The Expansive Soil Landslide Investigation and Administration of an Expressway

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Abstract: By exploring the expansive soil landslide of an expressway, this article analyzes the geologic characteristics and sliding mechanism of the landslide, and offers comprehensive measures. It accumulates experience for the other analogous areas for highway construction, and has certain reference significance.

1. The geological outline of landslide
This project is located in the right side of K84+580~K84+800 of an expressway, belongs to low mountains geomorphic zone, which crosses the expansive soil in cutting slope form. Because of thicker soil and larger excavation depth of this cutting slope, its biggest excavation depth is about 22.7 meters, which causes the landslide sliding in the right side of cutting slope on the way forward. For treating landslide in efficient method, and making sure construction and transportation safety, it has been investigated and protected.

2. Investigative plan and means
On the basis of collecting data, this exploration adopted the comprehensive survey means of geologic surveying and mapping in field, drilling, geophysical prospecting, laboratory test and in situ testing.

(1) The geologic surveying and mapping in field: using the topographical map on a scale of 1:1,000 as a base for construction, and adopting walking out way arranged annotation point at the location of the landslide boundary, crack, steps, slip cliff, drumlin, etc. The landslide boundary, landslide steps and other landslide elements were measured by GPS and exploration well. The characteristics of formation lithology, geological structure and subminiature terrain of the landslide were investigated, with emphasis on the deformation and failure characteristics, elements of the landslide and the scale, origin and nature of the main ground cracks.

(2) The geologic engineering drilling: Based on the landslide characteristics and geological condition of engineering, arranged 3 cross section lines and 10 drills at the main landslide slide direction to find out stratum structure and properties of slippery body and smooth the bed, emphatically looked for the feature and buried depth of the slide zone.

(3) Geophysical exploration: Though routine drilling can solve a lot of problems in geotechnology of expressway, however, in the case of tight time, short construction period and complex terrain, engineering geophysical prospecting methods such as high density resistivity are also a good supplement to the investigation means. High density resistivity has been widely used in geotechnical investigation of highway engineering \cite{1-4}, which has the advantages of one-time electrode placement and abundant data collection. Geophysical prospective work was arranged at the sliding surfaces and...
main slip direction for this investigation, the main objective was to find out Earth-rock interface and gliding planes. Four geophysical prospecting profiles were laid out by using the high density electrical method.

(4) Laboratory experiments and in situ testing: The routine laboratory tests and saturated shear tests were conducted on undisturbed soil samples of clayey soil, some samples were continuously collected. Disturbed soil samples were taken from the layer which undisturbed soil samples couldn’t be taken by the drilling to carry out residual shear strength tests under natural and saturated conditions. Rock samples were taken from rock strata for compressive tests, standard penetration tests and dynamic penetration tests were carried out in boreholes.

3. Geological characteristics of the landslide site

3.1. Stratum characteristic
The rock soil mass types in exploration depth could be divided into four main sections based on their forming era and their origins, buried distribution, lithology and physical mechanical properties by geologic surveying, mapping and exploration. From top to bottom was divided as follows:

1. Silty clay (Qd2): brown yellow, maroon, plastic - hard plastic, contains Fe - Mn oxides and rubble. The rubble was not distributed homogeneously, its content was about five to fifteen percent and ingredient was heavy weathering andesite, particle size was 2-15 cm, maximum size was over 20cm. The layer was incompact, good in permeability. After the digging, the slope would be easy to lose stability in the presence of water. The layer belonged to weak expanded silty clay and was about 2.3-6.3m thick.

2. Silty clay (Qd2): tan, maroon, hard plastic- hard, contains Fe - Mn oxides and calcareous concretion. The calcareous concretion content was about five to ten percent and particle size was 3-30cm, mixture with rubble, some part contained boulder, fissure was well developed. The layer belonged to weak expanded silty clay and was 5.5-18.0m thick.

3. Andesite (Pt): taupe, pewter, strong weathering, it was mainly composed of quartz and feldspar, porphyaceous texture, massive structure, fissure was developed. The core was broken, which occurred generally as fragmental structure, and was 7.1-14.9m thick.

4. Andesite (Pt): taupe, pewter, medium weathered, fissure was well developed. The core was completely, which occurred as long cylindrical, and had good engineering properties.

According to the relevant regulations of Specifications for Design of Highway Subgrades to assess slope stability, and calculate landslide pushing force, and after verifying of the inverse calculation, calculation parameters of every rock and soil layers were shown in the following table:

| Rock and soil number | Name of the layer | Natural density (g/cm³) | Saturated density (g/cm³) | C1/KPa | φ1/(°) | C2/KPa | φ2/(°) |
|---------------------|------------------|------------------------|--------------------------|--------|--------|--------|--------|
| ①                   | Silty clay       | 1.75                   | 1.87                     | 20     | 14.2   | 10     | 6      |
| ②                   | Silty clay       | 1.81                   | 1.95                     | 30     | 15     | 11     | 8      |
| ③                   | Andesite         | 2.6                    | 2.65                     |        |        |        |        |
| ④                   | Andesite         | 2.7                    | 2.75                     |        |        |        |        |

Note: c1, φ1 were shear strength under native status; c2, φ2 were shear strength under saturated condition.

3.2. The hydrogeology condition
During the survey, the rainfall in the project site was frequent. water leakage points were discovered at the bottom of the excavated cutting slope, but didn’t form catchment and surface water. The rain coalesced along the slope surface to the foot of the slope, forming local water.

Some of the rainwater drained away through the surface, the other infiltrated into the soil and formed water-bearing block, which were mainly recharged by atmospheric precipitation and were
mainly excreted by evaporation and deep infiltration. After the rain the seepage discharge and scope of water-bearing block would increase, which had great disadvantage to stability of the slope project.

3.3. Expansibility assessment of expensive soil
Expansive soil is a special clayey soil, which is mainly composed of strong hydrophilic minerals and has obvious properties of swelling, shrinking, shrinkage and bulking repeatedly. Expansive soil landslide is the most pervasive and special slope deformation phenomenon in expansive soil area, and it is also one of the major geological problem [5]. The free expansion ratio was 40%-56% of silty clay layer in the upside, which had weak expansion. When the embankment was excavated, the expansive soil was affected by atmosphere factors and caused landslides.

4. The shape and cause analysis of the landslide

4.1. The shape of the landslide
Part of the slope was instability and appeared the landslide. There was a small-scale landslide nearby K84+780, the area of the landslide was 123.539 m². The landslide near K84+650 was the worst, the circumference was 1151.193m and the area was 15794.072 m², which was a little-model landslide. the leading edge of landslide crossed the first step about 10m, several tensile cracks appeared at the trailing edge, with a general width of 10-30cm. The largest crack was located at the left side of the back of the side, with a width of 1-1.5m. After excavation of the slope, there were large amounts of rainfall infiltration, and the water was visible in some places of the bottom of slope. On the whole, the landslide was a small-scale pull-type accumulation landslide.

4.2. The causes of the landslide
Based on the work of geologic surveying and mapping, it was concluded that the cause of the landslide was both natural factors and artificial factors, which effected comprehensively. Weight instability caused by excavation was the proximate causes of the landslide, and secondly, the landslide was caused by soil properties and underground water in the area.

(1) Rock stratum factor: Weak expensive silty clay was primary rock soil mass in the slope area. the upper layer contained incompact uneven rubble, which resulted in smaller stable angle of the entire natural slope. In the process of cutting excavation, the steep slope made the soil in an unstable state , thereby causing the soil instability.

(2) Hydrogeological factor: during surveying, rainfall was frequent at the slope site. Because of the upper layer was incompact residual soil, some part of the rainwater drained away through the surface, the other infiltrated into the soil. When the lower soil layer became saturated, the expansive soil would be swelling-shrinkage and soften, and the strength of the soil would be greatly reduced, which intensified the landslide of the upper strata. After the rain, water content of the slope was increasing, which caused more adverse influence to stability of the slope.

(3) Inducement factors: before excavation, natural slope of the area was about 25 degrees. After excavation free surface was formed, which disturbed the natural soil and destroyed the natural stability of soil structure. The design slope rate was 1:0.75, 1:1, 1:1, and the slope was too steep, which caused the instability of the upper soil, and then caused massive landslide.

In summary, main factors of the landslide were particular stratum structure and continuous intensity monsoon, and the combination of the cutting slopes of highway, mechanical vibration and the foregoing factors played a certain role in promoting the occurrence of landslide.

5. Disposal plans
Based on the above analysis, geological features of expansive soil, hydrogeological characteristics, disrupted status of the slope, considering the requirements of environmental protection, through large amounts of scheme comparison, put forward the following disposal plans from the construction risk,
construction difficulty, schedule, project cost, environmental protection, occupation of land, landscape effect and operation safety:

(1) According to the topographic conditions, the slope was slowed down according to the slope rate 1:1.5, and the platform with a width of 2 meters was set every 8 meters. After step-slope excavation as planned, the landslide push-force of K84+600 was 492.7KN when the safety factor was 1.25 in natural state; when the safety factor was 1.15, the landslide push-force was 1705.8KN, while the landslide push-force was 3604.2KN in the case of rainstorm or continuous rainfall. Therefore, anti-slide piles were used to reinforce the slope.

(2) Anti-slide pile was disposed on the first step of excavation platforms. The section size of square pile was 2x3meter in general road, and the section size was 3x4 meter in K84+640~K84+750. The pile spacing was five meters, and top beam was set. The average pile length was 12~22meter and 45 piles were set.

(3) Stage for heaping debris and the first step of platforms were four meters in width, and the other platforms were two meters in width. In order to reinforce sliding resistance and prevent the slope of the pile head from instability, the second and third stage of the slope use the anchor frame or anchor cable frame to reinforce according to the calculation results, and hollow hexagonal edge was filled in the frame, while the other slopes adopt arched skeleton and hollow hexagonal edge planting Protection.

(4) To reduce the influence of water penetration and rain to the slope, the intercepting drain was set 5 meters away from the sliding surface of the slope top. And all cracks were filled with clay; excavation platforms were provided with drainage ditches, and all slopes were set with the upward oblique drain holes, which together formed a perfect drainage system.

6. Conclusions
Now the expressway has been opened to traffic, the landslide has been in a stable condition. It is verified that the survey and treatment scheme of landslide is effective and correct. As long as attention is paid to the design and construction of the expansive soil slope with similar conditions, various diseases can be prevented and reduced.

References
[1] Zi Min, Geng Dongqing. The application of high-density resistivity method in embankment seepage reconnaissance [J]. Geotechnical Engineering Technique, 2003, 17(5):272-275.
[2] Zhang Liangguo, Xu Yixian, Wang Yunan. Application of high density resistivity method in
Hu-Rong highway survey [J]. Geotechnical Engineering Technique, 2004, 18(4):187-190.

[3] Liu Faxiang, He Peng, Xiao Xunkai. Application of the multi-electrode resistivity method in geotechnical investigation for weathered rock site [J]. Geotechnical Engineering Technique, 2006, 20(5):225-228.

[4] Deng Jianhong, Li Wenbiao, Zhang Dingshan. Application of high density resistivity method in slope investigation for Highway [J]. Geotechnical Engineering Technique, 2008, 22(1): 27-30,35.

[5] Liao Shiwen. Expansive soil and railway engineering [M]. Beijing: China Railway Publishing House, 1984.