NEW ANALYSIS METHODS FOR EARTHQUAKE INDUCED LANDSLIDES CONSIDERING TENSION FAILURE AND THE TRAMPOLINE EFFECT

張, 迎賓

https://hdl.handle.net/2324/1398338

出版情報：九州大学, 2013, 博士（工学）, 課程博士
バージョン：

氏名・(本籍・国籍)	チャン　イン ビン 張　　迎　賓（中　国）
学位の種類	博士（工学）
学位記番号	工博甲第２２５１号
学位授与の日付	平成25年9月24日
学位授与の要件	学位規則第４条第１項該当　工学府　建設システム工学専攻
学位論文題目	NEW ANALYSIS METHODS FOR EARTHQUAKE INDUCED LANDSLIDES CONSIDERING TENSION FAILURE AND THE TRAMPOLINE EFFECT（地震による引張破壊とトランポリン効果を考慮した斜面安定および崩壊土石運動における解析手法に関する研究）
論文調査委員	（主　査）教　授　陳　　光　斉 （副　査）教　授　濵　田　秀　則　　教　授　島　岡　隆　行

論　文　内　容　の　要　旨

A large number of landslides can be induced by a strong earthquake and they can cause very serious damage to both lives and properties. Much research has been carried out and a series of countermeasures have been developed to reduce the adverse effects of landslide disasters. In the planning and design of countermeasures, it is necessary to analyse the stability of a slope and movement behaviours of a potential landslide under seismic loadings. Therefore, this study focuses on analysis of (1) slope stability and (2) landslide movement behaviours.

Two major approaches for slope stability analysis are studied. One is to calculate the pseudo-static safety factor of a slope. The other is to calculate earthquake-induced permanent displacement. The following problems are found in existing studies. (1) Most solutions for slope stability analysis are derived just based on shear failure mode, even though tension failure may exist in earthquake-induced landslides. Thus, how to analyse slope stability according to both shear and tension modes is an important problem. (2) The Newmark method is widely used to calculate the earthquake-induced permanent displacement. Determining the so-called critical acceleration a_c is a key problem in the Newmark method. In traditional applications, a_c is estimated as a constant according to an equation derived from a pseudo-static model. However, since seismic loading is a dynamic process, the critical acceleration should be estimated using a dynamic model. These problems are discussed in detail, and both analytical and numerical methods are presented to solve them.

In the study of landslide movement behaviours, long run-out, one of the major behaviours of earthquake-induced landslides, is discussed. Since the mechanism is still not clear, a new movement translation model (MTM) is proposed on the basis of the so-called trampoline effect. Additionally, a practical numerical simulation program is developed to clarify movement behaviours of earthquake-induced landslides in practical simulations.

The thesis comprises the following chapters.

Chapter 1 introduces (1) the study background, (2) two main issues in the study of landslides, namely slope stability and landslide movement behaviours, (3) the scope and objectives of this study, and (4) the organization of the thesis.

Chapter 2 reviews two aspects of existing studies on earthquake-induced landslides: slope stability analysis and landslide movement simulation. The merits and demerits of each method are stated.

Chapter 3 develops a new method for slope stability analysis based on both shear and tensile failure modes under seismic loadings. Most solutions of existing slope stability analysis methods are derived only according to the shear failure mode because shear failure dominates in ordinary landslides. However, tensile failures have been found for many earthquake-induced landslides in recent field investigations, especially for the 2008 Sichuan Earthquake. Therefore, tension failure must have a significant effect on slope stability. For this reason, an analytic solution of

slope stability is derived according to both shear and tension failure modes. In addition, an approach is proposed for how to consider tension failure in addition to shear failure in widely used $FLAC^{3D}$, a finite difference method, so that stability analysis can also be carried out for a slope with a complex slip surface. It is shown that the safety factors estimated using the analytical and numerical methods are almost the same for a homogeneous slope. Additionally, it is shown by a large number of analysis examples that the effect of tension failure on slope stability is significant and the safety factor will be incorrect if tensile failure is ignored in the case of seismic loading.

Chapter 4 presents new methods for calculating the earthquake-induced permanent displacement of a slope. Estimating earthquake-induced permanent displacement of a slope is also a kind of slope stability analysis. The Newmark method is widely used for this purpose. Determining the so-called critical acceleration a_c is a key issue in the application of the method since it greatly affects the analysis results. A traditional way is to estimate a_c as a constant because the equation is derived from a pseudo-static model that depends only on the corresponding static factor of safety. However, since seismic loading is a dynamic process, the critical acceleration should be estimated using a dynamic model. For this reason, at first, all the loading models proposed for the Newmark method are reviewed. Problems related to the traditional models and treating vertical seismic loading are clarified. A dynamic model for estimating dynamic critical acceleration is then presented. A new approach of adopting the dynamic critical acceleration in the Newmark method is also proposed. In addition, a rigorous dynamic sliding block method based on the dynamic critical acceleration is presented for calculating the earthquake-induced permanent displacement instead of the Newmark method for some simple slopes. Practical applications show that (1) the results obtained with the new method are in agreement with those obtained with the Newmark method and (2) the dynamic critical acceleration and the vertical seismic loading significantly affect co-seismic displacements of slopes. Finally, regression models of co-seismic displacement are constructed and an approach is proposed to use them to produce a geographical information system (GIS)-based hazard map. Additionally, a primary-hazard map is produced for the area of the 2008 Sichuan Earthquake.

Chapter 5 presents a long run-out model based on the so-called earthquake-induced trampoline effect and develops a practical numerical simulation program for estimating landslide movement behaviours. Effective design of a countermeasure depends on better understanding the movement behaviours of a potential landslide. Long run-out is one of the major movement behaviours of earthquake-induced landslides. Although hypotheses have been proposed for explaining the long run-out mechanism, they do not explain why there were such long run outs for the landslides induced by the 2008 Sichuan Earthquake. Therefore, a new MTM is proposed for the long run-out mechanism of the earthquake-induce landslide. The MTM is derived from mechanism analysis of the earthquake-induced trampoline effect. The original discontinuous deformation analysis (DDA) is extended. A practical numerical simulation program is developed by incorporating the MTM into the extended DDA. After an extreme ground movement with the peak ground acceleration (PGA) of 4000 gal is successfully reproduced, some large-scale landslides induced by the 2008 Sichuan Earthquake are analysed in practical numerical simulations. The results show that (1) the proposed new long run-out model is reasonable and applicable and (2) the movement behaviours of earthquake-induced landslides can be analysed using the numerical simulation program.

Chapter 6 presents a case study to verify the proposed new methods from slope stability analysis to landslide run-out analysis. The Daguangbao landslide, the largest scale landslide induced by the 2008 Sichuan Earthquake, is analysed using a numerical simulation program as well as $FLAC^{3D}$. The results show that the vertical component of seismic loading may play an important role in both stability analysis and run-out analysis, as larger tension failure and trampoline effects may be induced by the vertical seismic force, which has generally been ignored up to now.

Chapter 7 concludes the results and achievements of the study, and states the problems to be solved in future studies.

論 文 審 査 の 結 果 の 要 旨

本論文は，地震による斜面崩壊の特徴である引張破壊モードとトランポリン効果に着目し，地震による斜面災害防止に必要な高精度な斜面安定解析手法および崩壊土石の運動特性を解明する実用的な数値シミュレーション手法を開発することで，地震による二次災害における防災力を向上させたものであり，地盤工学および防災工学の面で寄与するところが大きい。よって，本論文は博士(工学)の学位論文に値するものと認められる。