Emergency disposal plan of landslide dam in Taiwan

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***ABSTRACT*:** In August 2009, Typhoon Morakot struck Taiwan and brought a high-intensity, long duration and wide range rainfall. A series of natural hazards such as landslide, debris flow, flood and landslide dam were triggered by the rainfall. Among these natural disasters, the information of landslide lake and landslide dam cannot be obtained immediately through field investigations due to the remote location of landslide dams and severe weather condition. Furthermore, an appropriate response guideline to landslide dam is still not available in the emergency disposal plan of landslide lake. The jurisdiction areas of Taiwan Forestry Bureau are the high-risk areas of landslide dam occurrence. Sixteen landslide dams were formed during Typhoon Morakot and many of them collapsed within 3 days. Therefore, based on the experience learned from the event of typhoon Morakot, Taiwan Forestry Bureau proposes the guidelines for monitoring, field investigation, dam stability evaluation and short-term treatment strategy in order to quickly obtain the information of the landslide lakes and evaluate the stability of the landslide dams. A portable monitoring system, which can provide water level, rainfall and real-time image of landslide dam for the detail evaluation of the dam stability, is also developed. The collected information allows decision makers to understand the situation of landslide lake.

KEYWORDS: Landslide dam; Emergency disposal plan

1. Introduction

In Taiwan, Forestry Bureau, Council of Agriculture, Executive Yuan governs forest land which mostly located in the upper reaches of the catchment area. This governed area has high frequency of landslide dam occurrence. During Typhoon Morakot event in 2009, the cumulative rainfall reached 2000mm. This record-breaking rainfall occurred in the southern Taiwan with area of 2230.88km^2 (Figure 1). This high-intensity, long duration and wide range rainfall caused 14 landslide lakes and 7 of these lakes still exists in September 2009. (Figure 2).During the early stage of landslide dam formation, the information collection of the landslide dam is extremely difficult due to the extreme weather condition. The lack of information results in huge challenges for emergency response. Hence, the major issues of emergency disposal plan of landslide dam are efficient landslide dam investigation, monitoring, and corresponding response.

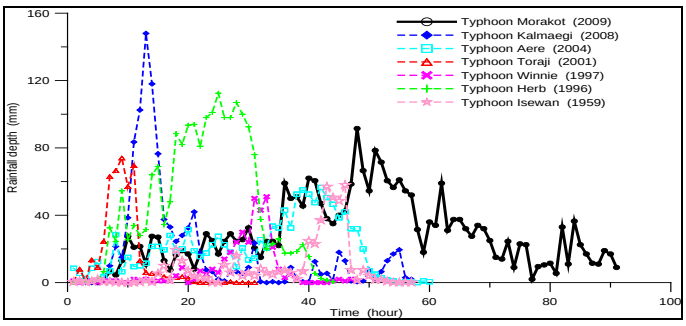

Figure 1 The rainfall record of typhoon events during 1996 to 2009 [Shieh(2009)]

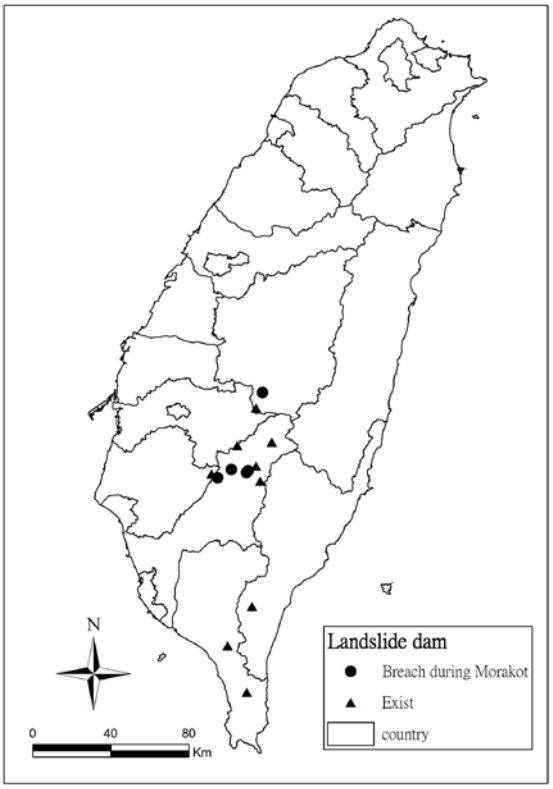

Figure 2 Map of landslide dams distribution in Taiwan during Typhoon Morakot

2. Major issues of emergency disposal plan of landslide dam

A landslide dam is composed of loose materials of soil and rocks. Due to the loose structure and low strength of the dam body, the landslide dam could be easily damaged by an earthquake or a rainfall event. The dam failure may cause surge wave and debris flow which could result in serious damage at the downstream area (Shieh et al., 2008). Costa and Schuster (1988) indicated that 44% of landslide dams last less than one week before the dam failure. Some dams failed within a few hours. Therefore, the major challenge for disaster prevention and response is the limited time. In addition, where landslide dams located usually is not easy to reach and lack infrastructure such as power and communication. Investigation and monitoring are not easy. Accordingly, information collection is a big challenge. Because the landslide dam body is composed of composite materials with high diversity. Insufficient information of dam composition increases the difficulty of disaster evaluation and response. Therefore, the key of landslide dam emergency response is how to perform rapid evaluation and response subject to limited time and insufficient information.

3. Development of emergency disposal plan of landslide dam

This study develops an emergency disposal plan of landslide dam considering the limited time and insufficient information. The plan includes three strategies: (1) multiple investigation methods, (2) standard operation procedures, and (3) decision support system.

3.1 Multiple investigation methods

■ Map evaluation

Map evaluation can provide some information of the landslide dams which is very useful for dam stability analysis such as dam geometry and its storage space. The map evaluation uses the topographic map obtained before the landslide event and the satellite images or aerial photographs obtained after the landslide event. The map evaluation can provide fast evaluation of the landslide dam and is not restricted by terrain and transportation limitations. The disadvantage of the map evaluation is that the image quality may be affected by the cloud condition.

■ Field investigation

If the landslide site is accessible, field investigation and survey can be performed. Field investigation can obtain high quality field data, but high risk and long investigation duration are disadvantages.

■ Aerial survey

If map evaluation and field investigation are not options due to weather condition, helicopters and unmanned aerial vehicles (UAVs) can be used to perform aerial survey. However, the Helicopters and UAVs are still restricted by weather condition.

■ In-situ monitoring

After the landslide dam is formed, the storage space, groundwater level, dam geometry, and the local terrain are continuously changing. In addition to the field investigation, 24-hour in-situ monitoring of the landslide lake and the dam body is needed. The collected information can be used to evaluate the risk of the landslide dam and prepare the corresponding countermeasures. The in-situ monitoring equipments may be restricted by poor power and communication infrastructure in field.

In the early stage of the landslide event, limited time is the major challenge. After receiving the information of landslide dam formation, the above mentioned methods can be used to collect the data for fast evaluation of the landslide dam (the flow chart is shown in Figure. 3).

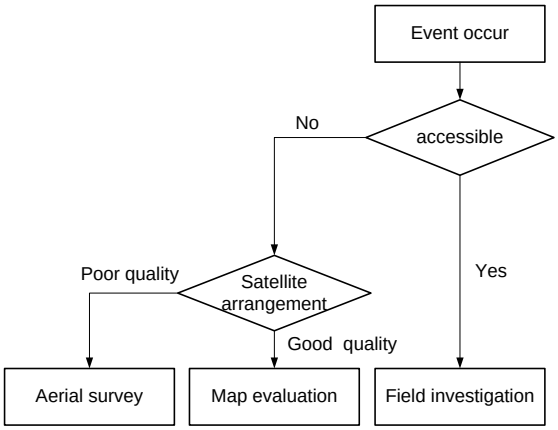

Figure 3 The flow chart of emergency investigation

3.2 Standard operation procedure for the landslide dam response

For rapid response to the landslide dam and perform efficient disaster reduction operations, the Forestry Bureau proposed a guidelines for each stage after the landslide formation based on the experience obtained from Typhoon Morakot. As shown in Figure 4, there are three stages for a landslide dam event: (1) early stage, (2) emergency response stage, and (3) long-term process stage. In the early stage, verification of information obtained from different sources is needed. If a landslide is formed, it is necessary to notify the relevant competent authorities. Otherwise, clarification of the false information is needed. In the emergency response stage, major works are data collection, rapid assessment of the risk, emergency countermeasures, preliminary evacuation plan, and preliminary engineering treatment. In the long-term process stage, major works include continuous monitoring, re-evaluation of the risk, countermeasures, the evaluation plan and the engineering treatment.

(1) Early stage (First stage, step 1~ 3)：

The key points are verification of the reported information and announcement of the necessary information to public or to the relevant competent authorities. Once the reported information of the landslide dam formation is verified, it is needed to notify the relevant competent authorities. Otherwise, clarification is needed to avoid pubic panic. The major works of this stage are:

- Verify the information of the landslide dam formation.
- Verify the location and the site condition of the landslide dam.
- Announce the verification result to the relevant competent authorities.

(2) Emergency response stage (Second stage, step 4~ 7)

The major works of this stage are to rapidly evaluate the risk of the landslide dam under limited time constraint and insufficient data as well as provide emergency countermeasures and a preliminary evacuation plan. In addition, investigation and in-situ monitoring should be performed for data collection. Any data in this stage can be very helpful for risk assessment and decision support. The major works of this stage are:

- Preliminary investigation of the landslide dam.
- Monitor changes of the landslide dam. The monitoring method can be determined by the site condition.
- Preliminary risk assessment of the landslide dam.
- Perform emergency engineering works considering the engineering feasibility and necessity.
- Develop preliminary alert system and evacuation mechanism. (Define the alert value and the alert zone.)

(3) Long-term process stage (Third stage, step 8~ 12)

Based on the urgency and the investigation feasibility, each plan of detail investigation and risk evaluation should be re-evaluated for each landslide dam event. The corresponding countermeasures and the evacuation plan should be updated accordingly. The major works of this stage are:

- Detailed investigation (considering accessibility and safety)
- Evaluate the risk level based on the investigation result
- Update the countermeasures and the evacuation plan (update evacuation moment and alert level)
- Update and strengthen the monitoring system based on the investigation result (considering the site condition and necessity)
- Perform necessary long-term disaster prevention engineering project based on the detailed evaluation results.
- Re-evaluate the risk level of the landslide dam based on the site condition and the countermeasures.

3.3 Decision support system

A proper disaster prevention operation includes data collection, evaluation of risk level, relevant emergency response, and information delivery. The collected data are used to evaluate the risk level of the landslide dam and prepare the emergency response plan such as emergency countermeasures and evacuation plan. A well developed information delivery platform assures all participants kept updated during a landslide dam event.

A decision support system is developed based on the needs of each disaster prevention stage. In addition to the landslide dam management platform, the decision support system can provide real-time monitoring information of the landslide dam and deliver instant messages to all relevant competent authorities. If the status of the landslide dam meets the alert level, the system can automatically announce the emergency alert to relevant people and initiate the evacuation plan to protect people. The decision support system provides the following service:

- Information update of the landslide dam for inquiry.
- Real-time monitoring information inquiry.
- Disaster announcement and notification.

- Alert level setup and announcement

The decision support system includes five subsystems: (1) integrated geographic information system, (2) real-time monitoring system, (3) notification management, (4) information management, and (5) system management. (Figure 5)

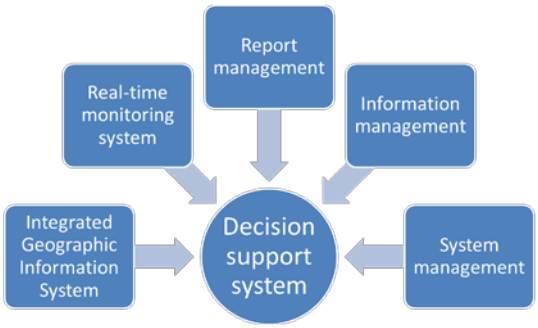

Figure 5 The decision support system

(1) Integrated geographic information system

Users can obtain real-time information of the landslide dam via the visualized e-map. The real-time information includes rainfall, water level, image, and the typhoon status. (Figure 6) If the observation of rainfall or water level meet the pre-defined alert value, the red light will flash to inform workers for announcement preparation. (Figure 7)

Figure 6 The integrated geographic information system shows the cloud map and the typhoon information

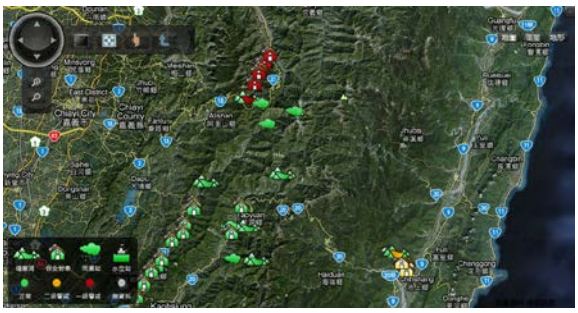

Figure 7 The integrated geographic information system shows the alert vales and the corresponding legend

(2) Real-time monitoring system

The subsystem offers the users to inquire about historical and real-time rainfall and water level information as well as provides the results in figures based on the selected events and time windows, as shown in Figures 8 and 9.

Figure 8 Rainfall information system

Figure 9 Water level information system

(3) Report management

There are three communication methods including fax, e-mail and instant massage in the report management subsystem to deliver useful

information, such as the disaster condition, real-time rainfall and water level information, etc. The subsystem can also utilize various communication methods to notify the relevant competent authorities to carry on the necessary precautions when the alert level is reached.

(4)Information management

This subsystem provides a universal information management platform which enables the relevant competent authorities to share and exchange all necessary related documents, important image materials (ex. pictures of the landslide dams). In addition, documents like standard operation procedures, templates of reviews, fax, e-mail, and instant message etc. can be developed using options inside the system.

(5) System management

The system management includes account management (to set up users' authorities), alert status development and revision (Figure 10), major event log upgrading, basic data modification (Figure 11), information treatment of the objects protected, typhoon events initiation, notification list modification, coordinate transformation and the basic evaluation of dam body stability, etc.

Figure 10 Alert value management - alert value setup for a precipitation station

Figure 11 Landslide dam management - basic data modification system

4. Conclusion

This study develops a procedure for disaster prevention and response based on pluralistic investigation methods, standard operation procedures, and the decision support system. For future research, a rapid risk evaluation method is needed to improve the efficiency of the disaster prevention and response.

5. Acknowledgements

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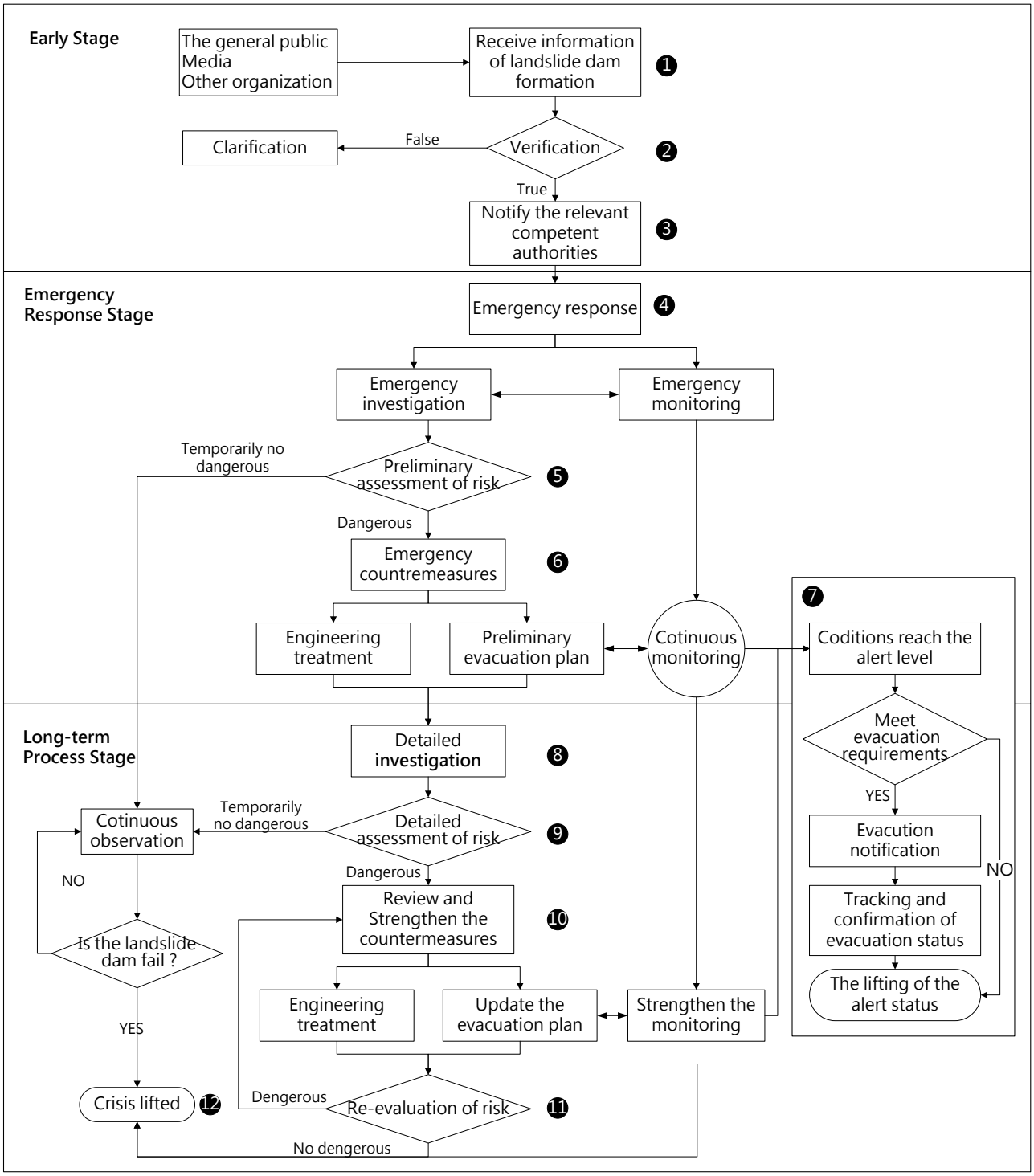

Figure 4 standard operating procedure steps (SOPS) for preventing the disaster of landslide dammed lake