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On-site Monitoring and Comparative Analysis about Surrounding Rock Pressure Variation with Time in Unsymmetrial Loading Tunnel

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Abstract : Bias Tunnes are common seen and it has complicated variation on their surrounding rock pressure. It is crucial for the security and stability of a tunnel to determine the variation law of surrounding rock pressure and on-site monitoring technology. This essay compares the experimental data to the theoretically calculated data of a certain tunnel according to the data from on-site monitoring and theoretical analysis. The result indicates that the real data of surrounding rock pressure of three chosen cross sections is close to the calculated data from grade V surrounding rock. To be specific, the vault and the arch waist are in good agreement. The pressure on the tunnel is obviously unsymmetrial. The data of surrounding rock pressure of arch waist and flank wall on the left side is larger than that on the right side.Also, there is a significant difference between the measured data and calculated data of pressure of horizontal adjoining rock. The horizontal stress of surrounding rock on the bias tunnel is over-released. The measured pressure data on flank wall is much larger than its calculated data.In conclusion, The timbering system should be reinforced in the early stage of construction and the rigidity of timbering system should be chosen carefully. The result of this research can contribute to the tunnel construction design and construction safety in the future.

1. Foreword

With the continuous development of transportation, more and more tunnels have to pass through areas with complex geological conditions, so more bias tunnels appear. Under the influence of bias loads, which have adverse effects on the support and construction of tunnels[1-3].The mechanical properties of surrounding rock of bias tunnel are complex, and the distribution of in-situ stress is uneven, what's more, the stress of the structure of bias tunnel is not clear, so it is difficult to analyze the stability of the tunnel and to construct it. Therefore, the engineering accidents such as support instability and secondary lining cracking are easy to occur[4-5].

After tunnel excavation, the stress of surrounding rock is released, which directly generates the load acting on the supporting structure, that is the surrounding rock pressure. The release law, action form and calculation method of surrounding rock pressure have always been the core issues concerned by academia. Because of the complex geological environment, the calculation method and theory of surrounding rock pressure proposed by scholars have not been well applied. On-site monitoring is a direct reflection of surrounding rock pressure, and analysis based on monitoring data can provide guidance for tunnel construction, support and design[6-9].

The pressure release law of surrounding rock of bias tunnel is complex,while there are many factors affecting the pressure of surrounding rock, and the geological environment of different areas is also quite different. Because of the existence of bias pressure, it is difficult to accurately calculate the pressure value of surrounding rock in theory. Therefore, many scholars have researched the pressure of surrounding rock[10-12]. Liu Yingqi and Zhang Xiedong obtained the stress release rate of surrounding rock of shallow tunnel based on back analysis of displacement through finite element software simulation calculation[13]. Anyonglin et al, who had analyzed the relationship between surrounding rock pressure of bias tunnel and ground inclination, burial depth and surrounding rock conditions, which combined with the theoretical formula of surrounding rock pressure of bias tunnel[14]. Gong Jianwu and Xia Caichu had achieved certain research results through theoretical calculation and on-site monitoring data analysis[15]. Zhong Zuliang et al. who had researched the surrounding rock pressure of bias tunnel by considering the interaction between the left and right tunnel construction[16]. However, due to the different geological environment and too many uncertainties, the theoretical analysis and field monitoring of surrounding rock pressure of bias tunnels still need to be further explored.

Based on field monitoring data, this paper researched the variation of surrounding rock pressure with time. By comparing the measured and calculated values of surrounding rock pressure, the error sources of theoretical and measured values of surrounding rock pressure in bias tunnel were analyzed. The purpose is to provide reference for the design and safe construction of similar tunnels.

2. On-site monitoring and analysis of surrounding rock pressure

In the research section of tunnel ZDK35+353~ZDK35+410, the groundwater was well developed and the surrounding rock stability were very poor, and monitoring was carried out in collapse-prone sections. There are three monitoring sections. The contact stress between surrounding rock and initial support (i.e. surrounding rock pressure) was measured by vibrating string double membrane soil pressure cell.

2.1 Monitoring Program

The test section was excavated by CRD method. The test section was arranged in ZDK35+393.0, ZDK35+382.5, ZDK27+373.1. According to the construction progress, the soil pressure cells were buried at the corresponding measuring points. While the soil pressure cells were arranged outside the steel arch. At present, each measuring point had been buried, the second lining of each section had been poured, and the temporary support had been removed. The layout of each measuring point was shown in Figure 1.

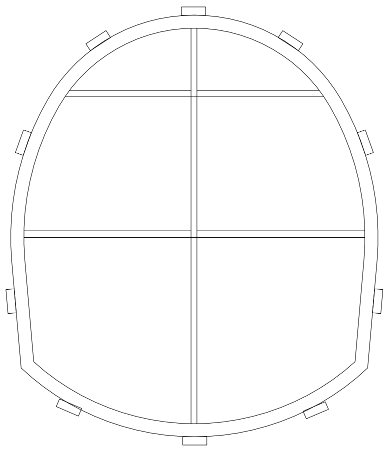

Fig.1 Layout of Soil Pressure Cell

2.2 Monitoring and Analysis of Surrounding Rock Pressure in Test Section

According to the monitoring data, the surrounding rock of the tunnel section was fully weathered medium-fine granite porphyry, which belonged to V-grade surrounding rock. The measured surrounding rock pressure of each section was shown in Figure 2-4.

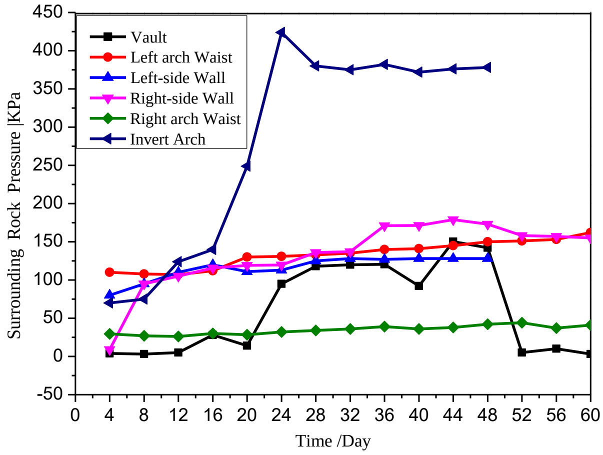

Fig.2 Time history curve of wall rock pressure monitoring section ZDK35+393.0
(Note: the measured value of the left flank wall in the figure 2 is 10 times larger than the data in the table)

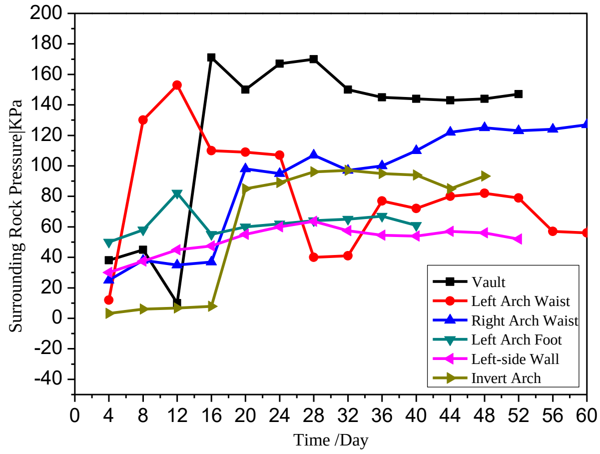

Fig.3 Time history curve of wall rock pressure monitoring section ZDK35+382.5

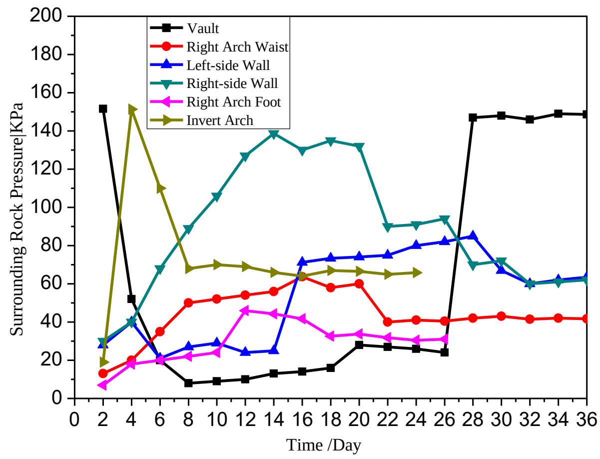

Fig.4 Time history curve of wall rock pressure monitoring section ZDK35+371.1

According to Figure 2-4, the monitoring data of three test sections ZDK35+393.0, ZDK35+382.5 and ZDK35+371.1 were analyzed. The change of surrounding rock pressure of test section mainly went through three stages. In the first stage, the surrounding rock pressure had the characteristics of fast coming. After tunnel excavation, the surrounding rock stress was released, and the load acted on the initial support system. The surrounding rock pressure increased rapidly and finally tended to be stable. According to the monitoring data, the maximum surrounding rock pressure date of the initial support, such as the arch waist and side wall, which was basically consistent with the maximum steel arch stress date, generally not more than three days. The second stage was that the surrounding rock pressure decreased after the completion of initial support, and finally tended to be stable. In the third stage, when the secondary lining was poured, the surrounding rock pressure of the vault, the left arch waist, the left-side wall and the inverted arch increased considerably, and finally tended to be stable, which showed that the secondary lining was effective. Due to the phenomenon of tunnel eccentric pressure, the surrounding rock stress was relatively high in the arch roof, left arch waist, left-side wall and right-side wall, so the initial support parameters should be raised in the initial support. The stress concentration on the left-side wall of section ZDK35+393.0 was obvious, and the stress on the supporting system was large,so we should pay close attention to the interaction of each process in the construction process.

Bias pressure existed in measured surrounding rock pressure of three sections. For example, sections ZDK35+393.0 and ZDK35+382.5 showed the characteristics that, the maximum pressure of the surrounding rock of the left arch waist and the left-side side wall was larger than that of the right.Due to the quality of surrounding rock was not uniform as a whole, from the direction of the exit along the small mileage of the tunnel, we could also see that the degree of pressure bias of surrounding rock was getting smaller and smaller. The bias pressure of section ZDK35+393.0 was much greater than that of section ZDK35+382.5, while the pressure of surrounding rock on the right side was greater than that on the left side in section ZDK35+373.1.

2.3 Monitoring and Analysis of Surrounding Rock Pressure at Key Points of Typical Sections

According to the measured surrounding rock pressure of monitoring data, the phenomenon of bias in three sections ZDK35+393.0, ZDK35+382.5 and ZDK35+373.1 was obvious. Tunnel excavation method, excavation sequence and support form had great influence on the stability of surrounding rock under biased geological conditions. Under the dual action of eccentric pressure and excavation, the release of stress in surrounding rock would lead to a certain horizontal displacement of the tunnel ,which had a certain impact on the supporting body. Therefore, the surrounding rock pressure was analyzed by monitoring three typical sections.

The vault, the left arch waist , the upper vertical brace, and the upper left part of the temporary inverted arch of the upper left pilot pit were the key excavation parts, which were subjected to high surrounding rock pressure, so the support strength should be strengthened. The surrounding rock pressure at the left-side wall was particularly high, while the lateral temporary invert in temporary support was equivalent to the two-force bar, so the tension and pressure were relatively large. These parts were the key positions of the typical section.

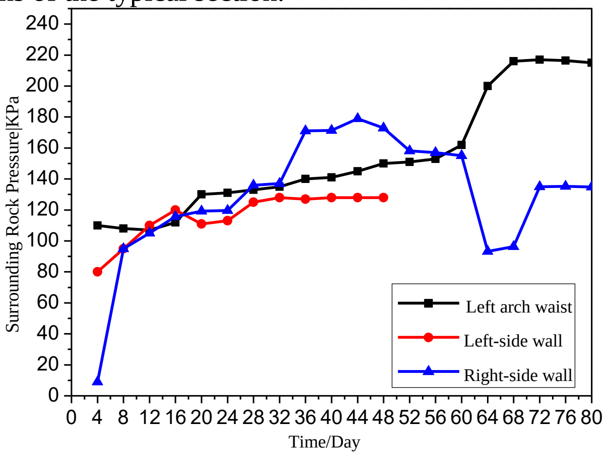

Fig.5 Time history curve of surrounding rock pressure of key section ZDK35+393.0

(Note:the measured value of the left flank wall in the figure 5 is 10 times larger than the data in the table)

Fig. 5 showed that the surrounding rock pressure of the left arch waist of section ZDK35+393.0 reached 110.9 KPa rapidly and then tended to be stable. After the second lining, the surrounding rock pressure increased rapidly to 220.1 KPa, and finally remained stable. The surrounding rock pressure of the left-side wall reached 904.4 KPa on the sixth day. Due to the existence of bias voltage, it quickly reached 1283.9 KPa and finally tended to be stable. The surrounding rock pressure of the right-side wall increased rapidly. it quickly reached 115.8 KPa on the eighth day. Due to the influence of bias pressure, the phenomenon of stress concentration appeared. After initial support, the surrounding rock pressure continued to increase, and finally reached 185.4 KPa on the 44th day. After the completion of secondary lining casting, the surrounding rock pressure gradually decreased to about 100.5 KPa.Due to the influence of construction process, the surrounding rock pressure tended to be stable after increasing in a short time, and the secondary lining was effective.

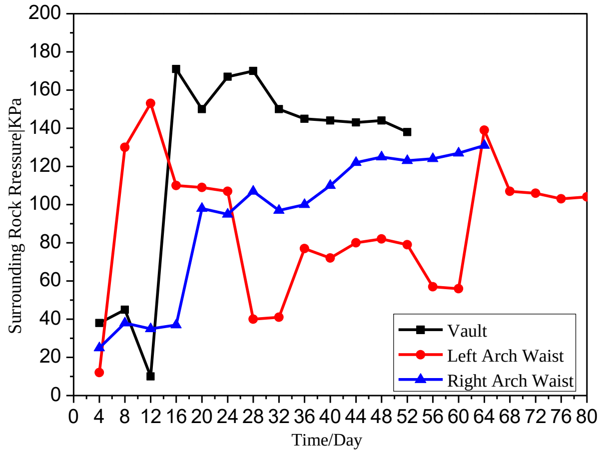

Fig.6 Time history curve of surrounding rock pressure of key section ZDK35+382.5

Figure 6 showed that the surrounding rock pressure of left arch waist of ZDK35+382.5 section quickly reached 153.4 kPa, and after initial support, the surrounding rock pressure droped to 38 kPa on the 27th day. With the influence of construction process on the key position, the surrounding rock pressure increased slightly afterwards, but the surrounding rock pressure increased rapidly to 148.3 kPa when the second lining was completed. After the lining, the surrounding rock pressure decreased and eventually became stable. The maximum pressure of the surrounding rock of the vault was 171.1 kPa and that of the right arch waist was 98.7 kPa during the initial support. After the initial support, the surrounding rock pressure tended to be stable after a small increase.

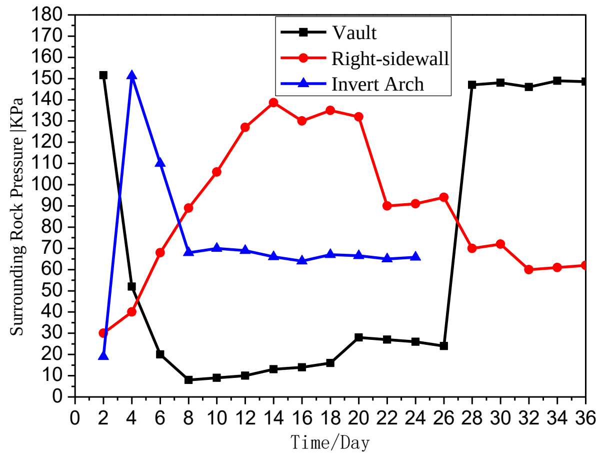

Fig.7 Time history curve of surrounding rock pressure of key section ZDK35+371.1

Figure 7 showed that the surrounding rock pressure of the initial support vault of ZDK35+371.1 section increased rapidly, which reached 151.6 kPa the next day, then droped rapidly to 9.9 kPa after the initial support, and increased rapidly to 149.2 kPa during the second lining, and then tended to be stable. On the 13th day, the maximum pressure of the right-side wall reached 138.6 kPa, and the increase was relatively slow. After initial support, the pressure of surrounding rock tended to be stable, but after secondary lining, it slowly decreased to about 67.4 kPa, and finally tended to be stable. The surrounding rock pressure of inverted arch quickly reached 154 kPa on the fourth day. With the completion of initial support, the surrounding rock pressure dropped to 66.3 kPa, and then tended to be stable.

In summary,The law of surrounding rock pressure variation with time is particularly remarkable. which can be divided into three stages: rapid growth, slow growth and stabilization. After tunnel excavation, the surrounding rock stress is released and the initial support is not completed. During this period, the surrounding rock pressure increases rapidly. Surrounding rock is disturbed before the completion of secondary lining construction, but the pressure of surrounding rock increases slowly due to the completion of initial support. After the completion of secondary lining, the surrounding rock pressure tends to be stable, which indicates that the construction of secondary lining has played a positive role in the stability of surrounding rock. Because of the complex construction procedure of CRD excavation, the stress mechanism of surrounding rock changes frequently,so the small details of construction will affect the change of surrounding rock pressure.However, the pressure of surrounding rock tends to be stable after a small fluctuation increase with time.

3. Contrastive analysis of field test data and theoretical calculation value

3.1 Theoretical calculation value of surrounding rock pressure

Current Code for Design of Railway Tunnels (TB10003-2005) stipulates that the surrounding rock pressure of deep-buried tunnels is considered as loose pressure, and the vertical *q* and horizontal uniform pressure *e* are calculated by the following methods.

(1) Vertical uniform pressure *q* is calculated by the formula below

$$q=\gamma h \tag{1}$$

$$h=0.45\times 2^{s-1}\omega \tag{2}$$

In the formula: *q*-Vertical Uniform Pressure (*kPa*), *γ*-Surrounding Rock Bulk Density (kN/m^3), *S*-Surrounding Rock Grade, *ω*-The Influence Coefficient of Width, $\omega=1+i\times(B-5)$, *i*—Surrounding Rock Pressure Increase or Decrease Rate for Every Increase or Decrease of 1 m, According to the calculation standard of vertical uniform pressure of surrounding rock when B = 5 m, when B < 5 m, *i*= 0.2; B >5 m, *i* = 0.1.

(2) Calculation of horizontal uniform pressure *e*

Horizontal uniform pressure e and vertical uniform pressure *q* are calculated in Table 1

Table 1 The relationship between horizontal uniform pressure e and vertical uniform distribution pressure q

Surrounding Rock Grade	III	IV	V	VI
Horizontal uniform pressure e	＜0.15 q	(0.15～0.3)q	(0.3～0.5)q	(0.5～1.0)q

The tunnel is constructed by drilling and blasting method. The width of the tunnel is B=9.46m under the condition of grade V surrounding rock. The loose pressure of surrounding rock calculated by the above method is as follows.

$$\omega=1+i\times(b-5)=1+0.1\times(9.46-5)=1.45 \tag{3}$$

$$h=0.45\times 2^{s-1}\times\omega=0.45\times 2^{5-1}\times 1.45=10.4(m) \tag{4}$$

Vertical Uniform Pressure:

$$q = \gamma h = 18.5 \times 10.4 = 192.4(KPa) \quad (5)$$

Horizontal Uniform Pressure:

$$e=(0.3\sim0.5)q=(57.72\sim96.2)(KPa) \quad (6)$$

3.2 Contrastive Analysis of Field Measured and Theoretical Values of Surrounding Rock Pressure

From the comparison of measured and calculated surrounding rock pressure, the following conclusions can be drawn.

(1) The maximum pressure (150.2 kPa, 171.1 kPa, 151.6 kPa) of the vault surrounding rock measured at ZDK35+393.0, ZDK35+382.5 and ZDK35+373.1 sections is slightly smaller than the loose pressure (192.4 kPa) calculated under the V-grade surrounding rock condition, but the difference between them is not significant.

(2) Comparing the measured horizontal surrounding rock pressure with the calculated value under the condition of V-grade surrounding rock, the difference is great. For example, in ZDK35+393.0 section, the theoretical calculation value of surrounding rock pressure at the side wall is 57.72 kPa, but the measured pressure on the left-side wall is 22.2 times of the calculated value. The phenomenon of eccentric pressure is obvious, for example, the measured pressure of the left-side wall of ZDK35+393.0 section and ZDK35+382.5 section is larger than that of the right-side wall. The measured surrounding rock pressure at arch foot is smaller than the calculated value, but the difference is not significant.

In summary, the measured surrounding rock pressure of the three sections is basically consistent with the calculated value under the condition of V-grade surrounding rock, but there is a general phenomenon of biased pressure at the horizontal side wall.

3.3 Guiding Significance of Surrounding Rock Pressure Monitoring in Engineering

Over-release of surrounding rock pressure will lead to large non-linear deformation problems, such as large deformation of steel frame, inconsistent failure of deformation and so on. Therefore, we should optimize the design parameters and strengthen the support stiffness in the engineering design. In support design, the whole process should be considered, and the location of pressure release in surrounding rock of bias tunnel should be found by field monitoring data, so as to judge the rationality of support design process [17].The surrounding rock is destroyed after construction, the influence of construction process on tunnel stress and deformation must be considered. The optimum stress path can be determined by on-site monitoring, and the construction sequence can be reasonably selected to ensure that the disturbance to surrounding rock is small, and the construction sequence plays an important role in controlling its stability.

4. Conclusion

Through the above monitoring and analysis, the conclusions are as follows.

(1) The overall and local heterogeneity of surrounding rock mass will result in stress concentration, which will lead to the phenomenon of bias pressure in the tunnel.

(2) The change of surrounding rock pressure basically passes through three stages, which increases rapidly in the initial support, but tends to be stable after the completion of the initial support. When the secondary lining is carried out, the surrounding rock pressure continues to increase. After the completion of the secondary lining, it generally increases for a period of time and finally tends to be stable, so the secondary lining is effective.

(3) In the initial support, the measured surrounding rock pressure at the vault roof and arch waist of three sections is roughly consistent with the loose pressure calculated under the condition of V-grade surrounding rock.However, there is a phenomenon of local stress concentration in the side wall.

(4) Surrounding rock pressure is closely related to key processes, When the upper, middle and lower three pilot pits are under construction, the influence of each pilot pit on the surrounding rock pressure and stress variation of other pilot pits is not very obvious. But it has a significant influence on

the surrounding rock pressure and stress changes of the same pilot pit, especially when each pilot pit closes, it will have a positive impact on the surrounding rock pressure.

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