Case study of using complex reinforced structure to repair mountain road landslide in Taiwan

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ABSTRACT

The uses of complex reinforced structure technology have been increasing rapidly for the past decade in Taiwan. In this paper, there are two cases of repairing projects after natural disasters as the examples. Using them in combination with other relevant geosynthetic material such as pile, RC wall, anchor and so on, becomes complex reinforced retaining structures and increases the security. This paper is to present the damage cases of some Taiwan mountain roads and the restoration work, and to provide relevant case analysis, design information for reference.

Key words: reinforced structure, slope,

Introduction：

Taiwan is located in subtropical monsoon climate zone and on the circum-Pacific seismic belt. Its geographic position is unique. Natural disasters occur frequently. Due to its young, complex and fragile geology, bad cementation of the rock formation and steep slope terrain, the disasters such as landslides, debris etc. happen easily. In addition, the improper exploitation in the mountain areas these years has resulted in serious damage to mountain roads because of the heavy rain during the typhoon season. The collapses and traffic disruption affect people's lives and property safety. Prompt repair after disasters and the prevention from the failure reoccurrence are what all the engineers continuously work toward. Security is the main concern for repairing slope failure. However, there are several types of repair methods in accordance with the destruction. Reinforced retaining structure is one of the methods. Generally known as reinforced retaining structure in accordance with its surface can be divided into types of wrapped reinforced retaining wall, landscaped soil retaining wall, pre-cast panel reinforced retaining wall and steel mesh reinforced retaining wall. In certain special geological conditions, reinforced retaining structure requires to use different methods to repair the slope such as the concrete walls, piles, anchors, soil nails, etc. It is the so-called complex reinforced structures, that is, using different methods to combine the advantages and procesed the rehabilitation works. By analyzing the design, compared to the traditional method, it can provide better stability and consistent with ecological work to the structure. This paper is to present the damage cases of some Taiwan mountain roads and the restoration work, and to provide relevant case analysis, design information for reference.

Case description

Case one

1. Project Summary ：

It is for Baoshan township in Hsinchu County, the down slope of a road. It was collapsed after Typhoon Nari swept and was repaired by reinforced structure in 2001. In 2004, it was completely disrupted during a typhoon caused by continuous torrential rain. The scope of destruction was about 70m wide, 10m long and 19m deep. The collapses dropped to the adjacent valley about 50m in depth. The collapsed interface was steep, and looked like planar sliding damage (Figure 1). The main reasons of the damage can be divided into natural factors and human factors. The natural factors were due to the successive heavy rainfall of up to 200mm/day. A large number of water infiltrated into the structure and stayed in it causing the soil shear strength greatly reduced. The human factors were, judged by the observation of the scene, the reinforced material were placed only 0.5 to 0.6H. The above factors were the main cause of the damage.

2. Geology Survey :

According to the exposed surface, the geological condition in this case can be obviously observed that the stratigraphic distribution from the top to down was roughly divided into : (1) Topsoil layer: yellow brown silty sand and with a trace of clay, SM soil classification to a thickness of about 3 ~ 5m; (2) Rock layer : a highly weathered brown yellow sandstone, content of plant fossil, small particles, bad cement, poor bedding and joints or developed, the thickness of about 10 ~ 15m. The layers in the depth of about 10m and 15m respectively nearly parallel, about 10 to 60cm thick gray brown mudstone, the position about N70°E/15°NW and crossed with the bare structure (Figure 2).

Figure 1. Steep collapsed interface like planar sliding damage

Figure 2. Geology structure of exposed collapsed interface

In this case, a serious threat to the safety of the local traffic occurred. So the repair plan aimed at re-building the roads and restoring the transportation. The ideal principle of the general disaster repair plan is to repair from the foundation. Therefore, in this case, the ideal repair plan should construct from the more stable bottom foundation upwards to the road part. Nevertheless, due to the higher cost and numerous repairing cases in the same region, the project budget was insufficient to cover the expenses. The repair strategy was based on the bearing strata and using the structural support to restore the collapsed slope so that to root the possible sliding road section into the stable bedrock.

In this case, the damage type was overall collapse occurred in the interface between the reinforced and original stratum. Therefore, the basic damage cause should be considered in the repair plan to solve the problem and have great effect of repair. The research aims at the various factors such as the construction, cost, safety, time and environmental conditions of the site to evaluate and the proposed repair construction method was to install the reinforced concrete rigid foundation and piles, above set up the wrapped reinforced structure, but the bottom layer changed to excavate the original layer stage by stage so that expanding the overall width of the reinforced slope and enhancing its interface stability (Figure 3).

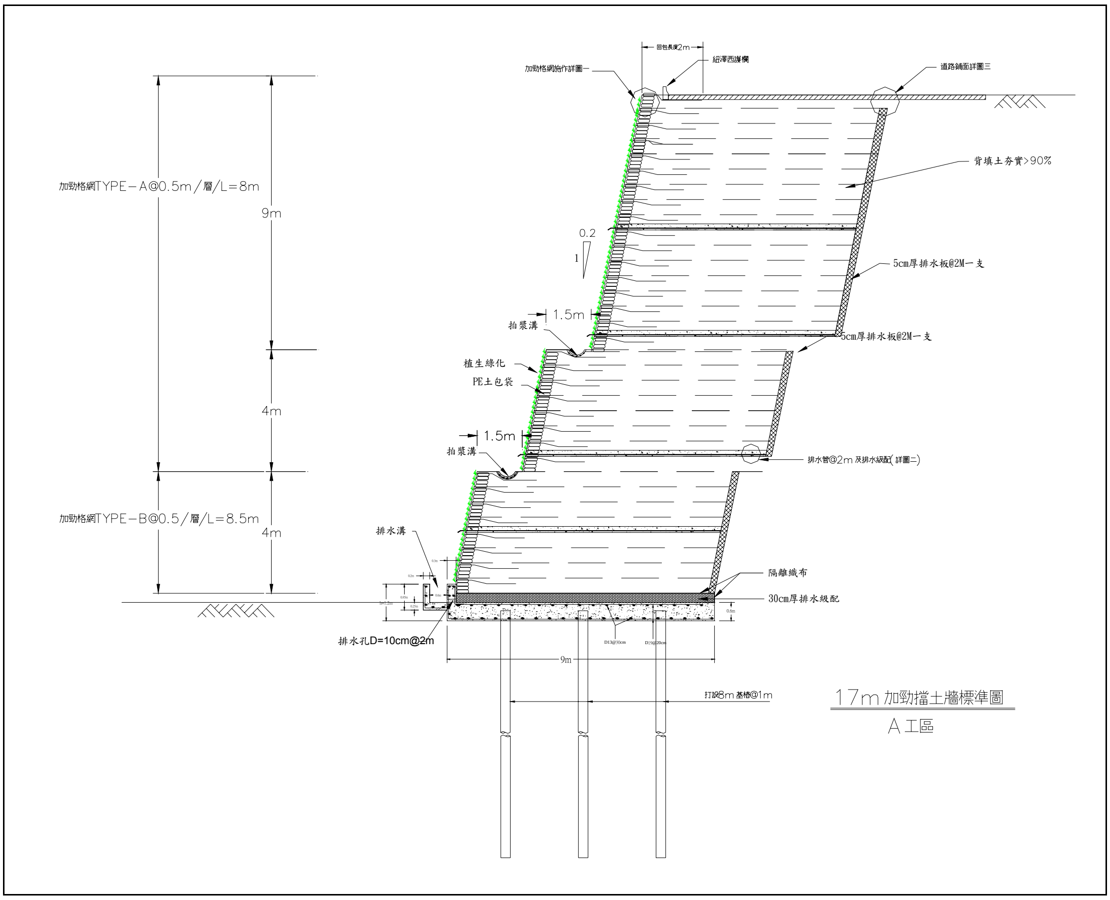

Figure 3. Advising plan – Reinforced Method

Safety Analysis

The research is aimed at the safety of the repair project. Using the computer program STEDwin and entering the stability analysis parameters in Table 1&2 analyze and check the normal, earthquakes and rainstorms models. The rainstorm condition should consider the effect of cohesion reduction. Stability analysis parameters and collation of results are as Table 1&2. The analysis revealed that the proposal is consistent with the safety standards.

Table 1 Stability analysis parameters

Soil Parameter / Strata Type	Total Unit Weight (kN/m^3)	Saturated Unit Weight (kN/m^3)	Cohesion c (kPa)	Friction Angle ψ (°)
original layer	20.0	20.8	345	33.0
reinforced layer	20.0	21.5	114	23.6
mudstone layer	21.9	22.2	535	25.8
Concrete foundation	25.0	25.0	1000	0.0

Table 2 Slope stability analysis

Analysis Mode / Safety factors	Normal	Earthquake	Storm (High water level)	Storm (c*=0.25c)
Standard	1.5	1.2	1.1	1.1
Advice	4.05	3.82	3.45	2.07

Discussing the relation of two different models of storm analysis with different design plans, the results of the analysis showed that two different design options when analyzing the storm model by its high water level or intensity reduction, the trend of the safety factor is the same, but strength reduction value is from 51 to 60% of the water level reached value. These figures show that the choice of the rainstorm analysis pattern does have remarkable impact on the forecast of the slope safety. Its relevance is worth further exploration.

The failure type in this case is overall collapse occurred in the interface between the reinforced and original strata. Such failure mode exists commonly among the mountain road widening engineering and retaining structures in excavation areas. And to repair such damage, using complex reinforced structures can reduce the traffic impact fast and effectively. The photographs before and after construction are as figure 4&5 below.

Figure 4. before construction

Figure 5. after construction

Case Two

Project Summary

The roadway (No.24) in Wutai, Pingtung County in Taiwan, 23K to 24K +090 +960 section occurred the roadbed slope collapse due to the heavy rain on June 9 2005. The 3rd Maintenance Division of Highway Administration Bureau appointed a consultancy firm to design and in October 2005 the project preceded the bidding operations. Collapse of this section was only 60m in length. The original design was RC wall and the wall base was located at the weathered rock. The topsoil of the slope was loose and soft. The downpour on June 9 softened the upper slope because of the excessive moisture and caused it slid down to the road slope and became mass shallow destruction. Related design content and construction process is described below.

Design and Construction Process

Design Parameters

According to the geological survey, the soil parameters of the design analysis are as shown in Table 3. Collapsed soil is used to backfill.

Table 3. Soil parameters of stability analysis

Soil layer	γ（kN/m^3）	c（kPa）	ψ（deg）
Weak shale	20	35	35
Backfill soil in reinforced area	18.6	10	29

Design Result

The collapse zone in this case was mainly on the road slope. A large number of earth not only destroyed the original RC walls, but also covered up the original road and so was the slope. The scope to restore the traffic was outward extension than before, but after being covered under the rock, the slope was about 55 degrees within about 13 to 15m range. It was too steep and difficult to locate the retaining structure on this slope. The slope was more flat of about 25 degrees in over 15m range, and thus it was where the wall base was built. In the design, the road was 8m wide, a gravity retaining wall of 2.5m high was on the slope, between the wall and road was an L-shaped ditch and the road edge of down slope was a barrier where the slope was required to install the retaining structure to increase the land.

The case was to maintain the connection with the outside for Wutai people after the failure occurred after rainstorm. Therefore, the earth and rocks were cleaned up rapidly after the collapse. However, because many rocks fell on the slope downside, the road slope was instable and the rocks couldn’t be estimated in the failure zone. Moreover, because of the broken stratum, the foundation design was using the board piles to resist the slide. The piles were as long as the distance to install into the bedrock. Above the piles using the thickness of 1.5m pile caps to link piles and transform the lateral force to the above retaining wall.

Above the piles was built a 18m high retaining wall to reach the scheduled road elevation. Reinforced retaining walls are divided into four stages, three of which are above the piles, 5m each and a total height of 15m. Its slope is 1:0.5. The top step is the reinforced retaining wall, 3m high, and the slope of 1:1.5. The geogrid tensile strength and the placed length were calculated by the stability analysis. The design was as shown in Table 4. The geogrid used in this retaining wall was placed every 0.5m and was woven from high-tenacity, multifilament polyester yarns and coated with black PVC.

Place a horizontal draining pipe in the reinforced retaining wall every 2m in both horizontal and vertical directions. Outside place some small stones in order to facilitate drainage. The internal vertical drainage was to place a drain board every 2m horizontally and connect it to the horizontal pipes. Design a ditch at the withdrawal space of every stage of the reinforced retaining wall and so the surface water would be drained through the ditch into the vertical water-cut ditch where the construction of 30 meters (central part of the wall), and then discharged into the underground wells.

The design section of reinforced retaining wall is shown in figure 6. The situation before, during and after the construction is shown in Figure 7. Till now, nearly a year after the construction, the reinforced retaining wall remained stable overall except the slight subsidence on the top of it.

Stability Analysis

This project is based on FHWA - NHI-00-043 design processes for internal and external stability analysis. The analysis of the overall sliding part was more complicated and therefore using STBL6.0 to analyze. The results of the design are shown in Table 5.

Table 4. Tensile Strength and the laying length of the geogrid

Elevation H (m，from the surface)	Tensile strength (kN/m)	Embed length (m)
0-5	400×50	10
5-10	200×100	7
10-15	150×30	4
15-18	150×30	3

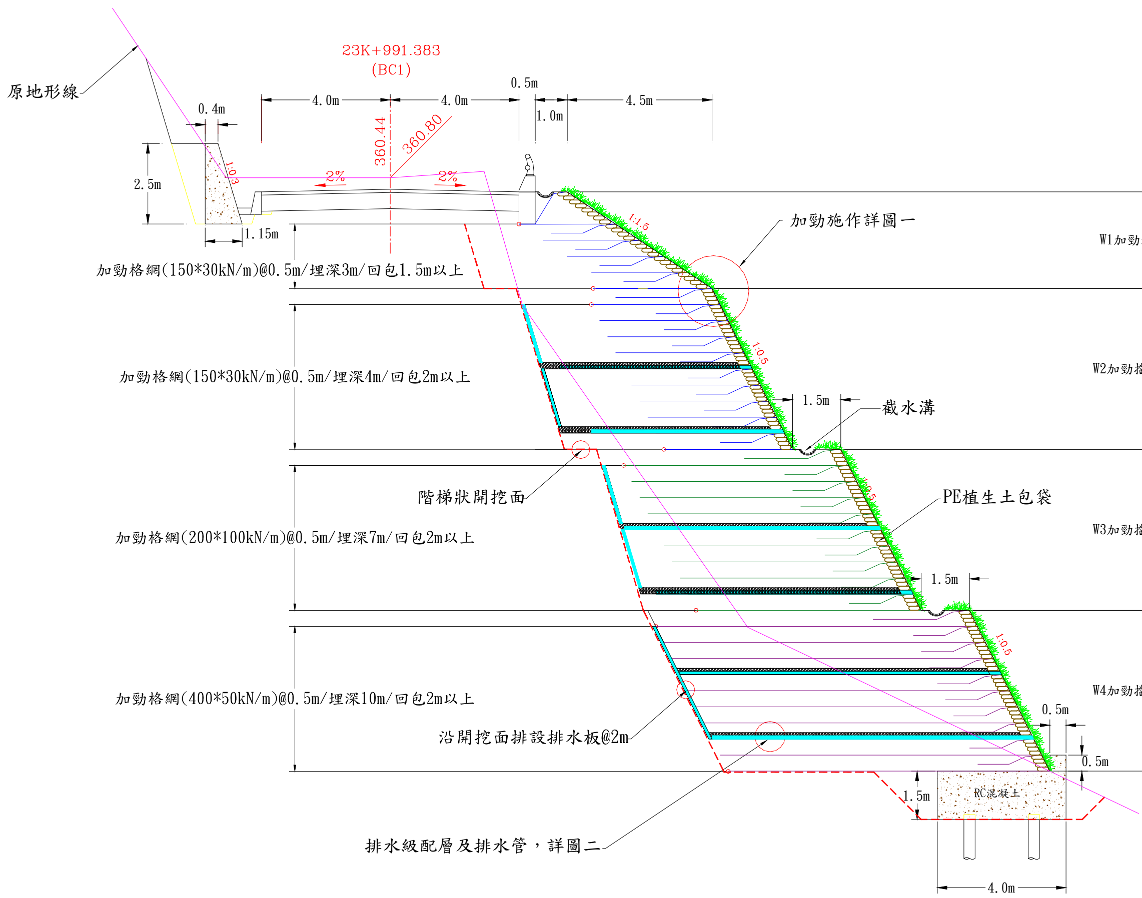

Figure 6. Reinforced retaining wall section

（a）Before construction

（b）During construction

（c）After construction

Figure 7. Before, during and after construction

Table 5.　Internal and External Stability Analysis

Item		Minimum Safety Factors		
		Normal	Seismic	Storm
Internal	Breaking Strength	3.8	3.8	
	Pull-out Resistance	6.5	5.8	--
External	Slide	24.1	20.9	--
	Overturning	256.4	215.3	--
	Bearing	71.2	71.2	--
	Overall	1.52	1.22	1.12

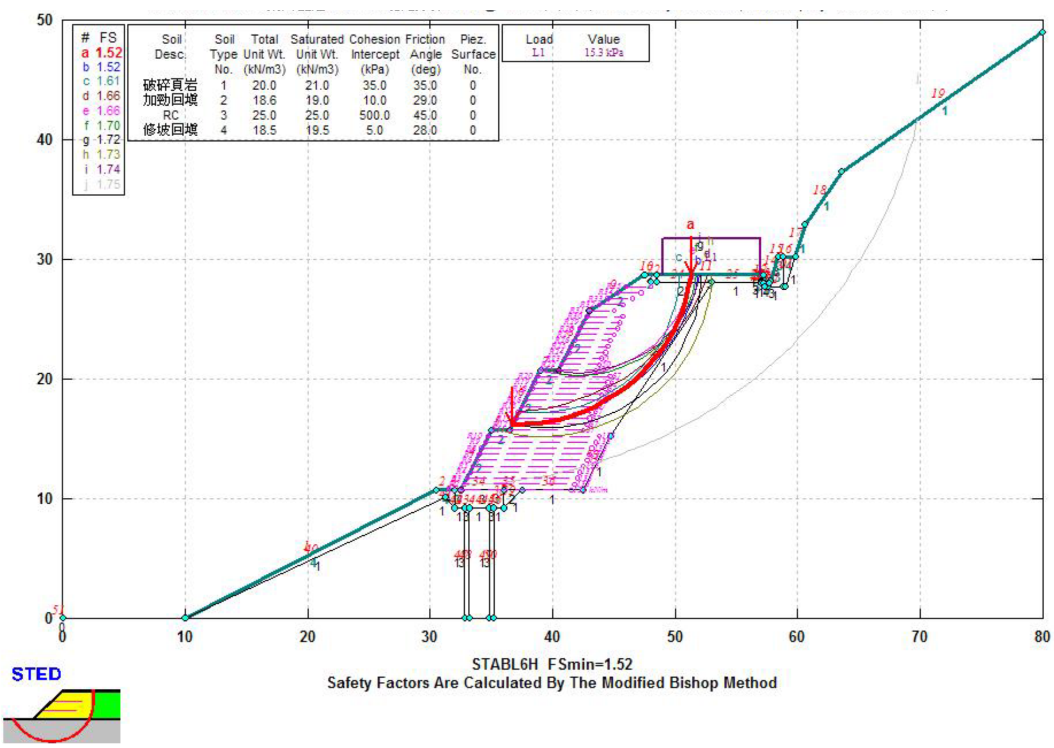

Figure 8.　STABL6.0 Results of stability analysis（Normal mode）

Conclusions

Most disasters of Taiwan mountain road damage are similar to the above cases. In recent years, more and more reinforced retaining structures were used to repair the road damages. In this paper, the road reinforced slopes of comprehensive collapse after natural disasters are the examples. Using them in combination with other relevant geosynthetic material such as pile, RC wall, anchor and so on, becomes complex reinforced retaining structures and increases the security.

Every time after the typhoon or rainstorm, the mountain roads collapsed or damaged and repair projects after disasters abound. Yet how to propose appropriate planning under well considering various factors is the real wisdom test to the engineers. The repair work either design or installation, time is extremely tight. Therefore, complex reinforced retaining structure is the option for resolving the mountain road repair. Besides, these cases are successfully experienced several natural disasters. In addition to a well thought-out of engineering design in advance, it requires more attention to the construction quality and thus to ensure the safety of reinforced retaining structures. To sum up, complex retaining structures are more economical, easy to construct, higher flexibility and seismic energy absorption capacity. Compared to traditional retaining structures, complex retaining structures applied in repairing the damaged mountain roads after disasters are, after all, a safe, economical, ecological landscape method.

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