Review of the Research on Debris Flows in Taiwan during Past Thirty Years

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Abstract—This paper presents a historical review of research on debris flow during past thirty years since 1980. The content includes mainly the mechanics, mitigation and assessment of debris flows and divided into the following ten subjects related to debris flows: (1) initiation process; (2) fundamental rheology; (3) velocity distributions; (4) stoppage and deposition; (5) impact force on structures; (6) mechanics and characteristics (theoretical, numerical, experimental and in-site investigation); (7) debris-flow countermeasures; (8) hazard prediction and assessment; (9) monitoring and alert; (10) case studies. Review on the development and suggested future research topics will be explained.

Keywords—Debris Flows, Disaster Mitigation, Historical Review, Natural Hazards, Researches in Taiwan.

I. INTRODUCTION

Debris flow is a flow composed of mud, clay, sand, gravels, water, air and so forth, flowing down mainly due to its gravitational force. Natural disasters caused by debris flows often occur all over the world recently and there are many natural or manmade factors leading to these tremendous accidents [1-2]. Development of prevention techniques is obviously based on the understanding and analysis of the mechanical behavior of debris flow [3].

Occurrence of debris flow depends highly on local topographic, meteorological, geologic, and hydrologic conditions. However, there are many factors influence the occurrence of debris flow in a region. For example, the special features and natural reasons that cause debris flows often occur in Taiwan and can be referred to the two published books on debris flows [4, 5].

There are also some important research papers concerning about the historical review on the debris-flows analysis, hazards and mitigation works (Jan and Shen, 1993; Chen et al. 2004; Wu et al. 2006; Lin, 2006).

The Water and Soil Conservation Bureau of Council of Agriculture of Executive Yuan, Taiwan, published Debris Flow Annual Report since 2003 and has built up a website named Debris Flow Disaster Prevention Information from which people can browse a lot of information on debris flow in Taiwan.

Figure 1 Website for debris flow disaster prevention information

There are many researchers conducted a lot of studies on debris flow in various topics. Their research works usually published and can be searched from some famous periodicals related to the debris-flow study such as:

(1) Journal of Chinese Soil and Water Conservation;
(2) Journal of Soil and Water Conservation;
(3) Sino-Geotechnics;
(4) Journal of Taiwan Disaster Prevention Society;
(5) Journal of Slope Land Hazard Prevention;
(6) Journal of Chinese Agricultural Engineering.

(7) Journal of the Chinese Institute of Civil & Hydraulic Engineering;
(8) Journal of Technology;
(9) Journal of Crisis Management;
(10) City and Planning.

In the following the researches on debris flows in Taiwan during past 30 years since 1985 to 2014 are reviewed and summarized. The percentage of each concerned topic (from the statistical data of the reference list) is illustrated in Fig. 1 from which we can understand that hazard prediction and assessment of debris-flows got the highest attention (18.75%); the second is the initial process of debris-flow (14.77%); while the third is case studies (10.80%); and those lower than 5% need to be improved in the future.
II. INITIATION PROCESSES OF DEBRIS FLOWS

The study of initiation process is very important for understanding the mechanism of the occurrence of debris flows. A lot of researchers in Taiwan are interested in this topic. They were concerning about many influence factors, e.g. geometric factors (Wu and Chiang, 1985), rainfall characteristics (Chiang and Lin, 1991; Fan and Mao, 1997; Chen et al., 2011; Chen et al., 2012), excess pore pressure (Chou and Liaw, 1998; Chen and Yang, 2000), critical angles (Yu, 1987; Huang, 1991, 1993; Lin et al., 1993; Huang and Hsiao, 2014), characteristics and mechanism of initiation (Zheng and Chiang, 1986; Feng, 1988; Shieh et al. 1995; Lien, 1996; Lien and Chiao, 1996; Chen et al. 2010); relation to typhoons and/or earthquakes (Lin and Wang, 2006; Lin and Lu, 2007; Wang and Lin, 2010; Tsai et al., 2011), seepage effect (Hsiao, 2012). Some important topics in this category are of much interest to the researchers: initiation of debris flows due to mechanical vibrations such as vehicle moving, piling and explosion, etc; relationship between debris-flow initiation and slope instability; mechanism of debris-flow occurrence from the point of view of fluidization of porous media.

III. FUNDAMENTAL RHEOLOGY OF DEBRIS FLOWS

Some researchers in Taiwan has conducted these studies (Jan, 1993; Jan et al. 1997; Tseng and Yu 1997; Jan et al. 2009; Liu and Wu, 2012). However, these studies require support from laboratory experiments and theoretical background. It is expected in the future more investigations on this fundamental research topic can be conducted.

IV. VELOCITY DISTRIBUTION OF DEBRIS FLOWS

Most of researches on the movement of debris flows concern about the uniform flows in an open channel due to the mathematical simplicity. Following the researches of Takahashi (1991) there are some research works on this topic: Yu and Chen, 1990; Su et al., 1993; Lien et al. 1993; Ho, 1997; Huang and Hsiao, 2014.

There remained a lot of extended topics to be studied such as three-dimensional effects, boundary-layer effects, unsteady effects, viscosity effects, effects of Raynolds number, Froude number and Bagnold number, etc. Theoretical analysis of the velocity distribution for three-dimensional, unsteady, rapid-varied, non-uniform debris flows is very complicated and might be resorted to numerical analysis and/or experimental investigation.

V. STOPPAGE AND DEPOSIT OF DEBRIS FLOWS

The stopped area usually forms a deposition fan of various shapes. Correct estimate of deposit length and deposit fan for a debris flow can be valuable for hazard mitigation, prediction and rescue. There are two main research interesting topics: one is deposit length (Chiang and Lin, 1987; Yu and Lin, 1991; Yu, 1992, 1993; Lin et al. 1993; Huang and Su, 2007; Tseng 2011) and the other is deposit fan (Chen et al. 1993; Chiang, et al. 1993; Jan, 1994; Shieh et al. 1995; Shieh and Tsai, 1997; Tsai 2011).

VI. IMPACT FORCE OF DEBRIS FLOWS ON STRUCTURES

Debris flow carrying stones and mud can cause catastrophic destroy of the structures when it impacts on the structures. Some researches works mentioned this topic: cantilevered beam (Yu, 1992); dams (Lin, 1994); slit dam (Shiau, 1995); debris dams (Liu and Lee, 1996; Liu et al. 1997); curved dams (Liu and Yu, 1996; Ting et al. 2006). However, the study on impact load of debris flows acting on various structures such as beams, plates, shells are of interest to the structural engineers for design of countermeasures.

VII. MECHANICS AND CHARACTERISTICS OF DEBRIS FLOWS

A. Theoretical Studies

Theoretical studies on debris flows include: Lien, 1997; Huang and Hsiao, 2014. More theoretical formulation and mathematical background is required for comprehension of the characteristics and mechanics of debris flows.
B. Numerical Simulations

On the other hands there are a lot of numerical studies on the debris flows were conducted. Many schemes of computational fluid dynamics (CFD) were employed for debris-flow simulation: Shieh and Hsu, 1992; Liu et al. 1993; Shieh and Tsai, 1994; Liu and Yang, 1994; Jan et al. 1996; Shieh et al. 1996; Liu and Huang, 1996; Liu and Yang, 1997; Jan, 1997; Jan et al. 2000; Liu and Lai, 2000; Liu and Huang, 2006; Tsai et al. 2011. Hsu et al. 2014.

There remained many research interests on this topic, e.g., convergence, stability, precision of the numerical schemes and applications of various of numerical methods to debris flows such as finite difference methods (FDM), finite element methods (FEM), finite volume methods (FVM), boundary element methods (BEM), spectral methods as well as mesh-free methods.

C. Experimental Tests

Many researchers conducted experimental tests on the characteristics and mechanics of debris flows: effects of dam and downstream bed’s characteristics (Chiang, et al. 1992), grain size effects (Yu and Lai, 1996), vertical rotating flume (Jan and Chen, 1997a, b); hydraulic failure (Chang, 1998); surface run-off and groundwater effects (Lin and Wang, 1999); seepage effects (Chen and Yu, 2003); sediment concentration distribution (Lien and Tsai, 2003); saturation effect (Yu et al. 2006); run-off simulation (Lin et al. 2007); sediment transportation (Yu et al. 2007); stability of slope (Chen et al. 2011); muddy flow in rotating drum (Liu and Ai, 2011).

D. In-Site Investigations

In-site investigations are valuable because many practical data of debris flow hazards can be obtained and collected for further research: basic field investigation (Yu and Chen, 1992); Hualien and Taitung (Shieh et al. 1992); Tung-Men (Chen et al. 1993); Lan-Young east area (Chang and Shieh, 1996); Central Taiwan (Chang and Shieh, 1997); Chen-Yo-Lan Creek (Chuang et al. 2000).

VIII. Debris Flow Countermeasures

A direct approach to protect the debris flow hazard is the design of countermeasures.

Many debris dams are studied: gravity-type sabo dams (Chiang and Lin, 1988); S-type slit dam (Chiang and Wu, 1990); bottom-infiltration screen (Chiang and Huang, 1992); preventive practices (Yu, 1993); open dam (Chiang et al. 1993; Chen and Ho, 1997); open-type sabo dam (Lin et al. 1997; Lin et al. 1997); sabo dam with rectangular slit (Tsai and Lien, 1997; Lien et al. 1997); grid dams (Ho and Chen, 1997); prevention works (Tuan,1997); cushion characteristics (Chen, et al. 1997; Liou et al. 2000); slot dam (Lien, et al. 1998; Lien, 2003); application in Hsu-Mei-Chi Creek (Huang, 2000).

Study on design and analysis of various kinds of debris dams is required in the future. On the other hand, both passive and active disaster prevention technologies can be investigated along the way.

IX. Hazards Prediction And Assessment Of Debris Flows

Prediction and assessment of natural hazards is an important task for disaster prevention. Some researches concerning about the disaster potential at an specific area: three counties in the northern Taiwan (Lee, 1981); Li-Yu-Tan watershed (Yu et al. 1991); Chen-Yu-Lan Creek (Su et al. 1999); Song-He Village (Li and Liu, 2010; Lin et al. 2011); Daniao Tribe (Liu et al. 2011); Gao-Ping and Lin-Bian (Su et al. 2014).

More researchers studied the approaches for prediction, assessment and management: danger ranks (Shieh and Chen, 1993); assessment and prediction (Jan 1994); zoning technique (Shieh et al., 1997; Lin and Lai, 1998; Yu and Lien, 1999); application of geography information system (GIS) (Cheng et al., 1997; Lin et al., 2000; Yu et al. 2006); mitigation program (Cheng et al., 1997); grading of risk (Shih et al., 1997); application of spatial analysis (Su et al., 1999); information system (Huang, et al., 1999); numerical modeling (Liu and Yang, 1999; Liu and Gilbert, 2000; Liu et al. 2009; Liu et al., 2011; Lin et al., 2011); application of probability theory (Chen and Jan, 2000); Hydro-meteorological and site factors (Cheng et al., 2000); secondary hazard caused by earthquake (Lin, et al., 2000); potential river model (Yang and Huang, 2003); application of cellular automata theory (Chen et al., 2005); case study (Wu et al. 2006); direct damage estimation (Liu and Li, 2006); emergency cost measurement (Liu and Li, 2007); rainfall induced sediment-related slope hazards (Lin et al., 2012); influence of accumulated precipitation (liu et al., 2013).
It is interesting that some researchers started to apply techniques related to artificial intelligence (AI) to debris-flow hazard assessment and prediction: expert systems (Lin, 2000); fuzzy reasoning system (Chen, 2006); case-based system (Tsai, 2007). In this trend of development there are many different expert systems can be attempted: framed-based, knowledge-based, learning-based (ANNs) and hybrid systems. Furthermore, some techniques in knowledge engineering (KE) can also be applied to assess and predict the debris-flow hazards.

X. Monitoring and Alarm of Debris Flows

Building up the monitoring and alert is the practical, efficient and direct approaches for real-time warning the occurrence of debris flows. Some researches had been conducted: forecast and alarm system (Lien, 1997); application of intelligent control theory (Chang and Lee, 1997); application of hydrologic and physiographic criteria (Fan and Lin, 1997); rainfall-based warning model (Jan and Lee, 2004); rainfall duration-based real-time monitoring (Chen et al., 2005); automatic monitoring systems (Yin, et al., 2006; Yin, et al., 2011); underground sound together with wavelet transform technique (Fang, et al. 2008; Fang et al., 2011).

There can be many trials on this topic including passive and active techniques, especially recent years rapid development of smart phones and hand-held tablets and Apps. The building monitoring and alarm system using smart phones via techniques of Bluetooth, Wi-Fi and remote communication can be attempted so that people can be alerted in time and prepared to escape from the potential disasters.

XI. Case Studies of Debris-Flows Hazards

Case studies of debris-flow hazards are sorrowful but valuable works for the researchers. Collecting in-site data for future study and disaster mitigation make researchers understand more on the occurrence, initiation, stoppage, deposition of the debris-flow and can conduct more study on prediction and assessment (Huang and Chiang, 1991). Taiwan is prone to occurrence of debris flow so that many case studies have been conducted: Feng-Chiu (Yu and Chen, 1987); Tung-Men (Yu, 1990); Chi-Nan Ravine (Chang, 1995); Hsu-Mei-Chi Creek (Huang, 1997, 1998); Central Taiwan (Chen, et al., 2004); Taipei City (Yu et al., 2006); Chai-Yi Feng-Shan watershed (Lien, et al. 2008).

Some researches concentrated on the study of landslides induced by typhoons: Morakot (Chen et al. 2009; Wang et al., 2010; Chen et al. 2011; Jan, et al., 2011; Lin, et al., 2011).

Case study of debris-flow induced by landslides (Liaw et al. 1999); erosion mechanism and mitigation (Chang and Wang, 2000; Chou, et al., 2000; Lin, et al. 2000); landslide dam breach induced debris-flow (Chen, et al., 2004).

There is a famous Chinese classic proverb: Human wisdom can prevail over nature. It is expected more researches can be conducted for thorough study on each debris-flow disaster occurred in Taiwan to build up complete data-bases for researches on the prediction, assessment and alert of debris-flow hazards. However, this is an time-consuming task and team-working is required.

XII. Concluding Remarks

A historical review of research on debris flows during past thirty years in Taiwan has been conducted. The content includes mainly the mechanics, mitigation and assessment of debris flows and divided into ten subjects: (1) initiation process; (2) fundamental rheology; (3) velocity distributions; (4) stoppage and deposition; (5) impact force on structures; (6) mechanics and characteristics (theoretical, numerical, experimental and in-site investigation); (7) debris-flow countermeasures; (8) hazard prediction and assessment; (9) monitoring and alarm; (10) case studies. Review on the development and suggested future research topics are also explained.

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