The Challenge of the Slope Failure Problem and Its Remedial Considerations at Mileage 39km, Mt. Ali Road, Taiwan

Le défi du problème du glissement de pente et des dispositions correctives apportées, au kilomètre 39, de la route Mt. Ali Road, àTaïwan

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ABSTRACT: Mt. Ali Road is a main scenic route to Alishan National Scenic Area and Yushan National Park in the middle of Taiwan. At Mileage 39Km, the downslope side of the road consists of a 200m deep 60° angle bare cliff with a creek passing around the slope's toe. Despite complex geologic conditions, the underlying slope materials appeared competent for about 20 years after the road opening. In 1999, however, a severe earthquake (Chi-Chi, M_w = 7.6) hit central Taiwan and caused numerous landslips in the mountain range of the island. Although no obvious damages to the road were observed after the time of shaking, the geologic setting of the site was deteriorating. During the attack of Typhoon Nari in 2001, the first serious effect on the road appeared and caused several parallel cracks along the alignment. Remedial work was initiated. Nonetheless, a loss of road base during the monsoon season next year had called for a stop of the work. The remedial plan was revised and implemented, but failed again due to Typhoons Talim and Longwang in 2005. The current repair works have been completed and generally show no major signs of slope distress. In view of repair histories and the geologic setting, this paper discusses the concerns and challenges for long-term stability of slopes at the site.

RÉSUMÉ : Mt. Ali Road est une route principale pittoresque qui mène à l'Alishan National Scenic Area et au parc national de Yushan, au centre de Taiwan. Au kilomètre 39, le côté aval de la route est formé d'une falaise nue de 200m de haut, inclinée à 60° avec un ruisseau la bordant en pied de pente. En dépit des conditions géologiques complexes, les matériaux de la pente se sont bien comportés au cours des 20 années l'ouverture de la route. Cependant, un violent tremblement de terre (Chi-Chi, *Mw* = 7,6) a frappé le centre de Taiwan en 1999, et a causé de nombreux glissements de terrain dans la partie montagneuse de l'île. Bien qu'aucun dommage apparent n'ait été détecté après la secousse, la situation géologique du site s'est détériorée. Les premiers effets conséquents ont pu être observés lors du typhon Nari en 2001, plusieurs fissures parallèles étant apparues le long du tracé. Un projet de confortement fut entrepris. Malgré cela, une rupture de la couche de fondation, de la route l'année suivante pendant la saison des moussons a necesssité un arrêt temporaire des travaux. Le projet fut révisé et remis en œuvre, mais a du être à nouveau arrêté en raison des typhons Talim et Longwang en 2005. Les réparations sont aujourd'hui terminées, et la pente ne montre en général aucun signe de désordre. Compte tenu de l'historique des réparations et de la situation géologique, ce document aborde les préoccupations et les défis concernant la stabilité à long terme des pentes du site.

KEYWORDS: slope failure, repair works, landslip prevention and mitigation, slope stability, case histories, Mt. Ali Road.

1 GENERAL

Mt. Ali Road is a main scenic route to Alishan National Scenic Area and Yushan National Park in the middle of Taiwan. As entering into the hilly terrain of central mountain range of the island, the road starts climbing up along the side of slopes for a distance of about 5Km until it reaches a hill top with an elevation of 460m MSL at the mileage of 39Km, where the road levels off and makes a loop around the hill. The downslope side of the road at this location consists of a 200m deep 60° angle bare cliff with a creek passing around the slope's toe.

Although both regional and local geology generally show a complex geologic structure at the site, the subgrade materials and underlying rock appeared competent for about 20 years since the road's opening. Figure 1 shows the regional geology of the area, and Figure 2 illustrates the geologic profile of the road section and its adjacent slopes.

On September 21, 1999, a severe earthquake (Chi-Chi, M_w=7.6) hit central Taiwan and caused numerous landslips or slope failures in the mountain range of the island, as indicated in Figure 3. Based on studies by National Center for Researches on Earthquake Engineering (NCREE 2000), approximately 1500-2000 landslides were directly induced by the earthquake. Although the shaking did not have immediate impacts at the site, the condition of the road and its adjacent side slopes appears to be deteriorating.

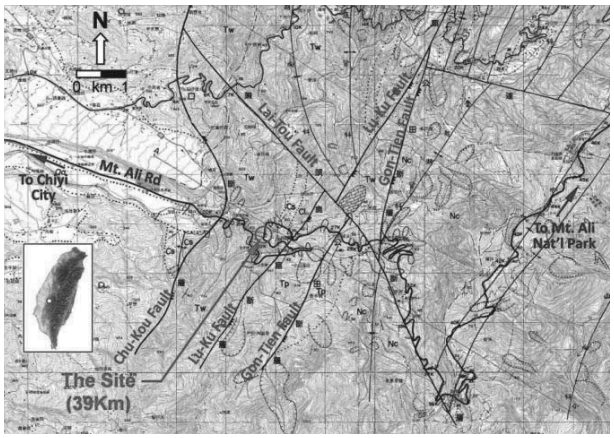

Figure 1. Regional geology of the area (Liu & Tseng 2000).

The monsoon season normally starts from early April to the end of September in the island. Annual precipitation is around 2150mm (Sinica 1999). Figure 4 shows accumulated rainfalls of the site in 2001 & 2005 were 4700mm & 4600mm, respectively. As will be discussed later, the abundance of rainfalls appeared to have contributed to the failures of slopes along the Mileage 39Km in 2001 & 2005.

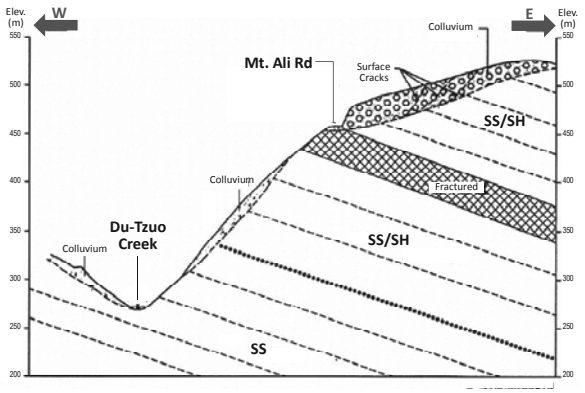

Figure 2. Geologic cross-section at the 39Km project site (CECI 2005).

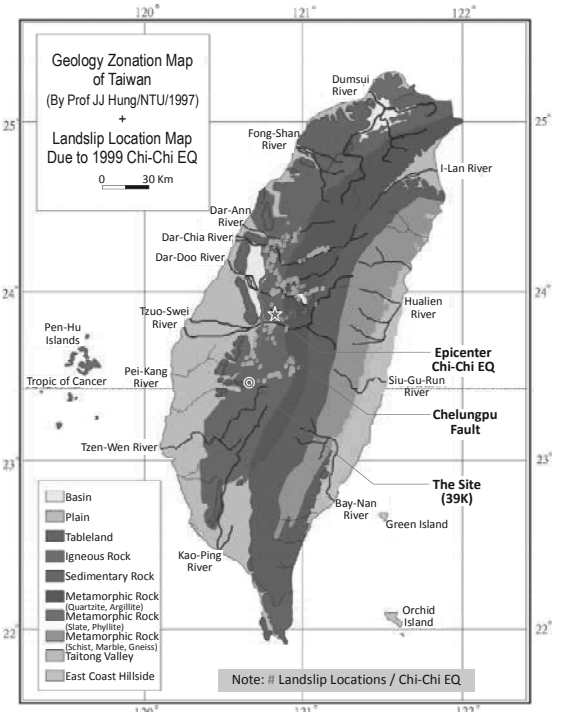

Figure 3. Locations of landslides due to Chi-Chi EQ (NCREE 2000).

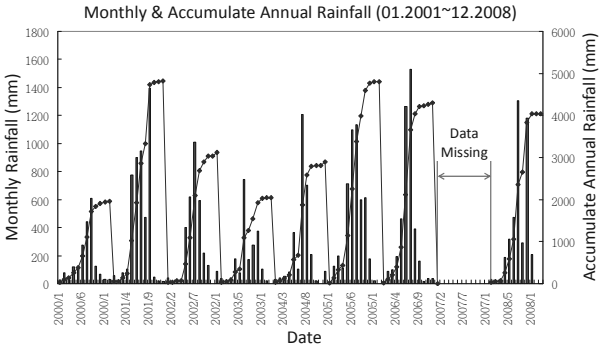

Figure 4. Monthly and accumulated rainfalls at the site (Peng 2009).

2 SLOPE FAILURE & ROAD REPAIR HISTORIES

Prior to failures of the subject slopes, a sever typhoon (Herb) with a rainfall of about 2000mm attacked Taiwan in 1996 and resulted in significant damages in central region of the island. Based on an official investigation report, the event had caused 91 landslips and 57 losses of road base along the entire length of Mt. Ali Road (DOT 1996). However, the subject road and its slopes were only experienced very minor effects due to this typhoon and had no influence on the slope stability.

Three years after the severe typhoon incident, a damaging earthquake (Chi-Chi, 1999) occurred. As mentioned previously, the earthquake had resulted in numerous landslips in central Taiwan. Although the site and its adjacent slopes appeared to be competent during the shaking, the in-situ earthen materials were apparently weakened and deteriorating due to the earthquake. In subsequent years, signs of slope distress and movement became obvious, and some key events and associated repair histories are discussed in the following sections.

2.1 *2001 Typhoon Nari*

Typhoon Nari swiped Taiwan in September, 2001, and brought about 1400mm precipitation to the site, 4700mm for the entire year. This had been the largest rainfall event since the attack of Typhoon Herb in 1996. The site had experienced a series of parallel cracks of 10~80cm in width along the road alignment which called for a temporary shutdown for one lane of the road.

A remedial action was subsequently taken by District V of Directorate General of Highways (DGH), Taiwan, that included the repair of surface cracks by a new AC paving and a planning on reconstruction of the road section by conventional retaining structure on the downhill side of the road.

2.2 *2002 monsoon rainfalls*

As the reconstruction work for the retaining structure was about to start in 8 months after Typhoon Nari, a failure in downslope of the road occurred (Figure 5). The failure was apparently due to the intense rainfall during the monsoon season. Recorded accumulated precipitation was greater than 1000mm within the two months prior to the failure.

Figure 5. Slope failure at Mileage 39Km due to 2002 monsoon rainfalls.

The original construction work had to be terminated and re-planned. In view of steep downslope and insufficient road width, DGH had once considered remedying the problem by cutting back and flattening the upslope. However, the plan was turned down due to unsuccessful negotiations with local ownerships of lands adjacent to the road.

The remedial plan was finally decided to limit within the extent of the road owned by DGH. Considerations of the road redesign had included a section of box-type concrete structure, as shown in Figure 6, which would provide a design with enough road width, structure rigidity, and relatively light-weight. The box structure was secured to the native ground by two rows of ground anchors, each of which with a total length of 35m, a horizontal spacing of 20m, and an anchor force of 45T. The

base of the box structure was also fixed to the ground by a series of mini piles of 16m in length.
Figure 7 shows the rebuilt road section after completion of the remedial works.

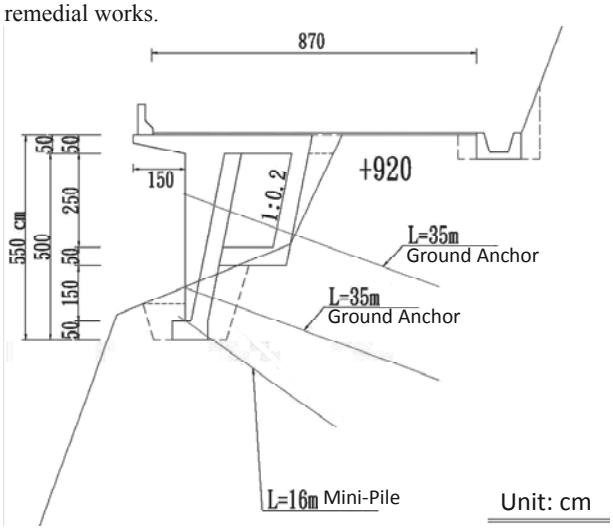

Figure 6. Box-type structure design for road section at Mileage 39Km.

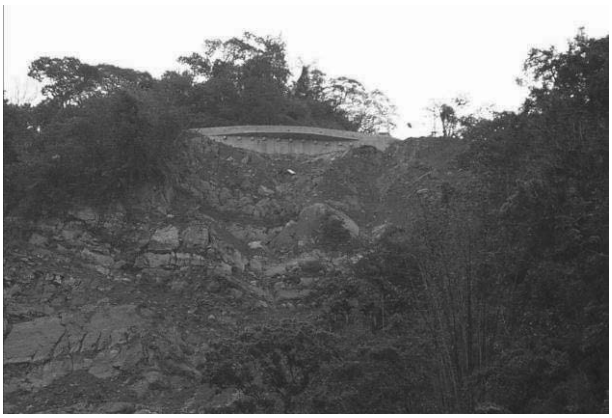

Figure 7. Completion of box-type structure at Mileage 39Km.

2.3 *2005 Typhoons Talim & Longwang*

The new road section appeared to be in good shape for the next 1-1/2 years until mid of 2005 when the precipitation started to reach another historic peak.

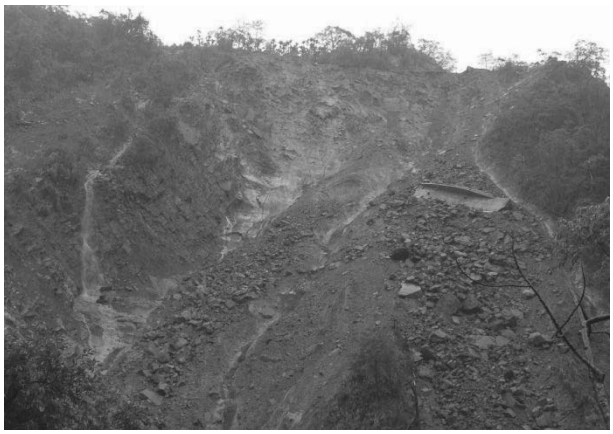

Figure 8. Failure of box-structure road section due to Typhoon Talim.

In late August of 2005, a severe Typhoon Talim slammed Taiwan. By considering a series of heavy rainfalls in the previous two months, the accumulated precipitation of the year at the site had exceeded 4000mm. As a result, the box-type structure finally gave up and the entire road section of about 100m in length fell into the valley (Figure 8).
Post-failure investigation had revealed that the loss of entire road section was due to the downslope movement of the uphill slope mass which pushed the box-type structure, tore down the ground anchor tendons, and sheared off the mini piles.
Emergency action was implemented right after the failure by constructing a temporary road to the uphill side and installing I-beams for the downhill support (Figure 9) in order to maintain the local traffic (DGH 2005).

Figure 9. Emergency repair of the road section due to Typhoon Talim.

In late September, 2005, the emergency measure failed again one month after the attack of Typhoon Longwang. The temporary road lost 5m of its road width. Site reconnaissance showed significant tension cracks at the crest of uphill slope.
District V of DGH had to launch another remedial measure to mitigate potential impacts on the road section in the future. The plan had considered mostly the upslope protections that included filling of tension cracks, rechanneling surface drainage, installing subsurface horizontal drains, and surface vegetation, etc. Figure 10 shows the completion of upslope remedial works after Typhoon Longwang.

Figure 10. Completion of upslope remedial works at Mileage 39Km.

3 FIELD MONITORING & STABILITY ANALYSIS

In the following few years after Typhoon Longwang, the annual precipitation of the site was decreasing. To date the road section and its adjacent slopes appear competent for maintaining local traffic. However, data from subsurface exploration and in-situ monitoring during the previous remedial works showed signs of slope instability at the site (LEC 2006). Figure 11 indicates potential sliding masses (slip surfaces) in the upslope that would have impact on the Mileage 39Km road section. The downhill side slope was not improved during the remedial works and its surface was bared with remains of previous slides, as shown in Figure 12.

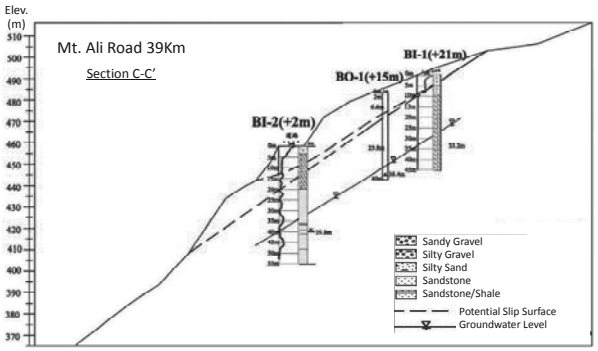

Figure 11. Material strata and potential slip surfaces at Mileage 39Km.

Figure 12. Downhill slope of Mt. Ali road section at Mileage 39Km.

4 CONCLUSIONS

In view of past failure incidents and associated remedial works, the road section at Mileage 39Km and the alongside slopes are still at perceivable risks of a potential slide. The signs of slope instability appeared to be pronounced since the attack of 1999 Chi-Chi Earthquake, which was believed that the shaking had weakened the underlying geologic units and thus accelerated the weathering process of materials at the site.

Conclusions on causes of slope instability and measures of slope mitigation for this site can be drawn and discussed below.

4.1 *Potential & triggering factors*

From a retrospective stand point, the factors that had caused instabilities of slopes at Mileage 39Km road section could be attributed to the following:

- A complex geologic structure at the site (Figure 1) where the underlying geologic units are generally fractured.
- The 1999 earthquake shaking that had weakened underlying geologic structure and enhanced deterioration process of the materials.
- The steep downhill slope geometry (60° angle & 200m deep).
- The potential uphill sliding masses (Figure 11).
- The unprotected downhill slope surface that enhanced rainfall infiltration and surface runoff erosion.
- A long-term erosion of slope toe by Do-Tzuo Creek (Figure 12).
- The abundance of groundwater that was observed seeping out of the surface of downhill slope.
- The prolonged and intense rainfalls that infiltrated, saturated and softened the slope materials, increased the perched water level, and directly triggered the slips.

4.2 *Long-term stability considerations*

The previous remedial works at site after Typhoon Longwang has been successful to date. However, the work details were mainly for improvements on surface protection of the upslope. From the analysis above on causes of slope failure, the current remedial activities would be helpful to mitigate the infiltration of rainfall and possibly prevent the triggering of a slide in the upslope. It would not be useful, however, for the stability of downslope, and would not either remove the concerns (i.e., potential factors) above that could be detrimental to the long-term stability of the road section and slopes at the site.

In accordance, more stability considerations and measures need to be taken to ensure the safety of the road section, and to maintain the transportation function of Mt. Ali Road as well. The considerations might include:

- Removal of potential sliding masses or reducing slope angle in the uphill.
- Downhill slope protection including vegetation and drainage installations.
- Road base and adjacent slopes strengthening by piling and anchoring.
- Subsurface drainage installations in uphill & downhill slopes.
- In-situ monitoring and warning system installation.

The above measures appear to be sound from an engineering standpoint. However, the total cost and time for all of the above works would be extremely high, in view of difficulties in access for construction and generally incompetent subsurface materials at the site. Another option would appear more favorable as to reroute the Mt. Ali Road away from this difficult section.

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