Seismic performances of highfill airports during the recent strong earthquakes in China

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Abstract. High-fill slope with gap-graded fillback material and impervious clay sublayer is the typical structure of airfield in mountainous area. The seismic response of such slopes under intense earthquake loadings is one of the major concerns in engineering practice. This paper presented seismic performances of three typical high-filled airports during the recent strong earthquakes in China, and the damage/failure mechanisms are discussed. The main finding of this study is that, although no direct airport fill failures were found during earthquakes, cracks formed in airfield by strong shaking could provide passages for rainfall, where preference flows develop gradually and will significantly soften fillback material and impervious clay sublayer, inducing slope failure. Numerical and physical modelling and mitigation techniques are of high priority. After earthquake, timely site investigation, monitoring and slope repairment are greatly needed to prevent destructive deformation during the rainy period.

1. Introduction

In the past decades, many airports are under construction in the western mountains areas of China with high earthquake intensity. Airports in mountainous areas play as key lifelines during earthquake. As most of these airports are constructed in mountain valleys with high fills up to several meters, the deformation and stability problems during and after earthquakes become dominant designing issues.

Airports in mountainous areas are characterized with high fill, gap-graded fillback materials and sandwiched profile under high earthquake intensity. Han (2010) explained the characteristics of highfill airports and important role of airport in earthquake resistance and disaster reduction[1]. Damage of some highfill airports has occurred in recent years. Many researchers systematically analysed the mechanism and treatment measures of the landslides in Panzhihua airport at Oct. 3, 2009[2-6]. The airport suffered from M6.1 earthquake at Aug. 30, 2008 and it is a typical failure case resulting from the combined causes of earthquake and rainfall. Some other highfill airports also suffered this kind of failure. Codes for seismic design have not cover the highfill airport, then the absence of detailed codes aggravates the earthquake disaster for the airports. Commonly, the pre-reinforcement was guided by numerical and physical modelling[7-12]. Database of foundation treatment for mountain airport in China was developed[13]. Engineering experience is also the major basis for engineering design[14].

The failure of mechanisms for highfill airports with gap-graded fillback materials and sandwiched profile should be noticed. This paper shows seismic performances of three typical engineering projects suffered from failure induced by combined causes of earthquake and rainfall and emphatically marked the combined failure mechanism. Some suggestions were given for seismic design of highfill airports.
2. Case study for Panzhihua Airport

2.1 General situation of site

Panzhihua city is located in the southwest of China along the middle and south of Panzhihua-Xichang valley. Panzhihua Airport is situated at southeast of Panzhihua city in the staggered mountainous region. The Panzhihua Airport was opened on 6 December 2003. The runway is 3.5km long and 0.7km wide. The elevation is 1,976 m above sea level. The number of excavation is over 58 million m³, and the number of fillback is up to 40 million m³. The depth of fillback is up to 123 m. The gradient of fillback material is 1:2, and the slope angle is 27°. Panzhihua Airport is one of the largest and most complex airports in China.

2.2 Engineering geological conditions

The stratum inclines from east to southeast with a slope angle 8°-18°. The bedrock content in the bottom is mudstone and interbedded carbonaceous mudstone and sandstone. Medium-thick siltstone lies in the middle of the bedrock and weathered carbonaceous mudstone with a thickness of 5m-15m at the top. Due to the numerous gullies, loose silty clay deposit with a thickness of 3 m -10 m developed here which causing geological hazards more frequently. The main component of the fillback materials is crushed limestone with silty clay. The diameter of limestone ranges from 5 cm to 50 cm, and the individual can reach 1.5 m (see Figure 1). This kind of hard bedrock-weak interlayer (silty clay)-hard fillback mudstone profile is called "sandwiched profile"[2, 7,12].

![Diagram of "Sandwich profile" for Panzhihua Airport](image)

2.3 Seismology and regional tectonic

Affected by the Yuanmou-Lvzhijiang fault, through the east of Panzhihua City, an MS 6.1 earthquake hit the junction of Renhe District of Panzhihua City and Huili County of Liangshan Prefecture (26.24° N, 101.89° E) on August 30, 2008. The epicenter was 10 km deep about 35 km away from Panzhihua Airport (26.54°N, 101.81°E) [11] In two days, aftershocks MS 5.6 and MS 4.9 occurred. The epicenter intensity reached VIII degree and the intensity at the airport intensity reached VI degree. The peak acceleration map refers to Figure 2 and the earthquake intensity distribution is shown in Figure 3. Earthquake induced initial damage of the airport. The fillback body suffered large deformation, and the settlement at shoulder of the slope reached 0.5 m [12]. There are many tiny cracks at the slope surface (see Figure 4). The applied shear stress approaches the shear strength of the silty clay layer, shear strain of the weak sublayer will develop considerably. Thus the weak layer between the bedrock and the overlaying fillback body developed a degree of initial yielding.
2.4 Earthquake and rainfall combined failure mechanism

Specialized monitors were assigned to measure the displacement of the ground\cite{3}. Since the cracks were repaired after the earthquake, the settlement and horizontal displacement creeped stably within an acceptable limit. When the rainy period arrived in June, the repaired cracks could not prevent the infiltration of rainfall, and the deformation increased dramatically. On September 27, 2009, after a heavy rain with a rainfall 42.8 mm, the cracks further developed and connected. Several days later, the landslide occurred suddenly on October 3 (see Figure 4). The relationship between rainfall and displacement is shown in Fig. 5. It can be seen that the settlement and displacement lag behind rainfall. The total rainfall is 51 mm from March to June. The average horizontal displacement is about 0.8 mm/d and the settlement of 0.9 mm/d. The repair is effective. In rainy period from July to August, the total rainfall reached 394 mm. The deformation increased dramatically with average horizontal displacement 3.9 mm/d and the settlement 2.3 mm/d. Driven by the heavy rainfall in September, the deformation velocity accelerated with a rate of 20 mm/d. Different deformation velocity in different regions induced landslide. It also can be indicated that the initial damage of earthquake provided the probability of rainfall-triggered instability. After the landslide, site investigation was performed. The pre-reinforced piles in the slope were found to be cut off near the sandwiched interlayer. The earthquake cracks provide passages for rainfall, and the pore water softened the impervious clay sublayer, leading to the fillback body sliding along the sandwiched interlayer. The mechanism of high fill airport failure is the combination of earthquake and rainfall.

Figure 4 Diagram of initial earthquake damage and final combined damage
Figure 5 Relationship between rainfall and deformation in 2009

3. Additional case studies

Another typical landslide case with "sandwiched profile" is Mianyang airport (32.2°N 101.2°E), which is the second largest airport in Sichuan Province. The airport was opened in April 2001. The site belongs to hilly topography. The runway is 2.4km long. The elevation is 519 m above sea level. The seismic fortification intensity is VI degree. The overlying soil layers are Quaternary artificial fill and gravel, the sandwiched sublayer is alluvial silty clay, and the underlying bedrock is silty mudstone[15]. The fillback material is mainly gravels and the depth of fillback is 28 m. As the record by Han (2010), some local cracks were found at southwest of the airport after 5.12 Wenchuan earthquake (Ms=8.0). The following heavy rain infiltrating along the cracks. The damage of drainage ditch aggravated the infiltration of surface water and resulted to the landslide afterwards. After the initial damage of earthquake, coupling of earthquake and rainfall induced the damage.

Guangyuan airport (32.4°N 105.7°E) is located at Sichuan Province, China. The airport was opened in September 2000. The elevation is 403 m above sea level. The runway is 2500 m long and 45 m wide. The fillback material is mainly sandstones and mudstones with a filling depth 38 m. The seismic fortification intensity is VII degree. After 5.12 Wenchuan earthquake, only some cracks were found, and the structure still stayed stable. While the following heavy rain infiltrated along the cracks, the earth pressure behind the retaining wall increased, resulting to local damage of the retaining wall (see Figure 6)[1]. Combined failure mechanism is a typical engineering practice. Deformation monitoring and repairment should be noticed to prevent secondary disasters in rainy season. Treatment of drainage systems is also an important issue.

Figure 6 Collapse of retaining wall in Guangyuan Airport (Han, 2010)

Kangding airport (30.1°N, 101.7°E) is the third highest elevation (4290 m) in the world. The maximum filling height is 50 m with fillback material boulders, the sandwiched sublayer is silt, and the bedrock material is granite[16]. It is also a representative of sandwiched profile. The seismic fortification intensity is IX degree. Kangding Earthquake (Ms=6.3) hit the airport on November 25, 2004 (see Figure 7). The airport is 16 km away from the epicenter. Some cracks were found at the
terminal, while the pavement and slope of the airport was still in good condition. Timely monitoring and reinforcement measures were carried out, no further damage was found until now.

4. Conclusions
Based on seismic performances of three typical highfill airports during the recent strong earthquakes in China, and the earthquake and rainfall combined failure mechanism were concluded. The initial damage by earthquake increased the probability of final failure in rainy seasons. Earthquakes usually attribute cracks which provide passages for the following rainfall. The preference flows develop gradually and will significantly soften fillback material and impervious clay sublayer. Highfill airport damage usually occur at rainy seasons after earthquake. Successful cases proved the effectiveness of timely site investigation, monitoring and maintenance, which should be paid more attention to prevent further deformation or even failure during the rainy period.

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