Comparison of Debris Flow Hazard Mapping between Empirical Function and Numerical Simulation - a Case Study in Taiwan

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In this study we performed field investigation of a debris flow hazard event in eastern Taiwan, and conducted debris flow hazard mapping with empirical (SWCB guideline) and numerical methods (RAMMS::DebrisFlow). Finally we compared the mapping results with the damage of the housings and infrastructures, and discussed the applicability of these two methods. The preliminary inundation area following the empirical method is the greatest (13 Ha), after modification with local topography it reduces to 4.6 Ha. The numerical simulation result is the closest to the actual scenario. By applying the hazard degree classification based on velocity and inundation height, a hazard map is provided. The high hazard degree in the map matched with the damage status on the field, indicating that the hazard map could be used for land-use planning and local protection engineering purposes.

Key words: debris flow, hazard mapping, numerical simulation, RAMMS

1. INTRODUCTION

Debris flow has been one of the most devastating sediment disasters around the world. The direct and indirect damages caused by debris flow had cost tremendous economic losses and great casualties [*Jakob and Hungr*, 2005]. In Taiwan, the steep terrain, frequent occurrence of earthquake and heavy rainfall has made debris flow a major natural hazard in mountainous region [*Lo et al.*, 2012].

Debris flow is a hazard with high repeat potential, thus mitigation based on the mapping of possible inundation area for debris flow hazard could effectively reduce the casualty and economic losses.

The technique of debris flow hazard mapping has been greatly improved in the past decade [*Yu et al.*, 2006; *Takanashi et al.*, 2007; *Uchida et al.*, 2009;], and both empirical and numerical methods had been proposed to estimate the run-out distance and inundation area of debris flow [*Scheidl and Rickenmann*, 2010; *Cui, et al.*, 2011; *Rickenmann*, 2016]. However, there might be different degree of impact, which would result to different degree of damage and losses within the inundation area, thus introducing a classification method is worth to study.

2. METHOD

In this chapter we will introduce the empirical method currently applied by the Soil and Water Conservation Bureau, Taiwan, and the numerical simulation model and hazard classification introduced from Switzerland studies.

2.1 Empirical method

To better practice the task of debris flow hazard mapping, the Soil and Water Conservation Bureau (SWCB), the agency in charge of debris flow hazard management and mitigation in Taiwan, published the Manual for Potential Debris Flow Torrent Mapping in 2013. The manual is a guideline based on empirical method derived from Japanese studies and modified with local experiences. With estimated debris volume based on watershed size, run-out distance based on topography inputs, together with some criteria of terrain in deposition area, one could follow the steps and complete the hazard mapping.

The empirical equations for designated volume and run-out distance follow the previous studies in Japan [*Ikeya*, 1981] and Taiwan [*Hsieh and Tsai*, 1997], are written as Eq.(1*a*) and Eq.(1*b*).

$$V = 70{,}992 \times A^{0.61} \qquad (1a)$$

$$\log(L) = 0.42 \times \log(V \times \tan\theta) + 0.935 \qquad (1b)$$

In which A=catchment area (km^2), V=estimated debris volume (m^3), L=run-out distance (m), θ=slope of torrent (transportation zone, in degree).

Usually the start point of the run-out distance is the apex of the deposition zone, with the run-out distance as the radius, a 105-degree fan would be drawn. The shape of the fan is then modified according to on-site investigation and local topography, the most important is delineating areas exceeded 10 to 12 m height from the riverbed, considering the height as none-influence area under normal condition [*Hsu et al.*, 2010; *SWCB*, 2013].

Following the concept of the manual, the inundation areas of 1,719 torrents with debris flow hazard potential were mapped out in Taiwan, and corresponding mitigation strategies were then conducted.

2.2 Numerical simulation

In this study we adopted the RAMMS (Rapid Mass Movement Simulation) software system developed by WSL (Swiss Federal Institute for Forest, Snow and Landscape Research) for debris flow numerical simulation. The RAMMS system contains avalanche, rockfall, and debris flow modules [*Bartelt et al.*, 2012; *Hussin et al.*, 2012; *Leine et al.*, 2013] and were applied in several case studies in Taiwan [*Chung et al.*, 2017; *Lee et al.*, 2016a, 2016b].

The debris flow module of RAMMS is designed for flow phenomena containing fast move particulate debris. The model is based on 2-D depth-averaged shallow-water equations for granular flows in three dimensions given by the coordinates of the topographic surface of the digital elevation model in a (x,y,z) coordinate system and at time (t) [*WSL*, 2017; *Frank et al.*, 2017]. With the input of DEM (digital elevation model) the model could chose either hydrograph (when only the rainfall hydrograph is available) or block release (when the specific volume of the event is known) to input the release volume, and with the setting of parameters the maximum flow velocity and inundation height as the output. The input process is shown in **Fig. 1** (for more detail of the RAMMS::DebrisFlow module, please see [*WSL*, 2017] or [*Frank et al.*, 2017]).

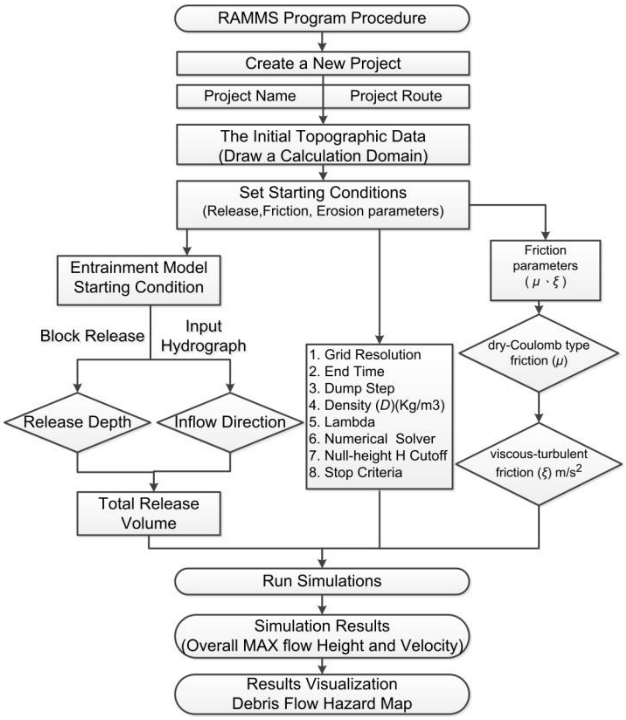

Fig. 1 RAMMS::DebrisFlow input procedure

2.3 Hazard mapping and hazard classification

In Switzerland the hazard mapping of natural hazards (floods, snow avalanches, and mass movements) had been developed for decades, with the preparation of natural hazard maps the spatial distribution of possible hazard hot spots become a vital information in land-use planning, infrastructure planning, and hazard mitigation. The Swiss hazard maps could be applied in the following purpose: spatial planning, risk reduction measures, instruments used in emergency planning, and raising the awareness among the population [*SDC*, 2005].

However the inundation area alone does not specify the intensity or the possible risks within the zones, thus it is difficult to classify and implant proper treatments. For example different intensity of velocity or inundation height may lead to different degree of loss, thus using velocity or inundation height, or both in combination, become a common method to classify the different degrees.

The hazard degrees were usually classified into high, medium, low and none-hazard, often shown on the map with respectively colors to indicate the differences. *BUWAL* [1997] and *Rickenmann* [2005] suggested the classification of debris flow hazards with different intensity combination of h (inundation height) and v (velocity), an update of the 2005 classification proposed by *Rickenmann* [personal communication, 2015] was adopted in this study, with more details in “medium” class, as shown in

Fig. 2.

The classification, definition and color of debris flow hazard degrees based on intensity are shown in **Table 1**.

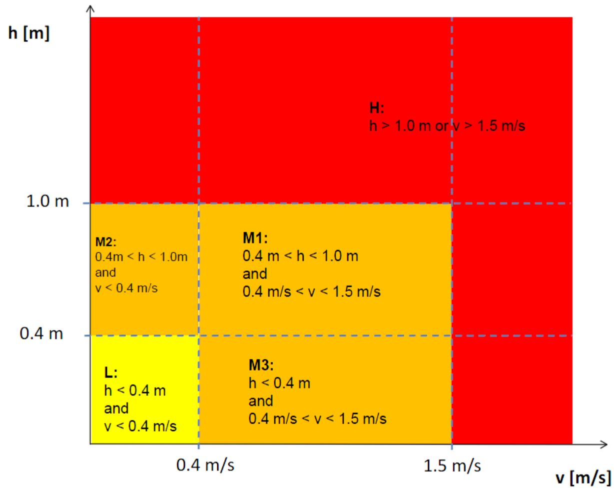

Fig. 2 Debris flow intensity classification [Rickenmann, personal communication, 2015]

Table 1 Debris flow hazard degree classification and definition

	Intensity classification	Hazard degree	Definition
Intensity	h>1.0 m or v>1.5 m/s	High	Persons are in danger both inside and outside their houses. Buildings are in danger of being destroyed.
	0.4m<h<1.0 m and 0.4 m/s<v<1.5 m/s	Medium	Persons are in danger outside their houses. Buildings may suffer damage and possible destruction depending in construction characteristics.
	0.4m<h<1.0m and v<0.4m/s		
	h<0.4m and 0.4m/s<v<1.5m/s		
	h<0.4 m and v<0.4 m/s	Low	Danger to persons is low or non-existent. Buildings may suffer little damage, but flooding or sedimentation may affect house interiors.

3. CASE STUDY

The Hualien DF168 potential debris flow torrent is located at the 8th settlement of Mayuan Village, Hualien County, which is at eastern Taiwan. There are approximately 40 households, 120 residents in the settlement, most of them indigenous people. The area of the catchment is about 18 hectare, the 1,226 m long torrent is east-west direction, and descending from 455 m (west) to 115 m (east), and the average slope of the torrent is 16 degree.

The upper part of the catchment consists of Tananao schist, which is rich of schist, limestone, and gneiss. The lower part consisted of tableland deposit, which mainly contained unconsolidated gravel deposits and were easily eroded and washed away by surface runoff. Also the region has some mining history with several abandoned mines around, with some mineral waste on the hillslope.

3.1 Hazard event

The record shows that the region had 2 debris flow hazard events, at the 1989 and 2001 typhoon events the accumulated rainfall were 447mm and 489.5 mm respectively. During July 2014 when Typhoon Matmo hit Taiwan, the rainfall and surface runoff eroded the banks of the torrent, resulted in torrent banks collapsed and formed a debris flow. The debris flow overflew at a box culvert and buried, damaged 3 residential houses of the 8th settlement. Fortunately the residents were evacuated in the previous afternoon so no one was injured.

From the rainfall hydrograph of nearby rainfall station, it is estimated that when the debris flow occurred (mid-night of July 23, 2014) the rainfall intensity and accumulated rainfall were 74.5 mm/hr and 328.5 mm respectively, the total accumulated rainfall of the event was 544 mm, which exceeded the debris flow red alert value (500 mm) set by the Soil and Water Conservation Bureau.

The field investigation of the disaster was conducted right after the event (Jul. 24, 2014, **Fig. 3**). The debris had blocked the drainage system and overflew. Three residential houses (Nos.157, 157-1, 157-2) at the left bank with their farmhouse, warehouse and farming machineries were buried by 1 to 1.5 m deep debris (boulders diameter ranging from 8 to 30 cm). Three other residential houses and a grocery store located at the right bank were close to the torrent and considered hazardous. The apex of the deposition zone was 80 m upstream of the drainage box culvert, the total deposition length is approximately 275 m with the terminate slope at approximately 2 degrees and the apex around 6 degrees. The inundation area was 4,782 m^2 and debris volume around 5,000 m^3.

The riverbed was full of collapsed boulders and the cross section was U-shape due to the eroded and transportation of the debris. Only some small size bank collapses were discovered at the transportation zone, totally less than 400 m^2. No large area of landslides could be found in the initiation zone, however a deep incision which resulted to bank erosion and collapse could be observed. The size of the boulders were mostly greater than 30 cm, some of them exceeded 2 m. It was estimated that the incision and erosion of the torrent bed and banks were the main source of the debris in this event.

Fig. 3 Hualien DF168 torrent before and after the disaster

3.2 Empirical run-out distance and numerical simulation results

From Eq.(1*a*) and Eq.(1*b*) the calculated run-out distance of Hualien DF168 is 400 m, as indicated by the yellow fan shape in **Fig. 4**. The modified inundation area based on local topography is shown as the red region in **Fig. 4**.

The input of RAMMS::DebrisFlow of this study is shown in **Table 2**, the simulation results (maximum inundation height and velocity) and hazard map are shown in **Fig. 5**.

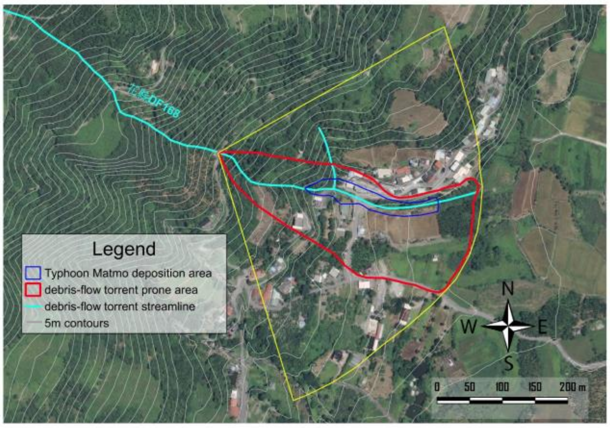

Fig. 4 Empirical run-out distance (yellow fan shape) and inundation area

The further downstream the hazard degree decreases, which is in consistent with the in situ gradient changes. The heavily damaged houses and culvert shown in **Fig. 3** located close to the apex appoint, which matched the red (high hazard) region shown in the hazard map (**Fig. 5**) and indicated that the debris would deposit at when the gradient has a sudden reduce.

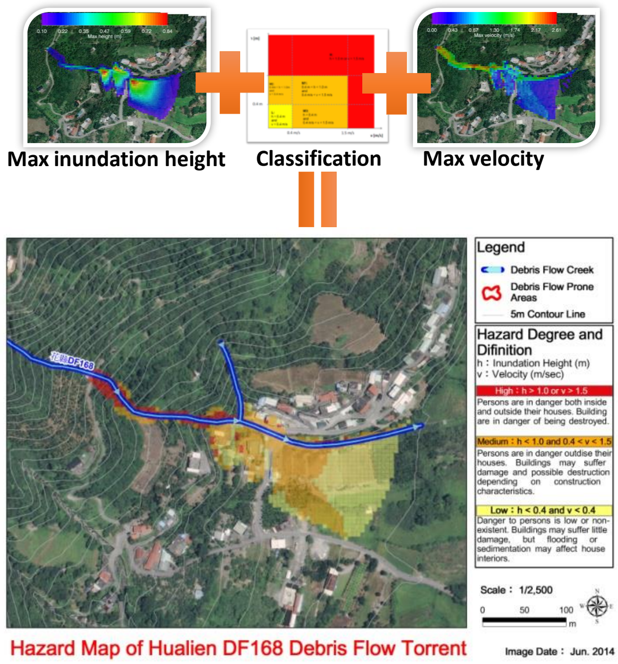

Fig. 5 RAMMS::DebrisFlow simulation result and hazard map

Table 2 RAMMS::DebrisFlow input data of Hualien DF168

	Input data
Terrain (DEM)	5 m*5 m
Dry-Coulomb type friction (μ)	0.225
Viscous-turbulent friction (ξ)	150 m/sec^2
Density (D)	2.65 kg/m^3
Stop criteria	12 hr or momentum < 5%
Block release	5,000 m^3
Hydrograph	2014/7/22 AM10:00 to 2014/7/23 PM21:00 rainfall data from C1Z030 station

4. COMPARISON AND DISCUSSION

By overlaying the areas we could compare the differences of the outputs (**Fig. 6**), the inundation area of the real event is 0.48 Ha (blue region in **Fig. 6**), the preliminary area following the empirical method of SWCB guideline is the largest (13 Ha, yellow region in **Fig. 6**), after modification and adjustment based on local topography this reduced to 4.6 Ha (red region in **Fig. 6)**, and the numerical simulation result (shown with 3 hazard degree color shades) is the closest to the actual hazard event.

After the delimitation of preliminary result, the inundation area reduced by 65% (from yellow to red region), however compared to the numerical result it is still 60 to 70% larger.

For evacuation purposes the empirical method would provide enough information alone, however for land-use planning, local protection engineering or insurance purposes the numerical method could provide more useful information.

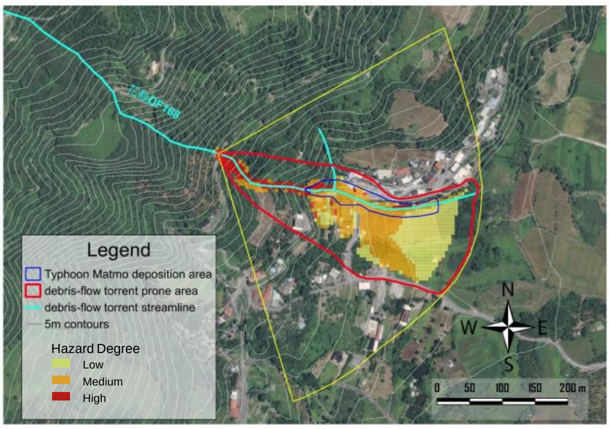

Fig. 6 Comparison the inundation area of empirical (yellow fan shape) and numerical (3 color shades) methods

5. CONCLUSIONS

Debris flow hazard mapping is an important task in the preparedness stage of natural hazard management, applying the empirical method could produce a hazard map more quickly, but the expert judgment and adjustment at the field would play a vital role. Also it would be difficult to further classify the hazard degrees within the inundation area. The numerical simulation could provide intensity information for hazard degree classification, but it requires more data and resources for calibration, choosing different parameter and inputs may lead to different results, which also requires expert and professional knowledge for interpretation [*Wu and Chen*, 2016].

In the future the hazard mapping of debris flow would still play an important role in land-use planning and hazard mitigation, a long-term data collection and observation of debris flow events together with post-event documentary could benefit both empirical and numerical approaches [*Tang et al.*, 2012].

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