The Case Study of the Taiwan Railway Express Train Derailment Caused by Debris Flow Following the 0403 Earthquake

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The Hualien Earthquake (April 3, 2024) triggered numerous landslides and sediment deposits in the upland area, which could easily flow downstream with rainfall runoff. This study takes the derailment of the Taiwan Railway Express train caused by the debris flow of Hualien Daqingshuishi Creek (DF024) on June 21, 2024. To understand how the debris flows affected the railway tracks, the satellite image, rainfall data, UAV photos, and numerical models were used to investigate the river channel variations, the impact of debris flow, and provide subsequent engineering improvement recommendations. The result indicates that the first wave of debris flows flush downstream on the afternoon of June 20, depositing lots of sediment in the channel. Due to the increment of riverbed deposition and characteristic of the river bend, the second debris flow surge flushed onto the railway tracks and caused the train to go off the rails on June 21. The engineering refinement of numerical simulation indicates that the river bend embankment can provide better protection to avoid debris flow erosion on the bank and debris overflow onto the rails.

Keywords: earthquake, Hyper KANAKO, debris flow simulation, engineering refinement

1. INTRODUCTION

Large earthquakes and related co-seismic landslides can disturb the duration of sediment activity, which is closely affected by rainfall threshold, peak ground acceleration, and post-seismic landslide susceptibility. The large amount of sediment deposited in the upland area will gradually be transported downstream by rainfall runoff. The co-seismic landslide was composed of plenty of fine sediment, which will increase the risk of unstable sediment transport activity and easily form debris flow disasters.

After a large earthquake occurred, the threshold for debris flow initiated was drastically reduced [Lin et al., 2004; Lin et al., 2006; Shieh et al., 2009] and the sediment activity reached a peak in the period of the first 5-10-year [Tang et al., 2009; Yu et al., 2014]. Due to the large number of loose sediments deposited on the hillslope, the post-seismic debris flow activity will be triggered easily by rainfall [Shieh et al., 2009; Yu et al., 2014; Chen, 2011; Liu et al., 2021]. The co-seismic landslide deposits on hillslopes will trigger debris flow activity, and the amount of deposited material gradually decrease, which can last from 10 to 40 years after the earthquake [Shieh et al., 2009; Tang et al., 2009; Tang et al., 2016; Tanyas et al., 2021].

The effect of the earthquake on debris flow activity was longer than expected because of the larger peak ground acceleration, abundant of co-seismic landslides, enough local relief, and different rainfall conditions on seasonality and extreme events [Yu et al., 2014; Tanyas et al, 2021]. Lin et al. (2004), Yu et al. (2014), and Chen and Huang (2021) reported that the rainfall criteria decreased from 1/6 to 1/3 of the value triggering debris flow before the larger earthquake, which indicates that the large earthquakes had a different impact on the individual area for rainfall threshold to initiate debris flow.

On 3 April 2024, the Hualien Earthquake triggered numerous landslides in Hualien country. The landslides identified by satellite image yielded 1,942 new landslides and those co-seismic landslide areas reached 1.521*10^7 m^2. The debris flow of Hualien Daqingshuishi Creek (DF024) flushed the debris flow in the condition of cumulative rainfall of merely 12 mm and induced the Taiwan Railway Express Train to derail.

To understand the impact of the Hualien Earthquake on the debris flow and its consequent effect on downstream traffic lines, this study mainly focuses on the Hualien Daqingshuishi Creek (DF024). The purposes of this paper are: (1) to use field investigations and numerical simulations to analyze the debris flow characteristics of this creek; (2) to introduce engineering refinement for disaster prevention management.

2. MATERIALS AND METHODS

2.1 Study area

The Hualien Daqingshuishi Creek (DF024) in Hsiulin district, Hualien County, has a catchment area of 5.29 km^2, and the downstream outflow area has Provincial Highway No.9 and Taiwan Rail pass-through. The landslides identified from the SPOT and Planet image after the Hualien Earthquake comprised 25 new landslides, the area is 316,788 m^2, and the new landslide ratio reaches 6 % (Figure 1).

The first debris flow event occurred in the afternoon around 4:00 to 5:00 PM (June 20, 2024) and the cumulated rainfall was 43.5 mm and rainfall intensity was 28.5 mm/hr (Qingshuituanyai, C0Z31). The second debris flow event occurred at 4:50 PM (June 21, 2024) and the cumulated rainfall was merely 12 mm and the rainfall intensity was 5 mm/hr (Figure 2). This railway accident caused 9 people to get injured and damaged part of the train (Figure 3). Analysis of the field investigation data, UAV photos, and 3D models reveal that the downstream reach is not a straight shape but with a mild curve. This topographic feature leads the debris flow flowing along the left side path and direct rush into the bridge approaches (Figure 4).

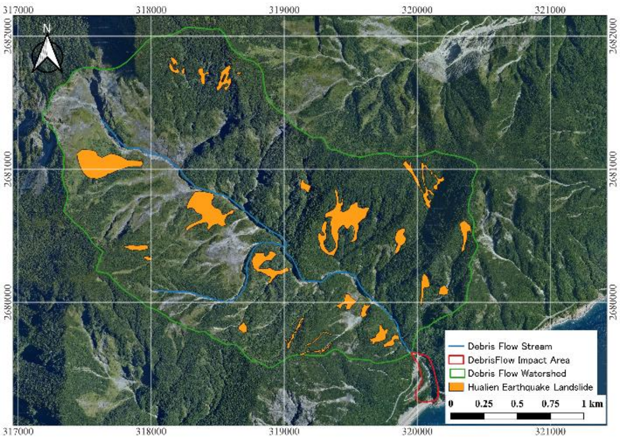

Figure 1 Site of the Study area.

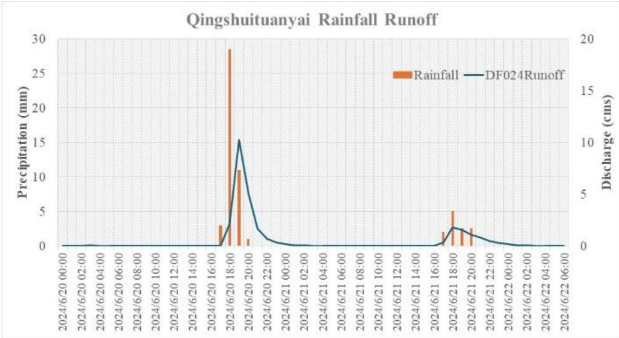

Figure 2 Rainfall hydrograph of Qingshuituanyai Rain Gauge.

Figure 3 Photo of Taiwan Railway Express Train derail (source: SETN.com).

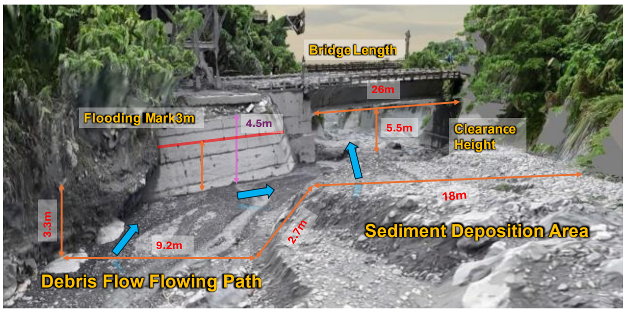

Figure 4 3D model of debris flow disaster area.

2.2 Study methods

The field investigations, DEM, rainfall records, satellite images, UAV photos, and 3D models are used as the basic data to set up the numerical simulations. The debris flow simulation applied KANAKO-2D to simulate the debris flow disaster and considered an engineering refinement of riverbank protection work. The KANAKO-2D was set up with the geometry data from DEM (resolution 2m x 2m) and inflow boundary calculated from rainfall station records. The parameters used in the model are listed in Table 1 and include the derailment accident event, a 50-year return period, and riverbank protection work scenarios.

3. RESULTS

The simulation of the derailed accident rainfall event indicates that the debris flow directly impacts the bridge embankment in its flowing path. The depth of debris flow was not higher than the bridge approaches, which means it shouldn't result in the train derailing (Figure 5 Left). Here our inference would be that the river bend effect on debris flow can result in the surge splashing onto the railway. The simulation of the 50-year return period case shows that the debris flow mainly deposits on the left side of the channel to form the maximum channel deposition depth and could overflow onto the railway (Figure 5 Right).

Due to the mild slope of the riverbed dredge, debris mostly deposits before the bridge approaches (Figure 6 Left). The engineering refinement consists of riverbed dredging with riverbank protection work possible to avoid debris flow rushing onto the railway (Figure 6 Right). However, the riverbank protection work will narrow the channel space and cause the debris to flow higher than only riverbed dredge work. The simulation result of the engineering refinement effect on the debris flow, which will not rush onto the railway (Figures 5 and 6).

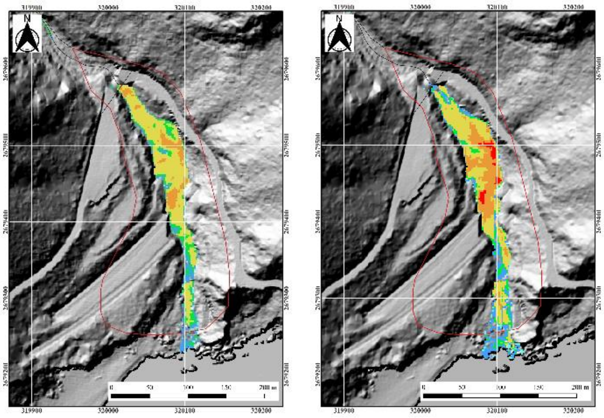

Figure 5 Simulation result of debris flow event (Left: rainfall event case; Right: 50-year return period case).

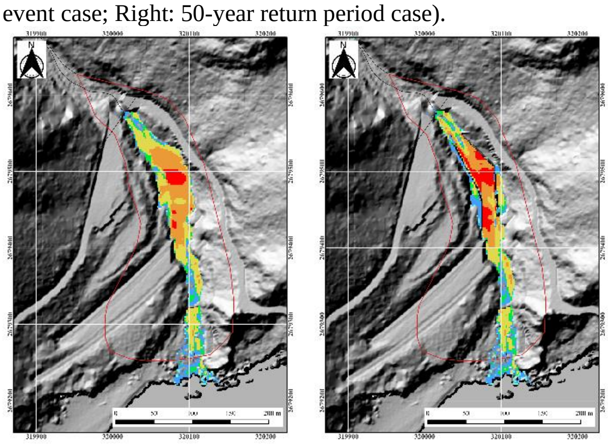

Figure 6 Simulation result of engineering refinement (Left: riverbed dredge case; Right: riverbank protection case.

Table 1 Parameters and values used in the KANAKO-2D

Case	Qp (cms)	Particle size (m)	Cv [%]	Protection work
Run 1	10	0.1	30	No
Run 2	135	0.1	30	Dredge
Run 3	135	0.1	30	Embankment

4. CONCLUSIONS

After the large earthquake, the critical rainfall threshold decreased for Hualien Daqingshuishi Creek (DF024), and lots of unstable sediment was deposited on the slopes. From the in-situ survey results, this debris flow stream presents issues related to maintaining river flooding conveyance capacity, avoiding increased concave bank erosion and convex deposition, and protecting the railway embankment from scouring. Considering the large amount of loose material deposits on slopes, we suggest regular river dredge work is needed. Numerical simulation indicated that riverbank protection work will narrow the channel space. Further research is needed to understand how the concentration of debris between the river section of Provincial Highway No. 9 and the railway bridge approaches is influenced by the reduction of the bridge conveyance capability.

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