Dip slope landslide at upper slope and circular landslide at 37.5k.

circular landslide at lower slope and mixed type landslide at 37.5k.

upper slope toppling failure at 59.1k

upper slope circular landslide, Dip slope landslide at lower slope at 71.1k

Figure 9 Type of slope failures on Alishan Route 18

Table 1 Causes of slope slide disaster in each section

location	Cause analysis of disasters	Failure types
37.5k ~ 40.1k	• Runoff erosion due to heavy rain • Shallow-rooted plant, poor soil and water conservation • No vertical and horizontal cut-off drainage facilities in slopes • Road drainage not properly segmented and discharged into stream, causing water overflow • The exposed toe of dip slope in the east side lead to landslide • Rainwater infiltration in west side colluvium deposits soften soil strength and reduce slide resistance of soil that lead to circular landslide of slopes	• The upper slopes are classified as dip slope landslide; the lower slopes belong to circular landslide and a large number of earth and rock piled on the roadbed 37.5k ~ 38k
59.1k	• Runoff erosion due to heavy rain • No vertical and horizontal cut-off drainage facilities in slopes • Formation steep, more broken joints in the upper shale slope, lots of rain infiltration in joints increase tension cracks. • Rainwater infiltration in colluvium deposits at lower slopes soften soil strength and lead to slope failure	• Topping failure due to the crest rock with high angle joints, the slopes in vicinity of tunnel belong to dip slope plane slide. Other sections are classified as circular landslide
71.1k	• Runoff erosion due to heavy rain • After rock crushing and highly weathered, the rain infiltration in rock cracks increase water pressure and soften soil strength. • This road section includes streams through, runoff flow wash out slope and rock rushed shift which results in steep terrain in some sections. In the upper slope of road, the heavy rainfalls leads to the broken rocks fall and accumulate on the roadbed. In the lower slope of road, the exposed toe of dip slope leads to landslide and the loss of roadbed.	• The upper slopes are classified as circular failure, the upper broken rocks fall and accumulate on the roadbed. • The lower slope valleys are wash out by rains, the exposed toe of dip slope lead to landslide in the lower slope.

3. EMEDIATION METHOD AND REHABILITATION STATUS

3.1 Mileage 37.5k

The slope protection works in this section will do best to adapt to the nature and reduce change on the natural environment. The vegetation for slope protection against erosion caused by rain washed is adopted in the safety flat slope. The steep slope or potential landslide will be treated as the possible slope failure. The free-form vegetation measure, lattice beams anchored or row pile retaining wall with rock anchors will be carried out, respectively. Also, the necessary vertical and horizontal drainage ditches will be implemented to reduce the ground runoff and infiltration so that a reducing driving force of landslide can be achieved. The layout of remediation is shown Figure 10. The results of remediation in before and after is given in Figure 11. The repair works are summarized as follows:

A.37.5k～37.9k

More buffer space is reserved for slope repair use in this and previous section. The vegetation way for slope protection are used in this section and Mileage 38.1k～38.5k. Moreover, the necessary vertical and horizontal drainage ditches, chute and crossing culvert are installed so that the runoff in the upper slope can be smoothly guided to the existing ditches in downstream for emissions.

B.38.1k～38.5k

This section is located at the area of colluvium circular landslide. A single row of ∮1.2m piled retaining wall with rock anchors is implemented in this section. In addition, the necessary vertical and horizontal drainage ditches and crossing culvert are installed so that the nearby runoff can be smoothly guided to the adjacent drainage system of Mileage 38k.

C.40.0k～40.6k

This section close to the collapse sources at County Road 130. The rock collapse leads to large area exposed in the slope and some plane slides occur in the dip slope. The circular landslide induced around 200 meters subsidence in the lower slope of the road. Lattice beams anchored near slope toe are used in the dip slope for the slope protection. Grouting anchorage of free-form format is adopted for the slope protection in the exposed area. A single row pile of ∮1.2m retaining wall with rock anchors are carried out in the lower slope due to the circular slide. In addition, vertical and horizontal drainage ditches and crossing culvert are installed so that the runoff in the upper slope can be smoothly guided to the existing ditches in downstream for emissions.

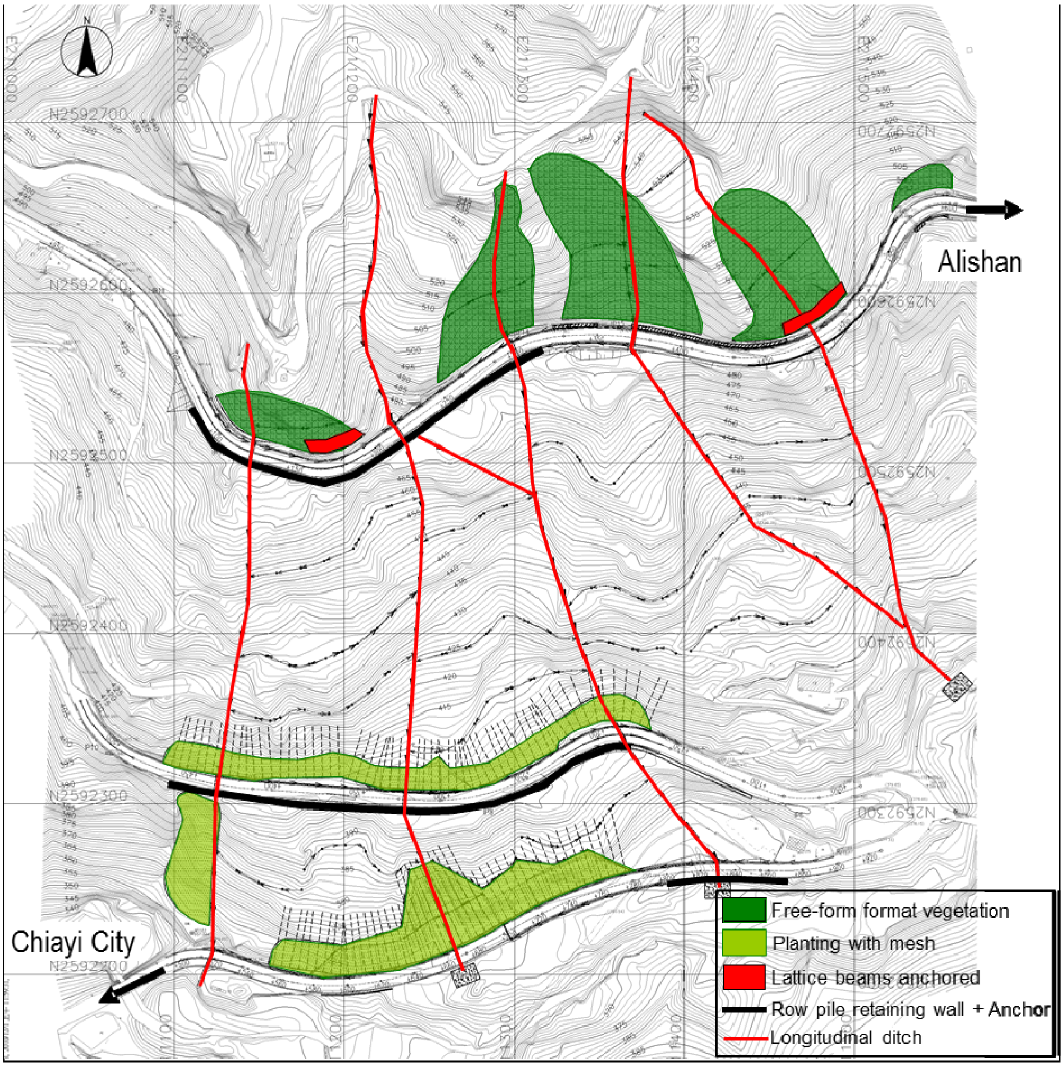

Figure 10 Layout of repair works at Mileage 37.5k ~40.1k of Alishan Route 18

before | after

Slope slides and roads cut-off | Repair method adaptation to local condition

Figure 11 Before and after Photos at Mileage 37.5k of Alishan Route 18

3.2 Mileage 59.1k

The road rehabilitation consists of renovations of upper and lower slops and making an appropriate discharge for slope as well as pavement drainages. In addition, the tunnel with lateral displacement and subsidence will be rebuilded. The layout of remediation is shown Figure 12. The results of remediation is shown in Figure 13. The repair works are summarized as follows:

A. The implementation of source remediation in the upper slide slope consists of removing dangerous wood, free-form vegetation for slope protection.
B. Gabion retaining wall is set up in vicinity of toe of landslide in the lower slope.
C. Colluvium deposits near the road belong to circular landslide so that a retaining wall with piles penetrated into bedrock has been installed to protect road embankment.
D. The tunnel structure at slope failure section will be demolished and replaced with a new tunnel rested on pile foundation that smoothly connect with the existing tunnel.
E. Retaining walls and rock anchor reinforcement are employed in the sidewall of the new replaced tunnel. The sidewall is also used for the construction access road.
F. Collapses at upper and lower slope of the existing road are fixed with slope protection and necessary vertical and horizontal drainage ditches. Two submerged dikes are installed at downstream of vertical drainage ditches to reduce undercutting of slopes.

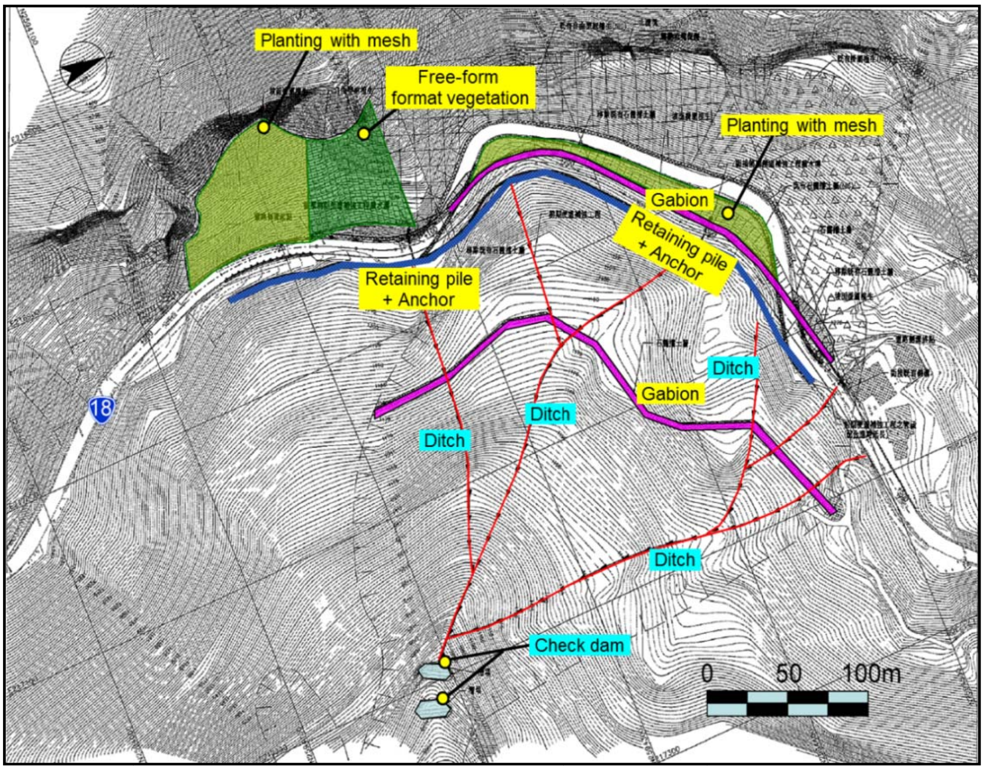

Figure 12 Layout of repair works at Mileage 59.1k of Alishan Route 18

Before

Plane landslide of slope, tunnel lateral movement

After

New tunnel with pile foundation

Circular landslide, road cut-off

Free-form frame and gabion retaining wall at upper slope, retaining with piles at lower slope

Figure 13 Before and after Photos at Mileage 59.1k of Alishan Route 18

3.3 Mileage 71.1k

The upper slopes are classified as circular slide failure. The downslopes belong to dip slope plane failure. It is difficult to use road rehabilitation plan when the road slope is steep and the hinterland is not adequate in this road section. The rehabilitation adopts a new bridge to avoid the landslides area. The main slope stability treatments consist of lawn nursery, rock fall fence and rock anchor curtain wall. The upper slope of bridge abutment (A1) in the east side implements free-form vegetation for slope protection and rock fall fence protection; The upper slope of east bridge abutment (A2) carry out rock anchor curtain wall (dip slope stratum). The vegetation for slope protection is installed in the lower slope. Layout of remediation work is shown in Figure 14.

In consideration of the site characteristics of collapse and the geological conditions, a bridge with steel structure is used in this project. The steel structure bridge can not only reduce the weight of the structure and also plan steel block size in accordance with the needs of transport and construction conditions. The steel structure is produced in the factory and its quality can be assured and have a rapid construction. The project employs a half-through steel arch bridge and gives a Tsou aboriginal name in accordance with the aboriginal culture and totem. Photos are shown in Figure 15.

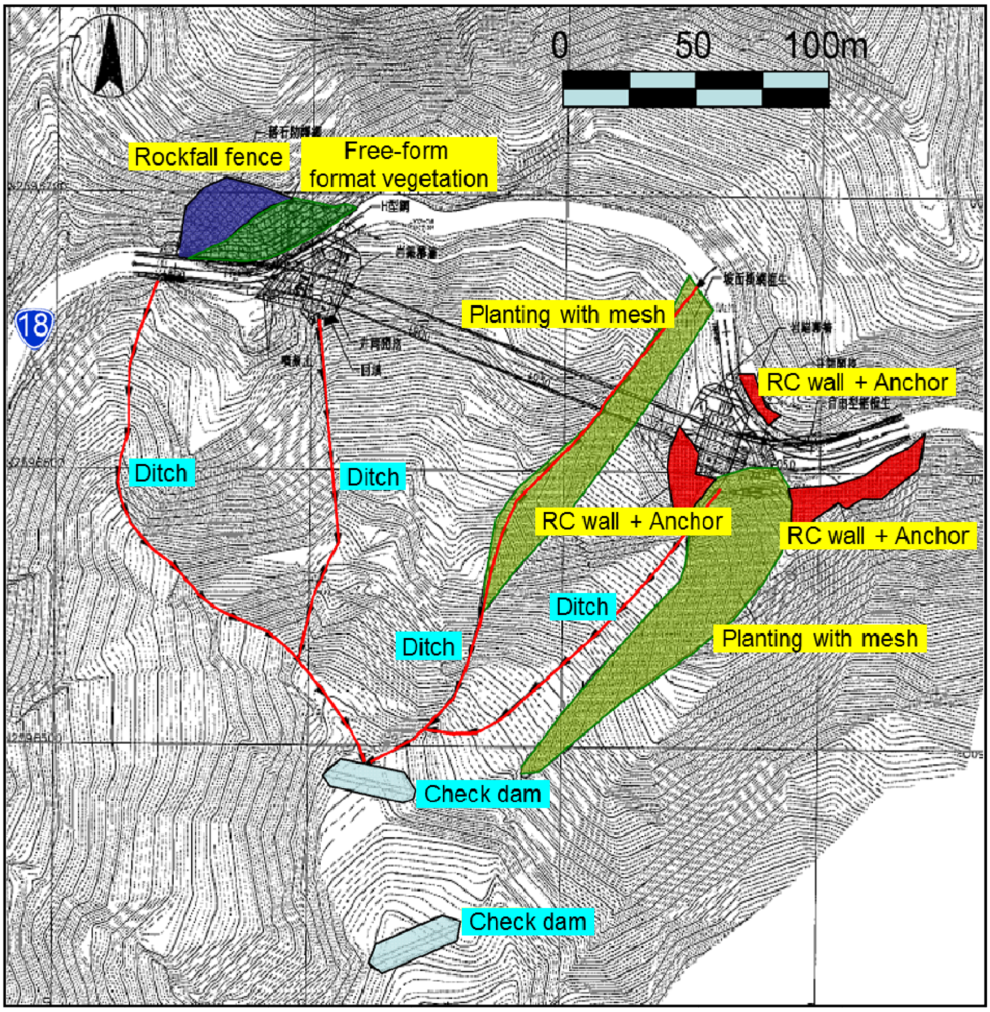

Figure 14 Layout of repair works at Mileage 71.1k of Alishan Route 18

Before

Circular and dip landslide, road cut-off

After

New bridge, avoid the collapse area

Figure 15 Before and after Photos at Mileage 71.1k of Alishan Route 18

4. CONCLUSIONS

Typhoon Morakot brought Taiwan an extra-heavy rainfall and resulted in landslide, debris flow, flooding, cut-off road and isolated island. From post-disaster rehabilitation and many years of relevant experience, the following conclusions can be summarized.

1. Mountain road slope disasters frequently occur in Taiwan. The disaster scale and frequency is getting higher in the past 10 years which is related to 921 Chi-Chi earthquake and heavy rainfall under extreme weather (such as Typhoon Morakot). Therefore, the design and operation of the future road slope shall include the factor of extreme climatic condition. In accordance with investigation results, the slope failure type can be divided into seven categories. They are debris flow, rock falls, upper slope slide of road, lower slope slide of road, the whole slope slide, riverbank erosion and gully erosion which can be served as the reference of disaster investigation, rehabilitation design and maintenance.
2. The upper/lower slope area and adjacent river of road may belong to different authorities. The range of slope disaster may extend many different authorities. Therefore, slope remediation shall deal with all the relevant authorities so that better results of rehabilitation will be achieved.
3. The road rehabilitation countermeasures shall be employed when the disasters range is large and slope slide is not yet fully stable. Rehabilitation must consider the in-situ redevelopment if it is unavoidable or the cost of provention is too high. Through the existing data collection, hydrogeological investigation and monitoring data, the rehabilitation methods and the implementation of design need to consider the causes of disasters and failure mechanism so that effective remediation can be achieved with the long-term safety.

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