consistency ratio CR was 0.045. All calculations met the consistency judgment principle. Therefore, the risk probability weight of each typical monitoring item was:

$$\omega = \begin{bmatrix} 0.415 & 0.224 & 0.098 & 0.098 & 0.098 & 0.043 & 0.024 \end{bmatrix}$$

3.3 Calculation of risk probability

Based on the actual monitoring results of each monitoring project, 60%, 70%, 80% and 100%[9] of the warning value were taken as the safety classification boundaries, and the corresponding relationship between monitoring data and risk probability was established. The risk probability standard of monitoring data conversion for each typical monitoring project was shown in table 5.

By converting the monitoring data of each typical project on a certain day into the corresponding risk probability P_i within the corresponding safety grade interval through interpolation, and then multiplying and accumulating with the corresponding weight w_i, the overall risk probability P of foundation pit could be obtained.

Table 5. Monitoring data conversion risk probability criteria

Indexes	Warning value	Safe	Tracking	forewarn-ing	Alarm	Dangerous
V1	30	[0,18)	[18,21)	[21,24)	[24,30)	[30,+∞)
V3	6000	[0,3600)	[3600,4200)	[4200,4800)	[4800,6000)	[6000,+∞)
V2	30	[0,18)	[18,21)	[21,24)	[24,30)	[30,+∞)
V4	30	[0,18)	[18,21)	[21,24)	[24,30)	[30,+∞)
V5	35	[0,21)	[21,24.5)	[24.5,28)	[28,35)	[35,+∞)
V6	30	[0,18)	[18,21)	[21,24)	[24,30)	[30,+∞)
V7	300	[0,180)	[180,210)	[210,240)	[240,300)	[300,+∞)
Corresponding risk probability P_i		0~0.4	0.4~0.6	0.6~0.8	0.8~1.0	1.0

The monitoring data of foundation pit was selected to calculate the overall risk probability, and the risk probability time curve was drawn in figure 1.

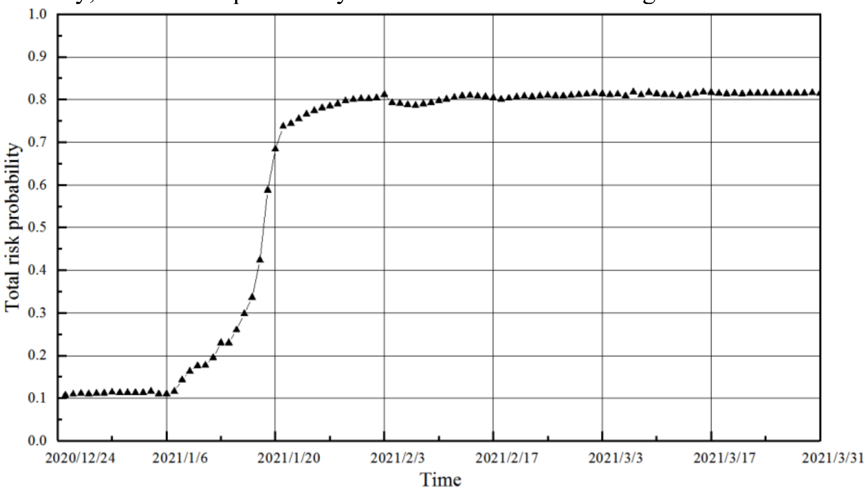

Fig. 1. Dynamic change diagram of risk probability of the foundation pit

The first 15 days were the preparation period for foundation pit construction, and the overall risk probability P was maintained around 0.1, so the foundation pit was safe. 16 to 20 days was the initial stage of construction, the value started to increase gradually, and the risk of foundation pit increased day by day. 21 days later, the foundation pit was fully constructed, the growth rate of P increased significantly. The overall risk state of the foundation pit changed from safety to tracking state, and continued to develop to early warning state.

On the 28th day, the monitoring unit made an early warning according to the change trend of *P*. After the relevant units took temporary reinforcement measures, the growth rate decreased significantly, and then slowly increased to around 0.8, and continued until the foundation pit was successfully completed.

Combined with the actual situation and measured data, monitoring values of several monitoring items gradually increased in the initial stage. On the 28th day, a long crack appeared on the northeast slope of the foundation pit. After the monitoring unit gave an early warning, the relevant units took measures to reinforce the foundation pit in time, such as cutting the slope, backfill and adding temporary support. Subsequent tracking found that the crack did not develop further, thus avoiding greater damage and loss.

4 Conclusion

In this paper, correlation analysis and grey correlation method were used to rank the primary and secondary factors of conventional monitoring projects, and a dynamic risk assessment system of foundation pit based on monitoring data was constructed. The system was applied to the foundation pit engineering of a pumping station in Wenzhou, which accurately showed the characteristics and trends of the overall risk development of the foundation pit, and had guidance for ensuring safe construction.

The system proposed in this paper could effectively grasp the overall safety state of foundation pit, improve the comprehensive judgment level of foundation pit safety, and make up for the limitations of traditional methods. In addition to the engineering examples in this paper, the risk assessment system had been applied in a gate station project in Hangzhou and a pumping station project in Taizhou, and the practical effects were good. Under the situation that the scale of water conservancy foundation pit is expanding, the situation is becoming more complicated and the requirements are increasing, this theoretical method is worth popularizing.

Of course, the system still has shortcomings. According to different engineering projects, the main factors and secondary factors affecting the safety of foundation pit may change, the risk assessment system still needs to be adjusted and optimized in monitoring project selection and influence weight distribution. At the same time, the 1~9 scale method can be subjective, and it is necessary to find a more objective and quantitative analysis method to distribute the weights in order to improve the rigor of the method.

Acknowledgments

This paper is financially supported by Zhejiang Province Water Resources Department Science and Technology Planning (RC2081).

References

1. Xu Y. and Cheng L. (2014) Analysis processing of monitoring data and forecast and early warning system of foundation pits. Chinese Journal of Geotechnical Engineering, 36(S1): 219-224.
2. Qu C., Ye M. and Sun H. (2019) Deformation Monitoring and Numerical Simulation of Deep Foundation Excavation of a Project. Construction Technology, 48(22): 59-62.
3. Li W., et al. (2022) Risk assessment of diaphragm wall leakage during subway excavation based on field monitoring data. Journal of Hefei University of Technology, 45(01): 60-66.
4. Wu J., et al. (2021) Rapid safety monitoring and analysis of foundation pit construction using unmanned aerial vehicle images. Automation in Construction, 128.
5. Liu X., et al. (2022) A Novel GRA-NARX Model for Water Level Prediction of Pumping Stations. Water, 19: 2954-2954.
6. Shao F. and Wang Y. (2022) Intelligent overall planning model of underground space based on digital twin. Computers and Electrical Engineering, 104(PA).
7. Aleksandr L., Nadezhda G. and Andrey R. (2019) Determining the processing modes of the low carbon steel by high-precision plasma cutting based on dimensionless complexes. MATEC Web of Conferences, 297: 01007.
8. Zhuen R., et al. (2019) A New Risk Assessment Model for Underground Mine Water In-rush Based on AHP and D-S Evidence Theory. Mine Water and the Environment, 3: 488-496.
9. Chen R., et al. (2019) Construction Risk Assessment of Deep and LargeFoundation Pit Based on Entropy Weight Extension Model. Mathematics in Practice and Theory, 49(2): 311-320.