BEHAVIOR OF STABILIZING PILES UNDER STATIC AND DYNAMIC LOADING BASED ON PLASTIC DEFORMATION THEORY

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(塑性変形理論に基づいた静的および動的荷重における抑止杭の挙動に関する研究)

区　　分　：甲

論　文　内　容　の　要　旨

Landslides occurring in both natural and cut slopes often result in serious damage to both lives and properties. Generally speaking, there are two categorized triggering factor for landslide: (1) static factor (e.g. raining, hurricane), (2) dynamic factor (e.g. earthquake). Recent years, the catastrophic earthquake occurs frequently, which results in many fatal landslides. For instance, more than 3000 landslides have been reported in Nepal after the Gorkha earthquake, in 2015. Therefore, considering the landslide risk reduction, it is very important to improve the stability of slopes. Especially, more focus should be put on the seismic performance of the earthquake induced landslide.

Stabilizing piles, as one of the most widely used application in reinforcement of slopes, has been proved to be an efficient solution against landslides. For dynamic analysis of pile reinforced slopes, the two-dimensional (2D) analytical method based on pseudo-static approach is usually used. However, it is commonly acknowledged that 2D plane-strain solutions are conservative to analyze slope stability comparing with three-dimensional (3D) solutions. Seeking a more accurate prediction of seismic stability in 3D cases could benefit the construction of slope. In this sense, it is necessary to provide a comprehensive accurate solution for reinforced slope subjected to seismic loading in 3D condition.

3D dynamic analysis of the pile reinforced slope stability involves two main aspects: (i) estimating of resistance force provided by the piles, (ii) 3D limit analysis of the reinforced slope subjected to specific seismic load. However, on one hand, in the previous literatures, the analytical solution of the soil-pile pressure (lateral force) of the pile is limited because of the different distribution between the predictions and field test results, which results in the misestimation of the slope stability. On the other hand, literature on the 3D seismic analysis of reinforced slope is scarce, which results in the miscalculation of the slope constructions.

Consequently, this study aims to present a comprehensive method to analyze the seismic performance of the pile-reinforced slope in 3D condition, incorporating the static analysis of stabilizing piles. Furthermore, this study also focuses on clarifying the soil-pile interaction and the failure mechanism of the pile-reinforced slope in dynamic condition. Specifically, two major approaches for the analysis of slope reinforced with piles have been studied. One is to propose a new method to provide an accurate prediction of the lateral force. The other is to calculate the permanent displacement of reinforced slope subjected to seismic load in 3D condition.

In the first approach, the theory of plastic deformation is modified by considering soil arching effects. A new analytical method is presented for estimating the ultimate lateral force due to soil movement, which provides a more accurate prediction than previous studies. Furthermore, the effect of the inclination of the moveable soil layer on lateral force is also analyzed.

In the second approach, earthquake induced sliding displacements are commonly used to assess the seismic performance of slopes. Therefore, an analytical method is proposed to evaluate the cumulative displacement of reinforced slope induced by specific earthquake load. The lateral forces provided by the piles are evaluated by the presented approach mentioned above. In the presented dynamic analysis, the 2D analytical procedure for displacement assessment is extrapolated to 3D condition.

The thesis comprises the following chapters.

Chapter 1 introduces (1) background of this study, (2) two main issues in current study, namely lateral force and the earthquake-induced permanent displacement, (3) the scope and objectives of this study, and (4) the organization of the thesis.

Chapter 2 reviews two aspects of existing studies on the subject of slope reinforced with piles: analyses of slope stabilized with a row of piles and landslide movement calculation. The merits and demerits of each method are stated.

Chapter 3 analyses the lateral force acting on piles due to soil movement. Combining with the 'plastic deformation theory', soil arching effects along the depth of the moveable soil between two neighboring piles are considered to estimate lateral force. Comparisons of the in situ observed results (from literatures) and the calculate results show that the proposed method yields satisfactory predictions.

Chapter 4 develops a limit equilibrium method to analyze the slope angle effect on the lateral force distribution of stabilizing piles. The soil arching zone is determined by Mohr's circle, which is a function of slope inclination. In addition, the lateral force in sandy slopes is obtained by considering the soil arching effects and the 'squeezing effect' between two neighboring piles proposed by Ito and Matsui. The numerical simulation results obtained by FLAC3D and the experimental data from the published literature are used to evaluate the proposed approach. It is shown that the proposed model could reasonably predict the distribution shape of the soil-pile pressure acting on the stabilizing piles. Parametric analysis is carried out to investigate the influence of the slope angle on the distribution of the soil-pile pressure. It is shown that the slope angle affects the distribution of the lateral force, rather than the magnitude.

Chapter 5 presents 3D limit analysis of seismic stability of slopes reinforced with one row of piles. The lateral forces provided by the piles are evaluated by the presented approach mentioned above. Based on the kinematic theory within the frame of the pseudo-static approach, a 3D model is proposed for evaluating the yield (or critical) acceleration. Furthermore, Newmark's analytical procedure is employed to estimate the cumulative displacement induced by the given earthquake loads. A simple example is studied, and the findings are: the yield accelerations of 2D mechanism are less than that in 3D mechanism with the same soil properties; the displacements in 2D mechanism are much larger than that in 3D conditions; it is possible to reduce the seismic displacement of the soil slopes using stabilizing piles both in 2D and 3D conditions.

Chapter 6 concludes the results and achievements of the study, and states the problems to be solved in future studies.