DEVELOPMENT OF LANDSLIDE-DAM PREDICTION SYSTEM OVER A WIDE AREA CONSIDERING SLIP SHAPES OF EARTHQUAKE-INDUCED LANDSLIDES

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「地震に伴う斜面崩壊の形態を考慮した広域天然ダムの発生予測システムに関する研究」

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論 文 内 容 の 要 旨

A strong earthquake can induce a large number of landslides, and an extensive landslide can create a landslide-dam when debris flows into and stops a river. The water impounded by a landslide dam can create a dam reservoir, which may raise the surrounding groundwater and cause back-flooding (upstream flooding). Because of its loose nature and absence of a controlled spillway, a landslide dam can easily fail catastrophically and lead to debris flows or downstream flooding. Many reports show that the earthquake-induced landslide disaster chain can cause very serious damage. For example, the 2008 Wenchuan Earthquake (Ms8.0) induced approximately 60,000 landslides and created 828 landslide-dams. More than one-third of the total loss (both property and life) from the earthquake damage was due to the disaster chain according to a related report. Moreover, a landslide-dam at Tangjiashan, which has a reservoir volume of $3.16X10^8$, threatened more than 1.3 million people in the downstream area. Fortunately the catastrophe was avoided because the dam was detected early so that the countermeasure was taken timely. Therefore, it is important to focus attention on prediction of earthquake induced landslide-dams in order to break the earthquake-induced landslide disaster chain.

In order to realize the prediction of earthquake induced landslide-dams in a wide area, it is necessary to solve the following key issues: how to (1) identify the slope mesh effectively, (2) assess the slope stability accurately, (3) estimate the landslide volume, (4) analyze debris runout path and deposit distribution. There are very few systematic studies on these problems up to now. Therefore, this study aims to develop a prediction system of earthquake induced landslide-dams by (1) proposing a new approach for slope mesh identification; (2) developing a new landslide hazard mapping approach using a more accurate 2D stability analysis method; (3) developing a new efficient landslide hazards mapping method using 3D slope stability analysis; and (4) developing an earthquake induced landslide-dam hazard mapping approach based on the newly released ArcGIS technology.

The thesis consists of seven chapters.

Chapter 1 introduces a geo-disaster chain model from earthquake and gives a brief review of previous research on earthquake-induced disasters. It also describes the scope and objectives of the study.

Chapter 2 reviews the existing landslide hazard assessment methods and gives a summary of issues that remain unresolved, such as slope unit identification, 2D and 3D slope stability analysis considering failure slip shapes, and landslide-dam prone hazard mapping.

Chapter 3 proposes a new slope unit identification approach. First, the problems of the existing method are analyzed. Then, a new approach is proposed to solve the problems by (1) developing a method to detect stream lines and catchment areas instead of detecting valley lines and ridge lines, which is the major reason of mis-identification in the existing method; (2) identifying slope units by cutting catchment areas with stream lines. Finally, the improvement of identification accuracy is shown by using the new approach.

Chapter 4 develops a new hazard mapping method based on the well-known 2D limit equilibrium analysis with a circular slip mode. The existing hazard mapping method is based on an infinite plane slip model (IPSM) because it is easy to implement in GIS. However, since most failure slip surfaces are not planes, a circular slip mode (CSM) is more popular than IPSM in geotechnical engineering because of its high accuracy and ability to accommodate the complex geometry, stratum and groundwater data. Also, the volume of a landslide can be estimated from CSM, which is necessary in landslide-dam hazard mapping. The issue is that IPSM is not easily incorporated into GIS. Therefore, a new hazard mapping method is developed based on the well-known Swedish Method, a 2D limit equilibrium analysis method with a CSM. First, a method for automatic extraction of a cross slope section is proposed based on the topography of each slope. Then, a GIS module for evaluating slope safety factors based on the Swedish Method is developed using C#. Finally, practical applications have been made and it has been shown that the accuracy of the slope stability analysis improves and the hazard mapping can be completed quickly and effectively.

Chapter 5 develops a hazard mapping method based on 3D limit equilibrium analysis. In order to estimate the volume of a landslide, a 3D slope stability analysis is necessary. A semi-ellipsoid slip model is used in general. The key issue is how to determine the ellipsoid parameters to obtain the minimum slope safety factor. The existing 3D method applies Monte Carlo simulation to determine the parameters. Because running the 3D limit equilibrium analysis with Monte Carlo simulation for an acceptable minimum safety factor is extremely time-consuming, the existing method is unadaptable in hazard mapping. Therefore, a new method for determining the parameters of an ellipsoid is proposed based on the 2D limit equilibrium analysis with the Swedish method. The circular slip determined in 2D analysis is used to estimate the lengths of two axes of a tri-axial ellipsoid, the other axial length is estimated directly from the slope shape. The GIS module of the 3D limit equilibrium analysis is developed using the new approach of determining ellipsoid parameters. Practical applications show that the new hazard mapping method based on the new approach for 3D limit equilibrium analysis can greatly reduce the processing time.

Chapter 6 develops a prediction system of earthquake induced landslide-dams for landslide-dam hazard mapping based on GIS. To date, there have been few studies on landslide-dam hazard mapping, although it is important for breaking the disaster chain. The new approach of landslide-dam hazard mapping includes: (1) identifying the slope units; (2) extracting possible landslide-dam prone slopes (LDPS) using the river buffer filter; (3) excluding impossible LDPS using the aspect filter to exclude slopes that cannot reach a river based on their aspects towards the river; (4) excluding impossible LDPS using the blockage filter, by which a slope that could not reach the river is excluded based on the blockage height along its way to the river; (5) excluding impossible LDPS using the stability filter to exclude stable slopes based on slope stability analysis; (6) excluding impossible LDPS using the volume filter to exclude slopes with a small volume of slide mass. In addition, DDA, a numerical simulation method, is adopted to verify the potential LDPS after filtering. Because we can obtain the run out distance, distribution and volume of debris from the DDA simulation, landslide-dam formation can be deduced based on river geometry and hydrology data together with the volume of the slide body. The effectiveness of the countermeasure using preventive structures can also be verified by DDA simulation.

Chapter 7 summarizes the results and conclusions of the study. Also, problems are highlighted for future studies.