PLAN DESIGN AND CONSTRUCTION MANAGEMENT STUDY OF KAO-133 HIGHWAY AFTER TYPHOON MORAKOT DISASTER

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ABSTRACT:

Typhoon Morakot was the most damaging typhoon to make rainfall in half a century, caused serious damages to southern Taiwan. Most major highways and bridges located in the area suffered severe damages such as landslides, rockfalls and debris flows in addition. It caused significant loss of lives, property and an economic loss of over US$5 billion. The administration system identified 675 dead and 24 persons missing in addition. One of the most important watersheds on the island (Taiwan), the Lawnon River Basin suffered from the severest slope disasters during this event, was selected for study. Previous studies have rarely shown this basin as susceptible to landslides and debris flows. Accumulated rainfall in the Lawnon River Basin was up to 2500mm.

Kao-133 highway located Lawnon River Basin alongshore was the major transportation line in Bolao-Hsinfa hot spring area, incurred severely damaged. This paper began with conducting extensive geological investigation and geophysical exploration analysis to preliminarily access the failure mechanisms of geo-hazards along Kao-133 highway. Moreover, propose some plan and design strategies for rehabilitation. To exchange a number of construction and management experiences eventually.

KEYWORDS: Typhoon Morakot, landslide

1. INTRODUCTION

Taiwan is an island with abundant rainfall. The torrential rainfall accompanied with typhoons frequently causes slope failures such as landslides and debris flows. Moreover, earthquakes also degrade the slope stability. In early August of 2009, Typhoon Morakot attacked Taiwan, and caused significant loss of lives and property. Accompanied with the typhoon movement, the southwest monsoon brought torrential rains primarily concentrated in the southern Taiwan. The accumulative rainfall in Lawnon River basin was up to 2500 mm, as shown in Fig. 1. The Lawnon River basins suffered from the severest slope disasters during this event. It also led to various types of damage to the infrastructures and transportation systems, as shown in Fig. 2-3. However, before Typhoon Morakot, rare large scale landslides ware observed in this area.

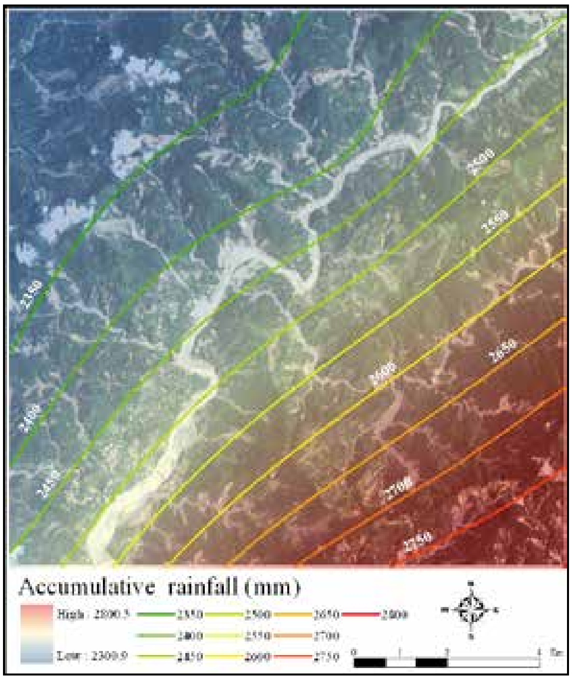


Fig.1 Rainfall record of Lawnon river basin

Fig.2 Bridges injured after Typhoon Morakot

Fig.3 Road damaged after Typhoon Morakot

According to the previous studies (Keefer, 1984; Schuster et al., 1996; Crosta, 2004; Lee et al., 2008a, 2008b), rainfall and earthquake are two of the principal mechanisms that induce landslides. For rainfall triggered landslides, precipitation data, such as accumulative precipitation and rainfall intensity, are usually applied to establish the thresholds of rainfall induced landslides (Caine, 1980; Vandine, 1985, Wieczorek, 1987; Keefer et al., 1987; Chen et. Al., 2005). Nevertheless, after some seismic activities, the stability of slopes would be influenced for a long period of time. In recent years, more and more researchers paid attention on the subsequent landslides triggered by heavy rainfalls for a region that has suffered a catastrophic earthquake (Lin et al., 2004; Lin et al., 2006; Ku et al., 2006; Chiou et al., 2007, Chen, 2008). In addition to the triggering factors of landslides, it has been generally accepted that slope failures are related to causative factors such as geomorphology, lithology, geological structure and land cover (Radbruch et. al.,1976; Carrara,1983; Varnes, 1978; Varnes, 1984; Hansen, 1984; Cruden,1993). Investigation of the relationship between landslides and the various factors causing landslides not only provides an insight into our understanding of landslide mechanisms, but can also form a basis for predicting future landslides and assessing the landslide hazard.

This paper aims to clarify the effects of rainfall on landslide occurrence variation and the lithology, topography, fractured zoning prone to slope failures in Lawnon River basin, first. Afterward, explains the rehabilitation strategy, principle and construction management attainment for providing the following related case reference.

2. METHODOLOGY

2.1 Geographical environment

The Lawnon River is 137 km long with a basin area of 1373 km^2.The upstream of the Lawnon River is typical valley topography, formed along a major thrust fault in southern Taiwan, the Lawnon Fault. The downward and lateral erosion has resulted in riverbank scouring, bank collapse, valley widening and riverbank retreating. The topographic characteristics of this section include river terraces, alluvial fans and steep riverbank slopes.

The study area is located in the upstream of Lawnon River Basin, around the Bao-Lai hot spring area with ambit of 130.4 km^2(Figure 4). The Bao-Lai hot spring region, the most populous area in the neighborhood, suffered a severe flood and landslides during Typhoon Morakot. Geology in the study contains four rock formations, including Tangenshan Sandstone (Tn), Changchikeng Fm.(Cc), Chaujou Fm.(Co), and Mt. Bilu Fm.(Ep). Among them, Tangenshan Sandstone (Tn) and Changchikeng Fm.(Cc) belong to sedimentary rock areas, and Chaujou Fm.(Co) and Mt. Bilu Fm.(Ep) belong to metamorphic rock areas. The Lawnon Fault is the boundary line between the sedimentary rock and the metamorphic rock. In addition, there are many hot spring sites within the study area, mostly located in Chaujou Fm.(Co).

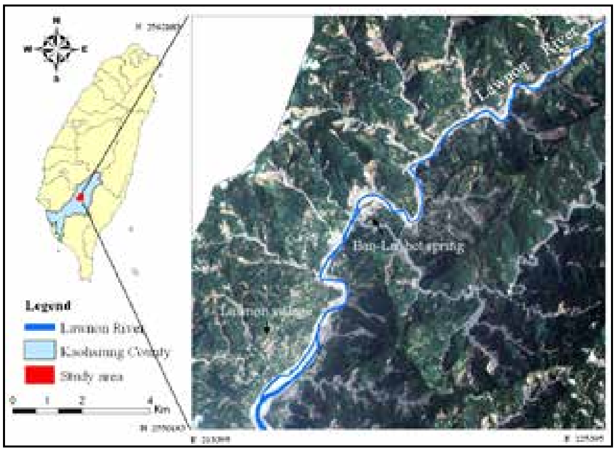


Fig. 4 Domain of study area

2.2 Data sources and database

2.2.1 Rainfall

The Water Resource Agency (WRA) and Central Weather Bureau (CWB) in Taiwan supplied digital files of hourly rainfall data for 12 rain observation stations. Extremely heavy rainfall data (those with twenty-four-hour accumulative rainfall over 130 mm) from 2005 to 2009 were collected from the rainfall observation stations within 15km of Bao-Lai area. Through pre-analysis of the rainfall data, ten significant typhoon and storm events with heavy rainfall from 2005-2009 were selected to evaluate effects on landslides, and corresponding rainfall data were collected for further statistical and spatial isohyet analyses.

2.2.2 Satellite images

This paper uses 16 images from FORMOSAT-II satellite from before and after the ten significant typhoon and storm events of 2005-2009. FORMOSAT-II satellite is a sun-synchronous satellite with orbit height of 891 km. It has high-resolution and daily revisit imagery and four bands with 8-m resolution color mode and 2-m resolution panchromatic mode. Colorful image includes blue, green, red and near infrared bands corresponding to the wavelength of 0.45～0.52m, 0.52～0.60m, 0.63～0.69m and 0.76～0.90m, respectively. Since the images were used to recognize the landslide areas in our study domain, the selected images were required to be cloud-free. Following the selection of satellite images, preprocessing tasks including geometric correction and radiometric correction were carried out before analysis of the images.

2.2.3 Geological and Topographical data

1:25,000 paper maps published by the Central Geological Survey (CGS) in Taiwan provided geological and topographical data. The data were stored in vector format within the Arc/info GIS software through manual digitization. A digital elevation model (DEM) of 40×40 m, obtained from Aerial Survey Office, Forestry Bureau, was constructed from the topographical dataset, and maps of slope-inclination angle and aspect distribution were then derived from the DEM. River networks, roads, and other basic geographical data were also digitized from the basic topographic maps.

2.3 Data digitization and mapping

The accumulative rainfall of each rain observation station was calculated by summarizing hourly records within the whole storm event. The accumulative rainfall data of 12 observation stations within the study area was processed to create the isohyets for 10 typhoon and storm events. The spatial analyst function of the GIS was adopted to conduct this work.

Satellite images identified the landslides, and landslide areas were manually digitized with Arc/info GIS software. Comparing pre-event and post-event satellite images, event-based landslide maps could be obtained. Reconnaissance works and in-situ observations were executed in the domain to understand geological and topographical conditions unseen in the satellite images. Since this study focuses on landslide areas, debris flows were not analyzed. To separate transportation and deposition segments of debris flows from the study area, this paper only considered land with slope gradient larger than 25°.

2.4 Landslide categorization

To better determine the characteristics, landslides recognized in each satellite image were firstly classified into existing landslides and incremental landslides. The difference in images before and after a storm event, showing landslides caused by a specific event between images, indicates incremental landslides. Existing landslides represent overlap in landslide images before and after the storm event. In order to assess how many landslides are expanded from existing ones, incremental landslides are further classified into new landslides and enlarged landslides. New landslides can only be observed in the new image, and enlarged landslides have expanded from existing landslides in the previous image. Figure 5 illustrates the distributions of existing landslides, enlarged landslides and new landslides caused by rainfall during Typhoon Morakot.

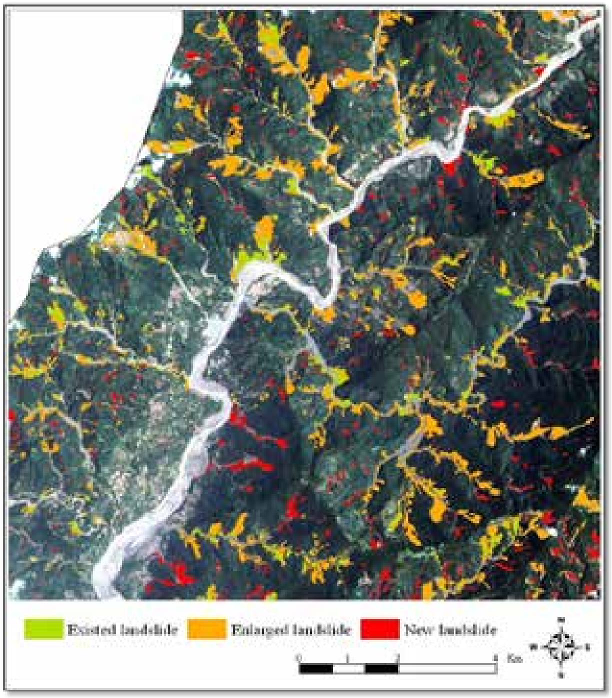


Fig. 5 Classification and distribution of landslides (after Typhoon Morakot)

2.5 Attribute assignment and combined database of landslides

Assignment various attributes to individual digitized landslides is critical to quantitative analysis of the relationship between landslides and their causative factors. Gathering and handling various attributes of landslides is a time-consuming task, usually requiring much field reconnaissance work. GIS makes managing digital databases faster and more accurate. Connecting the landslide database with other internal or external databases is an efficient way of assigning causative factor values to individual landslides.

3. ANALYSIS RESULT

3.1 Influence of rainfall on landslides

Rainfall, especially form storms, is the dominant factor inducing landslides. Combining the accumulative rainfall data and landslide ratio of each event(Fig. 6), landslide regions of the study area are observably growing in the past five years, though some small recovery appeared between two consecutive events. Herein landslide ratio is expressed as a percentage, yielded from total landslide area divided by overall area within a specific geological zone. Before 2008, the rainfall variation within the study area was not obvious, so the landslide areas variation was not significant. The extreme rainfall brought by Typhoon Morakot remarkably increased the scale of landslides. It is evident that rainfall dominates the scale of landslides. Comparing rainfall data among events, Typhoon Morakot has the highest accumulative precipitation (2502mm on average), followed by Typhoon Haitang (1882mm). However, it is significant that the average landslide ratio induced by Typhoon Haitang was only 1.29%, much less than those induced by Typhoon Jangmi and Kalmaegi.

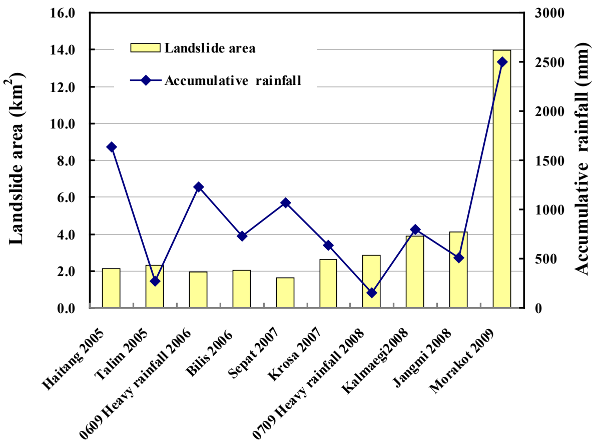
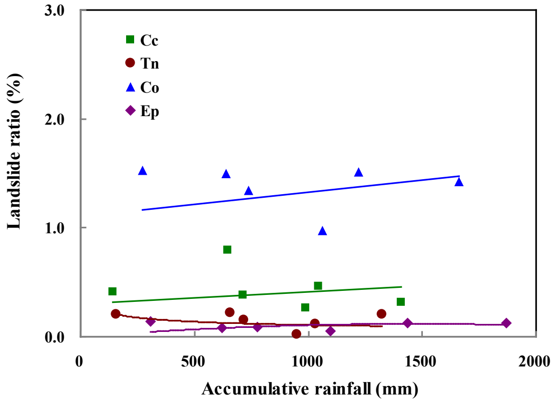


Fig. 6 Landslide ratio variation in 10 rainfall events

3.2 Influence of lithology on landslides

Figure 7 shows the variations of landslide ratio with respect to each geological zone, and the corresponded accumulative precipitation record is also plotted. The incremental landslide ratio of each geological zone generally remained below 2% before 2008(Fig 7(a)). The landslides frequently occurred in formation Co. However, after the 2008 earthquake the landslide ratios of sedimentary formations(Cc and Tn) surpassed those of metamorphic rock areas (Co and Ep) (Fig 7(a)). Fig. 8 illustrates the variation of enlarged and new landslides with respect to different geological formations. No matter the lithology, the failure ratios of enlarged landslides is larger than those of new landslides, which means most landslides came from regeneration and expansion of existing landslides. In other words, as a landslide occurs, it will precipitate subsequent failure nearby.

(a) Incremental landslide before 2008



(b) Incremental landslide after 2008

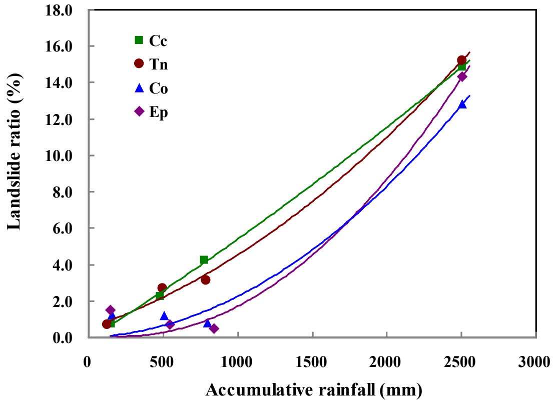


Fig. 7 Comparison of incremental landslide ratio

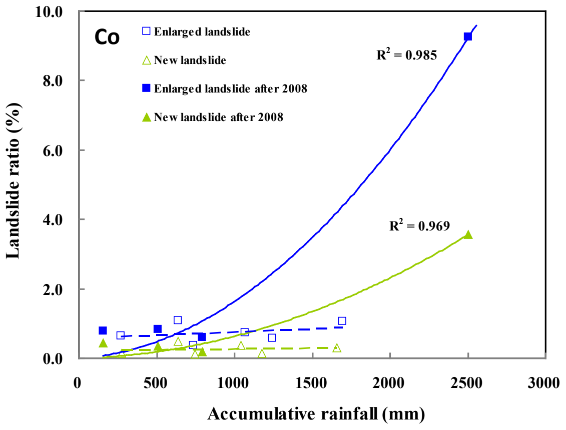


Fig. 8 Landslide ratio variation for enlarge and new landslides

3.3 Influence of dip slope on landslides

A dip slope means a topographic surface where the dip is consistent with that of the underlying strata. Dip slopes are commonly found in cuesta and vale topography. Usually, dip slopes are quite prone to landslides, due to the plane failure along persistent weak planes. In the Lawnon River Basin, dip-slope topography is commonly seen in the slope land. According to the definition of Central Geological Survey (CGS) of Taiwan, dip slopes are the slopes with difference of slope direction and dip direction of weak planes being less than 20 degrees. The distribution of dip slopes in the study area was digitized on the GIS platform as shown in Fig. 9. Figure 10 illustrates the variations of landslide ratios in the dip slope zone, and it indicates that dip slope areas indeed possess higher landslide ratios whether before or after the main earthquake in 2008.

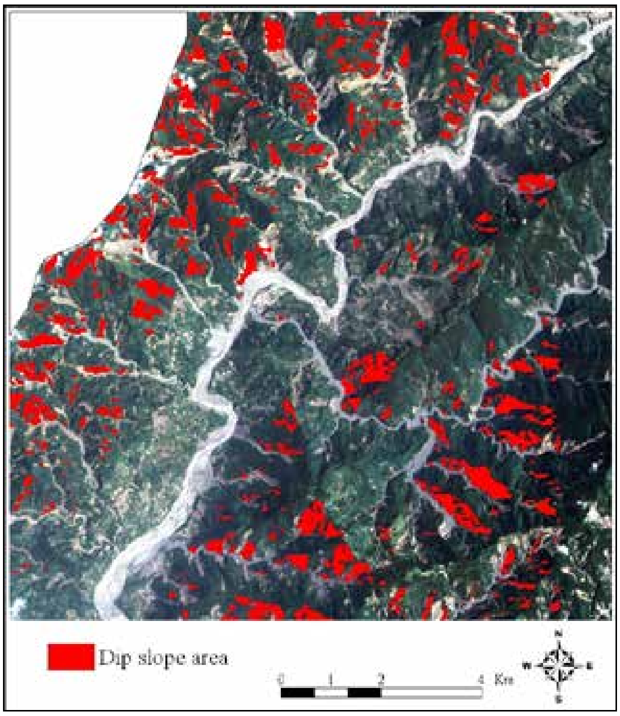


Fig. 9 Distribution of dip slope in study area

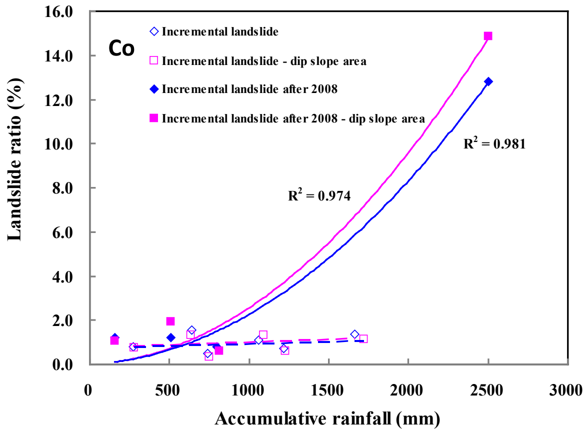
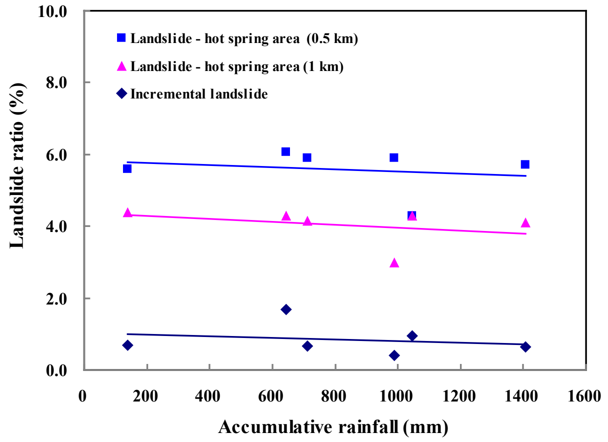


Fig. 10 Distribution of dip slope in study area

3.4 Landslides around hot spring area

Lawnon River basin is famous for hot springs, and there are 10 hot spring sites in the neighborhood of the study area, mainly distributed in Chaujou (Co) formation. Most hot spring sites destroyed and covered by landslides and debris flows after Typhoon Morakot. Geologically speaking, the hot spring could be considered as a kind of geological fractured zone. Therefore, in this study hot spring zones are taken into consideration as landslide causative factors. Investigation of the relationship between landslide occurrence and hot spring locations was also conducted. Buffering analyses of 0.5 and 1 kilometers around the hot spring sites were carried out to study their landslide ratios as shown in Fig. 11. The result shows the regions within 0.5 km buffering distance around hot spring sites have higher landslide ratios than those within 1.0 km buffering zones, and far higher compared to those of the whole study area. The phenomenon is more pronounced after the earthquake in 2008. This observation shows the slopes located or close to hot spring sites are more prone to failure as triggered by rainfall.

(a) Incremental landslide before 2008



(b) Incremental landslide after 2008

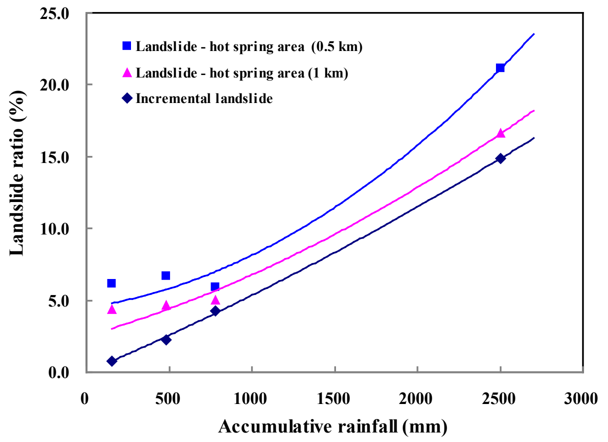


Fig. 11 Relationship of hot spring and incremental Landslide ratio

4. SUMMARY OF LANDSLIDE MECHANISM

This study investigates the triggering and causative factors of the storm event-induced landslides in Lawnon River basin from 2005-2009. The analysis results led to the following conclusions：

1. From 2005-2009, the landslide events and scales increased year by year and reached the peak value at the storm event of Typhoon Morakot 2009, which arouse attention to the landslide behavior in this area. Undoubtedly, rainfall is one of the primary triggering factors causing the slides. However, in comparison to rainfall data among the events except Typhoon Morakot, while Typhoon Haitang in 2005 had higher accumulative rainfall (1882 mm in average) than the other storm events, its landslide area is smaller. The patterns of landslide scale variation and rainfall record seem to be identical after 2008, which implies the existence of other factor(s) triggering the transition of landslide sensitivity.
2. Existing landslide areas are more sensitive to landslide enlargement or development. The enlarged landslides failure ratios are larger than those of new landslides, which indicates as a landslide occurs, it will more easily to precipitate subsequent failure nearby. As a result, the soil and water conservation works should be taken up soon to prevent further development of failure slopes.
3. The result proves that dip slopes have more pronounced landslide ratios compared to other slope land both before and after the earthquake in 2008.
4. Geologically speaking, hot springs are the products of geo-thermally heated water that breaks through the surface. The appearance of a hot spring is always the evidence of fracture zone existence. Slopes are more easily to slide as more fractured. The buffering and overlay analyses in this study shows the slopes located or close to hot spring sites are more prone to failure as triggered by rainfall and earthquake.

5. REHABILITATION PROJECT

5.1 Rehabilitation ploy

The rehabilitation work integrates the contents of new design/construction criterion and standard to guarantee the recover effect. The rehabilitation plan also takes will effectively to avoid as far as possible the flooded, debris flows potential and geological sensitive area. Meanwhile, resets the new retaining wall, roadbed, pavement and water conservation in according with the newest standard and criterion. More importantly, carries out “the mountain, the road, the bridge, the river altogether to harness” principle. It led to the following section：

(A) Bridge Rehabilitation

1. The bridge site should avoid as far as possible the debris flows potential area.
2. Pick larger span disposition to reduce columns
3. Avoid setting the column in the stream area
4. Arrange the column shape be helpful to diversion
5. Promote the structure anti-impact ability
6. Deepening foundation and increase RC-pile length

(B) Road Rehabilitation

1. Divides entire project to several documents: concentrates different disasters (roadbed outflow, landslide, bridge damaged and so on) in the identical project to construct. It will reduce the construction interface, increase the construction efficiency, and reduce the reconstruction completion schedule.
2. Path position: avoids the debris flows, flood and the environment sensitive potential area in the plan stage.
3. Reduce impact: picks the most suitable cross section of the path (traffic lane 3.0m~3.5m extend) to reduce rehabilitation project scale, schedule and the funds.
4. The road (bridge) the river altogether harness: approach the water conservation institution to handle jointly with the examination and assistance in the beginning of rehabilitation design and construction stage.

5.2 Rehabilitation practice

In view of the various disasters landslides, rockfalls, and debris flows exposed on the Kao-133 highway, the rehabilitation work mainly arranges piling or retaining wall to carry on the slope protection. In addition, sets the roadside box drain, drain tank, drain tunnel underneath the roadbed to release the rainfall current and avoid rainfall washout destruction. For blocking the potential glide stratification plane, it also disposes the pre-stressing ground anchor to fix the soil body, and establishes the monitor mechanism to examine the result as shown in Fig. 12.

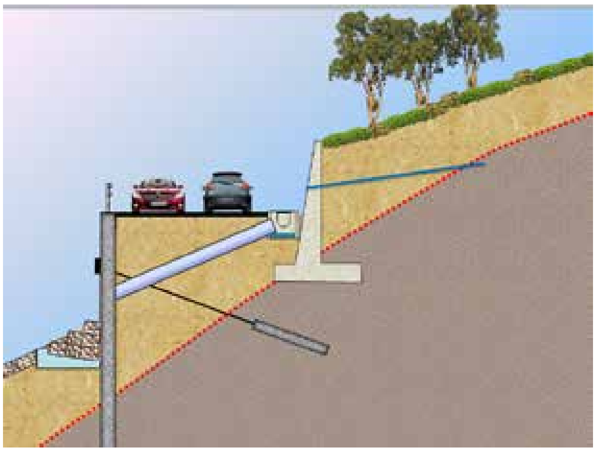


Fig. 12 The road rehabilitation schematic drawing

5.3 Rehabilitation management

In the construction control and management of rehabilitation project, it mainly has the following several achievement：

1. Steel arched bridge is divided to small components to construct. It reduces the inconvenient of transportation, the hoisting capacity limit, and the construction uncertainty or risk in the mountain. Therefore, it promotes the rehabilitation project construction efficiency.
2. In the planning stage of the project construction, the supervisor actively assists contractors carried on the synthesis self-criticism in view of the construction machines, disposition and the serviceability, to guarantee that may give dual attention to the security, the quality request and the time control.
3. Before constructing, the supervisor establishes the complete flood prevention and urgent contingency plan, and appoints the constructors inspect regularly around the construction area. As the river water level reaches the warning line or the danger risk occurs, the contractor namely calls the rescue teams to utilize the existing preparation construction materials to carry on the personnel evacuates the rescue. Meanwhile, looks for supports and assists from proprietor and local government police force to ensure the constructors safety. In addition, during the steel bridge hoisting period, the supervisor

positively claims contractor carried out the protection plan, especially against falls to maintain the traffic safety.

4. As high-water level tide season, the river/torrential valley catchment area is getting broader, the downstream place water level instantaneous rises suddenly due to upstream branches collected rainfall. It increases steel arched bridge hoisting risk, and endangers the personnel and machines security. Therefore, the supervisor actively assists contractor to plan the working procedure properly, adjusts the steel bridge hoisting schedule before typhoon and the river flood season. It makes sure that the rehabilitation work is safety and smoothly.

Fig. 13 Road rehabilitation construction

Fig. 14 The River bank protection works

Fig. 15 The Bridge hosting work

6. CONCLUSION

The rehabilitation project construction began in Aug. 2010, and will be completed in June 2012, which was two months earlier than the official completion date. It means that a well-considered construction scheme had to be proposed in the preliminary stage and then conducted during the construction stage. In fact, the project construction schedule always maintained 2-5% ahead, even though many unexpected weather, geology and construction problems took place during working period.

Fig. 16 Balaoshi Bridge Completion

Fig. 17 Night scene of the bridge completion

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