Analysis of Warning Threshold of Tunnel Monitoring and Measurement Based on Probability Statistics

Jianbing Qian
China Design Group Co. Ltd., Nanjing 210001, Jiangsu, China
Email: 243089747@qq.com

Abstract: In the process of tunnel construction, data on deformation monitoring magnifies the direct reflection of the stability of tunnel structure, and the setting of early warning value is more related to the safety of project construction. In this paper, a tunnel project is taken as an example, and based on a large number of previous engineering practices and the statistical characteristics of monitoring data, the probability statistics method is used to obtain the warning threshold, which is used to give suggestions for the construction of the tunnel project and provide technical reference for the monitoring and warning management of similar tunnel construction.
***Keywords*:** statistical analysis, tunnel, monitoring and measurement, warning threshold

The sate construction of hard rock tunnel projects can be guaranteed to a great extent by referring to relevant specifications and timely feedback and processing of tunnel construction monitoring information based on the practical experience of previous tunnel projects. However, for soft rock tunnel, its deformation is usually large, so how to set the warning value is related to the safety of tunnel construction. Then how to give a reasonable warning value to solve the safety problem of tunnel project construction? Based on the statistical characteristics of monitoring data, this paper will introduce the probability statistical analysis method, aiming to successfully predict the warning threshold of soft rock tunnel project and ensure the safety of the project.

1. Project overview

The overall terrain for subway tunnel project is relatively flat, which is characterized with artificial accumulation layer, quaternary Holocene alluvial diluvial layer, late Pleistocene alluvial diluvial layer. The stratum lithology traversed by excavation includes silt, sand and gravel. In the investigation scope of 42m depth, two layers of groundwater, including upper stagnant water and interlayer diving, were found to be stably distributed in the whole line. Soft soil layer, which has the characteristics of wide distribution, thick, low bearing capacity, high compressibility, mostly dark gray, gray black, saturated, flow plastic, containing a small amount of humus, with a rancid taste, uneven soil, containing more silt sand, often sandwiched with a thickness of 5~20cm silt or silt layer. Overall, the project has a wide distribution of soft soil foundation, moisture content of 58%~71%, soft-soil foundation with large soft soil foundation settlement, foundation deformation of large porosity, high compression easily happened problems, reduce the overall stability of the foundation, and reduce the bearing capacity of foundation, uneven settlement of soft soil distribution are also affect the uniformity.

2. Main factors of displacement and deformation caused by tunnel construction

In the construction of this project by shield tunneling method, the main factors causing displacement and deformation are summarized as follows:

(1) The soil mass on the excavation face moves during the excavation. Because the support force is smaller than the soil-water pressure on the outside, the soil mass moves into the shield structure, resulting in displacement and deformation above the shield soil. If the support force is larger than the water pressure of the outer soil, the soil will move forward and upward, leading to the formation uplift.

(2) In shield construction, the thrust generated by the jack at the moment when the equipment stops is smaller than the active earth pressure of the excavation face, and the displacement deformation caused by the collapse and loosening of the excavation face is caused in this case.

(3) The gap between shield tail was squeezed into soil. Due to the lack of timely grouting, insufficient grouting amount and inappropriate grouting pressure, the soil of the tunnel at the back of shield tail was unbalanced and collapsed, and finally the loss of the bottom caused displacement deformation.

(4) The advancing direction of shield construction is changed, such as correcting deviation, lifting head, cutting head

and so on, which also leads to the loss of the ground floor. The original designed axis of shield construction is increasingly offset from the actual axis of construction, and finally leads to the increase of stratum loss.

(5) Because of shield construction measures adopted in the precipitation. In the normal tunneling process, frequent water plugging, drainage and precipitation lead to changes in the original static water level of the stratum, and the final water level of the funnel surface increases the soil stress of the original water-bearing stratum, which is equivalent to increasing the load on the soil layer, resulting in soil consolidation settlement.

3. Probability statistics of tunnel displacement and deformation monitoring data

3.1 Historical data of longitudinal displacement and deformation measurement

This paper is mainly conducted on the prediction of displacement deformation, so the displacement deformation and uplift data in the construction process of shield tunneling method are selected to carry out the research. Table 1 shows the displacement and deformation information collected from the observation of the two sections of this section. It is found that neither section presents a single change, and both subsidence and uplift exist. In order to better describe the change rules of the two sections, the piecewise function is used to represent the uplift section, and the cubic polynomial is used to fit the uplift section. The equation for regression analysis of the settlement section is as follows.

Equation of the first section of surface subsidence curve are as follows:

$$S = 0.0005x^3 - 0.0048x^2 - 0.2155x + 0.42 \quad x < 8.5 \tag{1}$$

$$S = -6.27[1 - e^{-0.0298(x-8.5)}] - 1.48 \quad (x \geq 8.5) \tag{2}$$

The Surface subsidence curve equation of the second section:

$$S = -5.36[1 - e^{-0.029(x-7.7)}] - 3.32 \quad (x < 7.7) \tag{3}$$

$$S = -5.36[1 - e^{-0.029(x-7.7)}] - 3.32 \quad (x \geq 7.7) \tag{4}$$

Table 1. Displacement and deformation Tables of measuring points on two midlines of sections

Distance from excavation surface to measuring point (m)	Displacement and deformation of the first section (mm)	Displacement and deformation of second section (mm)
-20	-1.28	-0.48
-10	1.69	-1.22
0	0.43	-2.85
20	-3.92	-5.24
40	-5.65	-6.31
60	-6.14	-7.56
80	-6.71	-8.13
90	-7.15	-8.26
100	-7.45	-8.41
120	-7.51	-8.62

3.2 Process of probability statistics

Based on the historical monitoring and measurement data of the tunnel project as a reference, probabilistic statistics method is used to obtain the early warning threshold of displacement rate. The specific operation process is as follows:

The first step is to classify the historical data from the previous monitoring of the tunnel, including vault subsidence and peripheral convergence, and record the rate value.

The second step is to sort the displacement rate in a descending manner, and record the new variable of test times, which is denoted as times by N_i, and the test value N_i=1.

In the third step, the displacement rate values that have been sorted are divided into several deformation segments in a ascending manner, and the N_i values of each displacement deformation segment are statistically analyzed. Generally speaking, $N_i \geq 1$ is demonstrated. N_i will be taken as the ordinate, and the displacement deformation value is taken as the horizontal coordinate. The histogram drawn represents the occurrence times of a certain level of deformation (see Figure 1).

Later on, the center point of each histogram in the displacement rate histogram represents the deformation value, and the distribution curve of available scatter points is drawn without changing the ordinate N_i (see Figure 2). In this case, N value can be obtained by removing the subscript i from the coordinate N_i, which represents the measured times less than a certain deformation.

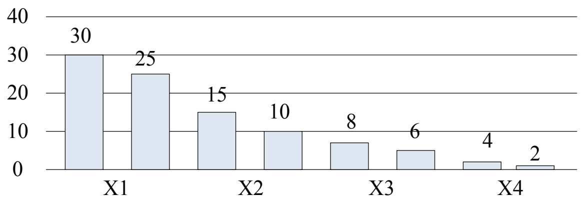

Figure 1. Statistical histogram of displacement deformation rate data

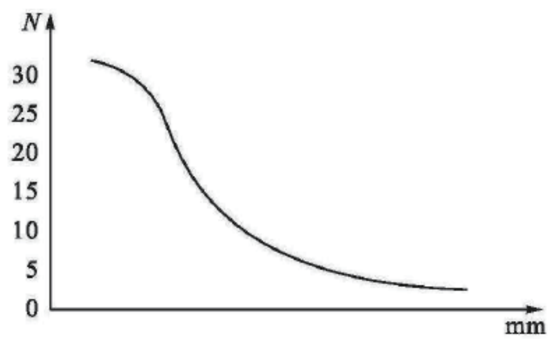

Figure 2. Statistical distribution curve of displacement deformation rate

Finally, by dividing the total measured times with the ordinate values, the probability distribution graph can be obtained, which represents the incidence rate when the deformation is greater than a certain amount. Although the two graphs have the same curve shape, the physical meaning of the two graphs has changed. The graph can also be transformed into a statistical list to calculate the probability of exceeding the value under a certain displacement rate value as a reference displacement rate warning threshold.

4. Recommended probability statistics method in the application of early warning threshold in this project

4.1 Analysis of probability and statistical data

According to the above method, the monitoring data of historical displacement and deformation were collected and sorted out, and the probability statistics of 650 data of maximum settlement displacement rate were conducted. According to the above steps, the statistics and inductive analysis were carried out, and the maximum displacement rate of historical vault settlement was obtained by taking the vault settlement as an example (see Table 2).

Table 2. Maximum displacement rate of historical vault settlement

Historical maximum settlement displacement rate (mm/d)	The number of section	Percentage (%)	Cumulative percentage (%)
<2.5	66	10	10
2.5~5	338	51.6	61.6
5~7.5	134	20.5	81.8
7.5~10	55	8.2	89.8
10~12.5	20	2.8	92.6
12.5~15	15	3	94.8
15~17.5	9	1.4	95.8
17.5~20	10	1.6	97.2
20~22.5	8	1.2	98.3
22.5~25	6	0.9	100
25~30	4	0.6	99.6
>30	5	0.6	100

According to the above table, it can be seen that the daily displacement rate data of the vault settlement is basically at the range of 2.5-5mm /d. According to the probability and statistical percentage results in the table, it can be found that the proportion of data less than 5mm/d is 61.6%, reflecting that if this is taken as the early warning threshold of displacement rate, it conforms to the actual situation of most construction areas. And will effectively control the safety of most construction areas. On the contrary, if the warning value is set at a high level, there may be large deformation without warning, and the risk cannot be controlled. If the warning value is set too low, such as 2.5mm/d, more than 90% of the construction area will have warning, resulting in low construction efficiency, and fail to achieve the purpose of informationized monitoring and dynamic construction.

4.2 Recommended warning thresholds

Taking the tunnel project as an example, Table 3 lists the recommended early warning threshold after probability and statistical analysis. The value is obtained based on the distribution of actual monitoring data and considering both construction safety and efficiency, which can provide a strong reference for improving the safety of local tunnel projects with the same type of surrounding rock.

Table 3. Recommended warning thresholds

Displacement monitoring item	Yellow alert	Red alert
Crown settlement	>5mm/d	>7.5mm/d

5. Conclusion

With tunnel project as an example, the probability statistics method is adopted in this paper to analyze the single-day maximum settlement rate of historical monitoring data during the construction of the tunnel project, and to give the recommended early warning threshold of displacement rate. In the study, it is found that this value needs to be adjusted dynamically, which can be adjusted timely according to the actual construction situation of tunnel projects and the construction method adopted, so as to provide important guidance for the construction safety of tunnel projects.

References

[1] Liu Qingfeng, Liu Qingzhi. Analysis of statistical characteristics and reserved deformation of tunnel monitoring data based on interval estimation method[J]. *Modern Tunnelling Technology*. 2020; 057 (001): 142-147, 161.

[2] Qiu Zifeng, Shen Jian, Fu Xudong, et al. Analysis of tunnel monitoring measurement data based on the optimum weighted combinatorial prediction model[J]. *Journal of Yangtze River Scientific Research Institute*. 2016; (5): 53-57.

[3] Sun Jun, Wen Haiyang. Application practice of artificial intelligence science in prediction and control of engineering construction deformation under soft soil — Theoretical basis, method implementation, refined intelligent manage-ment(Demonstrations)[J]. *Tunnel Construction (English and Chinese Version)*. 2020; 040 (001): 1-8.

[4] Hu Xianjin, Wang Zheng, Ren Ziqi. Data Processing and analysis of tunnel monitoring measurement[J]. *Communications Science and Technology Heilongjiang*. 2016; 39 (004): 119-120.

[5] Qiu Zifeng, Shen Jian, Fu Xudong, et al. Analysis of tunnel monitoring data based on optimal weighted combination prediction[J]. *Journal of Yangtze River Scientific Research Institute*. 2016; 33 (5): 5.

[6] Liu Zhinan, Yu Hailong. Application of tsp technology in geological advanced prediction of mount langya mountain tunnel[J]. *Engineering and Construction*. 2018; 32 (6): 33-35.

[7] Liu Gaohong, Wu Enqi, Min Rui, Hou Tianfan, Wang Xiaohui. Fault Prediction of rectangular shield Eccentric Cutter Head Based on Optimized BP Network[J]. *Software Guide*. 2020; 19 (10): 117-121.

[8] Zhao Ruichuan, Liu Chang, Zhang Guodong. Research on measurement data analysis and system development of tunnel construction monitoring[J]. *Journal of Highway and Transportation Research and Development*. 2018; 000 (005): 254-255.