Interaction between countermeasure works and landsliding mass: a case study

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Abstract

In this paper, we present differing filed monitoring data obtained from a landslide located near an airport in southwest China. This landslide originates from a dip slope with weak bed rocks and high earth fill. To stabilize this landslide, differing function structures had been constructed, and the deformation/displacement features of these structures had then been monitored and analyzed. We analyzed the possible stress state of these function structures during their construction, and examined the most unprofitable stress state that may result in large deformation of the structures. The relationship between the stress state and large deformation of these structures, as well as their relationship to the stability of slope, were analyzed. These results may not only provide good experience for us to perform countermeasures in stabilizing landslides in similar geoenvironment, but also can provide scientific evidences for us to better understand deformation or sliding mechanisms of similar landslides.

Keywords: Landslide movement, deformation of function structure, interaction, landslide stability, large deformation

1. Project Introduction

A certain airport located on the gently-inclined dip-slope regionally in the poor geoenvironment was built in May 2000 in southwest China and the most extreme height of high embankment near west runway goes up to 128m. So there has been sliding and settlement deformation in existence.

The No.12 landslide slid massively and integrally above the fossil landslide named Yushuping, which as the reason triggered it revival. As such, the landslide preventions especially flood preventative engineering was implemented from September 2009 to May 2010, which involved the anchor bolt frames, the steel pipe piles, shot-crete support and so on. But the slope remained sliding after the preventions had been implemented. Then the second emergency project were put out based on the original preventions on the trailing edge of the landslide, which arranged the anchor podiums, the anchor foundation beams and cluster steel pipe piles with prestressed anchor-cables in order to restraint the large deformation in the landslide and keep it steady temporarily(Liu et al., 2004). Only in this way can it be safe to continue constructing the most significant prestressed anchor-cable anti -slide piles on the slope toe.

2. Geological Summary

2.1 Geomorphology

Overall this field region is located in mountain ravines to landscape of Zhongshan whose terrain is ups and downs aslant from northwest to southeast. the airport where is situated on south slope of the ribbon mountain ridge where the strike trends to NE21° and approaches the south bank beside Jinsha river, branch of Yangzi river. There has a high earth fill left behind it with a height of about 128m and a average slope of 21° approximately.

The landslide area which lies east of the runway pertains to the mountain landscape with erosion landform. The topography of the landslide is complex and the average slope is 15-20° probably. Meanwhile, gullies of the landslide body develop entirely with spreading numerous ponds. Figure 1 is a photograph of the airport landslide profile(He et al., 2002).

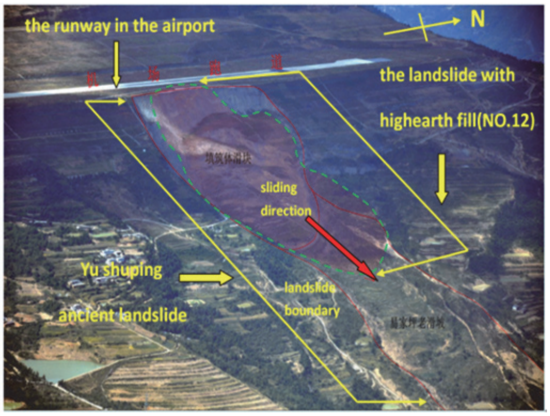

Fig. 1 the complete picture in landslide area

2.2 Stratigraphical lithology

The whole area of the landslide is underlain by Quaternary(Q4) and Jurassic(J3Y) Yimen formation. The Q4 stratum includes artificial fill, cumulative material and residual material, which are composed of gravel soil with massive rock. All of them mainly distribute fill section and posterior of the landslide. The massive rock content with a width of about 8-45m is high in artificial fill. Simultaneously, the cumulative material and residual material consist of gravel soil primarily with a width of about 15m-30m with fabricable status and water permeability. The Jurassic stratum for Yimen formation is based on carbonaceous mudstone and sandstone. One side, carbonaceous mudstone reflects moderate weathering even strong weathering and the moderate weathering component is argillic texture with weak anti-efflorescence and being apt to crumble and soften. The other side, the thick stratified sandstone reflects slight weathering in which argillaceous cement exists. The two inter banding stratum form together the foundation of the fill and the main body of the ancient dip bedding landslide as well. The condition illustrated in Figure 2.

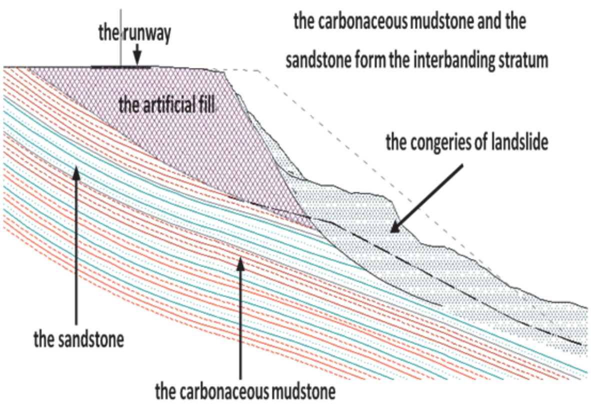

Fig. 2 the Stratigraphical lithology in landslide area

2.3 Tectonics Profile

In view of regional tectonics, the filed area is located on the south section of Panxi rift valley where the middle of the north-south structural zone in Chuan-Dian and "歹" shaped structural zone in Dian-Zang intersect. In general, tectonic situation such as fold and fracture develops complicatedly mainly based on the N-S and the E-W tectonic condition and the E-W and the N-W tectonic condition take second place.

The landslide area is based on syncline structure whose axial direction is from N-W to S-E crossing the center point of the runway nearby. The occurrence shows 130-140°∠12-14°, as shown in Figure 3.

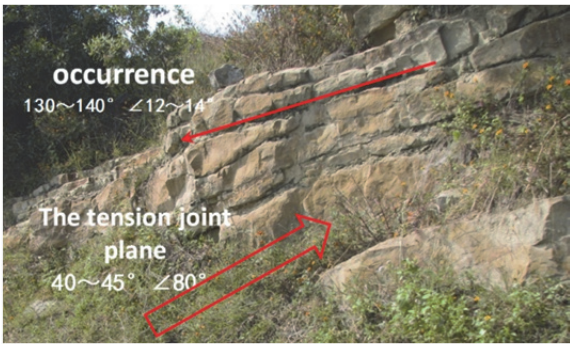

Fig. 3 the sketch map about occurrence

2.4 Meteorological and Hydrogeology

The climate of this area is tropical-DHV, which performs long summer period, strong solar radiation and undifferentiated seasons all year round. Rainfall happens in the rainy season during May to October. The largest annual rainfall is about 1000 mm and the average is about 800 mm, 95% of the whole year. On the contrary, the period from early November to May the following year is the dry season. The rainfall distribution is in the Figure 4.

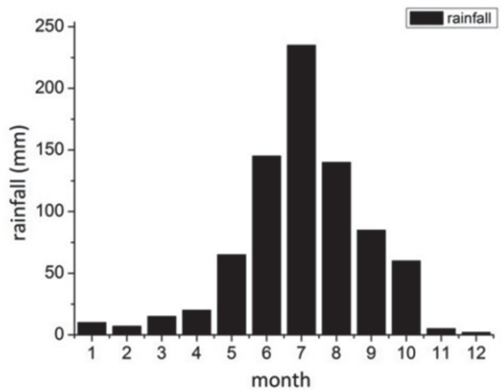

Fig. 4 average rainfall distribution in landslide area(2005-2009)

The ground water of the landslide is subjected greatly to the season and gives priority to the perception recharge but no unified underground water level. On one side, both sides of the platform near runway accepts atmospheric perception and converses it into the pore water in the fill. On the other side, the fissure water from the western sandstone recharges the groundwater from west to east alone the stratigraphical occurrence. Meanwhile, the carbonaceous mudstone and the argillaceous shale act as the relative impermeable layer.

3. Landslide (No. 12) Mechanism and stabilizing structures

The established procedure for NO. 12 landslide continues almost 2 years.

Rainy season in 2010, some deformation was detected on the fill with a height of 30m of the crown in the No.12 landslide, which may lead to large scale sliding endangering the runway . So it is essential to take measure for emergency projects(Liu et al.,2012).

April in 2011, the emergency engineering had been accomplished. So the airport succeeded in navigating. But the stabilizing structure on anti-slide piles were not executed before the rainy season in 2011.

15th July in 2011, large sliding occurred for numerous rainfall. Even though, some finished projects were ineffective.

The slide scope about No.12 landslide is similar to Yushuping landslide generally. The back scrap dislocates down about 40m with tractive cracks approaching near the runway. The volume of the landslide is totally about $320\times10^4m^3$ with a length of about 540m and a width of about 350m. Boreholes indicate the thickness of the landslide is between20m and 30m, even the deepest point reaches 35m. The furthest distance is 45m. All the information reveals the No.12 landslide proves to be a extreme large scale landslide. The failure condition as seen in Figure 5.

Fig. 5 The failure condition of the anchor cable frames

3.1 Formative mechanism

No.12 landslide is a accumulation landslide with highearth fill sliding alone the top of bedrock under. Main sliding zone is the surface where the bottom side of the fill and residual layer of the sandstone and mudstone intersect. So the reasons for sliding as follows:

1. Yushuping ancient landslide which had slid once is the basis of No. 12 landslide but sustains always creeping slip. As such, sliding weakens sliding resistance effected on the toe of the highearth fill.

2. The lack of recognition to unfavorable geological condition especially ancient landslide leaded to choose unreasonable airport position. Generally , it is unsuited to load on such a fill here particularly with a depth of about 60m-120m. Furthermore, original retaining structures and shear keys did not meet the requirement for stabilizing the highearth fill insufficiently.

3. The infill in such a highearth fill(60m-80m) spreads uneven with inferior gradation and substandard degree of compaction, which leads soil mass to be loose and pores to be dense. It is convenient to furnish channels for underground water filtrating. Moreover, the settlement and deformation makes the soil mass slake above the free-draining face, which produces many strain cracks and applies channels for superficial water infiltrating.

4. The climate of tropical-HDV arouses rainfall heavily and centrally here. So the slope area owns a large collecting area and then rain filtrates into the interface between the fill and bedrock to tenderize carbonaceous mudstone, which afterwards forms sliding zone. In addition, underground water line rises in the slope rapidly and provides hydrostatic pressure to reduce the stability of the slope. As show in Figure 6 is about the underground water variable condition of detecting hole.

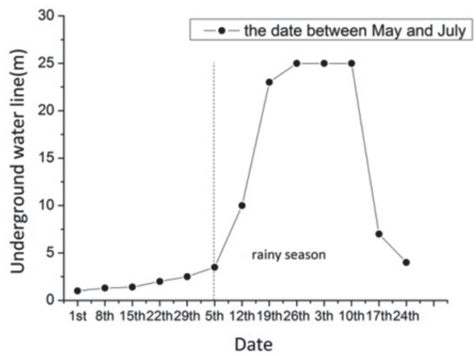

Fig.6 the underground water variable condition in detecting hole SJK 0

3.2 Landslide Stabilizing Engineering

Landslide Controlling Engineering mainly includes support engineering and drainage engineering. The specific measures are as follows:

3.2.1 Support engineering

The landslide sliding force is mainly the force caused by its own weight and the fill. As the landslide is large scale and the thrust is huge, the replacement and sliding belt destruction method was used To improve the stability of the landslide, with double-row prestressed anchored anti-slide pile sin order to reduce the fill amount and the landslide thrust, the reinforced soil was used after 85m of soil surfaced area was left for traffic circulation. The scheme for reducing landslide thrust is shown in Figure 7(failure mode), and the one with the largest decrease was chosen.

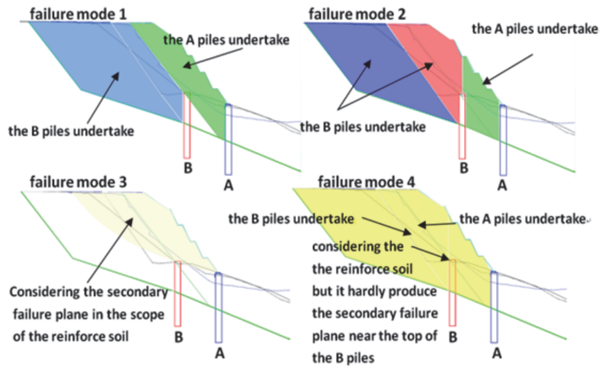

Fig.7 the tropical failure mode of NO.12 landslide

In particular, stabilizing structure is composed of double-row prestressed anchored anti-slide piles and prestressed anchored frame. In the front of supporting structure is D pile, and at the back is A pile. A pile is 2.8m × 3.8m in section size(Cao and Zhou, 2005), and has 6 prestressed anchors which are in a double row layout; D pile is 3.0m × 4.0m in section size, and has 5-row prestressed anchors; 3-row prestressed anchor cable frame beam(Xiao et al., 2014) is built outside fifth stage (from top to bottom) fill. Five-level reinforced soil is used when filling. Support engineering of landslide is shown in Figure 8.

3.2.2 Drainage engineering

It can be seen from the above analysis that surface water and groundwater in landslide area have significant effect on the stability of the landslide and that drainage of groundwater is the key to the successful landslide controlling. A drainage tunnel with a length of 1.6km was excavated on the west side of the airport to stop bedrock fissure water from penetrating into the landslide through sandstone and fissure. The water is directly discharged to the north side of the airport slope; the pore water between rolling soil and bedrock surface was discharged through the drainage tunnel as well. Where landslide belt was replaced, stepwise bottom was excavated, and a block stone with thickness of not less than 2m was put, which not only increase friction resistance at the bottom, but also serves as the drainage passage discharging the groundwater in sliding belt.

Surface water is one of the main supplying sources of groundwater. Therefore, it should be discharged from landslide when waterproof work is done in the soil surfaced area. Drainage engineering of landslide is shown in Figure 9.

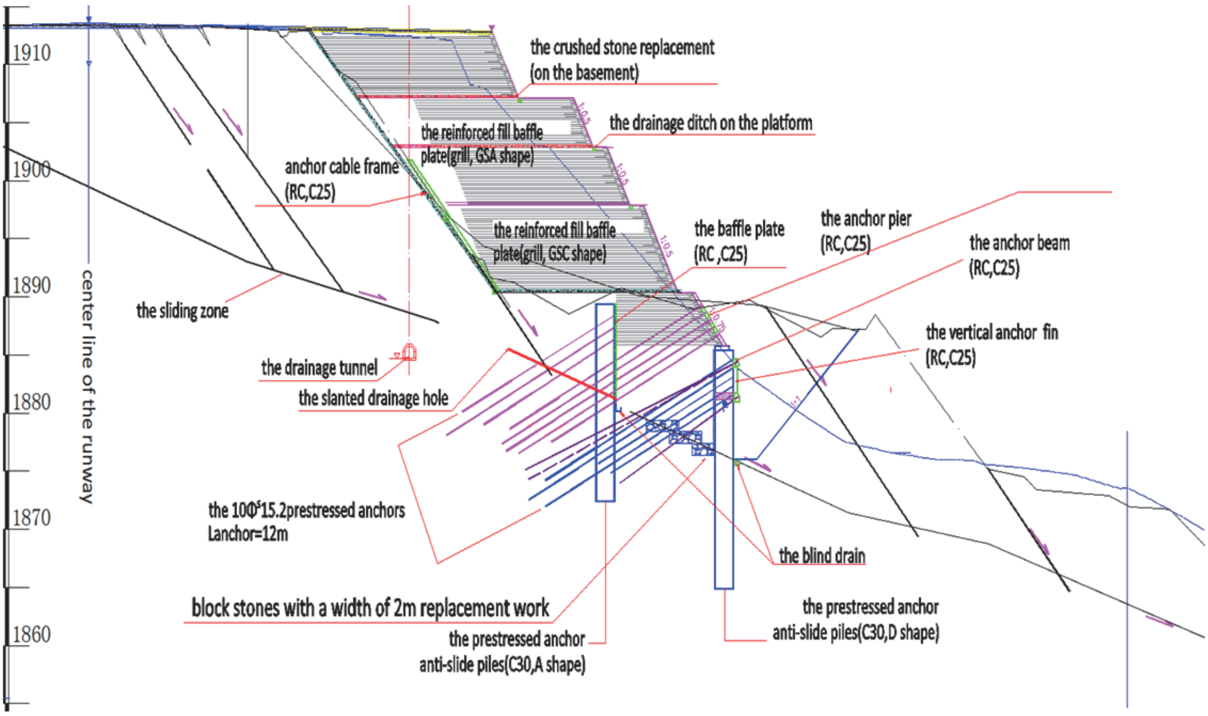

Fig.8 the sectional drawing for stabilizing structures

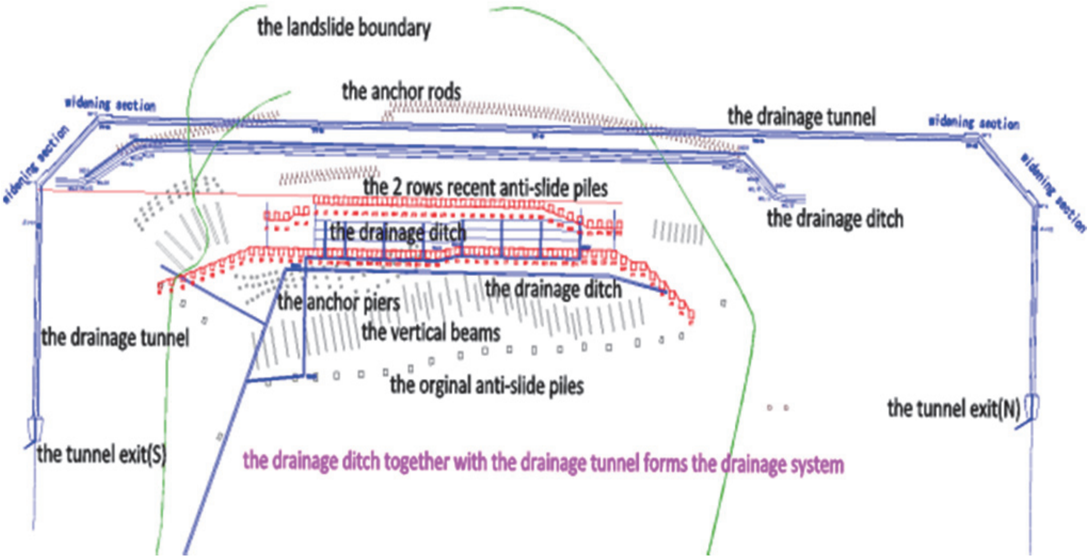

Fig.9 the drainage engineering system

4. Problems of the controlling

Engineering and the solutions Process sequence and construction quality are key factors influencing landslide controlling engineering. In the controlling process of this landslide, large deformation occurred to anti-slide piles and filling was stopped. The experts first suspected that there were design errors, but it turned out that it was caused by construction quality and process sequence. Reinforcement was performed and landslide was successfully controlled.

4.1 Large displacement of anchor anti-slide pile

The settlement of fill causes large secondary force for anchor. Tension is reserved when tension technique is applied, in case damage occurs to anchor due to large force. The construction company did not obtain the tension technique. As a result, the tension measured is far less than that designed. According to the design, anchor frame beam of the upper slope was 400 KN in tension, the back pile beam was 800 KN and the front pile beam 700 KN. The front pile beam measured was 250 KN in tension and frame beam 180 KN. As a result, large deformation of pile occurred. The displacement was far more than the design requirements (2cm). In view of the above, filling was stopped. After tension technique was applied, force for anchor was still far from the designed force. The front pile was only 450kN, and the frame beam was 250kN. Prestressed anchor cable beam was added to each anti-slide pile in the front to avoid excessive displacement of pile.

4.2 Deformation of high and steep reinforced slope

In order to reduce fill load at the back of landslide, reinforced soil is used instead of a given embank slope (Tang et al., 2011)rate after 85m of soil surfaced area is left for traffic circulation. This method not only reduces the fill amount, reduces the earthwork quantity by about 1/2, and reduces the thrust of landslide, but also reduces the controlling engineering. But in the implementation process, due to traffic pressure, reinforced earth construction was not implemented according to the design requirements. As a result, each layer was with lager thickness, and the degree of compaction was far from enough (compaction degree is less than 85). Large displacement and settlement of slope was followed. The maximum horizontal displacement on the top of the slope was 520mm, the beam 268mm; the settlement on the top of the slope was 470mm, the beam 6mm; the maximum horizontal displacement on the top of the slope was 2070mm, the maximum settlement 2700mm. As force of anchor in reality was far from the designed one (as mentioned above), double-row prestressed anchor cable pier were set between beams, in order to prevent the overall damage caused by tension of fill imposed on beam. Two-year monitoring verified that this measure was reasonable.

4.3 Deformation of back anti-slide pile

After the completion of back anti-slide pile, slide belt was replaced between piles. As force of anchor in reality was far from the designed one, large displacement occurs to back anti-slide pile when plane was excavated 15m below the pile. To allow traffic circulation, excavation of slide belt was stopped. Instead, three blind ditches were excavated. It was believed that large deformation appeared later might be associated with the termination of the excavation.

4.4 water drainage blind ditch

The maximum drainage is 350m3/d for water drainage blind ditch (1.6km) on the east side of runway in the rainy season, and less than 10m3/d in dry season. This water drainage blind ditch is used to discharge water delivered from bedrock to landslide. The blind ditch landslide at the back of slope has not yet been completed. It is stress-tolerant and the maximum drainage is 32m3/d. Drainage of groundwater is one of the effective means to control the landslide.

5. Conclusions

With regard to the comprehensive controlling engineering of NO.12 landslide with highearth fill near the certain airport, there are many challenging problems of design, construction, monitoring and measurement. These problems are how to perform filling with $68\times10^4m^3$ for the ancient landslide body, how to maintain stability of up to 50 meters reinforced soil slope, how to select destruction mode, how to handle the huge landslide thrust, how to handle the deformation of anti-slide pile, and how to handle secondary stress occurred in anchor when filling. Problems mentioned above were handled well with the engineering experience, and this controlling project is a success in general. But these problems will be further studied based on theory and engineering practice, in order to provide guidance and reference for the similar engineering.

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