DEVELOPMENT OF A 3D COUPLED SOLID-FLUID SIMULATION TECHNIQUE FOR FORMATION AND FAILURE ANALYSIS OF LANDSLIDE DAM

王, 偉

https://doi.org/10.15017/1785400

出版情報：九州大学, 2016, 博士（工学）, 課程博士
バージョン：

（様式２）

氏　　名 : 王　偉

論 文 名 : DEVELOPMENT OF A 3D COUPLED SOLID-FLUID SIMULATION TECHNIQUE FOR FORMATION AND FAILURE ANALYSIS OF LANDSLIDE DAM
(3 次元固体と流体の連成シミュレーションによる天然ダムの形成・破壊の解析に関する研究)

区　　分 : 甲

論 文 内 容 の 要 旨

Landslide dam is one of the most serious geo-hazards in mountainous area. A landslide dam is a natural damming of a river by some kind of mass wasting from landslide or debris flow. The water impounded by a landslide dam may create a dammed-lake, and when the surrounding water level rises it may cause back-flooding in the upstream area. Due to its loose nature and absence of controlled spillway, a landslide dam can easily fail catastrophically and lead to debris flows or downstream flooding often with great damages to people’s lives and property. Due to the high risk of landslide dam, it is very important and necessary to analyze the formation and failure characteristics of the landslide dam so as to carry out practical prediction and disaster-prevention measures.

Many studies have been made to analyze the formation and failure of a landslide dam. Most of them majorly use statistical methods or empirical formulas to assess the possibility of formation and failure based on geomorphological parameters of the dam and river. However, the formation of a landslide dam is not only related to geomorphological parameters but also to kinematic coupling between the river flow and the movement of the landslide mass. Particularly, the formation and failure of landslide dam always involves complicated solid-fluid interaction. Therefore, the kinematic characteristics and interaction process of river flow and landslide mass should be well analyzed. With the development of computer and computation sciences, various numerical methods have been developed and shown their powerful capabilities in simulating the solid and fluid dynamics. Among them, Discontinuous Deformation Analysis (DDA) shows great advantages in simulating rigid body movements from theory to practice, and Smoothed Particle Hydrodynamics (SPH) is very capable to model the free surface flow. Although there have been some studies on the coupling of DDA with SPH, the practical simulation technique for landslide dam formation and failure is still unavailable because of the following three unsolved key issues: (1) how to produce a river flow with steady motion under the SPH framework; (2) how to simulate a large-scale landslide movement over a complicated 3D topography; (3) how to accomplish the simulation involving large-scale, complicated solid and fluid phases and their interaction in practical landslide dam formation and failure.

In this study, a practical 3D coupled solid-fluid simulation technique is developed by using DDA and SPH to analyze the formation and failure characteristics of the landslide dam. At first, an Open Channel Model with Steady Flow (OCMSF) and a Particle Recycling Method (PRM) are proposed to solve the first issue. Then, an Ordered Blocky Method (OBM) is developed to solve the second issue. Also, the coupled DDA-SPH method is validated by a laboratory experiment, and a series of typical examples are performed to analyze the formation and failure characteristics of the landslide dam. Finally, a Three-stage Simulation Strategy (TSSS) is proposed to solve the third issue. The developed simulation technique is successfully applied to simulate a practical landslide dam and its effectiveness and practicality are validated.

The contents of the thesis are organized as follows:

Chapter 1 introduces the background and objectives of this thesis. The disasters from landslide dams are briefly introduced. The methodologies for analyzing the formation and failure of a landslide dam are reviewed. The existing problems of the current studies are clarified.

Chapter 2 reviews the developments and applications of both DDA and SPH. The fundamental theories are introduced, and their advantages for the numerical study of landslide dam are summarized. The three key issues as stated above in the development of practical simulation technique for landslide dam are clarified.

Chapter 3 proposes an Open Channel Model with Steady Flow (OCMSF) and a Particle Recycling Method (PRM) for producing a river flow with steady motion under the SPH framework. The dam formation is related to the depth and velocity of the river flow. The model for simulating the dam formation should consist of both the landslide-prone slope and the river. However, it is difficult to include such long river into the model with limited computation domain. Considering that a landslide dam can only block a short segment of the river, and the river flow before reaching the dam can be treated as the open channel flow with steady velocity and depth, an Open Channel Model with Steady Flow (OCMSF) has been proposed for modeling the natural river in the dam site. Then, a Particle Recycling Method (PRM) has been developed for realizing the continuous flow of OCMSF by reproducing the leaving particles to the source. A series of numerical examples have been performed for the model verification and sensitive analysis of control parameters. It is proved that the proposed OCMSF and PRM can be used to model a river with specific velocity and depth. The desired flow depth can be obtained by controlling the height of the open boundary, and the desired flow velocity can be obtained by changing the initial water column height in OCMSF. Finally, a four-step approach has been proposed to determine the control parameters for OCMSF with desired flow depth and velocity.

Chapter 4 develops an Ordered Blocky Method (OBM) to simulate large-scale landslide movement over a complicated 3D topography. Contact detection between moving blocks and the slope is one of the crucial techniques in 3D DDA because it affects the performance and effectivity of the program. An Ordered Blocky Method (OBM) is proposed to generate the slope model with complicated 3D topography by taking the advantage of gird-based terrain. Thus, the performance and effectivity can be much improved since whether a block is contacting with the slope can be easily detected by finding the related grids based on the location of the block. Also, a new pre-processor is developed to generate the slope model with grid-based terrain, which is available from the raster data derived from ArcGIS. The fast contact detection algorithm based on OBM is implemented into the existing 3D DDA program. Some simulation examples are conducted to evaluate the computational efficiency and demonstrate the applicability and performance of the proposed OBM.

Chapter 5 validates the coupled DDA-SPH method, and analyzes the formation and failure characteristics of landslide dams with a series of typical examples. Firstly, the numerical scheme of the coupled DDA-SPH method is introduced; a laboratory experiment is used to verify the accuracy of the coupled DDA-SPH method. Then, a typical model for landslide dam simulation is proposed, and a series of numerical simulations are carried out to analyze the formation and failure characteristics of the landslide dam. It is concluded that the possibility of dam formation highly depends on the kinematic characteristics of both landslide movement and water flow. Finally, a comparative study is conducted to investigate the effect of the block size on the formation and failure of a landslide dam.

Chapter 6 proposes a Three-stage Simulation Strategy (TSSS) to accomplish the simulation in practical engineering involving large-scale, complicated solid, fluid phases and their interaction. Since it is difficult to perform landslide dam simulation with a whole model including both the slope and the river due to computation capability, a TSSS is proposed to solve the problem. Stage 1 performs landslide simulation and records the landslide mass reaching the river bank. Stage 2 generates an OCMSF to obtain the steady river flow. Stage 3 performs the interaction process between landslide mass and river flow to simulate the formation and failure of the landslide dam. A practical landslide dam is simulated and the results show the effectiveness and applicability of the developed 3D coupled solid-fluid simulation technique in this study.

Chapter 7 summarizes the conclusions of the study, and makes recommendations for future research.