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Design and application of remediation plan for heading slope landslide in Feilongshan tunnel entrance

In order to effectively solve the hazards of heading slope landslide of tunnel entrance project in fractured strata, the geological conditions, human activities, meteorology, hydrology, and other factors of Feilongshan tunnel entrance are analyzed; by comprehensively taking into consideration of factors such as the environment, project duration, and safety of the landslide area, this paper proposes comprehensive control measures centered on anti-sliding, and systematically studies the effectiveness of slope-brushing protection, pipe-shed support, counter-pressure backfill mortar rubbles and other measures for controlling heading slope landslide of the tunnel entrance. The on-site monitoring results shows that the change trend of the vector displacement and plane displacement at each measuring point after the remediation is relatively stable, all within the allowable deformation range; the comprehensive remediation plan has clear construction process flow, obvious technical effects, and high construction efficiency and safety. The research results provide a technical basis and reference for the remediation of tunnel entrance landslide in complex and fractured strata.

Keywords: *Tunnel entrance, heading slope landslide, remediation plan.*

1. Introduction

At present, the landslide of highway tunnels in fractured strata in China is one of the most common engineering disasters. The accident of heading slope landslide at tunnel entrance often prolongs construction progress, increases construction cost, causes quality problems, endangers life safety of construction workers, and destroys the natural ecological environment. Even the tunnel could not be put into use normally [1]. Therefore, the security of the heading slope at the tunnel entrance has always been of great concern to the academic community, and many methods have been used to control the heading slope of tunnel entrance. However, up to now, academics and engineering circles at home and abroad have not yet formed a unified understanding of the deformation mechanism, prediction methods, and prevention and control technologies of soft rock in fractured strata, especially when facing special engineering practice, all theories and doctrines have certain limitations [2]. This paper takes the heading slope landslide accident at the entrance of Feilongshan tunnel on Yongyi Highway in Zhejiang province as an engineering example, and combines the site's actual situation, geological and hydrological conditions, human activities, and monitoring measurement data to conduct a comprehensive analysis of the cause of the landslide. On this basis, prevention and remediation measures of slope-brushing protection, extension arch reinforce, pipe-shed support, counter-pressure backfill mortar rubbles for controlling heading slope landslide at tunnel entrance are analyzed. This paper studies and designs a targeted plan for the comprehensive management of heading slope landslide, and adopts strict construction process to realize smooth tunnelling, and at the same time, strives to reduce economic costs, improves construction efficiency and safety, and provides references for similar landslide control and management works.

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2. Project background

Feilongshan tunnel is located on the Yongyi highway in Zhejiang province and is designed as a two-way split six-lane tunnel with a design speed of 80km/h. In a single tunnel, the inner clear width is 14.0m, the clear height of driveway is 5.0m, with motor vehicle load level of highway level I, a total tunnel length of 1058m, and a buried depth of the tunnel top is 6.00 to 45.00m (left line, 4.00 to 45.00m). The original design of the entrance section is shown in Figs.1 and 2, respectively.

During the construction process, the right line entrance section YK35+597 ~ YK35+680 (left line ZK35+602 ~ ZK35+680) heading slope surface layer is el-dlQ with gravel silty clay, beneath the surface, from surface to center, there are strong, medium, and slight weathered silty sand and slight weathered tuff. The stability of surrounding rock is poor, and the surrounding rock grade is level V, drips and seepages occur along the F1 fractured structure. Sheet flow occurs in

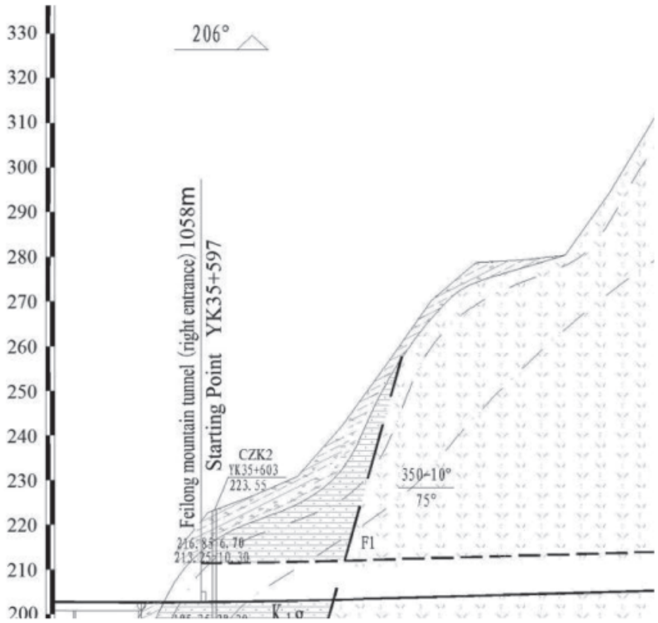

Fig.1 Vertical section design of the right entrance section (original design)

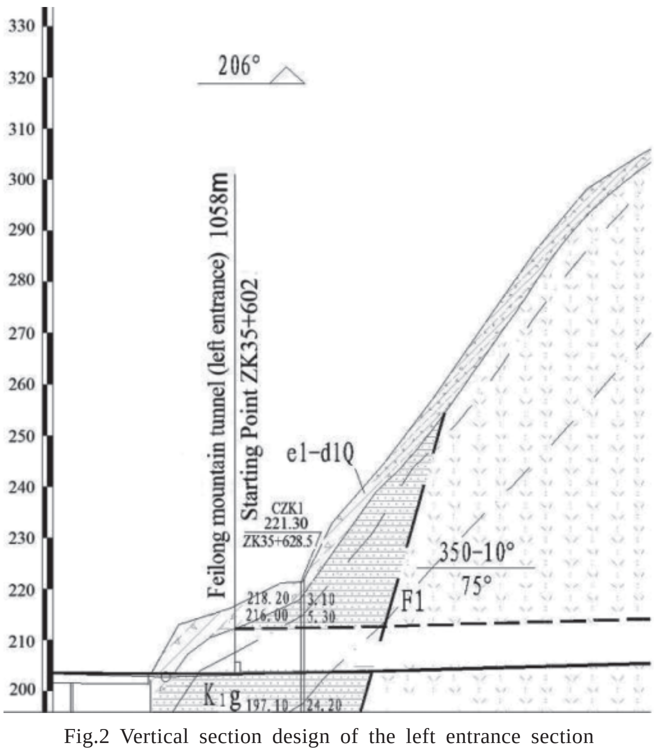

Fig.2 Vertical section design of the left entrance section (original design)

some part, and landslide occurs on upper plate of the F1 fault zone. The detailed landslide situation is: on August 7, 2014, major landslide occurs to the heading slope at the entrance of Feilongshan tunnel, the lateral width of the collapsed body is about 40m, landslide amount is about 5000m^3. On August 20, 2014, a second landslide occurs at the entrance of Feilongshan tunnel, the lateral width of the collapsed body is about 60m, landslide amount is about 15000m^3. On May 18th, 2015, during the construction of slope-brushing protection of the right tunnel of Feilongshan tunnel entrance, landslide happend for the third time, the lateral width of the collapsed body is 35m, landslide amount is about 1000 m^3 (Figs.3 and 4).

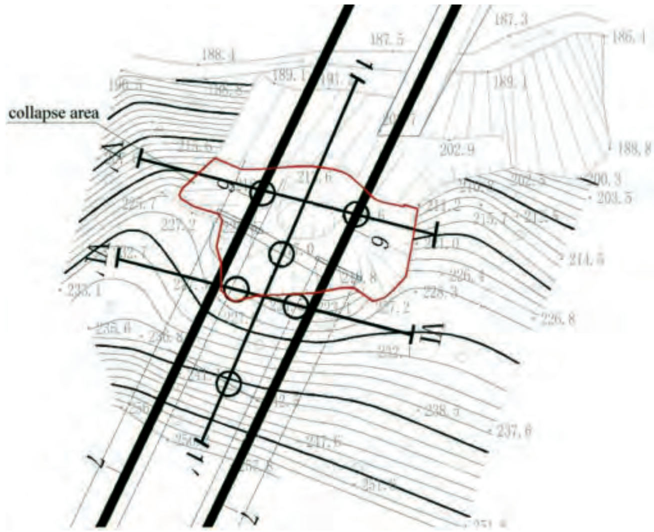

Fig.3 Schematic diagram of the landslide of entrance section

Fig.4 The third-time landslide in the entrance section

3. Analysis on cause of formation of the landslide body

The Feilongshan tunnel line runs 206° north-south and the landslide slope gradient is 23°. The formation of the landslide body is mainly the comprehensive result of geological structure, geological lithology, human activities and meteorological and hydrological conditions. Geological structure and geological lithologic conditions are the internal causes of landslide formation. Human activities and meteorological and hydrological conditions are the external causes of landslide formation [3].

3.1 Internal causes of landslide

3.1.1 Geological structure factors: due to the influence of regional structures, the joints and fractures in the landslide area are most developed, the distribution of joints and fractures in strata with different lithology is extremely obvious, namely in the Cretaceous fine sandstone formations, they are more developed and most developed, and in Jurassic tuff formations, they are less developed or not developed. Joint fractures mainly develop in two groups, with the occurrence of 320-350°/75-80° and 210-230°/50-75°. The inter-laminar fractures mainly develop into two groups. In tuff the occurrence is mainly 65-70°/25-40°, and in Cretaceous fine sandstones and glutenite the occurrence is mainly 80-110°/16-22°. Most of the joint surface are flat, mainly micro tension joint, and a few are semi-closed. The extended length of the joint surface varies greatly. The extended length in the Jurassic strata is large, most are longer than 1.0m, usually 2.0 to 3.0m; in Cretaceous strata, most extended length is less than 1.0m, shorter ones are only a few centimeters to tens of centimeters. From Fig.5 we can see that, the IV-grade structural plane is the most developed along the N-W-W trend, the second most developed is along the N-N-E trend and N-N-W trend.

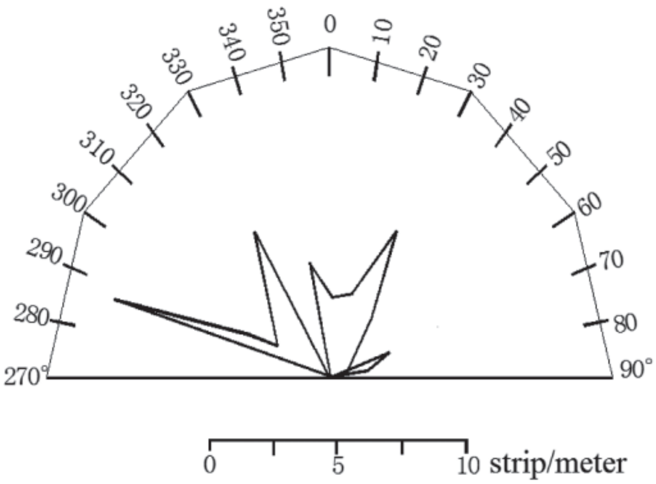

Fig.5. Rose diagram of strike joint

3.1.2 Strata lithologic factors. The outcropped lithology within this landslide body is fine sandstone with overlying el-dlQ of the quaternary period, which mainly consists of crushed stones with cohesive soil, with local distribution of block stones, mixed distribution of soil and crushed block stones, the porosity is large because of the obvious aerial structure function of the crushed block stones, and good permeability provides good conditions for the infiltration and reserved of water precipitation; heavy weathered fine sandstones are weathered strongly, joint fractures are most developed, the rocks are most cracked, and the seepage effect of surface water and groundwater are strong [4]; for medium weathered fine sandstones, the joint fractures are more developed, local rocks are more cracked, which is inconducive for the development of the structural surface [5].

3.2 External causes of landslide

3.2.1 Human activity factors: at the foot of the slope, a steep artificial heading slope is formed due to the tunnel excavation construction and the excavation of the opencut tunnel side wall foundation. The slope height is generally 5 to 8m, and the slope angle is often more than 60°, making the front slope foot be in a free status, and no slope protection measures have been adopted in time. In the process of manually excavating the heading slope, the rock loosens and cracks increase due to the impact of blasting, the rock further fractured, exacerbating the decline of the rock mass.

3.2.2 Meteorological and hydrological conditions: during the construction period, it rained a lot, and the rainfall is big, sometimes with rainstorm. During the rainstorm period, the surface water flow is large, water infiltrated intensely along the cracks, affected by the surface water, the cohesive force in the rock and soil is reduced, resulting significant drops in the anti-sliding force of the weak surface, and at the same time, rain soaking increases the weight of the soil quickly and induces the landslide [6].

4. Remediation plan design and construction

According to the characteristics of the Feilongshan tunnel project, the geological condition of the heading slope, and the actual situation of the landslide, through the analysis of the above-mentioned causes of the landslide and comprehensive consideration of the environment, project duration, and safety of the landslide area, comprehensive anti-sliding measures have been adopted. Landslide remediation adopts engineering measures combining water control and anti-sliding, and timely monitoring landslide dynamics through monitoring methods to ensure the effectiveness of landslide remediation.

4.1 Plan Design

4.1.1 On the basis of the original slope protection design plan for the heading slope, stick to the principle of “stabilize the slope first, clear the landslide second, and reinforce the tunnel last” [7] , on condition that the entrance heading slope is stable, the construction and operation environment are safety, this paper studies and designs a remediation plan that is tailored to local conditions, and is safe, reliable, economically reasonable, and technically feasible.

4.1.2 According to the actual situation of landslide of tunnel entrance heading slope, through the comparison and selection of technical solutions, several comprehensive remediation plans are prepared for the slope-brushing and protection of heading slopes that did not landslide at the left and right tunnel entrance, third-time heading slope landslide remediation, extension arch reinforce, pipe-shed support, counter-pressure backfill mortar rubbles, clear collapsed body, opencut tunnel extension, counter-pressure backfill soil and stone, etc. [8]. After meetings and discussions between project development unit, design unit, supervision unit and construction unit, the final remediation plan is modified and determined (Figs.6 and 7).

4.1.3 The comprehensive remediation plan requires that

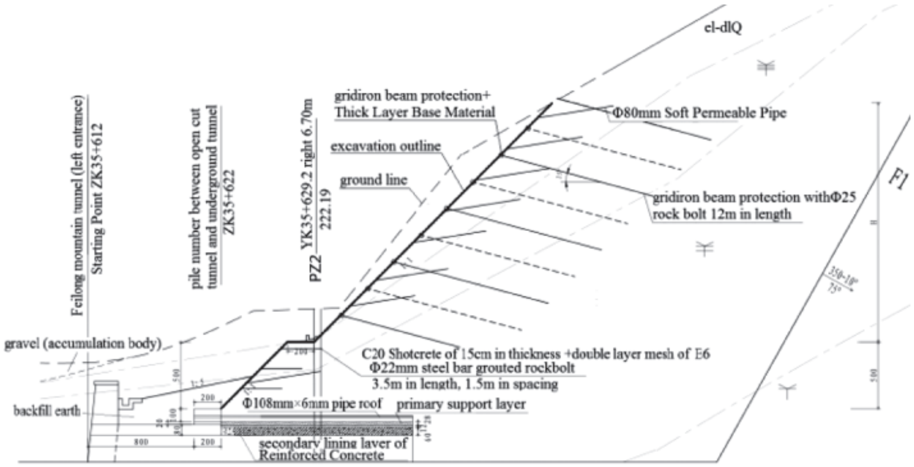

Fig.6 Schematic diagram of the of the left tunnel heading slope protection

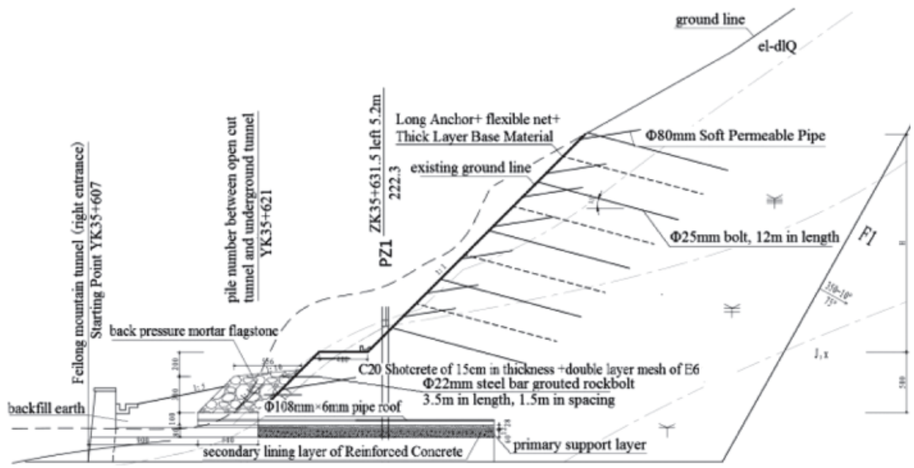

Fig.7 Schematic diagram of the of the right tunnel heading slope protection

the construction should be carried out in a sunny and dry season. During the construction, measuring points should be set at the entrance of the tunnel and on top of the slope, and observations should be strengthened to provide timely feedback.

4.2 Construction process and key points

According to the comprehensive remediation plan design, we draw up the construction process as follows: slope-brushing and protection of heading slopes that did not landslide ® third-time heading slope landslide remediation extension arch reinforce pipe-shed support counter-pressure backfill mortar rubbles clear existing landslide body opencut tunnel extension counter-pressure backfill soil and stone. The specific construction key points are as follows.

4.2.1 Slope-brushing and protection of heading slope that did not landslide: the entrance heading slope is level II (upper part is level II, bottom part is level I) step slope, brush the slope while making protection of the slope in 1:1 slope ratio from top to bottom. The left tunnel level II slope uses anchor bolt-grid beam protection (anchor bolt length is 12m) + thick layer base material, the level I slope uses anchor-plate retaining (anchor bolt length is 3.5m). The right tunnel level II slope uses long anchor bolt + flexible net + thick layer base material (anchor bolt length is 12m), level I slope uses anchor-plate retaining (anchor bolt length is 3.5m) [9].

(1) Grid beam protection: for heading slope protection of left tunnel level II slope, the anchor bolt uses 12m long φ25 rebars, the grid uses C25 reinforced concrete to teem into a beam with 30cm width × 40cm thickness, before teeming, tying and binding the plants inside the grid, set embedded bar for slope protection. Reinforced steel frame joints are connected and fixed by fully-bonded screw thread steel anchor bolt, anchor bolts are erected perpendicular to the slope surface. The exposed ends are welded to the reinforced steel frame. On the frame, set expansion joint every 15-25m, the width of the joints is 2cm, and the joints are filled with asphalt oakum. In the frame, using adding soil-spraying for protection. When the slope surface lithology is soil or soft rock, the frame is embedded into the soil layer for 30cm, exposes 10cm; when the slope surface lithology is hard rock, the frame is embedded into the rock layer for 15cm, exposes 25cm.

(2) Anchor-plate retaining protection: for the level I slope protection of left and right tunnels, the anchor bolt uses φ22 rebar with a length of 3.5m, and is set up horizontally; for level II heading slope protection of the right tunnel, the anchor bolt uses φ25 rebar with a length of 12m, and a horizontal depression angle of 15°; the distance between the anchor bolts is 1.5m. Hanging double-layer E6 cold-rolled ribbed steel mesh with spacing of 20cm×20cm and spraying C20 concrete.

(3) Thick-layered base material slope protection: when the slope ratio of original heading slope is gentler than 1:1, the thickness of greening substrate material is 5-8cm. When the slope ratio of original heading slope is steeper than 1:1, the thickness of greening substrate material is 10-13cm. The compounding ratio of the base material mixture is: greening substrate material: fiber: loam soil = 1:2:2 (volume ratio). The greening substrate material is made of organic materials, soil conditioners, and other materials. The loam soil uses original land surface soil of the project site, or nearby farmland soil crushed and air-dried to a water content of < 20% and passed

through an 8mm sieve. For fiber, taking local straw or tree branches, smashed into 10-15mm long, water content < 20%. Before use, test the plant seeds for germination, the seeds can be used only if the germination rate is over 90%, for plant seeds that are hard to spout, apply germination-accelerating to the seeds before use. Leveling the slope so that the slope ratio is not greater than the design requirements, solid monolithic hard rocks or jutting single rocks are not cleared. After the anchor bolts can hold strength, nets hanging can be conducted and the nets must be tensioned, the lap width between the nets > 5cm, and they should be firmly tied with 18# iron wires at an interval of 30cm.

4.2.2 Remediation of third-time landslide of heading slope: the construction process is: clear cavity of the landslide body → erect anchor bolts to the slope surface after landslide + flexible net protection → excavate the retaining wall platform → drill holes, stick pipes → construct retaining walls → backfill the cavity behind the walls → construct intercepting ditches → thick-layered base material protection.

(1) Clear cavity of the landslide body: clean up the accumulation body of the third-time landslide.

(2) Erect anchor bolts to the slope surface after landslide + flexible net protection: after cleaning up the accumulation body, use φ22 reinforced mortar anchor bolt and flexible net to reinforce the protection of slope surface.

(3) Excavate the retaining wall platform: in the landslide cavity area, dig the retaining wall platform with a width of 2m at a distance of 3m from the top of the slope, the platform length is 33m.

(4) Drill holes, stick pipes: drill holes on the retaining wall platform, and stick a 3.5m long φ89×5mm hot-rolled seamless steel pipe, of which 3m is stuck into the basement of the retaining wall, 0.5m is reserved and stuck into the retaining wall.

(5) Construct retaining walls: C25 reinforced concrete retaining wall is constructed on the retaining wall platform.

(6) Backfill the cavity behind the walls: use the soil and stones after heading slope-brushing for backfilling the cavity behind the retaining walls and compacting it.

(7) Construct intercepting ditches: C20 concrete intercepting ditches is constructed on the middle steps of the tunnel entrance level I and level II heading slopes.

(8) Thick-layered base material protection: the thick-layered base material protection of the third-time landslide of heading slope is the same as the thick-layered base material protection of the slope-brushing and protection of the slopes that did not landslide.

4.2.3 Extension arch reinforce, pipe-shed support: for the right tunnel arch reinforce, the original design is lengthened from 2m to 5m (the left arch reinforce remains the same), C30 concrete cover arch is used as the fixed end of the pipe shed, the cover arch is constructed outside the outline of the opencut tunnel and closely next to the tunnel face. Inside the cover arch set three sets of No.18 I-beam, which are welded to the pipe-shed steel pipes as a whole. In the construction of pipe-shed, stick the perforated steel pipe first, then stick the non-perforated steel pipe after grouting. The steel pipe joints adopt screw thread connection, the screw thread length is 15cm, and the steel pipe joints are staggered. The spreading radius of slurry in pipe-shed grouting shall not be less than 0.5m, and the slurry is grout with a water and mud ratio of 1:1, grouted with a pressure of 0.5-1.0 MPa. The steel pipe adopts hot-rolled seamless steel pipe φ108mm with a wall thickness of 6mm, a section length of 3m, 6m, the space in circumferential direction is 40cm, and an elevation angle of 2° in parallel with the midline of the route [10].

4.2.4 Counter-pressure backfill mortar rubbles: above right tunnel entrance cover arch, using mortar rubbles to backfill, the backfill height should be higher than the cover arch for 3m, the backfill platform length is 5.83m, backfill slope ratio is 1:1. The backfill surface shall be excavated from top to bottom, and must be supported while excavating, the lower part must be completed after the upper part support is completed.

4.2.5 Clear landslide body: after the heading slope is stabilized, and the cover arch is counter-pressure backfilled, clean up the accumulated landslide soil and stones.

4.2.6 Opencut tunnel extension: in the original design, the right line tunnel entrance pile number and shadow line pile number are YK35+597 ~ YK35+603, the opencut tunnel length is 6m, the left line tunnel entrance pile number and shadow line pile number are ZK35+602 ~ YK35+608, the opencut tunnel length is 6m. Now, construct according to the changed design, the right line tunnel entrance pile number and shadow line pile number are YK35+607 to YK35+621, the opencut tunnel length is 14m, the left line tunnel entrance pile number and shadow line pile number are ZK35+612 ~ YK35+622, the opencut tunnel length is 10m.

4.2.7 Soil and stone counter-pressure backfilling: in the backing of the opencut tunnel, using soil and stones to counter-pressure backfill until the foot of heading slope, the backfill slope ratio is 1:5.

4.3 Construction Precautions

4.3.1 Before the construction of the tunnel entrance, the stability of the mountain above the heading slope should be checked first, surface soil should be removed, and continuous monitoring measurement should be carried out during the construction period.

4.3.2 The construction of the earthwork of the tunnel entrance should be excavated from top to bottom, conduct layered anchor bolt-grid beam protection and anchor-plate retaining.

4.3.3 Drainage facilities such as intercepting ditches and side ditches shall be provided to ensure that the surface water

Table 1 Statistical table of surface monitoring results at the entrance end of Feilongshan Tunnel (unit: mm)

Measuring points	X Direction Displacement (mm)	Y Direction Displacement (mm)	Z Direction Displacement (mm)	Vector displacement	Plane displacement	Trend	Monitoring time
P1	5.30	-4.00	-3.40	7.5	1.2	trend stability	2015.5.15~8.19
…	…	…	…	…	…	…	…
P14	3.40	6.90	-20.80	22.2	1.7	trend stability	2015.5.15~8.19
…	…	…	…	…	…	…	…
P31	10.30	-0.80	-10.50	14.7	2.6	trend stability	2015.7.6~8.20
…	…	…	…	…	…	…	…
P62	-1.20	6.30	0.40	6.4	1.1	trend stability	2015.7.13~8.22

Remarks: The upward deformation of the surface measuring point is represented by "+"; the subsidence is represented by "-".

Fig.8 Diagram of surface subsidence measuring points at the entrance of Feilongshan tunnel (part).

does not scour the heading slope along the entrance of the tunnel and should be easy for drainage inside the tunnel [11].

4.3.4 In the tunnel entrance section, the subgrade, side slope and heading slope should be excavated from top to bottom, complete the earthwork at one time, the excavation personnel must not work on top and bottom at the same time; when they are working on the heading slope higher than 2m, special attention should be paid to the security protection.

4.3.5 The grouting of the anchor hole in the anchor bolt-grid beam should be injected once from bottom up of the hole. The grouting pressure should be > 0.8Mpa, and the process cannot be stopped halfway. The anchor bolt must be grouted within 6 hours after entering the hole. For holes with groundwater, when the holes are constructed and anchor bolts cannot be cast within 4 hours, the holes should be washed before casting the anchor bolts, quickly wash and cast the anchor bolts, quickly grouting. When grouting the anchor bolts, the grouting should only be stopped until the anchor hole cement slurry surface is stable, if not, it should be continued with slow pressure grouting, and it cannot be stopped until stable. Check all the anchor holes before sticking the ground beam to see if the slurry is full and if it is not full, inject grouting from the holes. When sticking the ground beam, still fill with concrete, and there must be no cavities or air holes.

5. Remediation effect analysis

After remediation of heading slope landslide of tunnel entrance, set 58 new measuring points on the protection grid beam or the anchor bolts of left and right tunnel entrance section heading slope, together with previous reserved points, there are 62 measuring points in all, as shown in Fig.8, respectively monitoring the surface subsidence in measuring points' X direction (longitudinal displacement of the measuring point along the axis of the tunnel), Y direction (lateral displacement of the measuring point along the axis of the tunnel) and Z direction (vertical displacement of the measuring point, i.e., the settlement of the measuring point), the monitoring results are shown in Table 1.

According to the analysis in Fig.8 and Table 1, no obvious plane displacement (maximum of 1.7mm) and vector displacement (maximum of 22.2mm) are observed at the measuring points, and both the vector displacement and the plane displacement trend are relatively stable. The measuring point displacement changes are within the allowable deformation range (accumulated displacement is not significantly increased). The monitoring measurement results show that the remediation measures for the heading slope of the tunnel entrance are feasible and the remediation effect is good.

6. Conclusions

The heading slope landslide of the tunnel entrance is a common geological disaster in the tunnel construction. Once a heading slope accident occurs, it will cause delays, increased costs, casualties, and ecological damage. Therefore, all parties involved in the construction of the tunnel must attach great importance to the prevention of the landslide and prevent the landslide accident.

After accident happens at the tunnel entrance heading slope, a full investigation should be conducted on the situation in the entrance section and the actual conditions of geological supplement drilling. The influencing factors such as site geological structure, geological lithology, human activities, and meteorological and hydrological conditions should be analyzed, reasonable, effective, detailed and feasible remediation plan should be designed accordingly.

In the course of the remediation of the heading slope landslide of tunnel entrance, according to the established remediation plan, reasonable and effective construction methods and procedures shall be adopted for comprehensive remediation, timely tracking and monitoring the soil of protective structures, and the remediation plan and construction methods should be dynamically adjusted accordingly to improve the stability of the heading slope protection and realize the effective control and remediation of the landslide.

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