DEVELOPMENT OF A PRACTICAL 3D DDA PROGRAM FOR HAZARD ASSESSMENT OF EARTHQUAKE INDUCED LANDSLIDES

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論 文 名：DEVELOPMENT OF A PRACTICAL 3D DDA PROGRAM FOR HAZARD ASSESSMENT OF EARTHQUAKE INDUCED LANDSLIDES
(実用的な３次元 DDA プログラムの開発および地震による斜面崩壊ハザードの評価への適用に関する研究)

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論　文　内　容　の　要　旨

Earthquake induced landslide is one of the most serious geo-hazards. Especially, for the coastal area with potential tsunami, evacuation sites and access roads for tsunami are generally located upland and surrounded by slopes. Since an earthquake can induce not only tsunami but also landslides, it is obvious that the tsunami evacuation sites and access roads are threatened by the potential earthquake induced landslides. Therefore, it is important and necessary to assess the hazard of earthquake induced landslides so as to secure the safety of tsunami evacuation sites and access roads.

Hazard assessment of earthquake induced landslides includes slope stability analysis under seismic loading, landslide runout estimation and the evaluation of preventive effectivity such as anchor-reinforcement for a dangerous slope. With the development of the computer and computing sciences, various numerical simulation methods have been developed and shown their powerful capability in the landslide research. Discontinuous deformation analysis (DDA) is one of these simulation methods and has shown its advantage in theory and practice. There have been many research achievements reported by using 2D DDA. In order to overcome the limitation of 2D analysis, the development of 3D DDA is also undertaken. However, there still exist some key problems, which inhibit its practical application, in the development of 3D DDA program. For example, there is no effective tool for 3D DDA model construction; it is unavailable to perform slope stability analysis under seismic loading and with the anchor reinforcement.

This study aims at (1) developing a practical 3D DDA program by solving the above problems and (2) applying the new 3D DDA to the practical hazard assessment of potential earthquake induced landslides in a coastal area with potential tsunami of Oita prefecture, Japan. The new 3D DDA includes (1) developing an effective pre-processor for the 3D model construction; (2) adding the function of seismic loading and (3) adding the function of using anchor reinforcement.

The contents of this thesis are organized as follows:

Chapter 1 introduces the background, objective and organization of the thesis. The existing numerical simulation methods for landslide study are reviewed. The development of DDA in theory and practical application is briefly introduced and the advantages of DDA are clarified.

Chapter 2 provides an overview on 3D DDA. The 3D DDA formulation, contact principle, and program structure are illustrated in detail. The following unsolved problems of the existing 3D DDA program are discussed: (1) without an effective pre-processor for complex slope model construction, which is especially fundamental and necessary for practical application to landslide study; (2) unable to perform slope stability analysis and landslide runout simulation under a potential earthquake; (3) unable to evaluate the preventive effect of using anchor reinforcement.

Chapter 3 performs a close comparison between the 2D and 3D DDA to reveal the limitation of the 2D analysis and the necessity of 3D DDA. Their advantages and disadvantages are illustrated based on slope stability analysis and run-out simulation. The current 2D DDA program contains effective user friendly pre-processor and post-processor, which are powerful and necessary for practical slope study. There have been many achievements reported from practical 2D DDA applications. However, the limitations of 2D analysis also become obvious. Since lateral effect of a 2D slope section model cannot be considered, the factor of safety is often underestimated and lateral spread movement cannot be estimated in run-out analysis. On the other hand, the lateral friction and the lateral spread movement can be considered in 3D DDA analysis, the factor of safety can be estimated and the reasonable run-out can be simulated more accurately. But, a practical 3D DDA program has not been developed.

Chapter 4 develops a practical pre-processor to easily construct a complex 3D slope model for the 3D DDA program. Since construction of a complex 3D slope model is always a troublesome problem which including the following two big issues: (1) how to cut the blocks; (2) how to generate blocks of the 3D slope terrain. The developed pre-processor solves these problems by taking the advantage of the commonly used commercial software: 3ds Max and ArcGIS. Arbitrary-shaped 3D bocks are made with 3ds Max and complex slope terrain mesh data are obtained from the ArcGIS. A pre-process program is developed to combine the output data from both 3ds Max and ArcGIS and translate them to the 3D DDA model format. It has been shown that a 3D DDA slope model can be easily and effectively made for any real slope with complex terrain by using the newly developed 3D DDA pre-processor, which makes it possible for applying 3D DDA to practical landslide study.

Chapter 5 extends the existing 3D DDA program by adding the function of seismic loading and the function of anchor reinforcement. The stability analysis and run-out estimation of a potential earthquake induced landslide need the function of dealing with seismic loading in a 3D DDA program. The added seismic loading function can use either displacement wave or acceleration wave, which depends on the data available. In addition, when a slope is judged unstable under a potential earthquake, the slope should be reinforced in general. Rock anchor reinforcement is one of typical preventive methods. Thus, it is necessary to evaluate the preventive effect and provide the useful information for optimum design of the size and number of rock anchors. By adding these two functions, the new 3D DDA program makes it possible to assess the hazard of earthquake induced landslides for securing the safety of tsunami evacuation sites and access roads.

Chapter 6 applies the new 3D DDA program to practical hazard assessment of earthquake induced landslides for securing the safety of tsunami evacuation sites and access roads in the coastal area of Oita prefecture. The Daiganji slope is taken as an example. An access road to a tsunami evacuation site and several houses are located at the slope downward. At first, the slope stability is analyzed by using both 2D and 3D DDA. The results are compared with those from the commonly used limit equilibrium method. The adaptability of DDA and the difference between 2D and 3D analysis are shown. Secondly, the factor of safety is analyzed by using earthquake loading. And the influence of seismic directivity on the slope stability is analyzed. The landslide run-out is estimated by using the new 3D DDA program under the condition of the earthquake. It is shown that the access road and some houses are threatened by the potential landslide. Finally, the stability analysis of an anchor reinforced slope is performed to evaluate the preventive effect. It has been shown that the new 3D DDA is very useful and powerful enough for hazard assessment of earthquake induced landslides.

Chapter 7 summarizes the results and achievements of this study. The problems for the future study are highlighted.