A FAILURE CASE STUDY ON REINFORCED SOIL SLOPE OF A 220KV SWITCHING STATION

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ABSTRACT

A switching station is planned to be built in Enshi City, Hubei Province, China. It locates in hill landform, and the elevation of the site is lower than that of surroundings. The site should be backfilled with surrounding soils. The embankment is of 4-16m in height, and is reinforced by TENSAR geogrid reinforcement. When the slope was backfilled about 8m in height, a series of sliding evidences was discovered at the northeast side of the slope, such as fissures, uplift, road damage and pinnate fissures. With the development of sliding, the dimensions of the landslide were 35m in width and 20m in length, the maximum horizontal displacement and vertical settlement were 2.5m and 1.5m, respectively. Through the stability calculation and field investigation, the designed slope is stable while the replaced gravel cushion was not set according to the design sketch during the construction, thus the reinforced soil slope slipped in push-sliding type. Besides, other failure causes were: (i) poor foundation, (ii) rainfall, (iii) bad drainage, (iv) no stepped excavation. Further geological survey and quantitative analysis reveal that the quick field judgment and stability analysis in this paper are reasonable. It is concluded that the soft soil improvement, drainage of surface and groundwater must be taken into great consideration, and carefully determined before the filling of reinforced soil slope.

Keywords: Reinforced soil slope, geogrid, failure, gravel cushion

INTRODUCTION

A switching station with a scale of 2 × 150MVA is planned to be built in Bajiao Village, Enshi City, Hubei Province, China. The site is approximately 550 kilometers west of Wuhan, the capital city of Hubei Province. The original ground surface of the site is fluctuating, with an elevation varying between 443-483m. The west part of the site is slightly higher than other parts. Trees, rice, tea and vegetables are planted within or around the original site.

The reinforced soil slope was designed with dimensions of approximately 230m × 280m; the shape of it was nearly rectangle. Its height varied between 4-16m, which largely depended on the condition of original ground surface. During the construction, a series of sliding evidences were found at the northeast side of the slope.

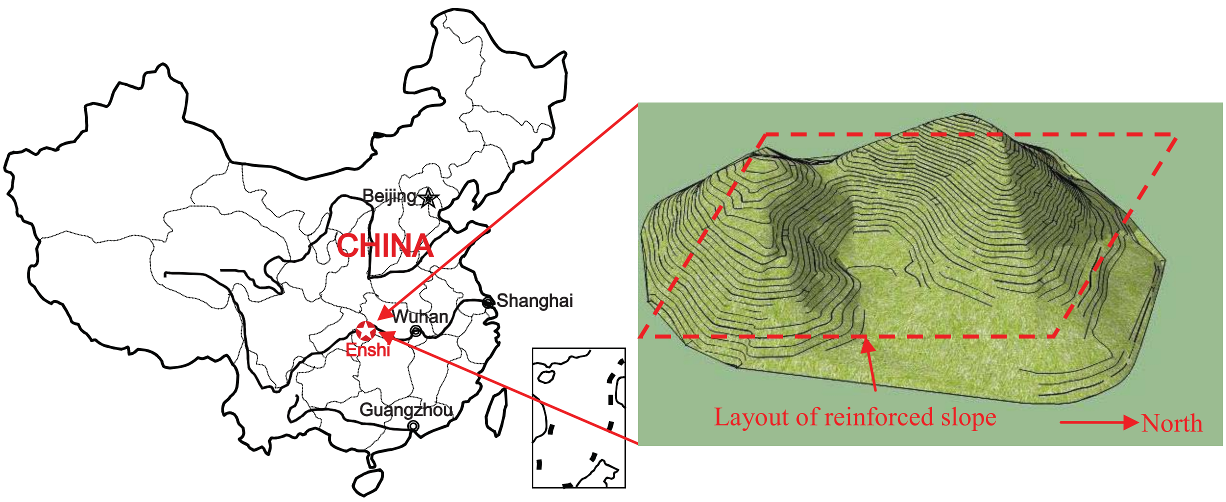

Fig. 1 Location and geography of the site.

Fig. 2 Panoramic view of the reinforced soil slope.

SITE GEOLOGICAL CONDITIONS

Lithology

Site of the switching station is situated in hill landform. Its elevation is lower than that of surroundings. According to the geological survey conducted by Hubei Electric Power Survey and Design Institute between July and August, 2009, the lithology of the site consists of artificial filled soil (Q_4^{ml}), alluvial-colluvial cohesive soil (Q_4^{al+dl}), eluvial- colluvial silt soil and silty clay(Q^{el+dl}). The bedrock is shaly sand of Cretaceous-Paleogene ($K\text{-}E_{d1;h1}$). Most part of the slope is seated in the gully area, which is of thick soil layer and the surface of the bedrock is undulant significantly.

Characteristics of lithology in this site are described as follows in accordance with the order from top to bottom.

Artificial filled soil (①): This layer is of reddish brown color, mainly consists of residual and strongly weathered shaly sand. It can be observed in the filling area of the site and reinforced soil slope region, with a thickness of 0.70-16.4m. The elevation of its top is 444.43-455.28m.

Silt (②-1): This layer is of black or dust color, flow plastic, spreads over the failure area of the slope. Its thickness is 0-3.6m; the elevation and the buried depth of its top are 442.85-445.41m and 0.75-7.05m, respectively.

Silty clay (②-2): This layer is of gray or black color, soft plastic, saturated. It can be found in the northwest and east part of the site. Its thickness is 0-3.5m; the elevation and the buried depth of its top are 441.96-446.63m and 0.7-8.6m, respectively.

Silty clay (②-3): This layer is of yellowish gray color, very wet and plastic. It can be observed along the original gully area, with a thickness of 0-4.65m and a buried depth of its top of 0.7-5.05m. The elevation of its top is 443.50-448.34m.

Silt soil (③): This layer is of brownish yellow or yellow color, slightly wet, and with plenty of silty clay and fine sand. It is a transitional layer between soil and bedrock, which spreads over the bottom of the original gully area. The thickness of this layer is 0-4.15m; the elevation and the buried depth of its top are 438.88-446.12m and 1.0-16.4m, respectively.

Shaly sand (④): This layer is of red or brick red color, strongly weathered, very weak. The elevation and the buried depth of its top are 438.06-445.14m and 3.1-17.0m, respectively.

A longitudinal section of the site, with a cutting direction perpendicular to the sliding direction, is shown in Fig. 3.

On the basis of field drilling, static cone penetration test and standard penetration test, Comprehensive geological parameters of each layer are illustrated in Table 1.

Groundwater Condition

Because of the filling work, runoff conditions of surface water and groundwater are changed. Coupled with rainfall infiltration and bad drainage of the slope body, the burial depth of groundwater level was 0.0-6.0m, which was higher than the initial site. Water was accumulated at the slope toe (Fig. 4).

Table 1 Comprehensive geological parameters of each layer.

No. of layers	Name of layer	Status	Unit weight (kN/m^3)	Shear strength		Compression modulus (MPa)	Characteristic value of bearing capacity (kPa)
				Cohesion (kPa)	Friction angle (°)		
①	Artificial filled soil	Loose- slightly dense	18.0	7	20	3.0	55
②-1	Silt	Flow plastic	16.5	10		2.4	40
②-2	Silty clay	Soft plastic	17.6	12	6	4.0	80
②-3	Silty clay	Plastic	18.0	15	8	5.1	100
③	Silt soil	Medium dense-dense	18.2	15	20	7.6	100
④	Shaly sand	strongly weathered	23.5	50	30	(45)	500

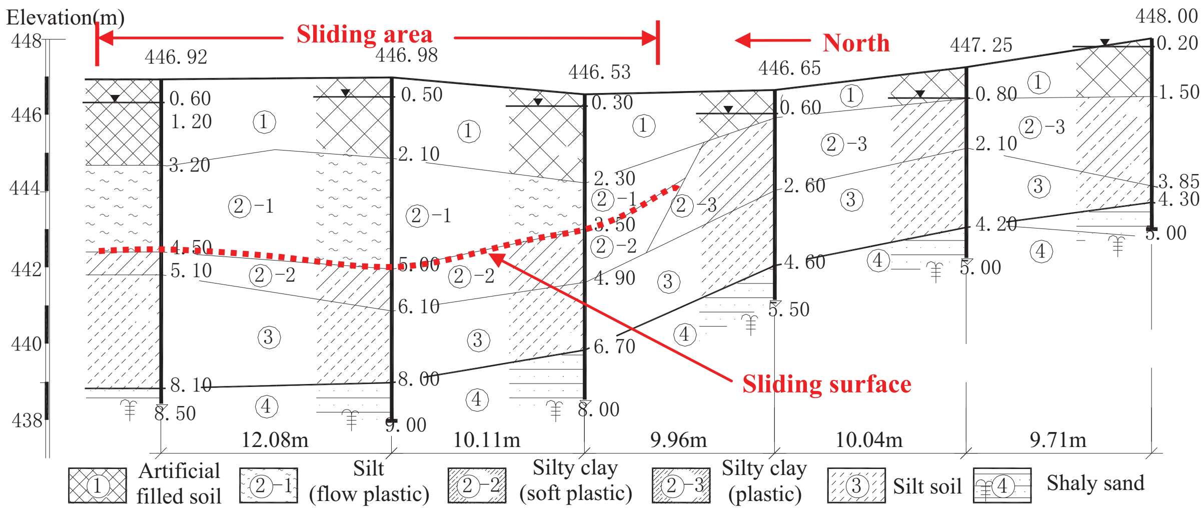

Fig. 3 Longitudinal section of the site.

Fig. 4 Water accumulation at the slope toe.

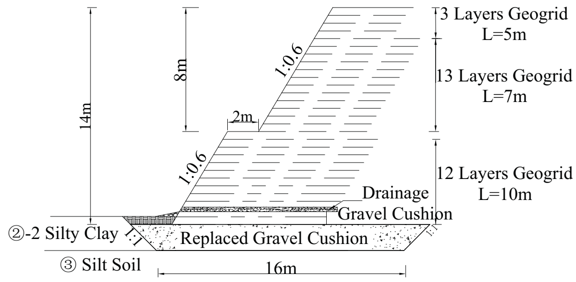

Fig. 5 Designed sketch of the reinforced slope.

DESIGNED REFORCED SOIL SLOPE AND STABILITY ANALYSIS

Designed Reinforced Soil Slope

According to the reinforced soil slope design (Mei et al., 2010), the switching station site should be backfilled with surrounding soils. The slope top should reach a ground elevation of 459.8m. The embankment is of 4-16m in height, and is reinforced by TENSAR geogrid reinforcement (Tensar, 1997). The slope ratio is 1:0.6, the tensile strength of geogrid is 70kN/m, laying length is 8-12m and laying spacing is 0.5m. Before the construction work, silt and soft-flow silty clay existed in the ground surface should be cleaned and replaced by gravelly cushion, to reach a high friction coefficient between the foundation and the slope body. Drainage cushion should be set at the bottom of the slope (Fig. 5).

The total length and area of the geogrid used in this project will be 489m and 108,060m^2, respectively. The entire volume of drainage cushion and replaced gravel cushion will be 1,168m^3 and 6,300m^3, respectively.

Stability Calculation

In order to analyze the stability of the original design, limit equilibrium methods, such as Bishop simplified method, Janbu simplified method, Spencer method and Morgenstern-Price method (Chen, 2003), are utilized to calculate the safety factor of the slope. The dimensions of the calculation model are 27m × 43m (Fig. 6). Material parameters of each layer are illustrated in the previous section. Software package Slide 6.0 (Rocscience, 2012) released by Rocscience Inc. and the Mohr-Coulomb strength criterion are employed in the calculation.

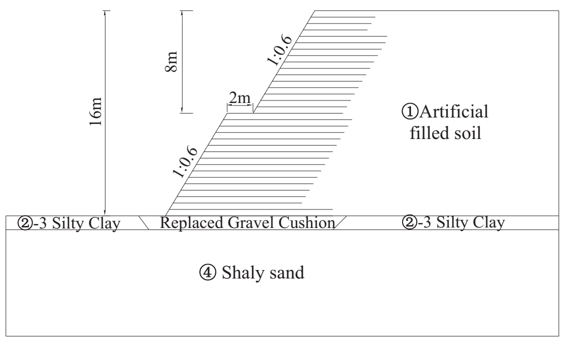

Fig. 6 Calculation model of the reinforced slope.

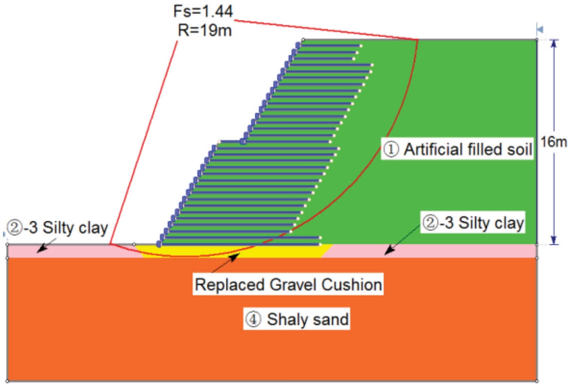

Fig. 7 Minimum safety factor of the external stability of the designed slope.

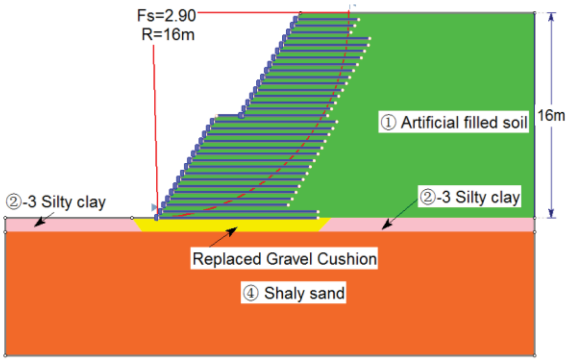

Fig. 8 Minimum safety factor of the internal stability of the designed slope.

Both of the external and internal stability of the designed reinforced soil slope are calculated using the Slide 6.0 package. According to the calculation, the minimum safety factors of the external and internal stability are 1.44 and 2.90, respectively (Figs. 7 and 8). The calculation results indicate that the designed slope, in terms of both the external and internal stability, is stable. And the internal stability is higher than the external stability.

FAILURE MECHANISM ANALYSIS

Failure Process

Construction of the reinforced soil slope started since May 15, 2009, and 75% of the backfilling was finished by July 26, 2009. When it was backfilled about 8m in height, in the morning of July 27, 2009, the workers found that a series of sliding evidence, such as fissures, initiated in the northeast corner of the slope. Then uplift, drainage ditch and road damage began to occur at the front and the toe of the slope. Pinnate fissures can be observed on the road and the slope berm (Figs. 10 and 11). On the basis of field judgment, the whole slope slid, while deformation and dilation did not appear within the geogrid-reinforced area of the slope.

Fig. 9 Failure sketch of the reinforced soil slope.

Fig. 10 Uplift and drainage ditch damage at the toe of the slope.

Fig. 11 Tension and pinnate fissures occurred at the berm of the slope.

Failure Model

As the sliding went on, fissures occurred at the rear of the slope, which formed a slide wall out of the reinforced region with a height of almost 2.5m. At the toe of the slope, because of the uplifting and tension fissures, a maximum horizontal displacement and vertical settlement of 2.5m and 1.5m, respectively, were developed. The dimensions of the landslide were 35m in width and 20m in length. The ground surface of the south part was higher than that of the north and west part. The sliding surface is along the boundary between the filling material and soft-plastic silty clay, partly cutting through the layer of flow-plastic silty clay or silt. The dip angle of the sliding surface is slightly bigger than the angle of the original ground surface. The horizontal thrust increases as the height of the slope goes up. Since the sliding source is at the rear of slope, this sliding could be classified as push-sliding type (Li et al., 2008) (Fig. 12).

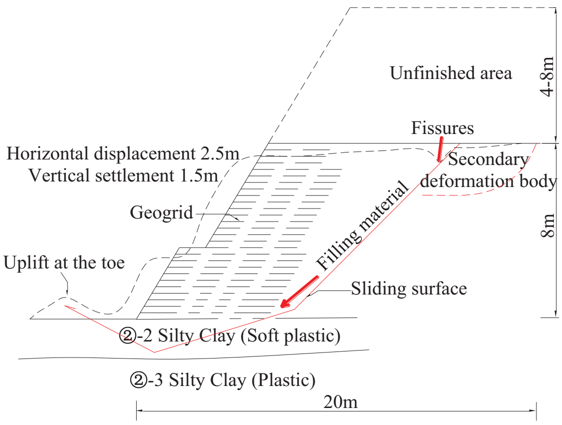

Fig. 12 Failure model of the reinforced soil slope.

Calculation of the Stability

In order to work out the exact causes of the sliding, Slide 6.0 package (Rocscience, 2012) is used again to calculate the safety factor of the failure model. The dimensions of the model are 14m in height and 30m in width (Fig. 13). Because the replaced gravel cushion was not set according to the design sketch during the construction, it is removed and replaced by silty clay (②-2) in this calculation.

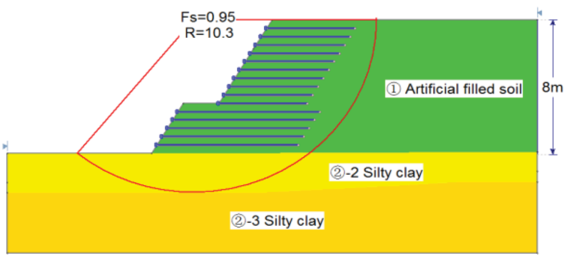

Fig. 13 Minimum safety factor of the external stability of the slope without gravel cushion.

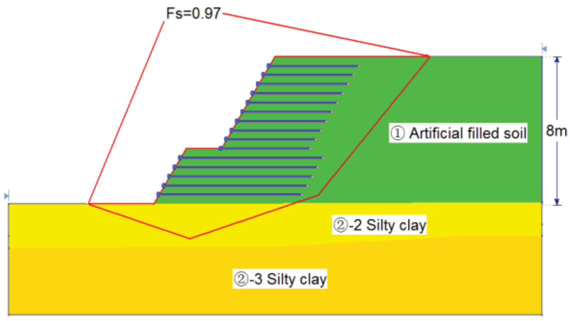

Fig. 14 Safety factor of the sliding surface in the failure model.

Because of the removing of the replaced gravel cushion, safety factor of the external stability is decreased to 0.95 from 1.44 (Fig. 13). The entire slope slides along the layer of silty clay (②-2), which clearly demonstrates one of the main causes of the sliding. Besides, safety factor of the sliding surface in the failure model (Fig. 12), which is 0.97, is also calculated and shown in Fig. 14. This also thoroughly indicates that the construction of the reinforced soil slope is unstable. All these calculation results agree with the judgment of the previous section. While in terms of the internal stability of the slope, it is the same as the previous calculation, because no element is changed within the geogrid-reinforced area of the slope when compared with the previous calculation model.

Failure Cause Analysis

The integrity of the reinforced soil slope is greater than that of the non-reinforced area (GAO and Bathurst, 2007). In terms of this reinforced soil slope, the internal stability is satisfied, while the whole slope is unstable. Besides, the geogrid-reinforced area is situated in the outside part of the slope; all these elements place a premium on the movement of the whole slope rather than only the geogrid-reinforced area of it (Jie et al., 2012).

From the analysis above as well as the field judgment, failure causes of this slope are illustrated as follows: (i) poor foundation, the surface soil, which is soft silty clay with high water content and low bearing capacity, was not cleared away before soil filled, and the layer of replaced gravel cushion was not set according to the design sketch during the construction; (ii) rainfall, water is considered as the key cause factor; (iii) bad drainage, the earthwork was filled in a low place, drainage cushions were not installed in the foundation, surface water was easy to accumulate and hard to drain, and many water outlets in the slope foundation could be found; (iv) no stepped excavation, the initial ground surface dipped to northeast, i.e. the sliding direction. Stepped excavation or anti-skating measure was not taken in the slope foundation. All these contributing factors mainly lead to the sliding of the slope.

CONCLUSIONS

From the geological condition analysis, engineering characteristics of the site, as well as the failure analysis, the integrity of the reinforced soil slope is greater than that of the non-reinforced area, which can meet the basic geological and engineering requirement. In addition, a large majority of successful cases within or outside China indicate that employing geogrid-reinforced soil slope to fill a slope with a height of 12-16m is reasonable (Xu and Ochiai, 1995; Xu et al., 2004). Therefore, utilizing reinforced soil slope as a measure of ground treatment in this site is proved to be feasible.

While during the construction, the gravel cushion was not set according to the design sketch, which leads to the safety factor of the designed slope dropping dramatically. In addition, because of the filling work of the reinforced soil slope, runoff conditions of surface water and groundwater are changed. Coupled with rainfall infiltration and bad drainage of the reinforced soil slope body, the burial depth of groundwater level was 0.0-6.0m, which was higher than the initial site. Moreover, poor foundation condition, without stepped excavation and neglect of the drainage cushion also play a vital role of the slope failure.

Further supplementary geological survey and quantitative analysis reveal that the quick field judgment and the analysis in this paper are correct. From the failure case study, it is concluded that the soft soil improvement, drainage of surface and groundwater, and friction coefficient of the interface between soil and geogrid must be taken into great consideration, and carefully determined before the filling work of reinforced soil slope.

REFERENCES

Chen, Z., (2003). Soil slope stability analysis : principle , method , procedures. China Water Power Press, Beijing, 87–119 (in Chinese).

GAO, W. and Bathurst, R.J., (2007). Stability analysis of reinforced slope loaded by a strip footing. Chinese Journal of Rock Mechanics and Engineering, 26(2): 374-380 (in Chinese).

Jie, Y. et al., (2012). Stability of high reinforced soil slopes. Chinese Journal of Geotechnical Engineering, 34(4): 660-666.

Li, H. et al., (2008). Stability study of a fill slope at 220kV Yanjin substation. Rock and Soil Mechanics, 29(12): 3459-3465 (in Chinese).

Mei, T., Wang, Y. and Wang, X., (2010). Instability analysis on reinforced slope of BaJiao 220kV substation. Geotechnical Investigation and Surveying, (S1): 501-508 (in Chinese).

Rocscience, (2012). Slide 6.0, Toronto, pp. http://www.rocscience.com/products/8/Slide.

Tensar, (1997). The design of reinforcement soil structure using Tensar Geogrids.

Xu, G. and Ochiai, H., (1995). Estimation of resistance of pullout test by geogrids. Memoirs of the Faculty of Engineering, Kyushu University(55(4)): 443-452.

Xu, G., Liu, F. and Tang, H., (2004). Modern reinforced soil technology and its engineering application. China University of Geosciences Press, China, 17-21 (in Chinese).