京都大学防災研究所年報　第 52 号 B　平成 21 年 6 月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 52 B, 2009

The Description of Taiwanese Disaster Risk Reduction Plan and Vulnerability Assessment of the Mitigation Facility for Debris Flow Disaster

Tingyeh WU*, Kaoru TAKARA, and Yosuke YAMASHIKI

* Dept. of Urban and Environment Engineering, Kyoto University

Synopsis

This paper describes a vulnerability assessment method related to the disaster risk reduction plan and debris flow disaster. Based on the government disaster mitigation strategies and historical data for debris flow in Taiwan, several insufficient of the disaster risk reduction plan are referred. Several suggested strategies are pointed out thereby. On the other hand, numerical simulations are done to the torrents with potential dangerous via Flo-2D software under the natural condition case, the detention basin case, and the levee case. It is clarified the efficiency of the detention basin case and the levee case when considering of different factors. Finally, conclusions are made according to the results.

Keywords: Disaster Risk Reduction Plan, Vulnerability, Flo-2D, Disaster Mitigation

1. Introduction

A systematically disaster risk reduction plan is imperative to efficiently control the damage or loss that might occur due to a natural hazard. This is mentioned by United Nations and includes the actions to reduce disaster risks before, during, and after disasters (United Nations, 2009).

The Taiwanese government reconsidered its strategy on sediment disasters after a severe earthquake occurred in 1999. This earthquake resulted in 2,418 deaths, 51,722 collapsed buildings, and significant agricultural loss. Meanwhile, the frequency of subsequent sediment disasters has increased due to earthquake in the past 10 years, particularly debris flow disasters in the mountainous area. This dictated that not only the engineering measures were essential, but also non-engineering measures such as the early warning system at a threshold rainfall value for debris flow. This latter strategy, which accounted for both accumulated rainfall and intensity as well as rainfall intensity and duration (Huang, 2002), determined 1510 torrents potentially dangerous that required monitoring during heavy rainfall periods (SWCB, 2009).

Elsewhere, the role of vulnerability in the natural hazard mitigation was clearly determined in the International Strategy for Disaster Reduction (ISDR) of the United Nations (ISDR, 2004). It was here where vulnerability was defined to have an interdisciplinary scope that includes not only the environmental condition, but also social, and economical conditions, as well. With these considerations in hand, vulnerability evaluation is conducted to determine the probability of the damage that may occur.

The challenge of reducing socio-economic vulnerability of a natural hazard due to the climate change is a main topic in many related studies. This has been accepted as a significant part of overall vulnerability assessment. So-called community-based indicators were divided to evaluate vulnerability in a small region, such as the proportion of people or property distributed in the hazardous area, the per capita production of the

Gross Regional Product (GRP), the facility or life-line which support the social system, etc (Petrova, 2006; Fuchs et al, 2007; Deng, 2008; Birkmann, 2007). These findings were then disseminated in map form to local communities in many countries. These show how a region is sensitive to a certain natural hazard at one time.

However, it is known that factors and conditions of vulnerability are constantly changing based on the differences of environmental or social conditions. Though evaluations are done in the same particular area, unique indicators should first be considered. Indeed, it is difficult to distinguish which evaluation is more persuaded than others without the prior checking of such indicators. Thus, the Taiwanese government designed a series of policies and strategies for improving a community's ability to cope against a threat within a long period of time with due consideration to vulnerability assessment. These strategies or mitigation politics intend to help the regional people avoid property damage, maintain hazardous area control, and pursue overall development. Along with the effort of changing the mitigation program after a period of time, a continuous procedure of the mitigation is set in place, making it possible to find out the changes on vulnerability in terms of the result after disaster.

Several differences in related mitigation frameworks implemented in different countries are noted. Kao (2005) proposed a relationship between land-use and potential disaster area and compared the different viewpoints in determining the hazard potential area in Austria, Japan, and Taiwan. Riu and Lee (2006) referred to a methodology of estimating the probable disaster loss. With some limitations, these studies aimed to connect the concept of risk management with disaster mitigation. The efficiency of the mitigation engineering facilities was conducted by Tsoa (2008), emphasizing the efficiency of risk assessment and mitigation. However, a clear and systematic discussion is still necessary. Therefore, a numerical model used to simulate the government strategies for sediment disasters is considered in this study. The efficiency if the strategies are discussed based on the simulation results of this numerical model and the current prize of the land-use categories.

2. The Study Materials

(1) Study area

Chenyoulanxi basin in Taiwan is our study area which experiences high frequency of the sediment disasters from 1995 to 2007. A total of 35 torrents in this area were determined as potentially dangerous (SWCB, 2004). In a previous study, we distinguished the danger levels of these 35 torrents according to the velocity and depth data of the accumulated area based on the numerical simulations results (Wu and Takara, 2007). Four torrents with potentially dangerous areas were selected in this study for further investigation (Fig.1). These are referred to as Nanyou 026 (A), Nantou 073 (B), Nantou 072 (C), and Nantou 027(D) (Fig.2). There are 68 families situated in Nantou 072, 2 in Nantou 073, and none in Nantou 026 and Nantou 027 (SWCB, 2009).

(2) Simulation Software and the input data

Flo-2D is used to model the torrents in this study. This is a 2-D horizontal physical model which is principally focused on the simulations of the flood or debris flow in many terrains, such as the urban area, the channels and/or floodplain.

The following data are required in the simulations:

(1) Digital Terrain Model: This serves as the main base data for the simulations. The grid-cell size is 20×20 square meters.

(2) Aerial photograph: This serves for checking the accumulation area and establishes the land-use data or mitigation facilities data. This was acquired from the Aerial Survey Office, Forestry Bureau of Taiwan.

(3) Parameters: Two sets of parameters are used. One set includes flow and sediment parameters (flow Manning n-value, floodplain Froude No., viscosity and yield stress to the sediment concentration, the Manning n-value, and the flow velocity). A second parameter set includes changes in the environmental situation, such as the detention basin volume, the location and area of detention basin levee length, and

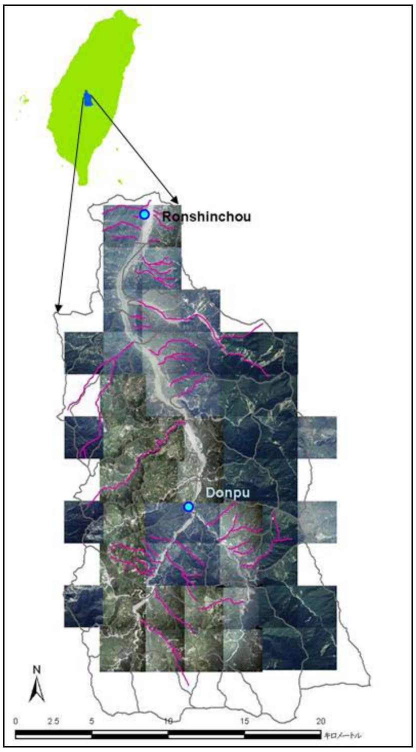

Fig.1 The Chanyoulanxi basin

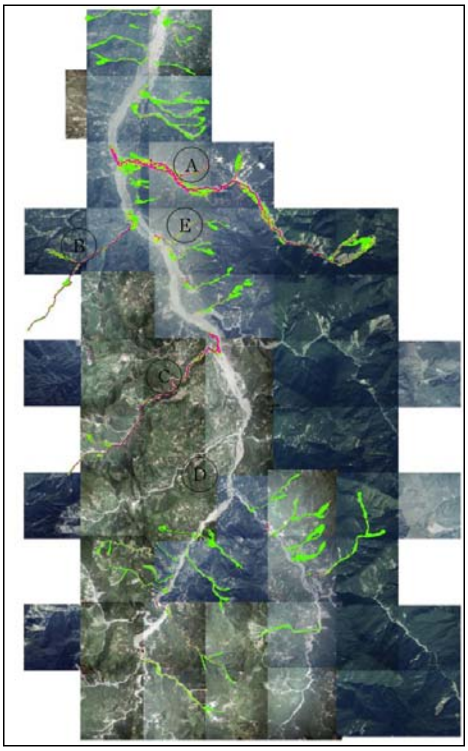

Fig.2 Simulation targets in the Chenyoulanxi basin

levee height. The flow and sediment parameter sets were the ones used in the previous study (Wu and Takara, 2007). The designed discharge of debris flow is the 200-year return period.

Several situations are assumed and simulated to evaluate the probable loss and vulnerability, which are natural situation, levee, and detention basin cases.

3. The historical mitigation policies in Taiwan

We focus here on mitigation strategies and policies for sediment disasters in Taiwan during 1958 to 2007. The history of the disaster risk reduction plan can be approximately divided into two periods, the period prior to 1999, and the period following 1999. The major disaster risk reduction plan was focused on the strategies and resources for sediment disasters due to the high frequency debris flow disasters after 2000 to 2005. The main law for disaster mitigation in Taiwan is Disaster Prevention and Rescue Law because of the severe earthquake in 1999. Other aspects of the mitigation strategies were established and designed after the law was enforced.

Natural hazard affairs are managed by several associations in Taiwan, for instance, Council of Agriculture and Ministry of Economic Affairs managed sediment and flood disasters. The main disaster risk reduction plans are made by the two departments. On the other hand, National science and technology Center of Disaster Prevention manages the disaster researches and National Rescue Command Center manages the training and education related to the disaster rescue.

The main strategies for sediment disasters are programmed by Soil and Water Conservation Bureau under Council of Agriculture which can be divided into five categories, including Landslide recovery, Erosion and sediment control engineering, the management strategies on hillslope (including protecting, supervising, and monitoring), the establishing and designing the village, and the special basin management (SWCB, 2000 to 2006).

The point of mitigation strategies in 2004 is an important change in recent years. Before 2004, the strategy for mitigation focused on restoring the areas affected by earthquake that occurred in 1999, training the rescue organization, investing the areas with potential dangers, and recovering collapsed infrastructure and lifeline. After 2004, the strategies focused on development and preparedness for further disasters, such as supported the development on local characteristic in 6 villages where the debris flow had occurred before in 2005, established the national earthquake memorize part in 2004. The procedure of the mitigation plan after 1999 could be integrated as establishing the mitigation framework, mitigation activities, and development activities. However, the mitigation program should be a long-term procedure and it is always easily ignored by policy planners (Wamsler, 2006).

On the other hand, in addition to the engineering and non-engineering strategies, the government also attempted to create disaster programs for sediment disasters, especially for the sediment control, due to the need for preventing sediment disasters and the insufficiency of the Disaster Prevention and Response Act. Therefore, an act for designated soil and water conservation are discussed after 2005. However, Disaster Prevention and Rescue Law is still the only formal act for disaster mitigation.

Though the engineering facilities can stem the sediment when the sediment disaster occurs, the engineering facilities should be considered and check the security and availability due to the high frequency of the sediment disasters. Due to the reasons, three aspects of the Taiwanese disaster risk reduction plan are mentioned.

4. Simulation Results

(1) Simulation results of the natural condition case

The accumulated area of the torrents and depth and velocity of each grid-cell can be acquired after the simulation. The accumulated area in the downstream are focused on because of not only the most of building, roadway, bridge, and agriculture facilities are located in the downstream area, but also the upstream area are the undeveloped forest area. Firstly, the results are shown in terms of the accumulated depth, which are 0-0.3m, 0.3-1m, 1-2m, and larger than 2m (Fig. 3, 4, 5, 6). According to the figure, it is clearly that the accumulated type can be divided into two types. Nantou026 and Nantou027 are the same type and Nantou073, Nantou072, and New defined torrent are another type.

In the type of Nantou026 and Nantou027, the sediment accumulates along the land beside the river way and at the downstream and results in a wide fan. Part of the sediment affects another side of the river. On the other hand, in the type of Nantou073, Nantou072, sediment accumulated in the river way which the most areas of the river way exceed 2m.

The accumulated areas are checked via aerial photographs. The accumulated depths less than 0.3m are ignored because of the damage will not occur under this depth. The accumulated volume which covers the land can be calculated in terms of the depth.

Based on the accumulated area in the downstream part, the range of the levee and detention basin are decided, especially the areas with buildings or roadways covered by sediment. The levees are designed along the river way. On the other hand, detention basin are designed according to the amount of sediment are assumed to be decreased. The detention basin was not designed to the new defined torrent because of the affected area is quite small. Table 1 shows the length of the levee and the volume of the detention basin.

(2) Simulation results of the detention basin case

The accumulated area under the detention basin case shows the efficiency of this strategy. The results can be divided into two types according to the first finding in the natural condition (Fig. 7, 8, 9, 10). The efficiency of the detention basin is positive in the type with Nantou026 and Nantou027, however, the same strategy shows negative results in the type with Nantou073 and Nantou072.

Table 1 The volume of detention basin

Torrent name	Detention basin volume (m^3)	Levee length (m)
A (Nan 026)	1,477,336	9749.36
B (Nan 073)	716,088	7363.22
C (Nan 072)	247,660	3110.84
D (Nan 027)	177,447	3289.64

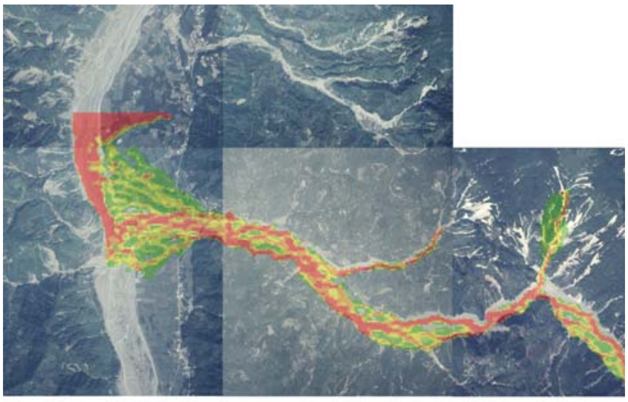

Fig.3 The simulation result — Nantou026, the depth in natural condition case

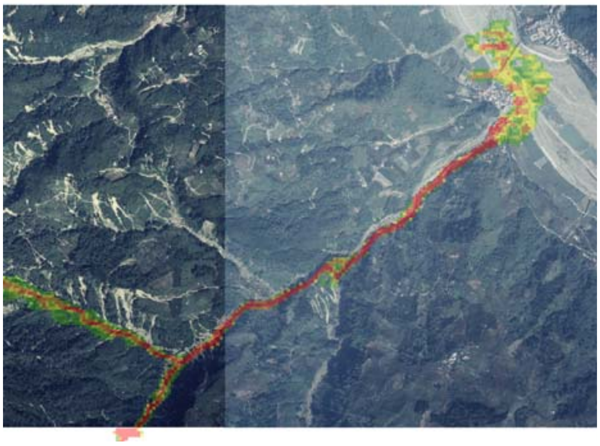

Fig.6 The simulation result – Nantou072, the depth in natural condition case

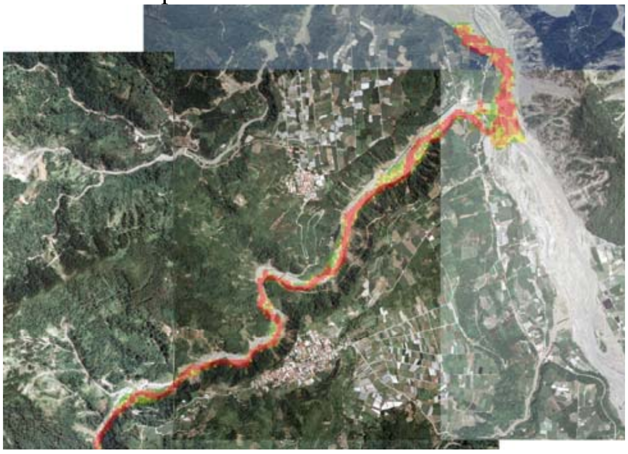

Fig.4 The simulation result – Nantou073, the depth in natural condition case

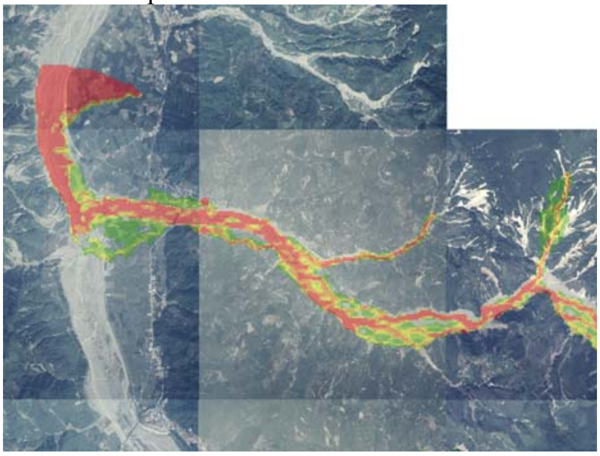

Fig.7 The simulation result — Nantou026, the depth in detention basin condition case

Fig.5 The simulation result – Nantou027, the depth in natural condition case

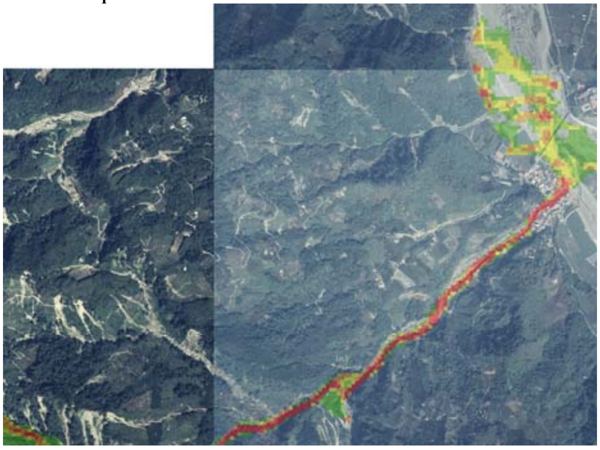

Fig.8 The simulation result – Nantou073, the depth in detention basin condition case

Fig.9 The simulation result – Nantou072, the depth in detention basin condition case

Fig.10 The simulation result – Nantou027, the depth in detention basin condition

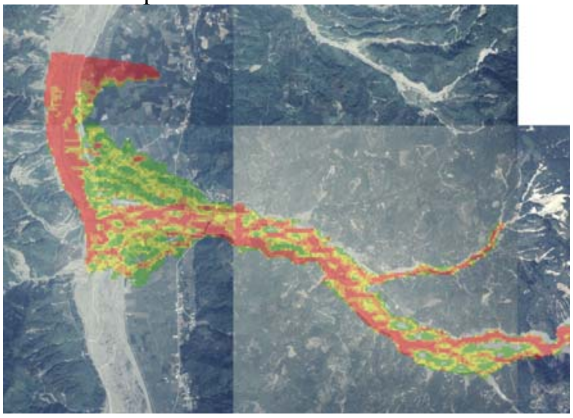

Fig.11 The simulation result – Nantou026, the depth in levee case

Fig.12 The simulation result – Nantou073, the depth in levee case

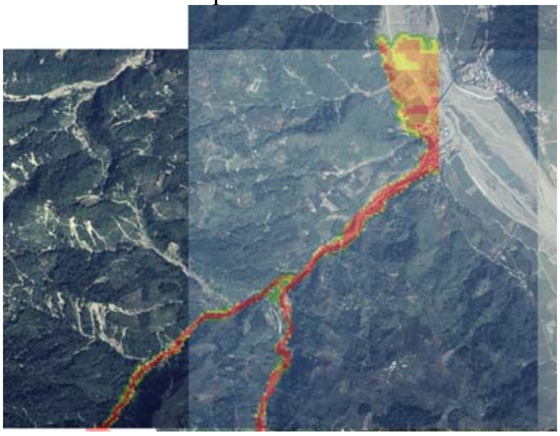

Fig.13 The simulation result – Nantou072, the depth in levee case

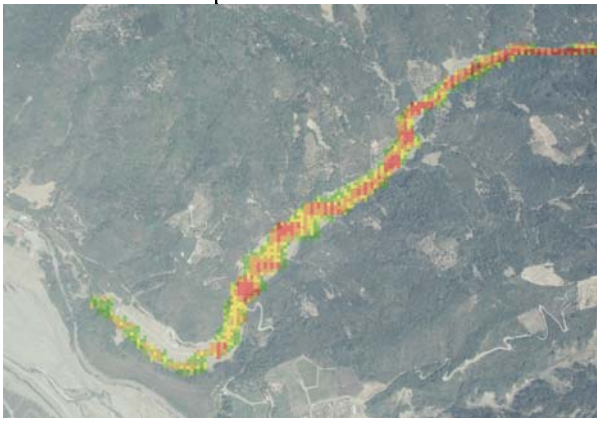

Fig.14 The simulation result – Nantou027, the depth in levee case

Table 2 The simulation results of the three cases

Torrent name	The natural condition case		The detention basin case		The levee case	
	Accumulated volume (m^3)	Accumulated area (m^2)	Accumulated volume (m^3)	Accumulated area (m^2)	Accumulated volume (m^3)	Accumulated area (m^2)
A (Nan 026)	1,466,432	962,400	1,548,628	787,600	1,282,324	796,800
B (Nan 073)	529,810	255,600	175,856	83,600	321,956	166,800
C (Nan 072)	206,508	141,200	248,696	132,000	348,852	193,200
D (Nan 027)	47,791	34,900	1,933	6,000	40,020	20,600

Table 3 The detailed simulation results of each cases

Torrent name		The natural case (area and volume)			The difference with the natural condition case and the detention basin case			The difference with the natural condition case and the levee case		
		Roadway	Building	Vegetation	Roadway	Building	Vegetation	Roadway	Building	Vegetation
Nantou026	area	116,400	21,200	788,800	56,800	-5,200	34,400	0	1,200	-8000
	volume	210,308	21,236	1,234,888	127,040	-3,604	62,356	-19,444	1,504	-47,436
Nantou073	area	10,000	1,600	137,600	-10,800	1,200	49,200	-3,200	0	-14,400
	volume	23,328	5,380	401,700	-26,908	3,640	194,576	7,376	900	193,996
Nantou072	area	18,400	25,600	68,000	-3,600	15,600	36,000	6,800	-19,600	-68,400
	volume	46,920	46,808	109,180	-1,632	22,068	68,052	19,152	-48,612	-116,484
Nantou027	area	1,000	300	24,800	700	300	19,000	300	300	20,000
	volume	1,063	257	45,637	728	257	38,785	414	257	39,349

Table 2 shows the affected area and volume before and after the detention basin is designed. In Nantou026, though the accumulated sediment volume increased, most of the sediment accumulates in the main river way and the accumulated area decrease. Moreover, most of the land located at the convergence of the main flow and Nantou026 is not covered by sediment. In Nantou027, sediment are efficiently controlled by the detention basin, therefore the fan did not occur. In Nantou072 and Nantou073, the detention basin makes an effect on the accumulate area. However, the effect to the main flow and the lands along the main flow may result in a more serious disaster. Based on the results here, the detention basin shows an efficiently decrease in the accumulated sediment area. However, it also shows that some sediment will affected the hillslope land at the downstream of the torrents after the detention basin are built. The engineering facilities support the detention basin and the preparedness strategies for the resident are necessary.

(3) Simulation results of the levee case

The location and the length of levee are designed according to the simulation results of the natural condition cases. Downstream areas are emphasized because the community mainly situated in this region. Table 2 shows the affected volume and area of the torrents before and after levees are designed. The results can be divided into two types according to the first finding in the natural condition (Fig. 11, 12, 13, 14).

5. Discussion

We compared how the sediment accumulates in the natural situation case, the detention basin case, and the levee case (Table 2) and tried to evaluate vulnerability of the mitigation engineering facilities based on the currency value and land use categories.

The main propose of the mitigation engineering facilities is to resist the damage occurring. The efficiency of mitigation engineering facilities is how much sediment is decreased after it has been designed. In other words, it can be said that vulnerability of a mitigation engineering facility is how negative efficient it is or how much loss and damage it may cause. Due to the restriction of the data, we show vulnerability of mitigation engineering facility by concerning the negative efficiency from simulation results.

In table 2, the accumulated sediment volume and accumulated area were shown and were divided into building, roadway, and vegetation areas after overlaying with aerial photographs. Building contains all kinds of building, roadway contains the asphalt road and bridge, and vegetation contains the other areas in the covered range. The sediment depth less than 0.3 m was ignored because it is not vulnerable to the disaster under this standard (Tsao, 2008). The accumulated volume and area in the natural condition case were shown in the first column. In the second and third column, the value showed the difference value *(Ds)* of the value in the natural condition case *(A)* minus the value in the detention basin case *(B)* or the value in the levee case *(C)*, which is shown as follows.

$$Ds1 = (A) - (B)$$

$$Ds2 = (A) - (C)$$

Where *Ds1* is the value in the second column and *Ds2* is the value in the third column.

The positive value shows that the mitigation engineering facility has a positive effect to the debris flow disaster, and the minus value means the effect is negative.

From the results (table 2 and table 3), the detention basin case the higher efficiency in the most cases and in the whole torrents than the levee case. When the detailed category is emphasized, it is clear that torrent Nantou027 has the best mitigation effect in these cases. On the other hand, building can be considered as the most vulnerable, roadway is the next, and the vegetation is fewest vulnerable due to the human and property density. According to this concept, it is not different to design detention basin or levee in Nantou027 and it is better to design levee in Nantou073 and Nanatou026 when considering the category building. In the category roadway, it is clear the levee case shows a better efficiency on Nantou073 and Nantou072.

In order to represent the different value of the land use categories, the each category prize was concerned in currency value. According to the data from National Statistics and Soil and Water Conservation Bureau, the roadway is about 250 dollars per meter to recover from the sediment disasters, the building is 3,000 dollar for each one and the vegetation is 0.001 dollar per square meter. Based on the prize here, we calculated the efficiency of the two mitigation engineering strategies and represented in table 4. From the results, detention basin will have a higher economical effect if it is designed for Nantou073, Nantou072. On the other hand, it is higher economical effect if the levee was built on Nantou026 and Nantou027. This result only concerned the final total number with the economical meaning but does not prove the mitigation effects.

Table 4 The efficiency calculation of the three land-use categories

Torrent name	The difference with the natural condition case and the detention basin case			The difference with the natural condition case and the levee case			Mitigation engineering strategy efficiency	
	Roadway	Building	Vegetation	Roadway	Building	Vegetation	Detention Basin case	Levee case
Nantou026	559	-156,000	34	42	36,000	-8	-155,888	36,034
Nantou073	-623	36,000	49	576	141	-14	35,426	703
Nantou072	0	468,000	36	407	-588,00	-68	468,036	-58,461
Nantou027	260	9,000	19	345	9,000	20	9,279	9,365

6. Conclusion

A description of Taiwanese disaster risk reduction plan for sediment disasters in recent years was made. Simulations due to the results of a previous study and the disaster risk reduction plan were made. Some of the conclusions were reached are shown as follows:

(1) The insufficient of Taiwanese disaster risk reduction plan for sediment disasters were clarified, including insufficiency on the institution, the policy aspects on risk reduction and the development by planner, and the security of the engineering facility.

(2) Flo-2D was used to simulate four torrents in the three different cases. The results followed the simulations in the previous study and could be divided into two types. The first type includes Nantou026 and Nantou027, which shows that the sediment was decreased in the alluvial fan area. On the other hand, the second type includes Nantou072 and Nantou073, the alluvial fan in unclear and the most of sediment are in the river way when it has influence to the downstream area.

(3) The simulation results show that the detention basin case shows a better effect on decreasing the sediment. When we separated with the land-use categories, building, roadway, and vegetation, the

detention basin shows better effects on vegetation and the levee case shows better effects on roadway and building in several torrents.

(4) After comparing to the landuse categories data and the current prize, the results shows that the levee case is better when considering it in Nantou026 and Nantou027 and the detention basin case is better when considering it in Nantou072 and Nantou0273. The conclusion was made by the accumulate volume, area, and the prize of building, roadway, and vegetation. It represented the economical efficiency but does not prove the best mitigation effect.

This study made interprets the methodology of vulnerability assessment for the engineering facility via accumulated sediment depth and volume from the numerical simulation results. The method simply shows the efficiency on detention basin and levee for the 200-year return period discharge. It should be considered in other engineering facilities and disaster magnitude as well.

Acknowledgement

The authors wish to show the appreciate to National Fire Agency, Ministry of the Interior for the disaster loss data on property and human injured and death, to Soil and Water Conservation Bureau, Agriculture Committee of Taiwanese government for the torrents with potential dangerous information and the debris flow loss data, and to National Statistics for the land-use data. The authors also want to show appreciate to Dr. Mondonedo for the precious comments on improving this paper.

References

Birkmann, J., 2004, Partnerships for reducing landslide risk.

Birkmann, J., 2007, Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies, United Nations University

Cabinet Office, 2006, Disaster Management in Japan, Director General for Disaster Management, Cabinet Office, Tokyo, Japan

Deng, L. B., 2008, Are non-poor households always less vulnerable? The case of households exposed to protracted civil war in Southern Sudan, Disasters, 32 (3): 377-398

Fuchs, S., Heiss, K., and Hübl, J., 2007, Towards an empirical vulnerability function for use in debris flow risk assessment, Natural Hazards and Earth System Sciences, 7: 495-506

Huang, T.H., 2002, Characteristics of rains triggering debris flows in the watershed of Chenyoulen Stream, Master Thesis (in Chinese)

ISDR, 2004, Living with the risk— A global review of disaster reduction initiatives, United Nations

ISDR, 2009, UNISDR Terminology on Disaster Risk Reduction, United Nations

Kao, Y.C., Chen, S.C., 2005, Differences on Disaster Potential Area: Compared to the Experience of Austria and Japan, 3rd Land-use science conference (in Chinese)

Liu, K.F., Lee H.C., 2006, The study of the direct damage estimation of debris flow, Journal of Chinese Soil and Water Conservation, Vol.37 (2), pp. 143-155 (in Chinese)

National Disaster Prevention and Protection Commission, www.ndppc.nat.gov.tw

O'Brien J. S. 2006, Flo-2D User's Manual, which is available on http://www.flo-2d.com.

Petrova, E., 2006, Vulnerability of Russian regions to natural risk: experience of quantitative assessment, Natural Hazards and Earth System Sciences, 6: 49-54.

Shieh, M. C., Huang, H. P., 2005, Evaluated the Structures on Debris-flow Disaster Mitigation Effect, www.twaes.org.tw/thesis/2005/09/57.pdf (in Chinese)

Soil and Water Conservation Bureau, Debris Flow Annual Report (from 2000 to 2006) (in Chinese)

Tsao, T. C., Hsu, W. K., Chen, C. T., Luo, W.C., Chen, C.Y., 2008, A Preliminary Study on Risk Analysis of Debris Flow, the report of National Science and Technology Center for Disaster Reduction (NCDR) (in Chinese)

Wamsler, C., 2006, Mainstreaming risk reduction in urban planning and housing: A challenge for international Aid organizations, Disasters, 30 (2): 151-177.

Wu, T. Y., Takara, K., 2008, Development of a hazard mapping method for debris flow in disaster-prone areas, JSCE, Vol. 52, pp: 145-150.

Yang, K. C., Huang, H. P., Su, L. M., 2003, Application of FLO-2D Model with GIS on Debris-Flow Hazard Simulation, The 1st Taipei International Digital Earth Symposium C1-6 (in Chinese)

土砂災害地域防災計画の検討と防災構造物に基づく脆弱性の評価

Tingyeh WU*・寶　馨・山敷　庸亮

*京都大学大学院工学研究科都市環境工学専攻

要　旨

本稿では土砂災害における防災計画，脆弱性について，概説し，評価している。この研究では台湾の1999年から 2006 までの防災計画に内容と施行方向を筆者らは述べました。また，この内容により，欠点を検討しながら，提案を示した。さらに，防災工程の効果を評価するため，DTMとFLO-2Dで自然条件と沈砂池を設置してる条件と土石流に脅してる地域をシミュレーションし，結果について議論しました。最後に，空中写真でモデルの結果を検証することにより，災害軽減ための工程構造物の脆弱性に適切なモデルを提案した。

キーワード：防災計画，災害脆弱性，FLO-2D，災害軽減