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

張, 迎賓

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SUMMARY

A large number of landslides can be induced by a strong earthquake and they can cause very serious damage to both lives and properties. Many researches have been carried out and a series of countermeasures have been presented to mitigate the landslide disasters. There are two important issues in landslide study: slope stability and landslides movement behaviours under seismic loadings. They are the subjects of this research.

There are two major approaches for seismic slope stability analysis. One is to calculate the pseudo-static safety factor of a slope. The other is to calculate earthquake induced permanent displacement of a slope. Although many slope stability analysis methods have been presented, the following problems are found in the existed studies. (1) Most of solutions for slope stability analysis are derived just based on shear failure mode. However, tension failure has been found in some laboratory model testes and a large number of post-earthquake investigations. The tension failure must be of significant influence on slope stability analysis under seismic loadings. (2) In the popular Newmark method for calculating the earthquake induced permanent displacement, the ground acceleration is parallelly applied to surface of a slope having a known critical acceleration which results in two important limitations: i) the critical acceleration only depends on its static factor of safety and keeps as a constant; ii) the vertical seismic loadings is unreasonably ignored. These problems are discussed and solved as the first part in this study.

Long run-out is one of the major behaviours of earthquake-induced landslides. Although there are many studies on the long run-out mechanism, most of them are for rainfall induced landslides and very few are related to seismic loadings. As the second part in this study, a new movement translation model (MTM) is presented to explain the long run-out mechanism of landslides and the so-called trampoline effect of earthquake loading is discussed and used to explain the long run-out mechanism of earthquake-induced landslides.

The thesis consists of the following chapters.

Chapter 1 introduces the following issues: i) the study background in which the research significance and some problems in the existing studies of earthquake-induced landslide are presented; ii) two main issues in earthquake-induced landslides: slope stability analysis and landslide run-out analysis; iii) the scope and objectives of this study, and iv) the organization of the thesis.

Chapter 2, at first, reviews the existed studies on earthquake-induced landslides from two aspects: slope stability and landslide run-out, and then, compares the merits and demerits of each method for slope stability analysis and landslide run-out analysis, respectively.

Chapter 3 develops a new method for slope stability analysis by considering tensile failure under seismic loadings. There are two possible failure modes: shear and tension. Since shear failure dominates in ordinary landslides, most solutions of the existed slope stability analysis methods are derived only based on the shear failure mode. However, tensile failure is often found in many earthquake-induced landslides recently, especially in the 2008 Sichuan Earthquake, thus, it should be considered in stability analysis. For this reason, an analytic solution of slope stability is derived using a new kinematic method of limit analysis based on both shear and tension failure modes in this chapter. In addition, an approach is proposed for considering both shear and tension failure modes in widely used $FLAC^{3D}$, a finite difference method, so that stability analysis of a slope with complex slip surface can be also carried out. It is shown that the safety factors from both the analytical and numerical analysis are almost the same for a homogeneous slope stability analysis. Also, it is shown from a large number of analysis examples that the influence of tension failure on slope stability analysis is significant and the safety factor could not be correct if tensile failure is not taken into consideration.

Chapter 4 presents a rigorous dynamic sliding block method for calculating the earthquake induced permanent displacement of slope. Estimating earthquake induced permanent displacement of a slope is another kind of slope stability analysis. At first, the following problems related to seismic loadings in the current calculation are discussed. (1) A constant critical acceleration is used, which only depends on the static safety factor of a slope. However, the critical acceleration of a slope also depends on its seismic situation, i.e. it’s a variable during a shaking. (2) Vertical component is not taken into account partly or completely, which is just based on the special loading model and on the consideration that vertical component is generally smaller than its horizontal components in usual. However, the popular loading model is not reasonable and in some situations, vertical seismic loading is so large that it should be considered. In order to solve the above problem, and then, a rigorous dynamic sliding block method based on a dynamic critical acceleration is presented for calculating the earthquake induced permanent displacement of a slope. In the method developed herein, the seismic loading may not parallel to slope surface and both horizontal and vertical seismic components can be considered. Practical applications show that both the dynamic critical acceleration and the vertical seismic loading have significant influences on co-seismic displacement of slope in some situations. Finally, regress models of co-seismic displacement are presented and they are used to produce a GIS-based hazard map for the 2008 Sichuan earthquake zone.

Chapter 5 proposes a new long run-out model of landslides in which the trampoline effect of vertical seismic loadings can be considered. Although many existed models are helpful in the estimation of the run-out distance. However, very few of them considered the seismic loadings. For this reason, in this chapter, a new movement translation model (MTM) was proposed and the trampoline effect of vertical seismic loadings is taken into account to explain the long run-out of earthquake-induced landslides. The discontinuous deformation analysis (DDA) is extended and used to incorporate the MTM model. A practical simulation using the extended DDA is carried out to analyze the long run-out landslide. The results show that the proposed new long run-out model is reasonable and applicable.

Chapter 6 gives a case study to validate the proposed new methods for both slope stability analysis and landslide run-out analysis. The Daguangbao landslide, the largest scale landslide induced by the 2008 Wenchuan earthquake, is analysed by two numerical simulation methods: FLAC^{3D} and DDA. The results show again the significant influences of vertical component on both the stability analysis and run-out analysis, as larger tension failure and trampoline effects are induced by the vertical seismic force. Hence, more attention should be paid to the effects of vertical seismic force on the initiation and run-out of earthquake-induced landside.

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