

# The Reconstruction of the Processes of Compound Disasters in Siaolin Village Caused by the 2009 Typhoon Morakot

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## **ABSTRACT**

In 2009 typhoon Morakot with copious amounts of rainfall struck Taiwan and caused catastrophic disasters. Different disasters including flood, landslides, landslide dams and debris flow occurred in Siaolin Village. The extreme rainfall has changed the disaster type, from “single” type such as flood or debris flow into “compound” type. The so called “compound disaster” is defined as a disaster by which floods or sediment-related disasters of a large extent occur simultaneously or consecutively in an event at a site. What happened in Siaolin Village is a significant example. It challenges the present warning, forecasting and response system of debris flow. New concept and new procedure are necessary to cope with the compound disasters triggered by extreme heavy rainfall. The rainfall hydrograph shows long-duration, high-intensity, high-accumulation and large-extent characteristics. It suggests the correlation of each disaster type with the rainfall characteristics by reference to the report of eyewitness memory. The causality between those in Siaolin Village occurred disasters could then be deduced. In order to characterize the disaster and suggest a strategy, it is necessary to try to rebuild the temporal order and spatial distribution of the disaster processes. This paper describes briefly each single disaster, the relationship among those disasters and the approach to rebuild the disaster process by field investigation, topographic survey, sediment core analysis, experiments, numerical simulation and satellite image processing. The results serve to intensify the disaster prevention system of debris flow and shallow landslide which then could be applied to the warning system of deep-seated landslide and landslide dam. The derivative issues and the approach to compound disaster prevention are suggested. The related discussions, evaluation and assessment are also summarized as the reference of further tasks.

**KEYWORDS:** compound disaster, Typhoon Morakot

## **1. INTRODUCTION (11pt, bold, capital)**

### **1.1 Background**

Typhoon Morakot struck Taiwan on 8 August 2009. Under the strong influence of southwesterly monsoon wind, Typhoon Morakot brought a record-breaking rain over Taiwan and caused catastrophic damages due its characteristic of long duration and high intensity. The extreme rainfall has

changed the disaster type, from “single” type such as flood or debris flow into “compound” type. The so called “compound disaster” is defined as a disaster by which floods or sediment-related disasters of a large extent occur simultaneously or consecutively in an event at a site. What happened in Siaolin Village is a significant example (figure 1). Different disasters including flood, landslides, landslide dams and debris flow occurred in Siaolin Village.

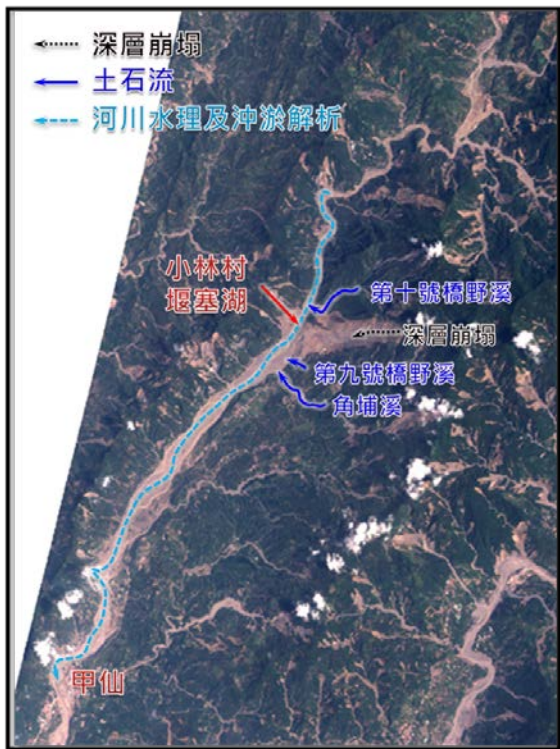


figure 1 study area (Siaolin Village)

The Jiasian metrological station registered an accumulated rain amount of 1,911 mm (figure 2) and a maximal intensity of 94.5 mm/hr. Sediment mass due to triggered slope collapse blocked Cishan River and formed a natural dam. The continuously heavy rainfall leads finally to dam break. The village was flooded by sediment flow, leaving 398 people dead or missing.



figure 1 distribution of accumulated rainfall by Typhoon Morako

The extreme rainfall has changed the disaster type, from “single” type such as flood or debris flow into “compound” type. It challenges the present warning, forecasting and response system of debris flow.

### 1.2 Objectives

New concept and new procedure are necessary to cope with the compound disasters triggered by extreme heavy rainfall. The rainfall hydrograph suggests the correlation of each disaster type with the rainfall characteristics by reference to the report of eyewitness memory. The causality between those in Siaolin Village occurred disasters could then be deduced. In order to characterize the disaster and suggest a strategy, it is necessary to try to rebuild the temporal order and spatial distribution of the disaster processes. This paper describes the approach to rebuild the disaster process.

## 2. METHODOLOGY

On the base of the results of field survey, numerical simulations were carried out to describe the sediment transport by Typhoon Morakot at Siaolin Village. Then the temporal and spatial order of the processes could be reconstructed. The study frame is shown in figure 3 and depicted briefly below.

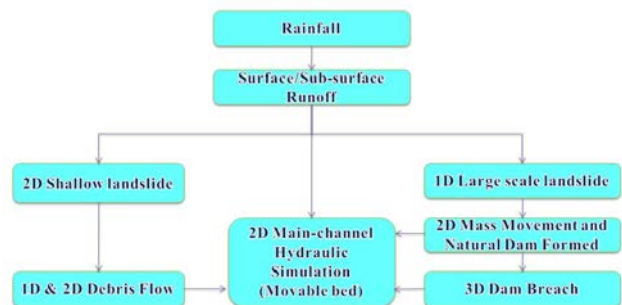


figure 3 study frame

The characteristic of the rainfall by Typhoon Morakot has significance influences on the whole event. The rainfall-runoff process was simulated

firstly to analyze its effect on infiltration. Simulation results provide the input information for landslide analysis. Results of landslide analysis are necessary to simulate debris flow because landslide is the main mechanism of sediment yield. Collapsed sediment could also block the flow to form natural dam. Landslide analysis is the initial step for further simulation of dam formation and dam break. The correlations of each analysis procedure are illustrated in figure 4.

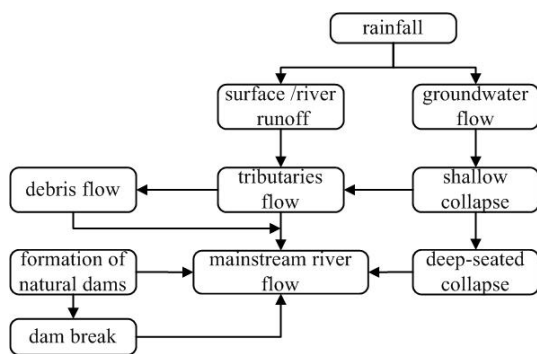


figure 4 illustration of components and interfaces for compound disaster analysis

### 3. CHARACTERISTICS OF THE RAINFALL WHILE TYPHOON MORAKOT

According to the recorded data of metrological stations, the rainfall hydrograph of Typhoon Morakot hat characteristics of high intensity, long duration, broad extent and large amount (figure 5 and 6). The figures show that the rainfall intensity of Typhoon Morakot remained high for 91 hours. The phenomena could explain the increase of landslide area of 36,000 ha, sediment yield of more than 1,000 million cubic meters and 14 natural dams. Showing the eyewitness report and rainfall hydrograph together (figure 7) a close correlation between the rainfall and each process is suggested. The preliminary reconstruction of the event serves as the base for further analysis and validation of numerical simulations.

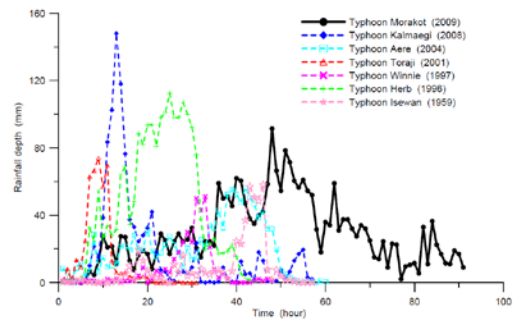


figure 5 accumulated rainfall depth of selected typhoons

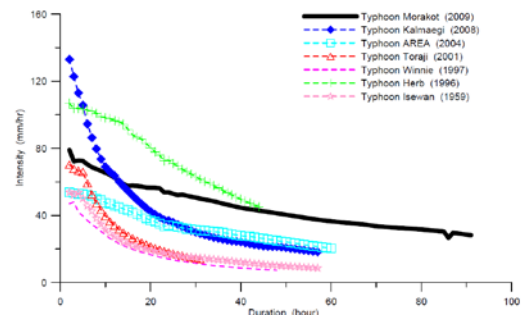


figure 6 Intensity-duration curves of the selected typhoons

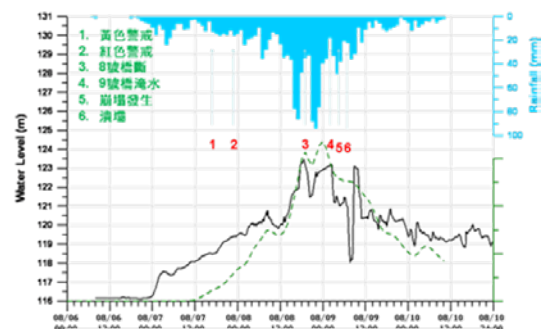


figure 7 a preliminary reconstruction of the event

## 4. SIMULATION RESULTS AND DISCUSSION

### 4.1 Shallow landslide

Simulation of shallow landslide provides the sediment yield as initial condition for debris flow calculation and morphological change of river bed. Infinite slope method was applied to determine the landslide site and collapse depth.

The analysis area is shown in figure 8. The area was divided into 31 units with a size of 100 m × 50 m. Coefficients are determined by satellite image processing, field survey and soil material test.

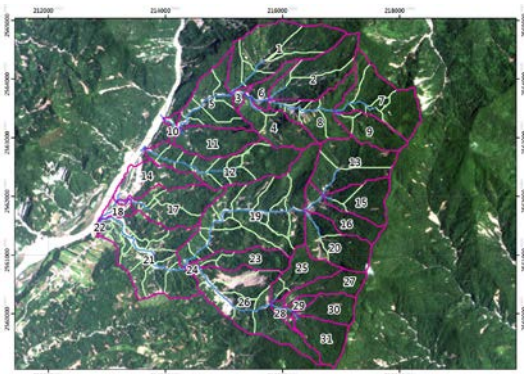


figure 8 analysis area of shallow landslide

New landslide area is about 122 ha totally. That leads to a sediment yield of 3.8 million cubic meters. If the safety factor (SF) is defined as the ration of resistant force to drive force, then the distribution of landslide sites and safety factors in the survey area are illustrated in figure 9. The green color marked the landslide area. The change of the calculated safety factor suggest the time when landslide occurred. A landslide occurs if  $SF < 1$  (ref. figure 10).

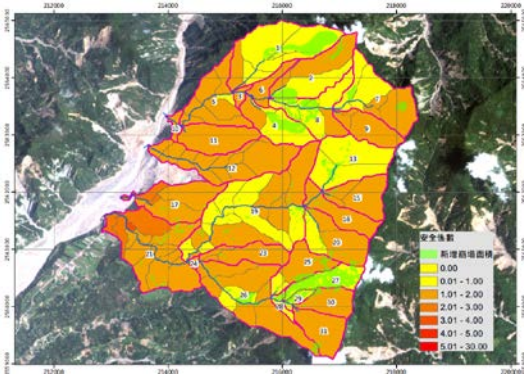
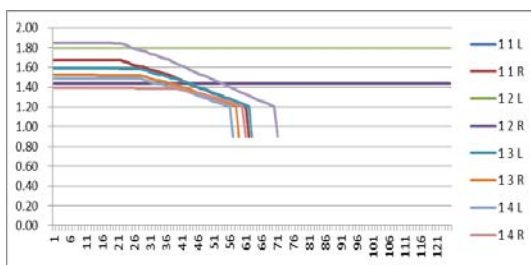
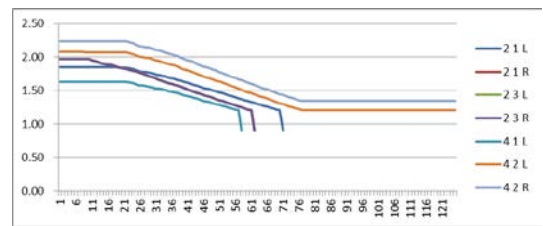


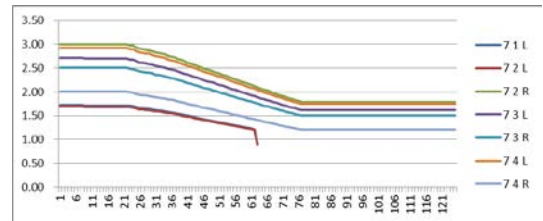
figure 9 analysis area of shallow landslide



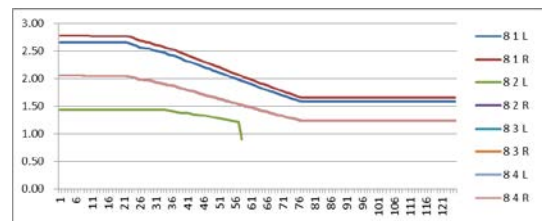
(a) unit No.1



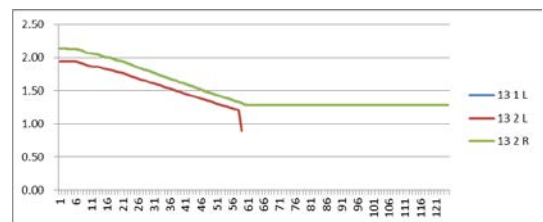
(b) unit no. 2 and 4



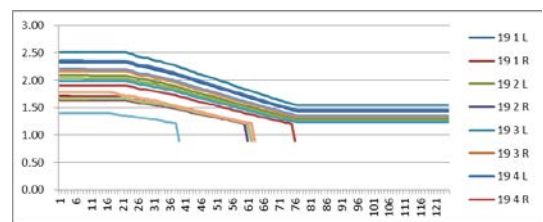
(c) unit no. 7



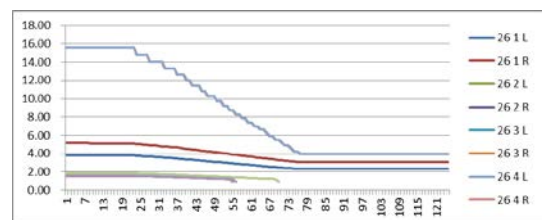
(d) unit no. 8



(e) unit no. 13

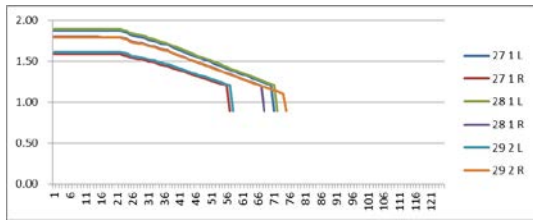


(f) unit no. 19



(g) unit no. 26

(hr)



(h) unit no. 27. 28. 29

figure 10 temporal change of safety factors

#### 4.2 debris flow

A Debris-2D model was used to simulate sediment erosion/ deposition of debris flow process to assess its impact area and change of river bed.

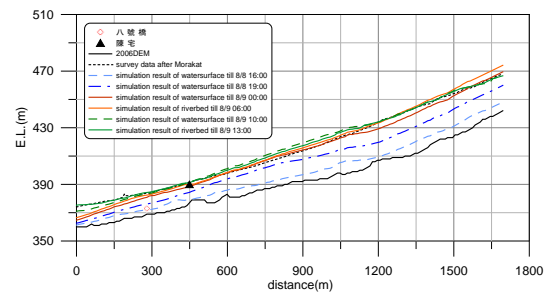
There are 4 debris flows in the survey area: creek at bridge no. 10, creek at bridge no. 10, Kaohsiung County DF006 and Kaohsiung County DF007 (figure 11). The sediment deposition fan were identified by making a comparison between the satellite image before and after Typhoon Morakot (figure 11 and 12). Then the related data were collected by evaluating 5m ×5m DTM, investigation and morphological survey including to calibrate the 2-d numerical model. Numerical simulations were carried out by using the calibrated Debris-2D model. The calculated changes of river bed of the 4 debris flows are shown in figure 13.



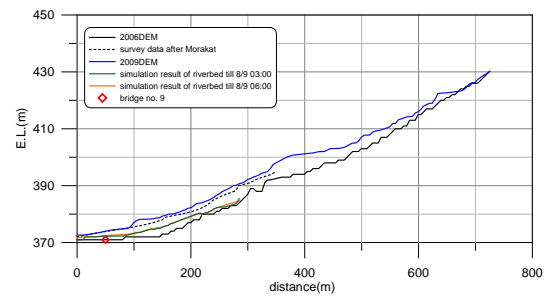
figure 11 location of debris flows in the surveyed area (before Typhoon Morakot)



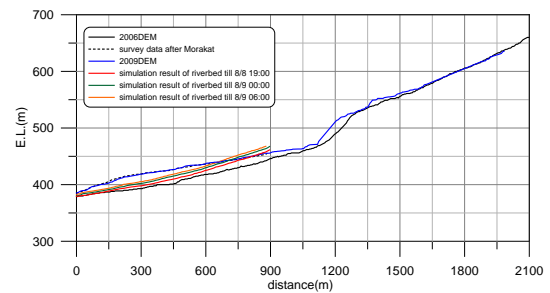
figure 12 the stand of debris flows after Typhoon Morakot



(a) bridge no. 8



(b) Kaohsiung County DF007



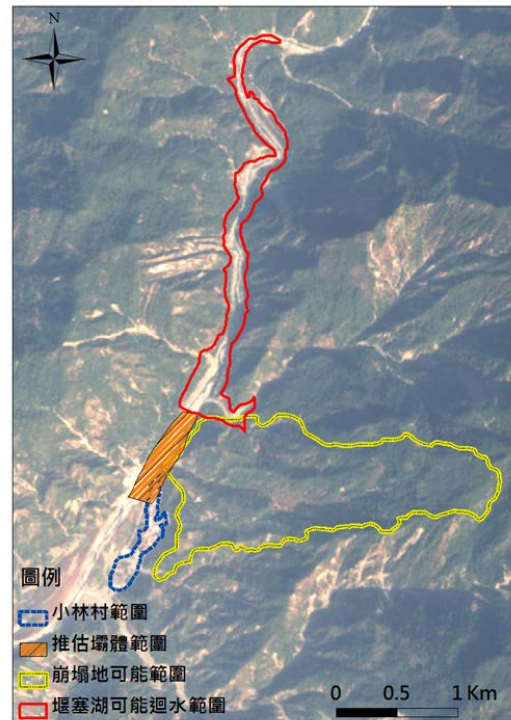
(c) bridge no. 10

figure 12 simulation results of river bed changes

The simulation results are approximated to the survey results and eyewitness report. It also suggests that the debris flow was a continuous process by Typhoon Morakot.

### 4.3 Natural dam

There were some natural dams formed by Typhoon Morakot (ref. figure 13). The dam break analysis was done by using PLAXIS model in combination with PLAXFLOW model. The coefficients for calculation are determined by satellite image processing (ref. figure 14), profile survey and soil material test. The simulated erosion process is shown in figure 15. According to the results, the storage capacity was full in 70-80 minutes after the dam was formed, and overflow occurred 70 minutes after the formation of the dam.



(a) Satellite image for analysis of natural dam (before Typhoon Morakot)

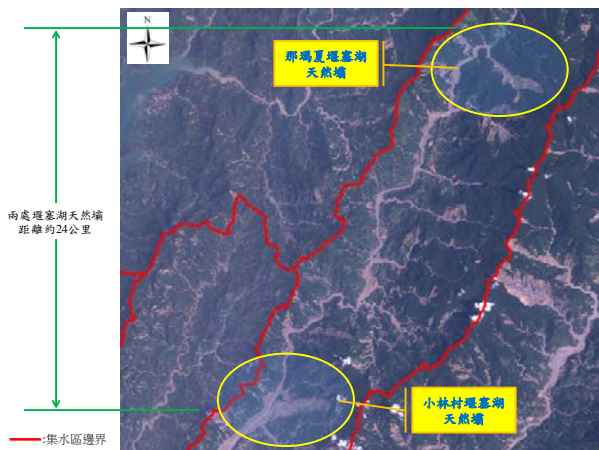
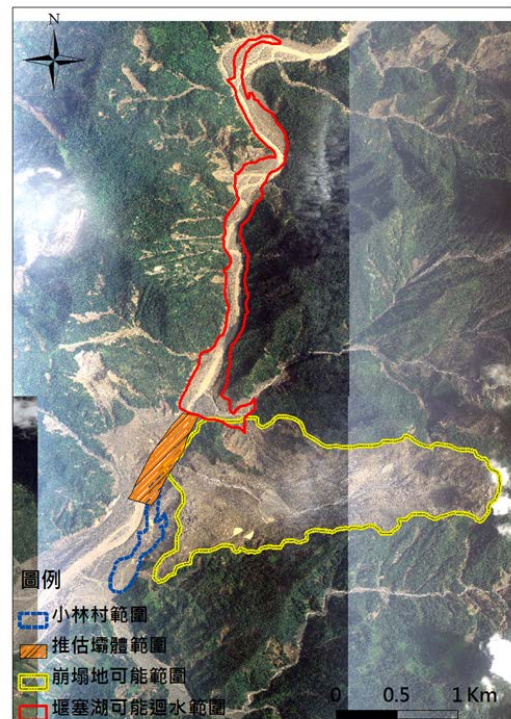


figure 13 2 natural dams at Cishan River



(b) Satellite image for analysis of natural dam (after Typhoon Morakot)

Figure 14 analysis figures of the investigated natural dam.

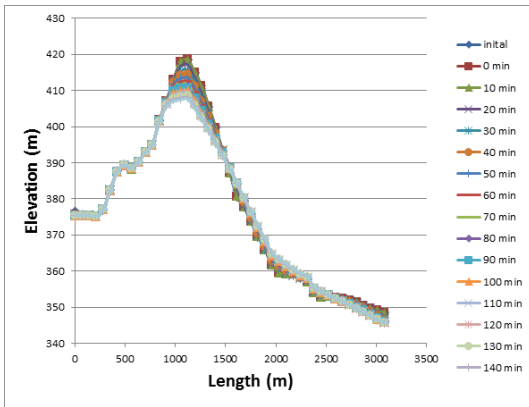


figure 15 simulated erosion process of the natural dam

### 5. Conclusion

The event of Typhoon Morakot at Siaolin village is reconstructed by using the available reports and collected data. The disaster process and the occurrence mechanism are analyzed. The results could serve to improve the disaster response capability and warning and monitoring of compound disasters. It reveals that insufficiency of the present warning system and evacuation system. A strategy draft was suggested in figure 16.

The subsequent regular inspection of the implementation of the strategy is the key to successfully manage the disasters.

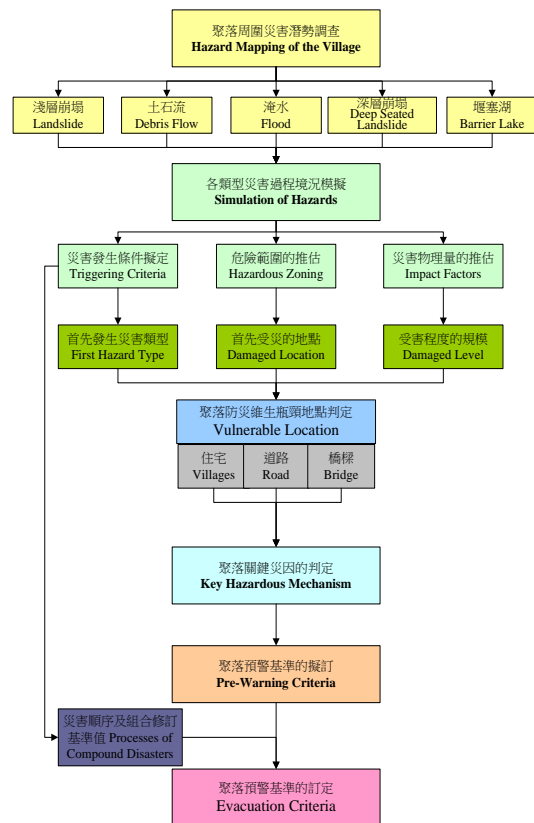


Figure 16 guide scheme to cope with compound disasters

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