DEVELOPMENT OF PRACTICAL ANALYSIS METHODS FOR DEBRIS FLOW CONSIDERING EROSION AND DEPOSITION WITH COMPLEX THREE-DIMENSIONAL TOPOGRAPHY

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Summary

Debris flow is one of the most serious natural disasters worldwide. Moreover, the frequency of debris flow events is increasing owing to development in mountainous areas and climate change caused by global warming. Since deposits from earthquake-induced landslides can easily become debris flow, which is one ring of an earthquake-induced landslide disasters chain, and can seriously damage property and claim lives, earthquake-related debris flow is a serious problem in earthquake areas.

To mitigate the adverse effects of debris-flow disaster, many preventive countermeasures, either hardware measures such as the construction of slit sabo dams and concrete dams, or software measures such as the construction of debris-flow hazard maps and warning system, have been developed. In designing the structural measures or constructing non-structural measures effectively, it is necessary to know the related parameters of debris flow such as the extension of the deposit, run-out distance, velocity, depth of the moving mass and impact force. Many numerical and analytical methods have been proposed to estimate these parameters. However, issues that remain unresolved are (1) how to predict the occurrence time of debris flow, (2) the development of a practical program that can simulate debris flow while considering both erosion and deposition processes with three-dimensional (3D) complex topography, and (3) how to cut an earthquake-induced landslide disaster chain from the view of debris flow.

This study focuses on the above issues and develops practical methods with which to solve the related problems. The content of the thesis is as follows.

Chapter 1 introduces issues related to debris-flow disasters and reviews existing studies on debris flow. Debris-flow disasters in China and Japan are introduced. Structural and non-structural mitigation countermeasures are discussed. To design the structural measures or non-structural measures effectively, it is necessary to know the intensity-related parameters of debris flow such as the extension of the deposit, the run-out distance, velocity and depth of the moving mass, and the impact force. Various categories of existing methods that can be used to estimate these parameters are reviewed; i.e., (1) one-dimensional empirical, (2) one-dimensional analytical, (3) one-dimensional numerical, (4) two-dimensional flow routing and (5) two-dimensional numerical methods. Their advantages and disadvantages are stated. Since the two-dimensional numerical method can be used to estimate all the necessary intensity parameters, it is studied in depth in this study. The chapter also describes the scope and objectives of the study.

Chapter 2 proposes a real-time method for predicting the occurrence time of a debris flow. The occurrence time is important for a warning and evacuation system. Although empirical methods have been proposed, they are difficult to use under conditions different from those under which they were established. For this reason, a 'critical concentration' is proposed for determine initiation condition of debris flow and it is derived from limit equilibrium method. The critical concentration is used to estimate the water volume which can be determined from real-time precipitation by using GIS technology. Therefore, the occurrence time of debris flow can be determined. As a practical application, a real debris-flow event that occurred in Yohutagawa gully in 2010 is analysed. The result shows that the estimated occurrence time is almost the same as the actual occurrence time.

Chapter 3 develops a practical program for simulating debris flow with complex 3D topography. In a review of existing numerical models, the Takahashi model is found to be the most suitable since it can be used not only to estimate all the necessary parameters but also to simulate the erosion and deposition processes. However, since there is no practical program based on this model for complex 3D topography, the use of the Takahashi model

is quite limited. For this reason, a practical program based on the Takahashi model is developed using GIS technology. The Takahashi model is solved with the leap-frog difference method and programmed with C++ language. The powerful pre- and post-processing tool based on a GIS is used, so that the dynamical movement of a debris flow can be visualized and a hazard map of the debris flow can be easily made. In verification of the program, the abovementioned debris flow is simulated and reproduced successfully. The results show that the estimated extension area of deposit, run-out distance, velocity and depth of the moving mass and impact force of the debris flow as well as the erosion and deposition areas are in good agreement with observations in a field investigation. As a practical application, the program is used to evaluate the effectiveness of an existing dam in various cases. Proposals can be made from the evaluations.

Chapter 4 develops an alternative model for practical simulation of debris flow with complex 3D topography. Since the Takahashi model requires many parameters that are difficult to obtain or estimate, an alternative model is presented in this study. In the new model, debris flow is taken as a single-phase mixed flow, and the flow resistance and erosion or deposition velocity are simply related to the depth and velocity of debris flow. Thus, the parameters needed are easily obtained or estimated. In addition, different types of debris flow can be modelled simply using their corresponding rheological models. In verification of the alternative model, the Yohutagawa debris flow is analysed. The results are almost the same as those obtained from the Takahashi model, even though far fewer parameters are input in the new model.

Chapter 5 presents an approach for cutting the so-called earthquake-induced landslide disaster chain through debris-flow simulation after a strong earthquake. The characteristics of debris flow after an earthquake are summarized and a disaster chain is introduced. In the approach, loose deposits from earthquake-induced landslides in a catchment are regarded as source materials of potential debris flows, and countermeasures can be taken according to the predication of occurrence time and intensity-related parameters obtained from the simulation of the potential debris flow. Not only erosion and deposition processes but also a debris dam can be handled by the approach, which is verified for another real debris-flow event that occurred in Hongchun gully in 2009 after the 2008 Sichuan earthquake.

Chapter 6 summarizes the results and achievements of the study. In addition, problems to be solved in future work are stated.