Landform variation analysis and safety evaluation for the Central-Traverse temporary detour

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ABSTRACT

The Guguan to Deji section of the Central-Traverse Highway has been blocked since Chi-Chi earthquake in 1999. Due to humane consideration, the highway has been detoured and repaired to passable stage in 2012.The Central-Traverse temporary detour is functionally defined for emergency and rescue purposes. In order to figure out the safety and the risk of the road under fragile geological conditions, an analysis of landform variation has been doing since 2012, by multi-period remote sensing images interpretation, UAV photography interpretation, and airborne LiDAR technology, to understand the progression of terrain change. On the basis of the landform variation analysis, geological investigation and disaster records are integrated into safety evaluation to define landslide-related disaster potential of the Central-Traverse temporary detour.

Keywords: The Central-Traverse temporary detour; landform variation analysis; remote sensing images; airborne Lidar technology; safety evaluation

1 INTRODUCTION

The Guguan to Deji section of the Central-Traverse Highway was damaged by Chi-Chi earthquake in 1999. It was rebuilt twice and intended to reopen to the public. However, 517-earthquake in 2000 and 72-flood in 2004 destroyed it again. The Secretariat of the Executive Yuan therefore stated that the reconstruction was suspended. Local residents continued to express their expectations and asked to rebuild in the after 3 years. Under such pressures, the Executive Yuan instructed the Directorate General of Highways to evaluate the feasibility of reconstruction in November, 2006. After the assessment, it was proposed to a simple re-construction at the end of May, 2007. On October 6, 2008, the 1,338th review conference of the Economic Development Committee of the Executive Yuan had concluded, "The Directorate General of Highways is asked to consider the feasibility of construction methods, geological conditions, construction safety, disaster risks, and limits of open objects, time zones, and traffic safety, etc. and adopt a method which can achieve quick recovery and implementation to avoid disturbing the slopes, shorten the construction times, and accelerate the handling procedure. Besides, the detour is defined for emergency and rescue purposes. Thus, traffic safety, management, and maintenance measures should be strictly controlled to prevent local residents and the public from misunderstanding their functionality." The detour project, 7 steel rock sheds and slope protections were constructed in the high and middle potential rock fall areas, was completed at the end of May, 2012. The detour is still under control and repaired immediately after being damaged.

Fig. 1. The Scope of the project

In order to figure out the safety and the risk of the road under fragile geological conditions, the Directorate General of Highways held a project, Landform Variation Analysis, Safety Evaluation and Study for the Guguan to Deji Section of the Central- Traverse Highway, to understand landform changing process, disaster trigger factors, and disaster potential for evaluating feasibility and safety of realignment plan, including route, bridges, and tunnels by an analysis of landform variation in March, 2012. The project covered the Central-Traverse temporary detour, 0~23.6K of provincial highway No.8 temporary 37 and the Central-Traverse upper route, 44~62K of provincial highway No.8, shown in Fig.1.

2 LANDFORM VARIATION ANALYSIS

2.1 Satellite images

Formosa satellite No.2 is the first domestic, self-controlled, optical, telemetric, scientific satellite. Due to its daily revisiting characteristics, it can provide nearly instant high resolution satellite images, which are beneficial to understanding disasters' condition well and mastering the timeliness of disaster relief works. Since its launch in 2004, it has participated in the collection of disasters information at home and abroad. The project has completed the analyses and the interpretations before and after the typhoon and the heavy rainfall events since 2006 to 2016, a total of 28 issues, from Formosa No.2's images. The result of the interpretation from the remote sensing image in 2016 is shown in Fig. 2.

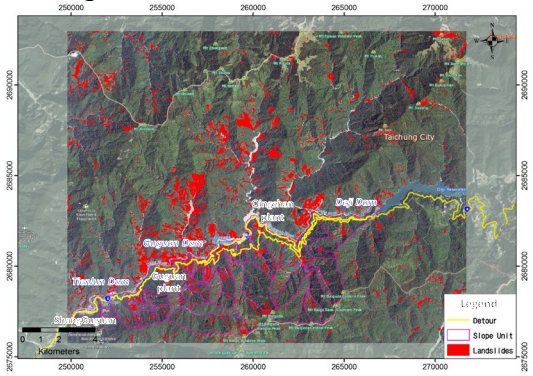
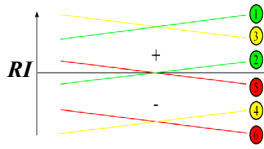


Fig. 2. The result of landslide areas interpretation from satellite images

The Typhoon Soulik in 2013, the Typhoon Matmo in 2014, the Typhoon Soudelor in 2015, and June, 2016, a total of 4 periods' satellite images are chosen in the project for estimating the Recovery Index (RI), the recovery trend in the recent years.

$$RI = \frac{recovery\ ratio - increased\ landslide\ ratio}{landslide\ ratio} \quad (1)$$

The calculations of RI are based on the slope units, which divide the slope areas into 59 parts and the Central-Traverse temporary detour into 31 sections. The results are classified into 3 types, shown in Fig. 3. The recovery trend in recent years of each section of the detour is listed in Table 1.



LIGHT	REGRESSION TYPE	CLASSIFICATION
Green	1、2	Continual Collapsing
Yellow	3、4	Partial Collapsing, Partial Recovering
Red	5、6	Continual Recovering

Fig. 3. Recovery trend classification by RI

In order to evaluating the transition of the landslide areas, the Japanese scholar Inoue's research (1995) are referred. Chi-Chi earthquake is taken as a major event, starting from the pre-earthquake and aiming for a total of 18 years' historical images from 1999 to 2016. The relationship between the landslide areas and time are analyzed for drawing the landslide areas transition curve (Fig. 4) by the second polynomial regression method. The curve shows 4 different periods of the project area. The project area is now located in recovered period and will enter stable period in 2025.

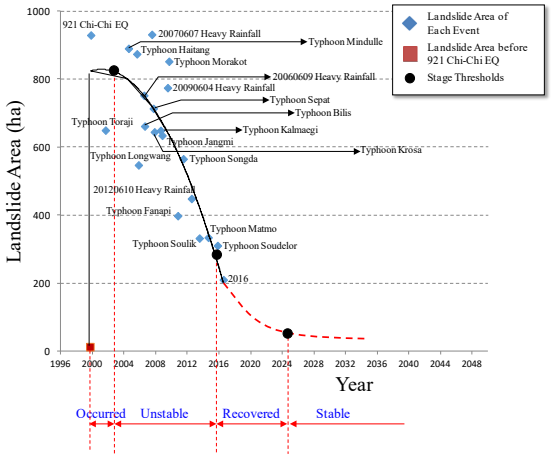


Fig. 4. :Landslide areas transition curve

Furthermore, the curve is used to estimate the long-term variation after Chi-Chi earthquake by calculating the landslide ratio corresponding to the ratio at the demarcation point of each period. Each section of the detour can be classified in 3 periods, unstable period (red light), recovered period (yellow light), and stable period (green light), which is listed in Table 1. as well.

Table 1. The evaluation results from the satellite images

Section	Mileage (K)	RI	Curve
1	0-0.5	Recovering	Stable
2	0.5-0.9	Recovering	Stable
3	0.9-1.0	Recovering	Recovered
4	1.0-1.6	Recovering	Stable
5	1.6-1.7	Partial	Stable
6	1.7-3.4	Recovering	Stable
7	3.4-4.5	Recovering	Recovered
8	4.5-4.9	Recovering	Recovered
9	4.9-5.6	Recovering	Recovered
10	5.6-6.3	Recovering	Recovered

Section	Mileage (K)	RI	Curve
11	6.3-6.7	Recovering	Unstable
12	6.7-7.1	Collapsing	Recovered
13	7.1-7.6	Recovering	Recovered
14	7.6-7.8	Recovering	Recovered
15	7.8-8.3	Recovering	Unstable
16	8.3	Recovering	Recovered
17	8.3-8.6	Collapsing	Recovered
18	8.6-9.6	Recovering	Unstable
19	9.6-10.7	Recovering	Recovered
20	10.7-10.8	Recovering	Recovered
21	10.8-11.9	Partial	Stable
22	11.9	Recovering	Recovered
23	11.9-13.1	Recovering	Recovered
24	13.1-14.3	Recovering	Unstable
25	14.3-15.8	Recovering	Recovered
26	15.8-17.1	Collapsing	Recovered
27	17.1-17.7	Collapsing	Unstable
28	17.7-17.9	Recovering	Stable
29	17.9-18.5	Recovering	Recovered
30	18.5-19.9	Recovering	Recovered
31	19.9-23.6	Recovering	Recovered

2.2 LiDAR DEM

The airborne LiDAR technology is used for producing high-precision digital elevation model, DEM. The terrain variation analysis is carried out with the LiDAR DEM of 2012 and 2016. The results of this 4-year-interval analysis are shown in Fig. 5. The method is simply to find out the elevation difference of each single grid between these 2 DEMs. If the value is negative, it means loss. Otherwise, it means deposit. After multiplying the area of the grid, we obtain the amount of terrain volume variation of a single grid.

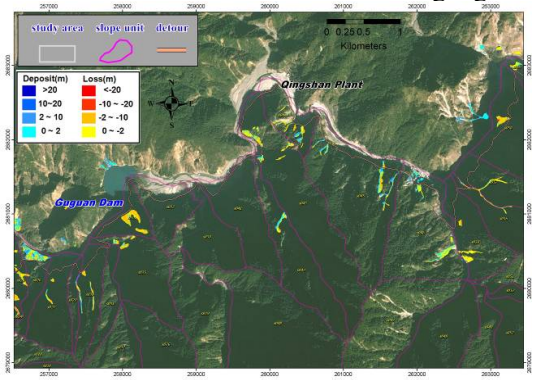


Fig. 5. The result of terrain differentials from DTM, LiDAR

If the differentials occur directly adjacent to the road, it will easily cause damages. 7 sections are considered as dangerous sections and their mileages are 0.5K-0.9K, 1.0K-1.6K, 3.4K-4.5K, 4.9. K-7.6K, 7.8K-8.6K, 11.9K-17.7K, and 18.5K-23.6K.

2.3 UAV photography

The unmanned aerial vehicle (UAV) used in this project is a mid-voyage, push-type, fixed-wing UAV. It worked for emergency imaging operation in response to the heavy rainfall incident on June 10, 2012. The task was planned according to the specifications, and characteristics of the UAV system and the terrain in the area was taking into account. The flight was taken off from the river embankment of the park in Shigang, Taichung, and it was flown into the work area along the Dajia River.

In order to improve the image overlap rate, when the camera reaches the shooting zone, the camera preset to take a photo every 3.4 seconds. The total number of photos taken was 1,284, and the computer on the UAV can accurately record each image's exposure position, external orientation (EO) data, flight path, and photo coverage. The result of the stitching images after correcting is shown in Fig. 6. After the artificially preliminary interpretation, a total of 42 landslides may affect the safety of the sections of the Central-Traverse temporary detour.

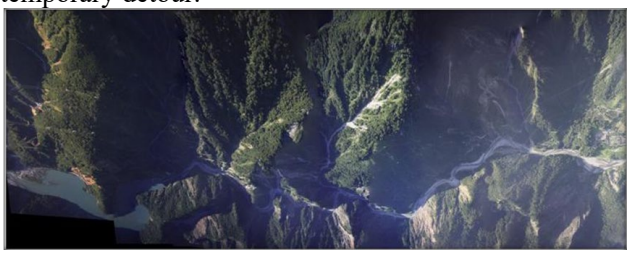


Fig. 6. The result of the stitching image from UAV (partial)

2.4 Site investigation

The site investigation is mainly for the vulnerable slope along the Central-Traverse temporary detour. Factual conditions of rock falls, debris slides, debris flows, rock mass slides, and erosion gully were detailedly recorded, such as types of the environmental geological hazards, characteristics of the hazards, vegetation, etc. In addition, the photos of the hazards with coordination by GPS, numbers, and directions were saved simultaneously. The disaster transition of the slope and the results of the site investigation were collected for subsequent analysis, evaluation, and countermeasures. The statistic from the investigation in 2016 is listed in Table 2.

Table 2. The statistic from the site investigation

	Rock Fall	Debris Slide	Debris Flow
Central-Traverse temporary detour (Before 6.8K)	17	9	6
Central-Traverse temporary detour (After 6.8K)	42	30	11
Central-Traverse upper route	26	30	14
Total	85	69	31

2.5 Potential analysis

The geological hazard potential analysis is based on the slope unit. The analysis is aimed at 4 different types of geological hazards, including rock fall, debris slide, rock mass slide, and debris flow. The mapping requirements and the required data for analysis include: slope unit, slope (grade) obtained from LiDAR DEM, and the various hazardous records, environmental geological factors, lithology combination, rock mass

strength, engineering geological parameters on the basic environmental geological map. Finally, the geological hazard potential maps based on the results of analysis and evaluation are produced.

2.6 Rock fall records

The non-vegetated bare slopes along the Central-Traverse temporary detour can be seen everywhere due to the fragile geology condition. Rock fall disasters are ubiquitous. The rock fall removal records were provided by the government for the past 3 years is used for the evaluation. However, this information mainly shows the frequency of the rock fall disasters occurrence and does not fully reflect its impact on the detour.

3 LANDSLIDE-RELATED DISASTER POTENTIAL EVALUATION

The detour section will be considered as with damage caused potential if it match follow conditions,

1. Satellite Image: either evaluation from satellite image, RI or Curve in Table 1, results in red light.
2. Digital Elevation: the differentials calculated by 2 period's DEM occur directly adjacent to the detour.
3. Unmanned Vehicle: the landslides may affect the safety of the detour sections after the artificially preliminary interpretation from UAV images.
4. Site Investigation: the detour sections correspond to the slope unit with geological hazards recorded during site investigation.
5. Potential Analysis: the detour sections correspond to the slope unit with high geological hazards potential.
6. Rock Fall: according to the rock fall records in Table3, for the sections which occurred 30~50 times per kilometer will be defined as yellow light; for the sections which occurred over 50 times per kilometer or more than 2 times caused the road interruption will be defined as red light.

The detour sections will be divided into 3 levels of landslide-related disaster potential through the principle below,

A. High potential

1. "Rock Fall" factor shows red light.
2. "Rock Fall" factor shows yellow light and "Satellites Images" factor concludes the detour section with damage caused potential.

B. Medium potential

1. "Rock Fall" factor shows yellow light.
2. "Satellites Images" factor concludes the detour section with damage caused potential and any 3 factors among "Digital Elevation," "Unmanned Vehicle," "Site Investigation," "Potential Analysis" conclude the detour section with damage caused potential.
3. All 4 factors, "Digital Elevation," "Unmanned Vehicle," "Site Investigation," and "Potential Analysis," conclude the detour section with damage caused potential.

C. Low potential

The rest of the detour sections that are not evaluated either high or medium potential.

The final results of evaluation are shown in Fig. 6.

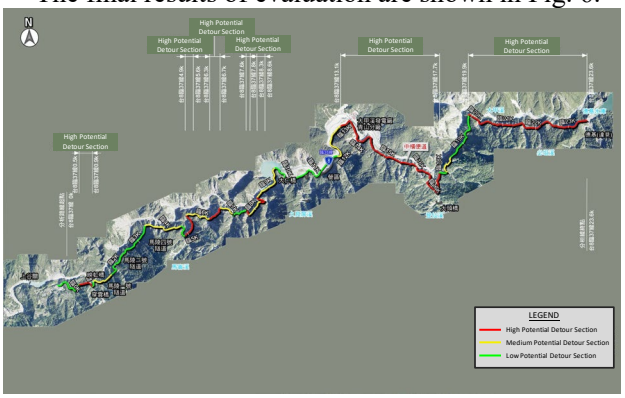


Fig. 6. The landslide-related disaster potential evaluation of the Central-Traverse temporary detour

4 CONCLUSION

The project is positioned as a pre-study before the feasibility study. The research results of the analysis of the landform variation show that the project area has now entered the recovered period. However, in recent years, climate change has caused extreme rainfall to occur frequently. Even though it is preliminarily believed that most of the unstable sources accumulated on the slope after Chi-Chi earthquake have been brought into the Dajia River by the rains over the years, it is still difficult to eliminate the possibility of the large scale and new landslide triggered by the extreme events in the future. The project will continue to track and monitor the landslide trend of the area and conduct a rolling review.

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