Ground Movement Analysis of Shallow Buried Tunnel during Construction in Gully Segment

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***Abstract* — For the research in this paper, on-site monitoring method was used in a gully segment to monitor the deformation of the strata in the construction process and prevent tunnel collapse. Surface monitoring results discovered that both sides of the slope have horizontal reciprocating movement, which is the main reason of the top of the hill tension cracks. The effect of the strata moving to free surface is greater than to the overhead, this effect is conducive to the stability of the slope. Formation transfer ratio has various values at different buried depth, it's close to 1.0 in the gully segment, showing the formation as a whole in sink mode. The cave monitoring indicates that the deformation of the supporting structure from the tunnel face is twice the hole cross that tended to be stable. The key step that influences supporting convergence was the side walls excavation. He study on the deformation characteristics in the excavation process is conducted by using 3 dimensions (FLAC3D) program, the result is consistent with on-site monitoring, while results show that the construction scheme through the gully is feasible, with some guiding significance on similar projects.**

Keywords - gully; shallow buried loess tunnel; ground movement; numerical simulation

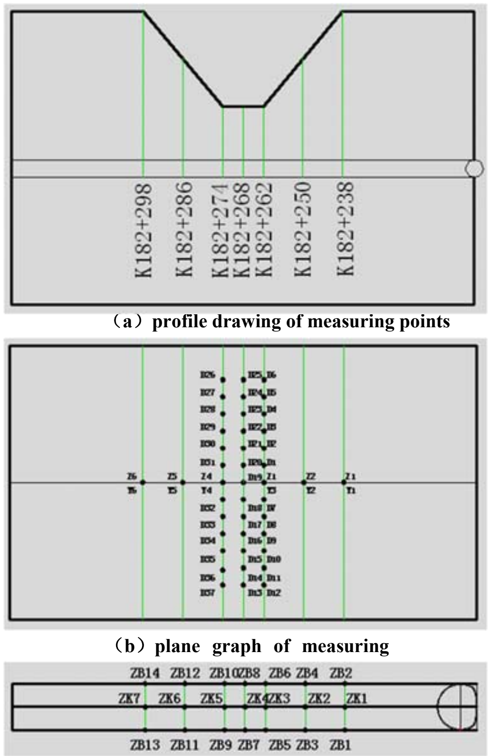
I. INTRODUCTION

Excavation of underground space will inevitably lead to the development of stratum deformation, as the ground loss is caused by construction process and the stress will be readjusted owing to the disturbance of surrounding rock, the process generally contains three phases, that is, the early small deformation, deformation increases rapidly, slow deformation[1-4].The deformation of strata has a connection with the depth of tunnel, size of section, construction method and stratigraphic conditions ,etc. Specialists and scholars have done several research about avoiding the accident which is caused by stratum deformation. Yue Xianghong [5] studied the synchronous change of surface settlement and vault settlement, the results show that the soil consolidation and soil particle loss caused by precipitation in surface settlement is slightly larger than that of vault settlement. Yue Guangxue [6] used a large number of measured data of the tunnel constructed by shallow subsurface excavation method, the statistical analysis of the factors affecting the stratum deformation is carried out, and the calculation formula for the final settlement of the shallow buried tunnel is derived. Currently the theoretical research and actual situation of the project is inconsistent, so the characteristics of ground surface settlement caused by the construction of large span loess tunnel have yet to be further studied.

The research aims to explore the stratum deformation and failure mode of shallow loess tunnel with gully section, which can guide safe construction of the tunnel and reduce the effect of excavation on the ground and underground.

II. SITE MONITORING AND ANALYSIS

A. Layout of Monitoring Point



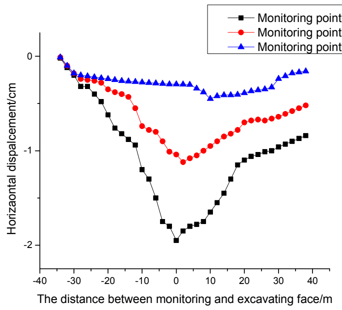
(a) profile drawing of measuring points

(b) plane graph of measuring

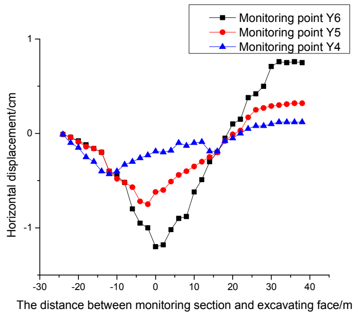
(c) layout of measuring points in

Figure 1. Monitoring point layout schematic

he tunnel is located in Shuozhou City, Shanxi Province (hereinafter referred to as the SPG tunnel).The monitoring sections are as follows, K182+238, K182+250, K182+226, K182+268,K182+274,K182+286,K182+298.Monitoring points from Y1 to Y6 were designed to monitoring horizontal displacement of gully slope, Z1 to Z6 were designed to monitoring settlement of gully slope in order to observe the deformation of the slope,Y1 to Y6 were designed to monitoring ground surface settlement ,ZK1to ZK7 were designed to monitoring vault settlement,ZB1to ZB14 were designed to monitoring peripheral displacement convergence .These measuring points are arranged as shown in Fig.1.



(a) horizaontal displacement curve of Y1、Y2、Y3



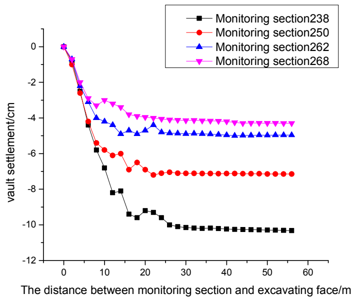
(b) horizaontal displacement curve of Y4、Y5、Y6

FIGURE 2. Horizaontal displacement curve

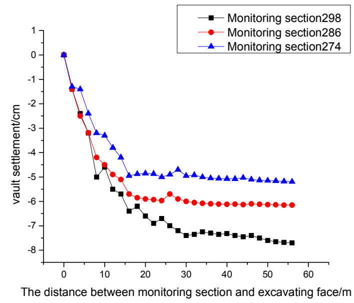
B. *Horizontal Displacement Analysis of Gully Slope Surface*

From the Fig.2(a) and Fig.2(b),although the moment of appearing displacement is almost the same, the deformation rate and the maximum displacement are different. The maximum displacement appears in the top of the slope, the displacement of toe of the slope is minimum. The maximum value is 2cm, which occurs at the top of the slope. This to-and-fro horizontal movement of the stratum goes against the slope stability, especially in the loess region, easy to incur transverse cracks. In addition, by the comparison between Fig.2(a) and Fig.2(b),the deformation of the slope surface among two directions do not show a simple antisymmetric relation, the moment of appearing deformation and the maximum displacement were also different. As for the reverse gradient slope, when the distance between measuring section and excavating face is about 24m, the horizontal displacement appeared.

C. *Deformation Analysis of Initial Lining*

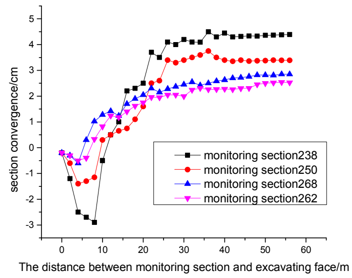


(a) vault settlement of K182+238~268

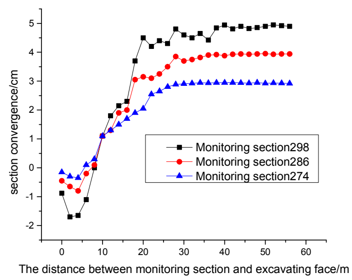


(b) vault settlement of K182+274~298

Figure 3. The vault sink-time curves of monitoring sections of the primary support



(a) section convergence of K182+238~268



(b) section convergence of K182+274~298

Figure 4. The vault convergence-time curves of monitoring sections of the primary support

From the Fig.3(a) and Fig.3(b),when the excavating is finished, initial lining is implemented timely and measuring points are arranged. With the working face moving forward, from the working face 14m (equivalent to a tunnel span),the vault settlement shows a sharp increase. This is because the vault pressure increase sharply owing to excavating, and the initial lining belongs to flexible support which causes yield deformation to surrounding rock. The deformation tend to be stable from the working face 34m.

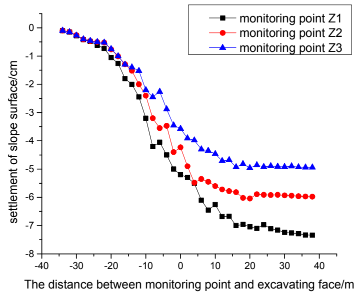
Compared to curve of vault settlement, the curve of section convergence is more complicated (Fig.4).The convergence can be divided into three phases generally that is, expansion phase, contraction phase and stable phase.

D. Settlement Analysis of Shallow Ground

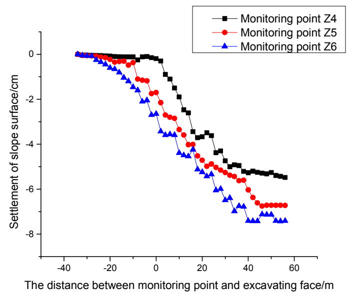
As can be seen from Fig.5, displacement curve of measuring points at the same elevation on both sides are different in terms of settlement process, the settlement rate in the process of working face arrived monitoring section is faster at consequent slope, and the settlement rate of reverse gradient slope is faster after the working face arrived monitoring section, it shows that the soil is more likely moving to free face than moving to the slope surface. From the analysis of the horizontal displacement curve of measuring points, the displacement of strata moving to free face is lager than the value of moving to slope surface, the displacement is beneficial to slope stability. But the to-and-fro horizontal movement of the slope is easily to bring a crack which is parallel to the direction of the slope, the crack will become a channel of rain infiltration in rainy season, then it is prone to occur landslide. So the surface survey should be strengthened during the process of excavating, cracks also should be handled in time.

As can be seen from Fig.6,the lateral influence area owing to excavating is mainly distributed on both sides of the center line within the range of 30 m, the main reason is that the buried depth of gully bottom is shallow, the stratum displacement limited in a certain area above the tunnel and beyond the scope, the impact is minor, it also shows that the scope of grouting treatment (both sides from the central line 50m)among gully section is reasonable. In addition, from the graph, although tunnel buried depth is the same, ground settlement is different. This is because the sections of K182+262 ,K182+274 located at the foot of the slope, the settlement was caused by the stress concentration.

Fig.7 shows that the surface and vault settlement ratio between 0.72 to 0.92. The ratio of shallow burial depth section is larger than the value of deep burial depth, the ratio is close to 1.0 in small buried depth section, it illustrates that the strata shows a whole sinking mode among shallow section, which is due to tunnel excavation in the small buried depth causing soil disturbance is relatively large, spreading to the surface, causing soil secondary consolidation, the deformation mode is harmful to stability of supporting structure in tunnel. Besides, from the graph, the ratio at the foot of the slope is slightly larger than the value in the middle part of the gully, that is,the ground settlement transfer ratio is related with overlying load.



(a) settlement of measuring points Z1、Z2、Z3



(b) settlement of measuring points Z4、Z5、Z6

Figure5. Settlement curves of the mileage slope points

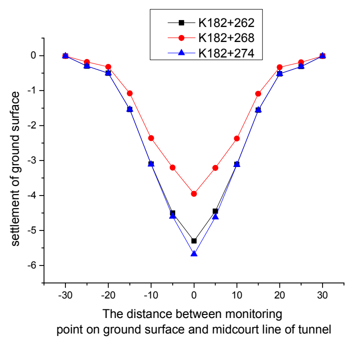


Figure 6.Gully ground accumulated settlement

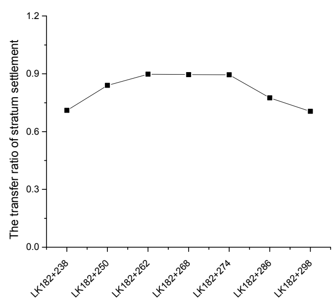


Figure 7. The ratio of final settlement of ground and vault

III. NUMERICAL SIMULATION OF CONSTRUCTION

A. The Establishment of Numerical Model

In order to simulate the movement of strata in the process of tunnel excavation and to compare with the results of site monitoring, FLAC is used to simulate the 3D excavation of the tunnel. The three dimensional calculation model is shown in Fig. 8.

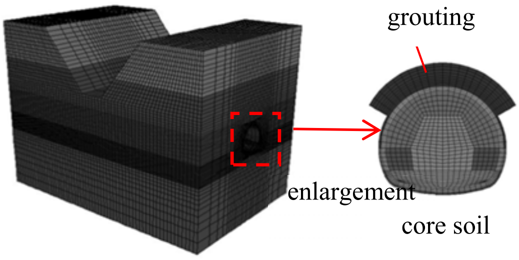


Figure 8. Calculating model

B. Calculation Parameters

The physical and mechanical parameters as shown in Table 1.In the calculation process, due to the depth of the tunnel is shallow, and the initial stress field is calculated by the self weight stress field, rock is simulated by elastic plastic model, and follows the Mohr Coulomb yield criterion.

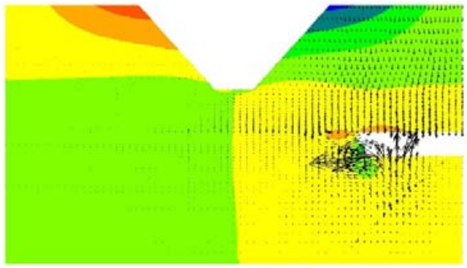
TABLE 1. PHYSIC-MECHANICAL PARAMETERS OF SUPPORTING STRUCTURE

materials	γ/(KN/m^3)	E/**G**Pa	c/MPa	Φ/°	v
Advanced support	21	0.0245	0.063	24	0.21
Initial support	25	30	4.2	53	0.2
Inverted arch	23	26	4.0	50	0.2
Secondary lining	25	35	5.0	55	0.2

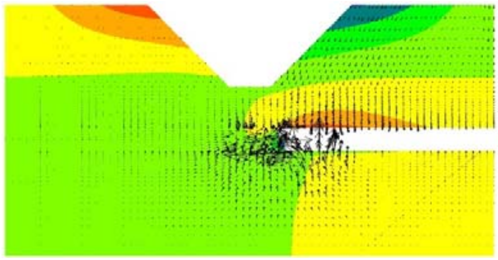
C. Analysis of Calculation Results

(1)Analysis of stratum movement

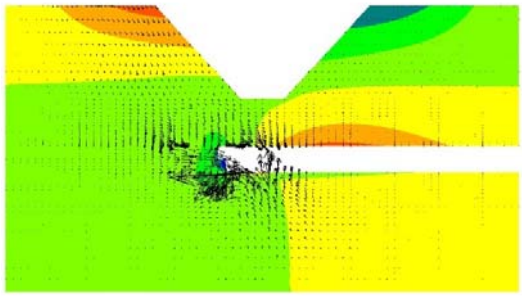
Fig.9 is the graph about displacement vector at the tunnel face excavation to different mileages. The vector direction of displacement of slope has changed during the construction of tunnel, t explains that the deformation of slope appears in different directions. From the displacement nephogram after reinforcement (Fig 9), compared with the pre reinforcement, displacement decreases obviously. The safety coefficient is 1.1625, on the whole, the slope is safe, achieving the expected effect of pre-stressed anchor cable reinforcement.The average value of negative X direction displacement is about 0.24mm, the maximum negative displacement is about 1.5mm, appeared in the junction between two faults, pointing to outside of the slope, mainly occurring in upper parts of the slope; positive displacement occurs mainly in the bottom left part of the slope, the average value is about 3mm. The negative Y direction displacement mainly occurs in the middle-under parts of the slope, the average value is about 2mm, pointing to the outside of the slope.



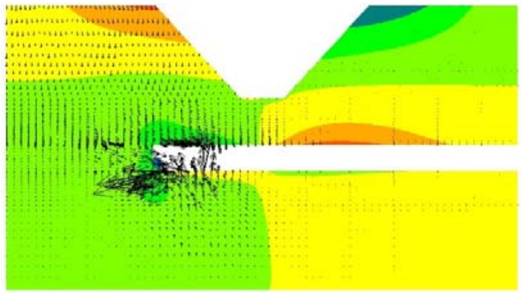
(a) displacement vector when excavating to K182+230



(b) displacement vector when excavating to K182+260



(c) displacement vector when excavating to K182+280



(d) displacement vector when excavating to K182+310

Figure 9. Displacement vector at the tunnel face excavation to the mileages

(2) Comparison between numerical calculation and site monitoring

Fig.10(a) and Fig.10(b) were the comparison between site monitoring results and numerical calculation results about the surface and vault final settlement amount of monitoring sections. As can be seen from the graph, both of them have a superior fitting, stratum settlement rule is consistent, which vault settlement monitoring results is smaller than the numerical calculation results, this is due to the complexity of the construction site conditions, the conversion of a number of processes, supporting and

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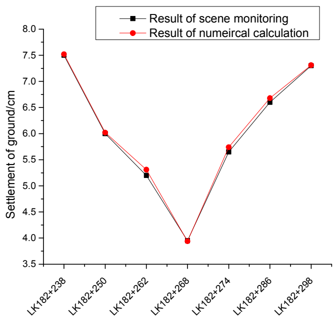
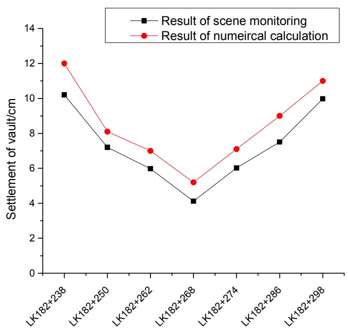
arrangement of measuring points is not timely, a part of the vault settlement has occurred at the beginning of the monitoring work.



(a) comparison of surface settlement



(b) comparison of vault settlement

Figure10. Comparison between in-situ monitoring and calculation

IV. CONCLUSIONS

(1) The deformation of the slope surface among two directions do not show a simple antisymmetric relation, the moment of appearing deformation and the maximum displacement were also different. But final deformation tendency and displacement are consistent. In addition, The to-and-fro horizontal movement of the stratum goes against the slope stability.

(2) The transfer ratio of strata deformation between 0.72 to 0.92. Different buried depth have different transfer ratio, the ratio is close to 1.0 in bottom of gully, it illustrates that the strata shows a whole sinking mode among gully section, the settlement mode is harmful to the stability of supporting structure in tunnel.

(3) Numerical simulation of strata movement is consistent with the results of site monitoring, displacement monitoring results show that the construction scheme of crossing gully is feasible.

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