Cutting slope reinforcement in reconstructed migrant cities in the Three Gorges Reservoir area of China

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Abstract: The Three Gorges project in Yangtze River is one of the biggest hydropower projects in the world. 20 counties and 277 towns are involved in the submerged area, 12 counties, 116 towns and 1629 enterprises have to be totally moved, and the total migration reaches 1.1056 million. This is a rare large-scale project in the history of the world. Up to now, 70% of emigrant people have been settled.

2760 high cutting slopes with total cutting area of 6.84 million m^2 have been formed during the reconstruction of the migrant cities; 39.76% of the slope area has been reinforced.

The author, commissioned by the state government, has conducted a program of the protection project for the remaining 1270 slopes. The slopes are classified into three categories and five sub-types in the programme, each with different kinds of deformation-failure modes. Six kinds of measures have been used for the reinforcement for different kinds of slopes including drainage, slope cutting, anchoring, cement jetting, retaining wall and anti-sliding-pile, etc. A series of photographs showing the slope deformation-failure modes and the slope reinforcement with different measures are illustrated.

Some defects such as un-effective drainage, irrational measures of reinforcement, etc. are pointed out from the previous works to caution and direct the project at the next stage.

Résumé: Les Trois Gorges projettent dans le fleuve de l'Yang Tsé Kiang est l'un des plus grands projets d'hydro-électricité dans le monde. 20 comtés et 277 villes sont impliqués dans le secteur submergé, 12 comtés, 116 villes et 1629 entreprises doivent être totalement déplacées, et toutes les extensions de migration 1.1056 million. C'est un projet à grande échelle rare dans l'histoire du monde. Jusqu'ici, des 70% de personnes d'émigrant ont été arrangés.

2760 pentes élevées de découpage avec l'aire totale de découpage de 6.84 millions de m2 ont été formées pendant la reconstruction des villes migratrices ; 39.76% du secteur de pente a été renforcés.

L'auteur, commissionné par le gouvernement d'état, a conduit un programme du projet de protection pour les 1270 pentes restantes. Les pentes sont classifiées dans trois catégories et cinq sous-types dans le programme, chacun avec différents genres de modes d'déformation-échec. Six genres de mesures ont été employés pour le renfort pour différents genres de pentes comprenant le drainage, le découpage de pente, ancrer, le nettoyage au jet de ciment, le mur et l'anti-glisser-pile de soutènement, etc. Une série de photographies montrant les modes d'déformation-échec de pente et le renfort de pente avec différentes mesures est illustrée.

Certains défauts tels que le drainage un-efficace, les mesures irrationnelles du renfort, etc. sont précisés des travaux précédents pour avertir et diriger le projet à la prochaine étape.

Keywords: Three Gorges Reservoir, emigrant cities, cutting slope, failure modes, reinforcement

INTRODUCTION

The Three Gorges hydropower station is the biggest hydropower project in the world. 20 county cities and 277 towns in provinces of Hubei and Chongqing are involved in the submerged area and 12 counties, 116 towns and 1629 enterprises have to be totally moved. The total migration population is 1.1056 million, 70% of whom have so far been resettled.

Because of the huge amount of migration and the reconstruction of the new county seats and towns, 2760 high cutting slopes with total cutting area of 6.84 million m^2 have been formed. The stability and safety of the slopes are the most restrictive factor for the decision for emigration and construction of resident buildings. For the reinforcement of the slopes, the state government has invested 401 million RMB for 214 of the slopes, and the local migrant departments have also carried out a series of engineering measures for the dangerous slopes. Totally about 39.76% in area of the slopes has been reinforced. For the safety estimation of the reinforced slopes and the protection of the remaining 1270 slopes, a state program has designed, and the authors conducted the program.

This paper is to briefly introduce the basic information of the program and some problems in its practice.

CLASSIFICATION OF THE CUTTING SLOPES

Geographical and geological background

The Three Gorges Reservoir stretches 574 km and the total length of the bank-line, including about 50 anabranches, reaches 5300 km. The reservoir covers an area of more than 1000 km^2 and submerges 600 km^2 of land area.

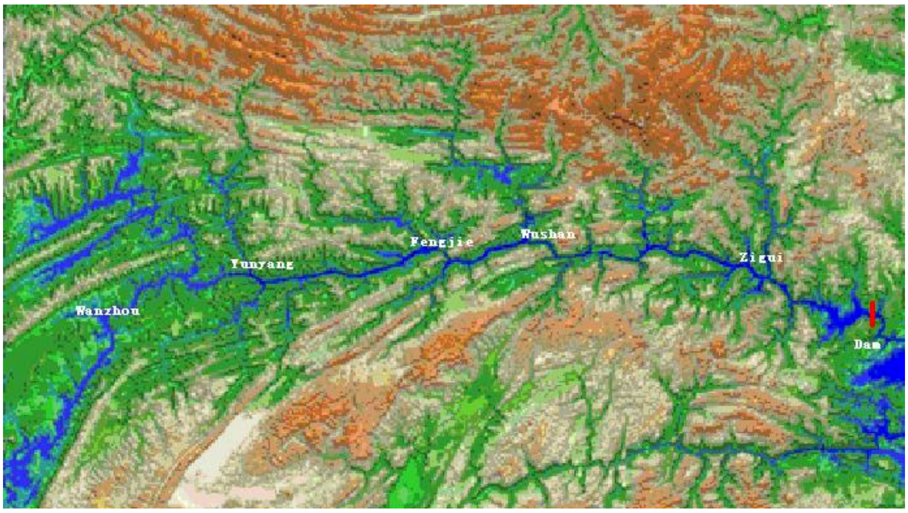

Figure 1. Digital elevation model of Three Gorges Reservoir area

The Three Gorges Dam is located on a huge rock mass of granite which is the core of the Huanglin Anticline. Upstream are mostly sediment strata from Pre-Cambrian through Jurassic including various sorts of sandstone, shale and carbonate formations. Thick limestone of Pre-Cambrian through Trias ages dominate in Zigui county but the Badong to Fengjie counties are dominated by soft sandy-clay and marls. From Yunyang upstream to Chongqing, mainly alternate layers of thick sandstone and shale occur. The properties of the strata are the most important factor for the stability of the cutting slopes.

At the head of the reservoir, i.e. the area near the dam, the Huanglin Anticline and Zigui Syncline and some faults occur. In the part from Badong to Fengjie county, a series of tight folds stretches at small angle with the river, and from Yunyang to Chongqing, alternately distributed with tight anticlines and wide synclines.

Over most of the reservoir, the essential seismic density is lower than VII degree.

The reservoir can be divided into two parts topographically. The eastern part, i.e., from the Dam to Fengjie, a deep-narrow valley area, and the western part, from Fengjie to Chongqing, with wide valley and gentle slope.

Rainfall in the area is concentrated in the period from May through September, and mainly .are strong rainstorms. Rainfall is an active factor for slope failure.

Geological classification of the slopes

Cutting slopes in the area are simply divided into 3 categories and 5 sub-types according to the media, structure of slopes, including 3 types of rock slope, one soil-rock slope and one soil slope (Table 1). Discontinuities or their intersecting lines inclining outwards slope are emphasized in the classification system for they may lead to slipping failure of slopes.

Slope heights are also limited for different medium types of slopes based on the experience in the past practice. A slope lower than the limit will not be financially supported by the state investment for slope reinforcement.

Table 1. Classification of cutting slopes

Category and sub-type		Media	Structure		Possible mode of failure
I	I_1	Layer or block	Height of slope≥15m	Block, with discontinuities	rockfall
	I_2			Layer with gentle angle inwards	rockfall
	I_3			With discontinuities or their intersect lines inclining outwards slope	slipping
II		Rock-soil	Height of slope≥10m	Soil at up part and rock at lower part	slipping within soil or along the interface between soil and rock
III		soil	Height of slope≥8m	Homogeneous	slipping

Failure modes of the slopes

Each type of slope may have some possible kinds of failure modes, and this will certainly affect the choice of measures for slope reinforcement (see Table 1).

For the slope with block-rock as thick layer sandstone or granite, or with inter-layers of sandstone and shale, the slope may fail by rockfall (Fig.2a, b). Differential weathering leads to grooves at soft clay layers, thus the blocks of sandstone over the grooves lose their support and fall down. This is a very common mode of slope failure in the area.

The most likely failure mode for the layer strata with suitable angle inclining outwards the slope is slipping. Fig.2c shows a typical failure phenomenon in Kaixian and Fengdu county.

For the slope with soil over rock, it may fail in the mode that slides within soil or along the interface between soil and rock. Figure 2e is the structure of this kind of slope in Wanzhou city.

And for soil slopes, sliding will be the possible failure mode. Figure 2f shows the fissures on an expensive soil slope in Jianfenglin new town, Wanzhou, induced by highway construction.

Besides, Figure 2d shows a special failure mode of marl slope. Unlike our experience, marl is much more corrosible and more easily weathered than pure limestone, and the course of corrosion and weathering takes place almost isochronously at the surface of rock block and within the block. This makes the structure of the rock mass weaken and loose simultaneously in a large range of the slope, thus failure of the slope in structural collapse is much easier to take place.

Figure 2. Failure modes for different types of slopes
(a) Rockfall of thick layers of sandstone in Wanzhou city;
(b) Rockfall of inter-layers of sandstone and clay caused by differential weathering;
(c) Slipping of layers along bedding surfaces in Kaixian county;
(d) Failure of marl by corrosion and weathering, Fengjie county;
(e) Failure of slope with soil at upper part and rock at lower part of the slope, Wanzhou city;
(f) Failure of soil slope in Wanzhou city induced by highway construction.

MAJOR MEASURES FOR REINFORCEMENT OF THE CUTTING SLOPES

Measures for reinforcement of the slopes are chosen including drainage, unloading by slope cutting, cement jetting, anchor or anchor with concrete lattice, retaining wall and anti-sliding-pile, etc.

Figure 3 shows four major measures used for slope reinforcement in new migrant cities in Three Gorges Reservoir area. Cement jetting with reinforcing meshwork (Fig 3a) is the most popular measure for rock slopes, especially for weathered or fissured rock slopes. Meshwork is designed as 200×200 or 300×300mm with a ф6-8mm steel bar.

An anchor is generally used for reinforcement of the slope of hard block rock, and an anchor with concrete lattice is often used for loose rock mass. This measure may be designed as "green slope protection project" (Fig.3b).

A retaining wall is mostly used for soil or soft rock slope. The wall may be constructed by concrete, reinforcing concrete, regular rock block, or irregular rock pieces (Fig.3c).

Table 2. Planned amount for different kinds of measures for slope protection

Province	Number	Slope area (m^2)	Amount for engineering treatment				
			Slope cutting (m^3)	Anchor & cement jetting (m^2)	Anchor with concrete lattice (m^2)	Retaining wall (m^3)	Anti-sliding -pile (m^3)
Chongqing	1031	3067440	1043238	1362145	631805	974951	46214
Hubei	239	1050894	547874	553072	76039	320018	35700
Sum	1270	4118334	1591112	1915217	707844	1294969	81914

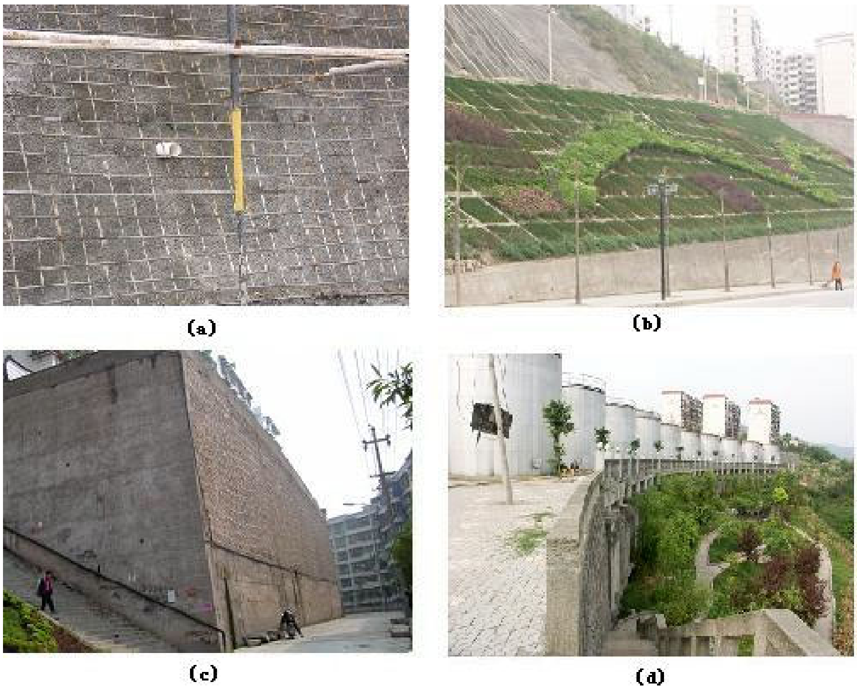

Figure 3. Major engineering measures for slope reinforcement
(a) Cement jetting with reinforcing meshwork;
(b) Anchor with concrete lattice in Wushan county;
(c) Retaining wall in Fengjie county;
(d) Anti-sliding-pile with baffle boards in Wanzhou city.

An anti-sliding-pile is also used in the area. However, because of the limit of cost and efficacy on deformation controlling, it is not a recommended method. It is often designed as a complex measure with baffle boards (Fig.3d).

Table 2 lists the planned amount for different kinds of measures for slope protection in the program, where Hubei province includes 4 counties in the head part of the reservoir and Chongqing covers 15 counties in the upstream part of the reservoir.

SOME PROBLEMS IN THE PAST PRACTICE OF SLOPE PROTECTION

Before 2002, most slope protection projects were not conducted by the state government. As a result of lack of planning, technical control and strict management, there have been some problems in the past practice of slope reinforcement.

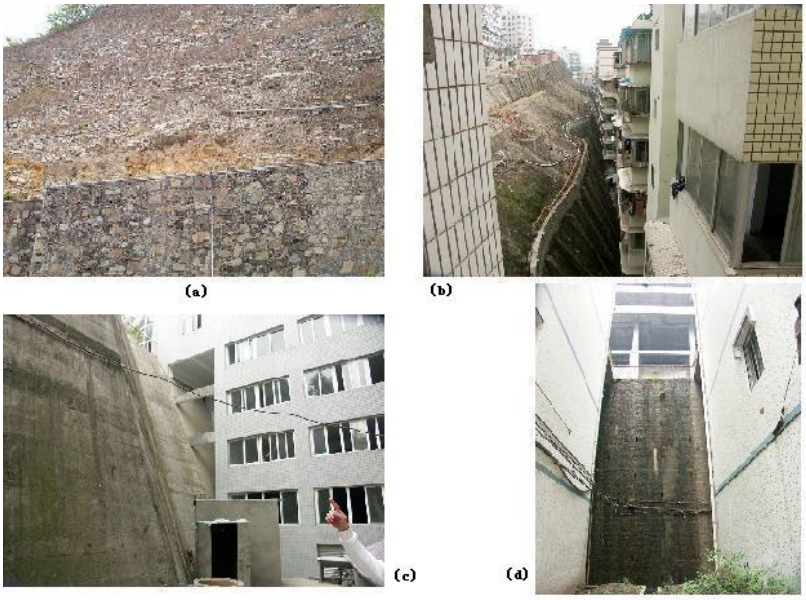

Figure 4. Problems in slope reinforcement
(a) The retaining wall is not high enough;
(b) Slope protection works are built too close to the buildings;
(c) Building is rigidly connected to the retaining wall with concrete bridge;
(d) The drainage pores fail to work.

Figure 4a shows that the retaining wall is not high enough to keep the detritus from moving down over the top of the wall. Many slopes have these problems and rock blocks fall down frequently, hitting people, buildings and vehicles, and blocking drain works.

Some retaining walls and slope protection works are built very close to the buildings as shown in Figure 3b, where it is only about 1~2 m spacing but more than 10 m high. Another case is that the building is rigidly connected to the retaining wall with concrete bridge (Figure 4.c). Any little displacement of the wall will induce deformation of the building.

Another problem is that the drainage pores fail to work. For a number of slopes, drainage pores in retaining walls have been plugged up, and groundwater overflows from the top of the wall (Figure 4c). This, as is well known, may lead to a remarkable increase of water pressure behind the retaining wall.

SUMMARY

About 2760 cutting slopes have been formed in Three Gorges Reservoir area due to the reconstruction of new migrant cities, and 1270 slopes have not been treated. A programme to reinforce the slopes has been conducted by the state government. A lot of measures have been and are to be used to reinforce the slopes including drainage, cutting, anchoring, cement jetting, retaining wall and anti-sliding-pile. Some problems from the past practice are discussed such as ineffective drainage, irrational reinforcement measures, and this will be helpful for the work in the next stage.

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