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Recent advances in high slope reinforcement in China: Case studies

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ABSTRACT

This paper reviews a number of engineering technologies and workmanships for addressing the challenging issues concerning possible landslides in large-scale slope reinforcement projects in China. It includes: (1) the multi-point anchored piles with a depth of 64 m in the Jietai Temple rehabilitation project, (2) soil nailing strengthened by driven pipe grouting technique covering an area of 530 m × 100 m (length × height) in the Xiluodu hydropower project, (3) the cantilever piles extending vertically from the slope toe to stabilize a 300 m high slope at the Xiaowan hydropower station, (4) a new and simple workmanship for building a pile with cross-sectional area of 20 m × 5 m in the Hongjiadu hydropower station, and (5) comprehensive reinforcement scheme proposed for excavation of a 530 m high slope in Jinping I hydropower station. These new technologies can provide valuable experiences for reinforcement of high slopes of similar projects in China and other regions and countries with similar geological conditions.

1. Introduction

Reinforcement of slope is a commonly used method to ensure the stability and safety of engineering slopes involved in mining, highway, railway and hydropower projects. The widely used slope reinforcement measures include drainage, cables, slope stabilizing piles, and soil works such as unloading at the slope crest and buttress at the toe (Duncan and Wright, 2005). As high cost in a reinforcement work can normally be reported, drainage is always considered to be the first choice due to its effectiveness in stabilizing slope associated with relatively low cost. Typical examples can be referred to as the giant Downie slide (Imrie et al., 1992). For large-scale slopes in civil and mining projects, some high-performance mechanical stabilizing approaches are basically considered, such as cables, soil nailing, and piles. General review on various technical problems related to ground anchorage can be found in Littlejohn (1992) and Barley and Windsor (2000). Retaining piles have been widely used for slope reinforcement in China, but their applications are limited in developed countries due to heavy manual work by labors in very crucial environments. Basically, construction of this kind of piles is roughly limited to 50 m in depth and a cross-sectional area of 4 m × 4 m approximately.

Some infrastructure projects in China involved in water resources, railway and highway engineering are large- to super large-scale, which are challenging problems in terms of landslides. In this circumstance, a number of new reinforcement technologies and workmanships mostly related to anchors and anti-sliding piles have been developed practically (Chen et al., 2005). These new technical methods have been marked as great advances in reinforcement of large-scale slopes. It is noticed that these new methods have been proposed for the reinforcement of different types of slopes associated with site scope of application. When conducting a slope reinforcement design, the following factors should be considered: (1) selection of reinforcement method corresponding to the failure mechanism of slopes; (2) layout of reinforcement measures in slopes

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Fig. 1. Landslide in Jietai Temple.

and practicability of construction technology used; (3) deformation and stability evaluations of reinforced slopes; and (4) monitoring and evaluation of reinforcement effects.

This paper presents those innovative reinforcement technologies used in five large-scale slope projects at present in China. After implementation of the reinforcement measures, the monitoring results indicate that the reinforced slopes are stable and safe. These new technologies provide valuable experiences for reinforcement of high slopes or landslides of similar projects.

2. Jietai Temple landslide: The deepest multi-point anchored stabilizing piles reinforcement

2.1. Outline

Jietai Temple was built in Kaihuang Administration in Sui Dynasty (A.D. 581) on the north foot of Ma'an Mountain in the west of Beijing, which has a history of over 1400 years. The Jietai Ordination Altar in the Temple, a national cultural relic, is the largest Buddhist Temple in China. It confers the highest commandment of Buddhism in history. The ridge of the mountain is 1200 m long from south to north and averagely 450 m wide from west to east. As a result of southward mining by 2 coal dykes at the depths of 122 m and 175 m in recent years, an opening was observed beneath the fourth level of the terrain. After a heavy rainfall on 20 July 2004, a penetrating fractured zone was formed in the temple yard on the ridge. Cracks were also observed in the yard of the temple, resulting in a rapid development of slope deformation, as shown in Fig. 1. Fig. 2 shows the damage of the buildings in Jietai Temple after landslide.

Investigation (Li and Yang, 2006) showed that there was a 230 m difference in elevation between the front and the tail borders of the landslide. The depth of the sliding surface was up to 47 m, and the total volume of the sliding mass was 9.2×10^6 m^3. Field investigation showed complicated geological conditions of the landslide. The major buildings in Jietai Temple are located on the landslide mass, which is in the tourist area heavily covered by plants. Therefore, massive earthwork construction was not suitable for the landslide reinforcement. In this case, slope stabilizing piles may be the first choice of available treatment measures. However, the depth of the sliding surface reaches over 40 m. To address this problem, a system of multi-point anchored slope stabilizing piles (Wang and Sun, 2007) was developed by Northwest Research Institute Co., Ltd., China Railway Engineering Corporation. In this system, the deepest pile reaches 64 m.

2.2. Reinforcement scheme

2.2.1. Multi-point anchored slope stabilizing piles

Fig. 3 shows the plan view of Jietai Temple landslide reinforcement scheme. For this project, the key in the reinforcement scheme using multi-point anchored slope stabilizing piles is the excavation of slope stabilizing piles with multiple anchors at different depths

(a) Cracked brick wall. (b) Hallowed ground.

(c) Leaned retaining wall. (d) Separated hallway.

Fig. 2. Damage in Jietai Temple after landslide.