CHALLENGES OF SEDIMENTARY HAZARDS EMERGENCY RESCUE OPERATIONS UNDER EXTREME RAINFALL CONDITIONS IN MOUNTAINOUS AREAS IN TAIWAN

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ABSTRACT

A sedimentary hazard emergency rescue operation procedure in the Taihe Village Meishan Township, Chiayi County during Typhoon Morakot (August 7-9, 2009) is reviewed and studied. A questionnaire was designed and conducted to survey the firefighters who had participated in sedimentary disaster prevention education, disaster preparedness, and emergency rescue and response prior to and during Typhoon Morakot. The survey results were integrated into the case study. Results of the analysis show that problems encountered during sedimentary hazard rescues during Typhoon Morakot include: (1) the magnitude of hazard exceeded the capacity of the firefighters; (2) shortage of trained professionals; (3) shortage of rescue equipment; (4) roads destroyed in mountainous areas; (5) communications cut off during severe weather conditions; (6) recurrence of hazards; (7) difficult to rescue buried persons; (8) administrative processes were inefficient; and (9) the integration of different rescue teams was inadequate.

Keywords: Disaster Prevention System, Typhoon Morakot, Emergency Rescue, Sedimentary Hazard.

I. INTRODUCTION

There were 2,620 fatal landslides recorded worldwide during 2004-2010 yrs, causing a total of 32,322 recorded fatalities (Petley, 2012). Landslide has been seen as a major global hazard. Climate change increasing the potential of extreme rainfall condition may be a contribution factor to landslide (Nadim et al., 2006). In the face of multiple, compound hazards (including flood, landslides and debris flows, and breached natural dams (Chen et al., 2011)), the relief workers feel helpless. The huge landslide in Southern Leyte, Philippines in 2006 caused 139 dead with 980 missing (Orense and Sapuay, 2006; Evans et al., 2007; Catane et al. 2007; 2008; Lagmay et al., 2008). Only 20 people rescued, two eventually died, in the landslide dam breaching induced secondary hazard (Catane et al. 2007).

Taiwan is regularly struck by powerful typhoons. Since 2000, typhoons Toraji (2001), Nari (2001), Mindulle (2004), and Morakot (2009) have caused numerous sedimentary hazards such as landslides and debris flows. Between 2006 and 2010, there were 305 sedimentary hazards involving rescue operations, injuring 70 and causing 619 deaths in Taiwan (National Fire Agency, 2014). Thirty-six of these hazards (roughly 25%), including 30 caused by Typhoon Morakot, occurred in Chiayi County in south-central Taiwan.

Typhoon Morakot made landfall on Taiwan from 7 to 9 August 2009, bringing the highest recorded rainfall in the past 50 years to southern and south-central Taiwan (Chien and Kuo, 2011). The massive rainfall caused immense damage to the natural and human landscape. A total of 9,333 landslides (2.26 km^2) were interpreted from change detection analysis of satellite images (Tsai et al., 2010). Numerous sedimentary hazards occurred, resulting in injuries, road destruction, and broken bridges. At Shaolin Village in Kaohsiung County in southern Taiwan, a giant landslide dam breach caused 398 deaths and buried at least 169 buildings during Typhoon Morakot (CEOC, 2014; Tsou et al., 2011). No one was rescued in the debris masses buried area. Landslide locations and magnitudes information were urgently necessary during the rescue emergency (Zhang et al., 2010). In such large-scale landslide disaster, speed, accuracy, and the maximum appropriation resources are crucial (Lagmay et al., 2008). "*A systematic and technically informed approach to search and rescue missions in large-scale landslide disaster, and the formulation of better disaster management policies are needed*" (Lagmay et al., 2008).

Given the urgent need for deeper assessment of disaster procedures and processes, this study reviews the sedimentary hazard emergency rescue procedure in the Taihe area of Chiayi County in south-central Taiwan during typhoon Morakot in 2009. The purpose of this study is to learn what problems were encountered during the rescue process and to offer recommendations for ameliorating these problems. By doing so, it can make important contributions to both the literature on disaster response and to the practical needs of disaster responders.

II. SEDIMENTARY HAZARDS EMERGENCY RESCUE MEASURES

In Taiwan, the procedure for sedimentary hazard emergency rescue operations is carried out by local fire departments (Fig. 1). It includes:

1. Confirm the magnitude of sedimentary hazard and request support needed. Sedimentary hazards could be rockfalls, slips, landslides, debris flows, and riverbank erosion. Query eyewitnesses to learn how many people are buried by debris mass and their possible locations. Supporting units may include:

(1). Other fire departments: If the sedimentary hazard requires more manpower, firefighters and rescue equipment may be requested from other fire departments.

(2). Non-governmental organizations (NGO): the control center coordinates NGOs to support the rescue action.

(3). Military support: The Emergency Operation Center (EOC) coordinates nearby military units to support the rescue.

(4). Heavy machinery: The EOC requisitions private business heavy earthmoving equipment such as power shovels or bulldozers to accelerate the rescue.

(5). Medical staff: The EOC coordinates doctors and nurses for injuries needing emergency care.

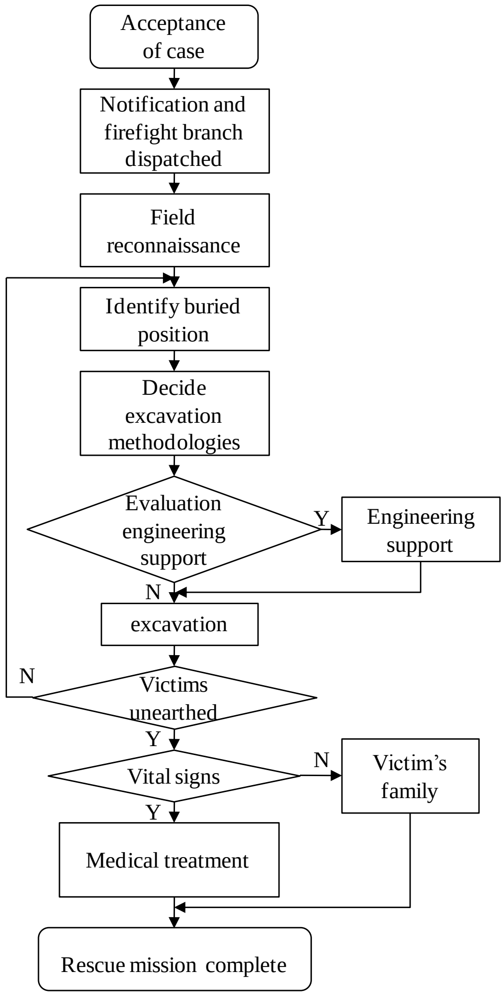

Fig. 1: Flowchart of Emergency Rescue Operation Procedure for Sedimentary Hazards (revised after Chiayi County Fire Bureau, http://w3.cycfd.gov.tw/)

2. Identification of possible locations of debris masses and buried people. The most direct method is by querying eyewitnesses or persons in the area. It is possible to survey locations of victims using field topography and scientific instruments.
3. Determine how to excavate. Excavation work by manual labor is required at the beginning to prevent heavy machinery from doing further injury to victims. Consent of the victim's family is necessary to permit use of heavy machinery to excavate after 72 hours have passed without manual labor resulting in rescue. Engineering support is required to prevent further collapse of debris masses. Excavation from the top of collapsed buildings downward is prohibited to prevent further hazard. The field commander is responsible for deciding on the type of excavation and for determining whether to re-survey to find the possible location of victims.
4. Emergency medical treatment: Victims will be returned to the family if they do not display vital signs. If the victims have vital signs or the family demands resuscitation attempts, the victim will be immediately taken to the hospital. The rescue action is finished at this stage.

Repeated hazards (buried building collapse or further slope slip) could occur under continued rainfall, during heavy machine excavation, or as a result of earthquake aftershocks. Firefighters are generally not professionally trained in judgment of secondary hazards and necessary engineering measures. According to the "Operating Procedures for Prevention of Repeated Debris Flow Disasters and for Recovery and Reconstruction" issued by the Soil and Water Conservation Bureau in Taiwan [15], SWCB workers and professional engineers should determine the possibility of repeated hazards at the scene. Emergency engineering measures are usually necessary to avoid repeated hazards. The procedure for the process of identification and emergency engineering is:

1. Field investigation

(1). Hazard identification: Contact the village head to confirm the hazards and their magnitude.

(2). Professional investigation: The SWCB is the department responsible for debris flow hazards prevention and mitigation in Taiwan. The SWCB and local government and professional engineers will investigate the hazard magnitude, the endangered area, and give professional suggestions for the safety of rescuers.

(3). GPS orientation: using GPS to locate debris flows, landslides, and hazard spots.

(4). Items for investigation: site location, type of disaster, affected areas, injured people, damages, magnitude (debris masses volume), estimated losses, and suggested engineering measures.

2. Emergency engineering measures and response

(1). Emergency soil and water conservation engineering measures: SWCB and local government will perform emergency soil and water conservation engineering measures such as strengthening buildings, stabilizing slopes, and other engineering disaster prevention measures for in danger sedimentary hazard areas.

(2). Rush to repair: Local government will make urgent repairs to blocked roads, damaged bridges, communications, and community facilities.

(3). Temporary protection measures: Local government should perform temporary protection measures for severely damaged areas and erect warning signals.

(4). Delineation of restrained area: local government should demarcate restricted areas to separate hazard areas and prohibit people from entering the area or ask them to leave.

(5). Checking drainage system: SWCB and local government should check and maintain the detention, deposit, and retention ponds drainage unobstructed in the jurisdiction to prevent riverbed deposition induced floods.

(6). Riverbed debris mass dredging: The responsible departments should dredge the debris in riverbeds to avoid further hazards.

(7). Building reinforcement: The responsible departments should dismantle broken structures and strengthen temporary support and protection measures for damaged buildings.

(8). Spoil and debris masses disposal: The responsible departments should establish safe deposition areas and exchange or recycling systems for landslides, road blockage, and dredged debris masses to prevent further hazards.

III. SEDIMENTARY HAZARDS EMERGENCY RESCUE PROCEDURE IN TAIHE VILLAGE

Taihe Village is located in eastern Chiayi County in south-central Taiwan (Fig. 2). From the plain to the mountainous village is two hours by car. Typhoon and torrential rainfall induced rock fall and traffic cutoff have been frequent in the area in recent years (SWCB, 2014).

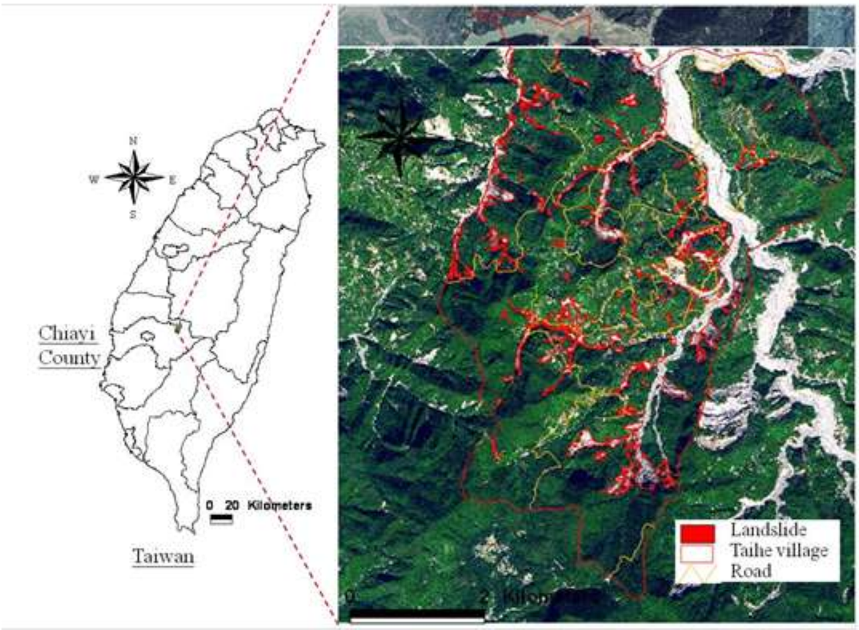

Fig. 2: Site Location and Landslides after Typhoon Morakot in the Study Area

Typhoon Morakot brought torrential rainfall of up to 1,812 mm to the Taihe area during 7-10 August 2009, equivalent to over 50% of the annual rainfall. Three potential debris flow creeks were identified by the SWCB (http://www.swcb.gov.tw). Morakot induced 243 landslides and debris flows with a total area of 2.75 km^2 interpreted from Spot 5 images in the area (Chen and Huang, 2013). Villages in the mountainous areas in Chiayi County were isolated and communications cut off by numerous landslides and debris flows caused by Morakot.

Emergency rescue was initially unavailable. Finally, at 7:05 morning on 9 August the Chiayi County Fire Bureau received a report that Taihe and nearby villages' had been cut off by landslides and 4 people had been buried by debris. The Fire Bureau put together a rescue team on 9 August, first driving and then walking to the scene, but the team was unable to reach the hazard scene. Finally, the firefighters walked to the village using a historical foot track.

The severe weather also stopped helicopters bringing food and other necessities to the hazard scenes until 10 August, when three firefighters took a plane to the village. A shovel loader was hanged by the helicopter for road to rush through urgently. A rough emergency road finally enabled a team of seven firefighters, one sniffer dog and two trainees, 30 soldiers and two big excavators, to reach the area on the 26th. The excavation started in the morning of the 26th and by the following afternoon the bodies of the four victims were unearthed (Fig. 3).

Fig. 3: Sedimentary Hazards Emergency Rescue in the Taihe Village (a) Excavators Removing Debris (b) A Sniffer Dog Searching for Buried Victims (c) A Shovel Loader was Hanged by the Helicopter for Blocked Road to Rush Through Urgently (d) Relief Workers Excavate Debris Masses using Hand Tools (August of 2009, Chiayi Fire Bureau, Chiayi County)

The rescue action lasted 20 days, from 9-28 August, 2009. The Chiayi County Fire Bureau sent 223 person, 40 vehicles, and support organizations assisted with a further 189 person, 65 vehicles (Chen and Chen, 2011). In addition, there were four evacuation shelters and six public buildings available for temporary shelters in the village. Most of the shelters were damaged or cutoff by landslides (Fig. 4).

Fig. 4: Damages of the Four Temporary Shelters in the Taihe Village

IV. QUESTIONNAIRE STATISTICS ANALYSIS

A total of 255 questionnaires (overall response rate 98.5%) were returned, including 159 by leaving method (100%) and 96 by internet survey (96%). The high rate of recovery was attributed to the fact that most of the interviewees are colleagues of the author. Twelve invalid questionnaires were removed, leaving 243 effective questionnaires (effective response rate 95.3%).

The results of the descriptive statistics analysis of questionnaires were generalized into the factors of hazard prevention and mitigation, professional training, equipment related, available resources, coordination of work, and other factors. The various factors and corresponding questions were listed in Table 1.

Table 1: List of Factors Affecting Firefighters on Sedimentary Hazards Emergency Rescue

Factor	Content
A. Hazard prevention and mitigation factors	1. Firefighters fully understand the characteristics and dangers of sedimentary hazards. Education and emergency operations are effective. (63.8% selected agree/strongly agree) 2. The fire department should use daily education programs to strengthen resident awareness of sedimentary hazards. (75.3%) 3. Residents are not aware of sedimentary hazards. It is difficult to do disaster prevention education. (66.9% selected agree/strongly agree) 4. The fire department can go to potential sedimentary hazards to strengthen disaster prevention and mitigation after a typhoon warning is issued. (77.8% selected agree/strongly agree) 5. Firefighters should persuade and exhort residents to evacuate historical and potential sedimentary hazard areas after a typhoon warning is issued. (79.4% selected agree/strongly agree) 6. Firefighters should force local residents to evacuate high potential hazard areas to prevent life and property losses. (78.6% selected agree/strongly agree)
B. Professional training	1. It is difficult to perform rescues in sedimentary hazard areas and fire departments should strengthen professional training and rescue equipment. (91.8% selected agree/strongly agree)

factor	2. The official training of firefighters is sufficient to enable them to cope with sedimentary hazards (60.5% selected disagree/strongly disagree)
C. Equipment related factor	1. The vehicles and equipment of the fire department are sufficient to conduct sedimentary hazard emergency rescue action (60.9% selected disagree/strongly disagree) 2. Firefighters can maintain vehicles, detection equipment, and stock enough fuel for emergency rescue in advance. (77.4% selected agree/strongly agree) 3. The fire department can supply and repair vehicles, equipment, and food soon for emergency rescue. (50.7% selected disagree/strongly disagree) 4. Emergency rescue equipment needed at the scene can be rapidly supplied. (38.3% selected disagree/strongly disagree)
D. Available resources	1. The fire department has established a detailed list of residents and manpower, and established emergency channels of communication. (73.3% selected agree/strongly agree) 2. The fire department has established a detailed list of resources in the jurisdiction to requisition for emergency rescue. (83.1% selected agree/strongly agree) 3. The fire department has established a detailed list of resources that can be contacted immediately and dispatched support for emergency rescue. (45.9% selected disagree/strongly disagree) 4. Volunteer firefighters, volunteers, Neighborhood Rescue Team in the community, and the financial resources of the people in the jurisdiction can help in sedimentary hazards rescue. (73.3% selected agree/strongly agree) 5. The fire department and non-governmental organizations have signed a contract to supply heavy machines for emergency rescue use. (64.2% selected agree/strongly agree)
E. Coordination of work	1. The fire department should cooperate with other departments to perform disaster prevention education and promotion and evacuation drills periodically. (82.7% selected agree/strongly agree) 2. The fire departments can cooperate well with other rescue teams (military, NGOs) and coordinate the division of rescue work. (45.7% selected disagree/strongly disagree) 3. The procedure to request support is varied and time consuming and their dispatch requires a top official to integrate. (75.3% selected agree/strongly agree)
F. Other factors	1. The fire department should pre-plan emergency rescue and response strategies for potential sedimentary hazards. (89.7% selected agree/strongly agree) 2. The greater magnitude of sedimentary hazards compared to the ordinary duties of the fire department means that sedimentary hazard rescue is not mature in all aspects. (95.9% selected agree/strongly agree) 3. The information and correction of sedimentary hazards are not clear and need verified, causing difficulties for firefighters in rescues. (89.3% selected agree/strongly agree) 4. Firefighters' needed food and water can be supplied soon during sedimentary hazard emergency rescue. (38.3% selected agree/strongly agree)

Interviewee responses were on a 1-5 scale ranging from "strongly agree" to "strongly disagree". Table 2 shows the aptitude trend analysis of the questionnaire. The designed middle value was 3 (no opinion) and mean values lower than 3 represent agreement with the questions while mean values greater than 3 represent disagreement.

Table 2: Statistics Analysis of Questionnaire Results from Firefighters

No. of Descriptive questions (corresponding to Table 1)	No.	Mean	Standard deviation
A1	243	2.51	1.166
A2	243	2.21	1.010
A3	242	2.33	1.073
B1	243	1.74	0.756
B2	243	3.44	1.164
E1	243	2.02	0.733
D1	243	2.25	1.024
D2	243	2.05	0.834
A4	243	2.19	0.949
A5	243	2.06	0.967
F1	243	1.91	0.647
C1	243	3.53	1.129
C2	243	2.15	0.702
C3	243	3.20	1.133
F2	243	1.62	0.654
A6	243	2.09	0.893
F3	243	1.84	0.716
E2	243	3.15	1.142
E3	243	2.08	0.892
D3	242	3.11	1.127
D4	243	2.28	0.830
D5	243	2.39	0.890
C4	240	3.09	0.972
F4	240	2.95	0.978

V. RESULTS AND SUGGESTIONS

The study reviews the emergency rescue process in Taihe Village during Typhoon Morakot using a questionnaire of firefighters. Results are summarized and listed below.

1. The magnitude of hazards exceeds the normal duties of firefighters (corresponding to F-2 in Table 2).

2. Lack of professional sedimentary hazard emergency rescue training (E-1)

3. Lack of sedimentary hazards emergency rescue equipment (C-1 and C-3)
4. Rescue action interrupted by communications cut off (C-1, C-3)
5. Unclear information causes rescue difficulties (F3)
5. Repeated hazards are hard to predict and increasing the risks to relief workers (A1)
6. Buried victims are hard to rescue (B1)
7. Process for requesting support is time-consuming (D5, E3)
8. Horizontal communication across different units is hard to integrate (E2)

Suggestions for resolving the aforementioned difficulties are listed below:

1. Promote professional training for relief workers

Educational units, for example, the Central Police University, the Taiwan Police College, and other practical training units should promote training in sedimentary hazard rescue. This training should include flowcharts of the rescue procedure, relief skills, information integration and transmission, equipment maintenance, coordination work with helicopters, and personnel safety.

2. Strengthen emergency rescue equipment

Rescue workers had to use hand tools to dig through the mud in order to rescue survivors. The questionnaire shows that equipment for sedimentary hazard emergency rescue are lacking. Commonly used equipment should be acquired. Table 3 lists the suggested procurement priority.

Table 3: Suggested Equipment Acquisition Priority for Sedimentary Hazard Rescue

Types	Equipment		
Communication	Waterproof wireless phone	Radios	3G cell phone
Rescue equipment	small shatter apparatus	small rock drilling machine	simple excavation tools
	dynamic rope and static rope	hook and pulley sets	bundle of goods or tie-downs
Power supply	small electric generators	solar battery chargers	-
Assist equipment	man-pack march tent	simple cooking equipment	-
Personal equipment	winter protection wear, hat and shoes	headlamps	waterproof gloves

3. Establishing rescue resources in potentially affected areas:

(1). Financial resources of the people

There are three volunteer organizations under the fire department available: Volunteer Firefighters, Women's Fire Prevention Promotion Team, and Phoenix Volunteers. Other non-profit organizations, for example, Neighborhood Rescue Team, need continuous financial and training assistances.

(2). Communication networks

Planning of available communication networks include police radio channels, satellite telephones in remote townships, and radio channels and frequencies.

(3). Relief vehicles, facilities, heavy machinery, and logistics

Periodically investigate and list other available government and non-governmental relief trucks, facilities, heavy machines, and supplies for sedimentary hazard emergency rescue.

4. Evaluation using advanced rescue equipment

It is important to plot out the landslides immediately to rescue victims urgently. Optical and microwave techniques of remote sensing were both used (Pohl and Van Genderen, 1998). Nevertheless, the severe weather in the mountainous area imposes serious technical difficulty upon remote observation at a regional scale (Zhang et al., 2010). Thermal imaging cameras and seismic listening devices were used in an attempt to locate survivors in the 1997 Thredbo landslide (Queensland Government, 2014). Ground-penetrating radar (GPR) has been used in a number of rescues in the 2006 Philippine landslide (Lagmay et al., 2008). GPR and other advanced detection equipment used in Taiwan including during Typhoon Morakot for Shaolin Village, for the No. 3 freeway 31.5k landslide on 24 April, 2010 (The Landslide Blog-AGU Blogosphere, 2014) and the Suhua Highway landslide on 23 October, 2010 (Taiwan News, 2010). The equipment was used for faster identification of the position of victims. Advanced equipment such as life detectors (Table 4) are not in common use among relief workers. Instead, their usage depends on the situation at the scene.

Table 4: Advanced Equipment for Emergency Rescue

Type	Equipment	Usage
detector	Ground-penetrating radar (GPR)	Uses reflection of radar wave to find the position of objects.
	Metal detector	Detect underground metal for possible locations of buildings, cars, or victims.
	Sonar life detector	Find the source of the victim's voice.
	Imaging devices	Flexible tube camera used in tight spaces, sonar life detector identified victim position, or boring machine drilled hole to take image of buried victims.
	Thermal imagery detector	Detect surface temperatures to find possible location of buried victims.
	Gas detector	Detect concentrations of hydrogen sulfide for indicating bodies.
	Drilling machines	Bore a hole 48~76 mm in diameter with a depth of 120 m for scene investigation.

5. Implementation of hazard inspection, reporting and notification mechanisms

Hazard notification involves firefighters, police, and non-governmental organizations. Fire departments should periodically coordinate, check connections, and update with the police and non-governmental systems. There are many police stations with radio and other wireless communications systems available in mountainous areas.

6. Establishment of disaster Incident Command System (ICS)

A standard procedure must be developed to improve how relief workers respond to natural calamities (Lagmay et al., 2008). Local government should erect a disaster ICS at the hazard scene. This command system should include a Commander, Security, Operations, Information, Communication liaisons, and Logistics officers. For large sedimentary hazards the CEOC should set up a Forward Command Center near the scene. The ICS should cooperate with the forward command center in hazard rescue.

7. Promotion of disaster response level

The National Fire Agency (http://www.nfa.gov.tw/) of the central government handled the CEOC emergency response, while local fire departments carried out hazard rescue during Typhoon Morakot. The multiple levels of operations led to inefficient integration and reduced efficiency during the emergency response. A professional institute for disaster prevention and mitigation and higher level control is suggested for emergency response.

8. Standardize military emergency rescue support equipment and communications

There was a limited interface between the relief workers and military during the response to the mudslide in southern Leyte in Philippines (Hall and Cular, 2010) and during the typhoon Morakot in Taiwan. Disaster prevention and emergency rescue became one of the missions of the military in Taiwan after Typhoon Morakot. The military should take the initiative in disaster rescue and pre-disposition of troops for potential affected areas according to the Disaster Prevention and Protection Act in Taiwan. Nerveless, the training and equipment of the military are not designed for disaster prevention and rescue. An interdepartmental effort is necessary now to establish measures and procedures for future disasters.

9. Communication of sedimentary hazard emergency rescue experience

Periodic workshops for sedimentary hazard emergency rescue experience exchanges and discussions with both domestic and international rescue workers are suggested to promote emergency rescue ability.

VI. CONCLUSION

The questionnaire results show that the relief workers lack sedimentary hazard emergency rescue training and equipment. The extreme rainfall conditions in the mountainous areas interrupted rescue action by cutting off communications. Information was unclear, increasing the risks for relief workers, and the buried victims were difficult to rescue under these straitened circumstances. Requests for support from other agencies are time-consuming and horizontal communication across various units is hard to integrate during the rescue action. The proposed suggestions for solving the aforementioned difficulties include promoting professional training for relief workers, strengthening emergency rescue equipment, and establishing rescue resources prior to disasters. Evaluations using advanced equipment, implementation of hazard inspection, reporting and notification mechanisms during the rescue are also suggested. A disaster incident command system, promotion of the disaster response level of the EOC, standardized military emergency rescue equipment and communications are needed as well. Finally emergency rescue efficiency can be enhanced by workshops for sharing the sedimentary hazard emergency rescue experience.

VII. ACKNOWLEDGEMENTS

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