DEVELOPMENT OF A COMPREHENSIVE METHOD FOR DEBRIS-FLOW ANALYSIS OVER COMPLEX TOPOGRAPHY CONSIDERING NONUNIFORM VELOCITY DISTRIBUTION AND BED-SEDIMENT EROSION

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論 文 名：DEVELOPMENT OF A COMPREHENSIVE METHOD FOR DEBRIS-FLOW ANALYSIS OVER COMPLEX TOPOGRAPHY CONSIDERING NONUNIFORM VELOCITY DISTRIBUTION AND BED-SEDIMENT EROSION
「不均一な速度分布及び河床侵食を考慮した複雑地形における土石流の総合的な解析手法の開発」

区　　分：甲

論 文 内 容 の 要 旨

Debris flow is one of the most serious geo-hazards threatening mountainous societies. Because catastrophic damage is often caused by debris flows, various kinds of countermeasures, such as sabo dams and concrete canals, have been developed for disaster mitigation. The key issue in the design of these countermeasures is how to estimate the parameters of a potential debris flow, such as flowing velocity, possible debris volume, and runout extension. Thus, it is necessary and important to develop a comprehensive debris-flow analysis tool for estimating the parameters so as to meet practical requirements.

With the rapid development of GIS techniques, the complex topography of the potential debris-flow catchment can be digitalized, and some methods, including empirical, analytical, and numerical methods, have been proposed for debris-flow analysis. However, several problems are found in the existing methods. One problem in urgent need of a solution is that important parameters of a debris flow over complex topography are often underestimated. For this reason, the following important issues are studied in this thesis. (1) The flowing velocity distribution issue: mean velocity based on a uniform distribution in a complex cross-section is commonly assumed in most existing methods. In fact, velocity variation (i.e., a nonuniform distribution in a cross-section), has been observed from many in-situ measurements and experiments, which have implied that the maximum velocity exceeds the mean value; (2) The bed-sediment erosion issue: the volume of a debris flow cannot be estimated correctly if no rational bed-sediment erosion model is considered. Rational erosion estimation remains a great scientific challenge; (3) The runout estimation issue: numerical simulation methods are commonly used to estimate the runout of a potential debris flow, but it is hard to obtain accurate results because either models neglect the sediment erosion, or must incorporate empirical laws that lack physical understanding of the erosion mechanism. It is obvious that the countermeasures cannot be effective if they are designed based on an incorrect estimation of debris-flow parameters.

The primary objective of this study is to develop a comprehensive analysis method for estimating the parameters of a potential debris flow by solving or improving the above-mentioned issues. The proposed method contains two preliminary analytical methods and a numerical simulation method for a rational estimation of debris-flow velocity, mass volume, and runout extension. The presented method’s effectiveness and usefulness are verified by analyzing the so-called 2010 Yohutagawa debris flow in Japan.

The thesis consists of the following chapters.

Chapter 1 introduces the background and objectives of this thesis. Debris-flow disasters and widely-used mitigation countermeasures are introduced. Since effective design of a countermeasure relies on the correct estimation of the potential debris-flow event, the three major kinds of methods (empirical, analytical, and numerical method) and their advantages and limitations are briefly summarized.

Chapter 2 gives an overview to the existing methods for assessing important parameters of a

debris-flow event. The commonly used methods are reviewed in detail; one of the major problems is clarified that important parameters of a debris flow over complex topography are often underestimated by the existing methods, which could lead to the failure of countermeasures. The following three core issues are emphasized: (1) flowing velocity distribution, (2) bed-sediment erosion, and (3) runout estimation. To deal with these issues properly, the adoption of both an analytical method and a numerical method is suggested.

Chapter 3 presents an analytical method for estimating the debris-flow velocity distribution in a complex cross-section. Estimating velocity is crucial for countermeasure design. In many countries, current technical standards against debris flow just estimate a mean velocity based on uniform velocity distribution in a cross-section. However, it has been reported that the velocity could vary significantly in a complex cross-section, and the maximum velocity could be much larger than the mean value. Thus, it would be dangerous if the design of a mitigation structure is based on the mean velocity. In this chapter, the complex cross-section is partitioned into a number of small segments by linear interpolation, and a numerical integral method is used with the well-known Manning-Strickler equation to estimate velocities distributed in the cross-section. The major advantage of this method is that the complex topography effect of a natural channel on the velocity distribution can be taken into account so that the maximum velocity can be estimated. An analytical result for a well-documented debris-flow event in China showed that maximum velocity could be twice as larger as the mean velocity at the flow surface along the thalweg.

Chapter 4 proposes a preliminary method to estimate the volume of a potential debris flow and to determine the channel zones where erosion may occur. In a plan for countermeasures, it is important and necessary to estimate the volume of a potential debris flow which depends on not only the sediment from landslide but also on bed-sediment erosion. However, how to estimate erosion is still a big challenge. In this chapter, a theoretical analysis of the erosion mechanism is presented. Sediment erosion occurs if and only if the bed shear stress of the flow becomes larger than the basal resistance of the bed. And then, the method for estimating possible erosion depth and erosion volume is proposed. A so-called critical line is first proposed for determining whether erosion occurs so that the potential erosion zones can be easily estimated just based on the topography of the sub-reach. Also, a Monte Carlo simulation method is further incorporated to deal with uncertainties in the geological and hydraulic parameters. The major advantage of the new method is that the range of potential debris volume and erosion zones can be rapidly estimated.

Chapter 5 develops a numerical method with a new dynamic erosion model for simulating the debris-flow process, so that important parameters for disaster mitigation can be estimated. How to deal with the bed-sediment erosion is a key issue for numerical simulation. The Takahashi model is widely recognized as good for considering erosion. However, since it involves some parameters that should be determined by complicated laboratory experiments and empirical adjusting, the adoption of this model has been very limited. For this reason, in this chapter an alternative model is proposed based on the momentum conservation of the fluid-sediment system. It can be easily incorporated into the continuity equation of the numerical method. The rapid change of pore-water pressure in bed sediment can be taken into account, and instantaneous erosion rate in each time step can be properly computed. A software package is developed for easy practical application.

Chapter 6 applies the developed comprehensive methods to analyze the 2010 Yohutagawa debris-flow event that occurred in Japan. Essential parameters, such as flowing velocity, total debris volume, and runout extension are assessed. Since the estimated results agree well with those from the in-situ survey, the effectiveness and usefulness of the tool are verified.

Chapter 7 summarizes the results and major contributions of the study, and also makes recommendations for future research.