

# A RECONNAISSANCE REPORT ON TYPHOON MORAKOT



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### **Disclaimer**

The information presented in this report is as accurate as possible based on the knowledge and findings of the authors at the time of study. This report summarizes observations of performance; it does not attempt to interpret their causes. The photos presented in this report, unless stated otherwise, were taken by the reconnaissance team. The authors identified and reported locations of the sites from *Google Earth*.

## 1. Introduction

Typhoon Morakot (or Typhoon #8) of August 8, 2009, caused significant loss of life and property in Taiwan. As of September 18, 2009, the National Disasters Prevention and Protection Commission has reported 639 identified and 62 unidentified deaths; 58 persons are still missing. An economic loss of over US\$3 billion has been incurred. Morakot was the most damaging typhoon to make landfall in Taiwan in half a century.

Typhoon Morakot had a maximum wind speed of 40m/s and lowest central pressure of 945 kPa. It was classified as a medium strong typhoon (equivalent to a Category 2 hurricane). It brought a new rainfall record of 2777 mm at Alishan (previous rainfall record of 1736 mm was set by Typhoon Herb in 1996). Morakot landed at Hualian, the eastern part of Taiwan, and left at Taoyuan on the western coast. The path of Morakot, its clouds at peak, and the accumulated rainfall from August 7 to August 9, are shown in Figures 1-1 to 1-3, respectively.

The typhoon passed through the central and northern parts of Taiwan. However, torrential rains were primarily concentrated in the south, thus the most heavily damaged areas were in this region. Flooding and landslides led to various types of damage to the infrastructure and geosystems. A total of 44 bridges and 138 highway sections were damaged. Figure 1-4 indicates the areas that were most seriously affected by this disaster.

The reconnaissance trips were made from September 2 to September 6, 2009. Some parts of the disaster area were inaccessible due to the breakdown of the roads and bridges. Reconnaissance sites were chosen along Route 18 (Chiayi County) and Routes 20, 21, and 27 (Kaohsiung County), which reflected typical types of failures due to Typhoon Morakot.

### Web References

National Disasters Prevention and Protection Commission  
<http://88flood.www.gov.tw/>

Central Weather Bureau  
<http://www.cwb.gov.tw/>

Japan Meteorological Agency  
[http://www.data.jma.go.jp/fcd/yoho/typhoon/route\\_map/bstv2009.html](http://www.data.jma.go.jp/fcd/yoho/typhoon/route_map/bstv2009.html)

Failures due to 2004 Mindulle Typhoon  
<http://www.civil.columbia.edu/ling/mindulle/>

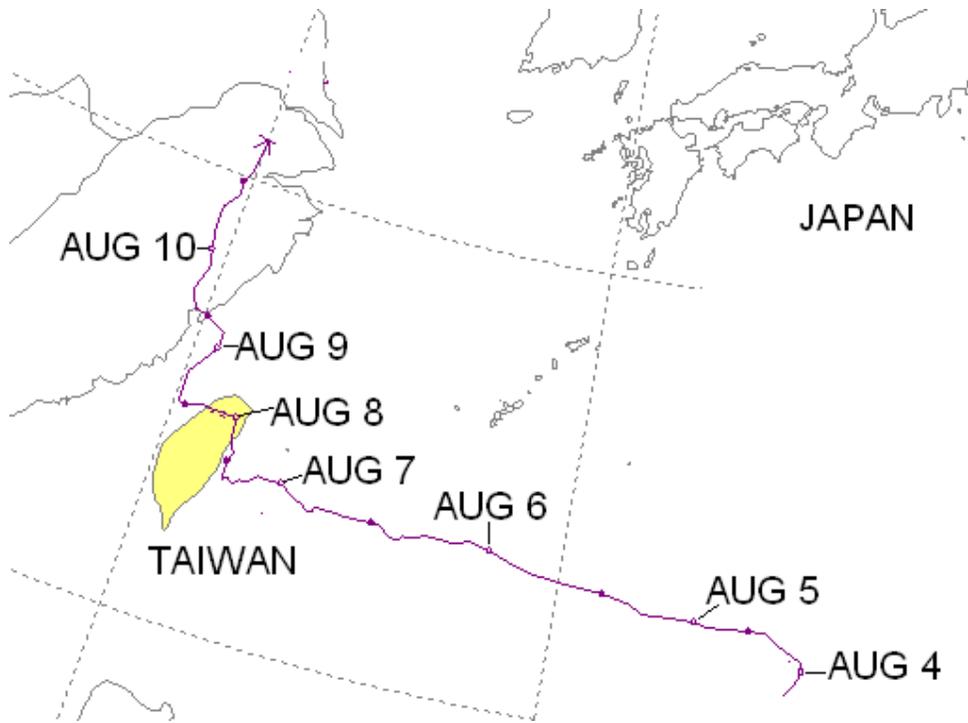


Figure 1-1. Path of Typhoon Morakot (modified from Japan Meteorological Agency).

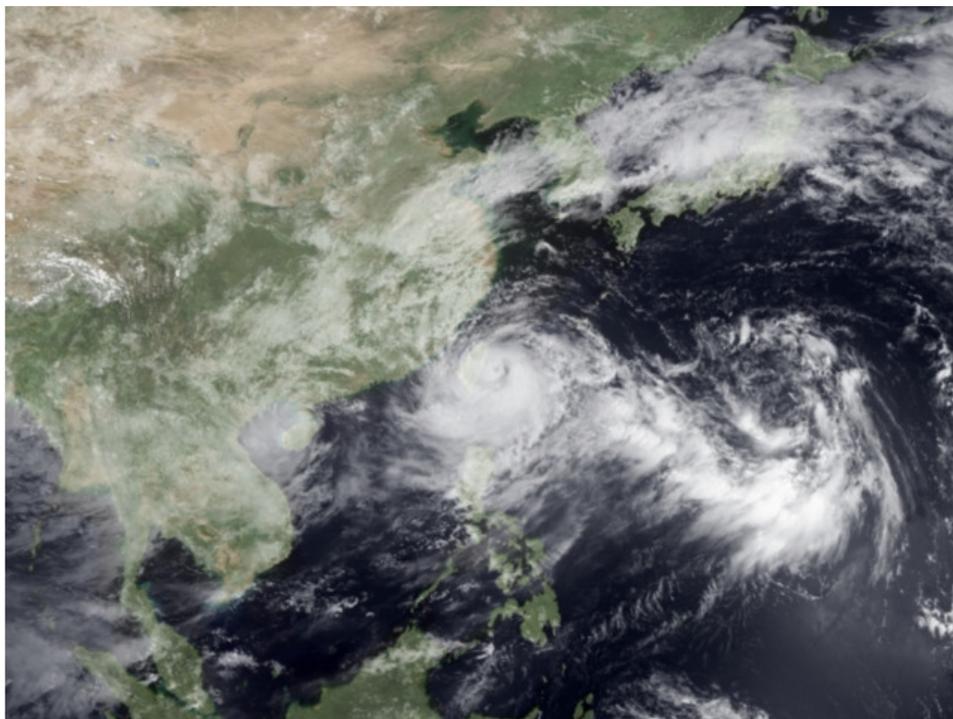


Figure 1-2. Satellite view of Typhoon Morakot on August 7, 2009 at 0130Z (source: [www.nnvl.noaa.gov](http://www.nnvl.noaa.gov)).

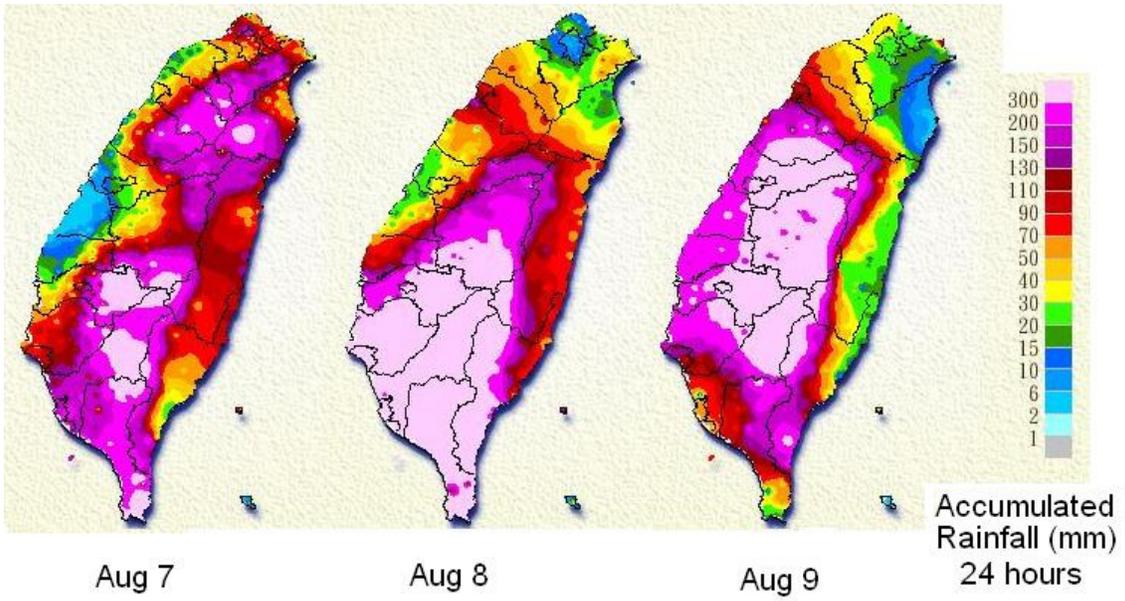


Figure 1-3. Accumulated rainfall due to Typhoon Morakot, August 7 to 9, 2009 (modified from Central Weather Bureau).

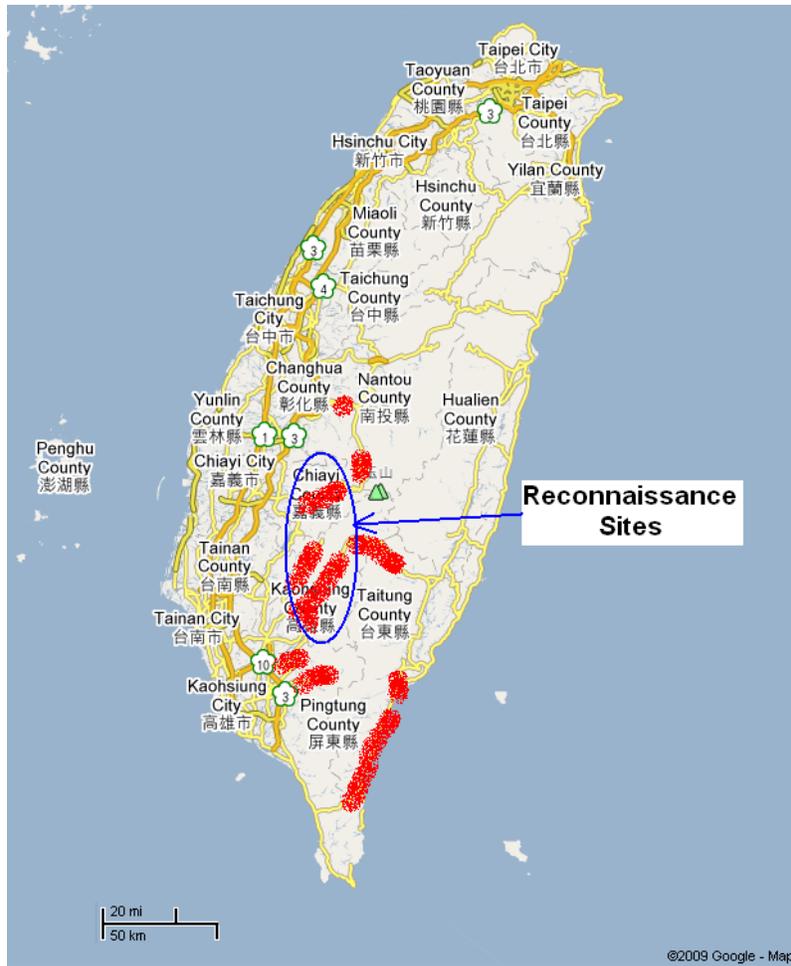


Figure 1-4. Major disaster areas due to Typhoon Morakot.

## 2. Route 20 - Nanbu Cross-Island Highway (南部橫貫公路)

There were many failures along Route 20. Several representative sites are presented in this section.

### 2.1 Jia Xian (甲仙鎮)



#### a) Jia Xian Bridge (甲仙大橋)

Sept 5, 2009; 10:33 am (23°04'51"N 120°35'06"E elev 242 m)

The Jia Xian Bridge was severely damaged by flooding (Photo 2-1-1) and a temporary access was built, as shown in Photo 2-1-2. Part of the bridge deck and piers (with steel pipe) disappeared. The retaining walls near the bridge abutment collapsed due to scouring (Photo 2-1-3).



Photo 2-1-1. Collapsed Jia Xian Bridge.



Photo 2-1-2. Temporary access bridge near Jia Xian Bridge.



Photo 2-1-3. Collapse of retaining walls at the abutment of Jia Xian Bridge.

b) Side Bridge (四德大橋, L= 240 m)  
Sept 5, 2009; 12:58 pm (23°05'26"N 120°35'17"E elev 255 m)

Side Bridge was also damaged by flooding. Almost the entire bridge deck disappeared, and part of the span was carried a distance down the river. Several piers disappeared, though the abutments remained. Timber debris piled at the site. The retaining walls near the bridge failed by scouring.



Photo 2-1-4. Part of the superstructure and pier foundation disappeared (Side Bridge).



Photo 2-1-5. A span was washed downstream (Side Bridge)



Photo 2-1-6. Scouring of the river bank and road. Note that part of a retaining wall stayed in the riverbed (Side Bridge).

Another bridge nearby the site (marked as 3 in the map;  $23^{\circ}05'44''\text{N}$   $120^{\circ}35'39''\text{E}$  elev. 262 m) remained intact, but significant amounts of gravel and timber debris were deposited under the deck and on the road (Photo 2-1-7). Many landslides occurred in the mountains near the site (Photo 2-1-8).



Photo 2-1-7. A bridge nearby Jia Xian Bridge remained intact. The river was filled with debris.



Photo 2-1-8. Landslides in the surrounding mountains.

c) Sept 5, 2009; 1:35 pm ( $23^{\circ}04'32''$   $120^{\circ}36'44''$  elev 458 m)

Along Wenhua Road (文化路), a debris flow inundated a residence and crossed over the road. Boulders of different sizes were observed (Photo 2-1-9).



Photo 2-1-9. Debris flow that originated from the mountain buried a home.



Photo 2-1-10. Overview of debris flow at the road (after cleaning up), leading to a stream on the right.

## 2.2 Taoyuan (桃源鄉)

In the area near Gao Chung (高中) along Baojian Road (寶建路) (Sept 5, 2009; 2:46 pm, 23°07'50"N 120°42'54"E elev 535 m), significant landslides occurred.

Not far from Taoyuan Village (桃源鄉) (2:43 pm; 23°08'24"N 120°43'47"E elev 558 m), a debris flow occurred. The abutment of a bridge failed, leading to the failure of the superstructure. See also the cover photo, which was taken from the end of the bridge.



Photo 2-2-1. Failure of the abutment and superstructure of a bridge.



Photo 2-2-2. Significant slope failure on both sides of the road in Jia Xian Village.

### 2.3 Baolai (寶來)

Sept 5, 2009; 2:20 pm



Baolai is an inland resort village, well known for its hot springs. At Baolai, significant scouring occurred along the banks of the river. Buildings were buried by debris or washed away by flooding. The gate of a temple was seen hanging on the bank after significant erosion [Photo 2-3-1; 23°06'39"N 120°42'17"E elev 399 m].

Landslides occurred over an extended length of Shinbao Road (新寶路) [Photo 2-3-2; 23°06'36"N 120°42'34"E elev 436 m]. Buildings and a hotel located at the river bank were partially buried by the debris [Photos 2-3-3, 2-3-4; 23°06'36"N 120°42'29"E elev 413 m].

One of the abutments of Baolai Bridge #2 (L=174.4 m; 23°06'41"N 120°42'18"E elev 398 m) was damaged (Photo 2-3-5; ). The depth from Bridges #1 and #2 to the water was reduced from 10+ m to just a few meters due to debris deposition (Photo 2-3-6). A building located at the north end of the village, close to Bridge #2, was damaged by the debris (Photo 2-3-7; 23°06'40"N 120°42'12"E elev 399 m). Landslides were seen along the sides of the river, at the northern end of the map (Photo 2-3-8; 23°06'48"N 120°42'08"E).



Photo 2-3-1. "Hanging Gate" of a temple [Location 1]



Photo 2-3-2. Large scale landslides along Shinbao Road [Location 2]



Photo 2-3-3. First floor of a hotel buried by debris [Location 3]



Photo 2-3-4. Buildings damaged by scouring and debris flow [Location 3]



Photo 2-3-5. Damaged abutment and deck of Bridge #2 .



Photo 2-3-6. The vertical clearance of Bridge #2 was significantly reduced by debris deposition.



Photo 2-3-7. A building near Bridge #2 was damaged by the debris flow.



Photo 2-3-8. Large-scale slope failure near the river bank [Location 4]

#### **2.4 Shinkai (新開部落)**

Sept 5, 2009; 3:59 pm (23°03'36"N 120°40'48"E elev 372 m)

In the village of Shinkai, 32 persons were buried alive by a debris flow. The village was cut off for many days due to the damage of its bridge. Buildings were covered by material deposited from the debris flow. Several buildings were excavated, leaving behind ponds of water.



Photo 2-4-1. Debris flow at Shinkai Village.



Photo 2-4-2. Excavation of buried buildings.



Photo 2-4-3. Car remains found near the village.

### 3. ROUTE 21

#### 3.1 General Observations

Many landslides occurred along Route 21. Slides were encountered approximately every few hundred meters. Some of the landslides and retaining wall failures led to the full or partial closure of the road (Photos 3-1-1 to 3-1-3). The soil along this route is composed of decomposed rocks and cohesive soils.



Photo 3-1-1. Typical landslide along Route 21. .



Photo 3-1-2. Typical case of retaining wall failure.



Photo 3-1-3. Typical case of retaining wall failure.



Photo 3-1-4. Typical case of retaining wall failure.

### 3.2 Jia Xian

Sept 5, 2009; 10:56 am (23°07'47"N 120°37'26"E elev 376 m)

Along Route 21 at Sanmin Industry Road (三民產業道路) near Jia Xian, debris had blocked the road. Evidence of damage caused by debris flow included damage to the bridge superstructure and blockage of the river due to debris deposition.



Photo 3-2-1. Damage to the bridge and road by debris flow

### 3.3 Hsiao Lin (小林村)

Sept 5, 2009; 11:07 am (23°09'39"N 120°38'36"E elev 377 m)

The reconnaissance along Route 21 ended at Hsiao Lin Village, where a bridge was damaged. More than 400 people were buried alive by debris flow. One debris flow originated from mountains to the left of the photo, while another debris flow occurred from the mountains on the opposite side of the river. The debris is estimated to be several meters deep, thus recovery of bodies has been abandoned.



Photo 3-3-1. Satellite view of Hsiao Lin Village before the disaster.



Photo 3-3-2. Hsiao Lin Village was devastated by debris flow. Only two houses were left, as can be seen on the right side of the photo. More than 400 people were buried by the debris.

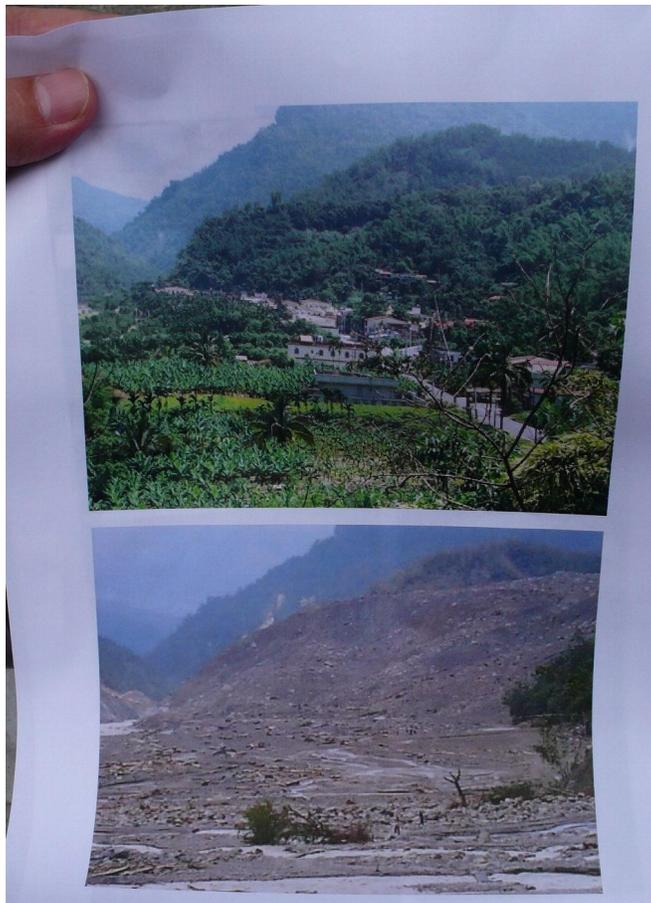


Photo 3-3-3. An officer showing the photos comparing the village before and after the disaster.

## 4. Routes 27 and 27A (Laonong River)

### 4.1 Liou Guei (六龜鄉)

a) Liou Guei Bridge (Sept 6, 2009; 10:24am; 22°59'42"N 120°38'23"E elev 232 m), located along Route 27A, was seriously damaged by flooding. Timber debris was left on the bridge deck and in the river. The river banks were seriously eroded. At locations close to the bridge, some retaining walls collapsed.





Photo 4-1-1. Part of Liou Guei Bridge was destroyed.



Photo 4-1-2. A closer view of Liou Guei Bridge.



Photo 4-1-3. Timber debris and sediments piled up on the deck.



Photo 4-1-4. Collapse of retaining walls near the bridge.



Photo 4-1-5. A temporary access road that crossed the river.



Photo 4-1-6. River banks were seriously eroded.

## 4.2 Route 27A

Down river (Laonong River), the road was seriously eroded (a major part of it had disappeared). An old tunnel that had been closed was temporarily reopened for traffic. The visitor center's buildings collapsed because of extensive scouring.



Photo 4-2-1. The primary road was damaged, thus part of the river bank was used as a temporary access road.



Photo 4-2-2. An old tunnel was reopened for traffic after the main road was damaged by scour.



Photo 4-2-3. The Liou Guei Visitor Center collapsed because of scour.

### 4.3 Maolin (茂林)

Routes 27 and 132

The old Dajin Bridge (大津橋) (Sept 6, 2009; 11:15 am; 22°52'47"N 120°38'51"E elev 146 m) was damaged by flooding. The deck disappeared entirely; only the steel members remained.

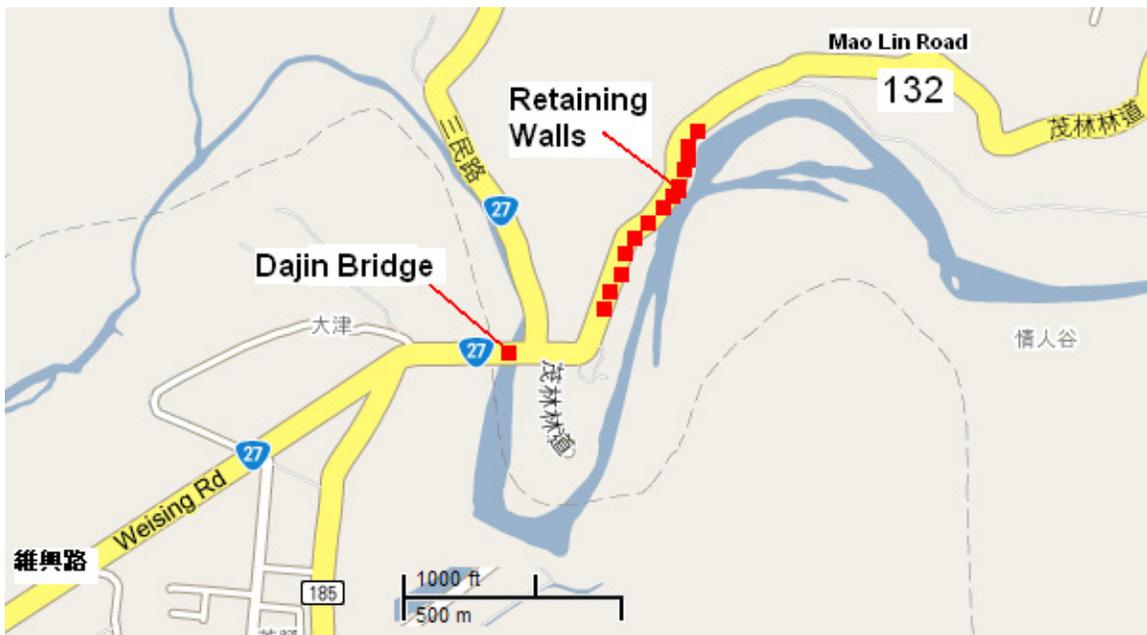




Photo 4-3-1. Dajin Bridge was damaged by flooding.

At the entrance to Mao Lin Village (茂林鄉), the riverbed was seriously eroded. The visitor center was washed away, leaving only debris.



Photo 4-3-3. Debris of Mao Lin Visitor Center.

A section of retaining walls were observed (Sept 6, 2009; 11:19 am;  $22^{\circ}53'02''N$   $120^{\circ}39'08''E$  elev 169 m). The upper retaining wall was partially damaged; however, it was able to arrest some of the rock debris. This portion was a gravity retaining wall.

The lower cantilever wall, which retained the highway, was partially damaged. Portions of the wall tilted significantly. This wall ranged from 6 to 12 m tall.

Beyond the retaining walls, the slope failed. This cut off Route 132, which provides access to Mao Lin Village.



Photo 4-3-4. Retaining wall on Route 132.



Photo 4-3-5. A closer view of collapsed retaining walls. Temporary access road under construction down on the river bank

## 5. ROUTE 18 - Alishan Highway

### 5.1 General

Route 18 is the only access road to the Alishan Township. Alishan is a mountainous area, and it is one of the most important tourist destinations in Taiwan. The region is also an important agricultural area for tea; some parts of the mountains have been cleared for beetle nut and tea plantations. This action drew criticism as a major cause of soil erosion. Alishan is also home several aboriginal tribes.

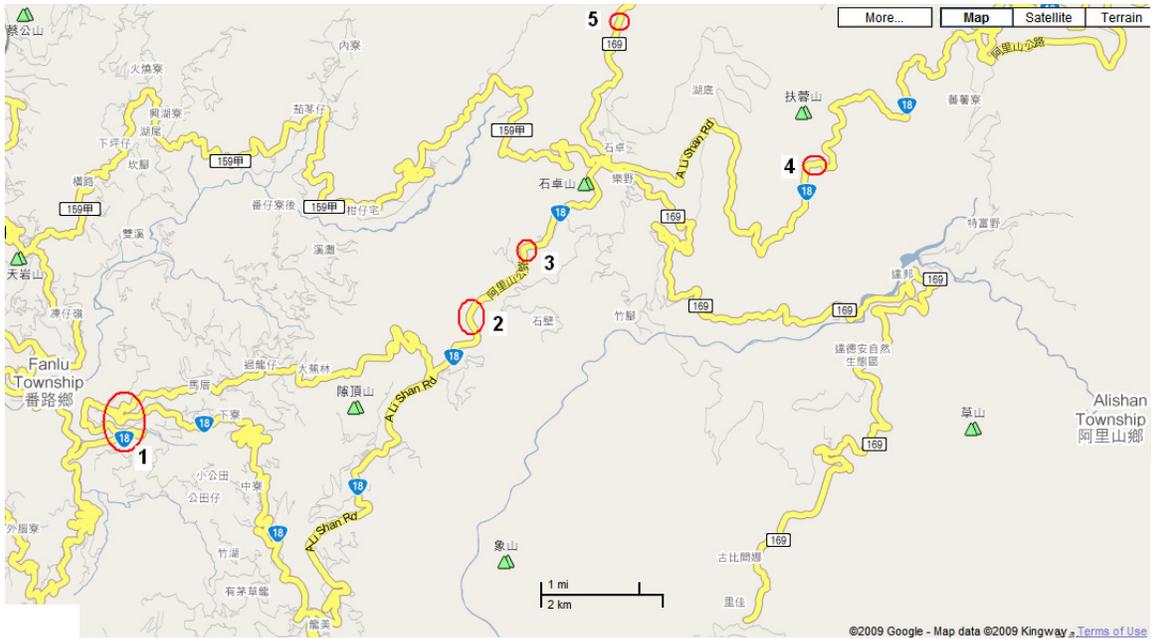


Photo 5-1-1. Beetle nut plantation.



Photo 5-1-2. Tea plantation.

Many sections of Route 18 were damaged by Typhoon Morakot. Reconstruction may take up to 2 years, posing a serious threat to the local economy. The damages of the following sites (1-5) are presented in this report.



## 5.2 Site 1

Sept 2, 2009; 10:15 am (23°26'03"N 120°37'06"E elev 393-497 m)



Photo 5-2-1. The road was buried by a debris flow which traveled from the top of a mountain down to a stream.



Photo 5-2-2. A retaining wall damaged by landslides.



Photo 5-2-3. Another damaged retaining wall.



Photo 5-2-4. Gabions were used in the lower part of the slope.



Photo 5-2-5. Pavement damaged by slope movement.



Photo 5-2-6. An electricity transmission tower damaged by landslides.



Photo 5-2-7. The beetle nut plantation was damaged by soil movement. Part of Route 18 and other landslide sites can be seen in the photo.

### 5.3 Site 2

Sept 2, 2009; 11:36 am (23°27'03"N 120°40'37" elev 1224 m)

At this site, a shed was constructed to protect the highway from debris flow and to divert the debris toward the valley. Since the shed was built in more than one section, soil movement caused differential settlement of the road within the structure. Part of the shed also moved laterally.



Photo 5-3-1. Debris flow was seen at one end of the shed. Part of the shed was buried.



Photo 5-3-2. Differential settlement of road inside the shed.



Photo 5-3-3. One of the sections of the shed displaced relative to the stable section.



Photo 5-3-4. The other sections did not exhibit relative displacement.

A short distance away from the shed, a large stretch of highway collapsed due to landslides.



Photo 5-3-5. Landslides damaged several hundred meters of the existing roadway. The mountain was cut to create a new access road.



Photo 5-3-6. The surrounding area was dotted with many landslides.

### 5.4 SITE 3

Sept 2, 2009; 12:13 pm (23°27'36"N 120°41'07"E elev 1240 m)

This was the site of a large landslide. The highway was lost and an access road was constructed.



Photo 5-4-1. Landslides. Note the original location of highway and new access road

### 5.5 SITE 4

Sept 2, 2009; 2:33 pm (23°28'22"N 120°43'55"E elev 1483 m)



Photo 5-5-1. Another site with the shed.



Photo 5-5-2. Construction joints remained intact; these did not show evidence of relative displacement.



Photo 5-5-3. Several hundred meters of the highway were lost due to a landslide.

## 5.6 SITE 5

Sept 2, 2009; 3:58 pm (23°29'36"N 120°42'01"E elev 1375 m)

This debris flow site was located at Route 169.



Photo 5-6-1. Source of debris flow can be seen in the distance, up the mountain.



Photo 5-6-2. Debris flow with boulders and gravel of various sizes. The road has been cleared for traffic.



Photo 5-6-3. A building partially buried by debris flow



Photo 5-6-4. The Jersey Barrier was reported to have blocked the water from draining during heavy rainfall



Photo 5-6-5. A different form of barrier which allowed free drainage of rainwater.



Photo 5-6-6. The loss of foundation due to landslides led to the collapse of many retaining walls.

## 5.7 OTHER SITES

There were numerous landslides in the area, as can be seen below.



Photo 5-7-1. Landslides



Photo 5-7-2. Landslides



Photo 5-7-3. A closer view of huge landslides of Photo 5-7-2



Photo 5-7-4. Landslides