氏　　　　名	えるはんだにや　よーせふ EL HAMDANIA, Youssef
学位の種類	博士（工学）
学位記番号	甲第１７７号
学位授与年月日	平成１８年　３月１８日
学位授与の要件	学位規則第４条第１項該当
学位論文題目	Study of Seismically induced Displacement in slopes （地震時の斜面運動に関する研究）
学位論文審査委員	（主査）　榎 明 潔 （副査）　木山英郎　　西 田 良 平

学位論文の内容の要旨

In seismically active regions, earthquake induced lamdslides have damaged lives and properties during all the humankind history, however a rational means of assessing seismic slope stability haven' t been developed until the middle of 20^{th} century. The earliest methods treated the seismic slope stability, basing on the conventional pseudostatic method, in terms of a simple factor of safety. In recent years, considerable attention has been focused on the analytical procedures for estimating seismically induced displacement in slopes, dams, and embankments (e.g. Newmark 1965, Bray and al. 1999, Matosovic et al. 1997, Rathje 1997, Augello 1997, Bray et al. 1995, Chugh 1994, Jibson 1993). This field of research still challenging specialists and engineers and requires regulations for evaluating seismic slope stability by developing of practicable and accurate analytical procedures..

The present work is an attempt to develop a method to evaluate the yielding state and the subsequent displacement response of slopes to earthquakes. The present inquiry into the dynamic response of slopes is based on the perfectly plastic, Coulomb-type model, assuming the soil mass to be homogeneous without performing any liquefaction. The author rested on the newly discovered continuity condition of acceleration to define the equations governing the motion of the soil mass moving relative to the base, and the displacement analysis method to compute the permanent displacement affecting slopes during earthquake. The method was applied to the infinite and finite slopes.

In *Chapter* 2 is overviewed the previous analytical techniques for estimating seismically induced permanent deformations in slopes, dams and embankments. The principal pillars of the proposed theory are presented and applied to the infinite slope model, which is the simplest problem and fits for assessing almost of natural slopes.

Through this work the extension of Khristianovich model of the rigid plasticity to the dynamic case (dynamic theory of rigid plasticity) was done. Five cases of stability problems were considered. Two cases corresponding to the dynamic problem of soil plasticity were proposed. These two cases formed a base in handling the dynamic stability problem of earth structures subjected to earthquake-induced accelerations.

For the infinite slope, which corresponds to almost of natural slopes, a concept of model of relative displacement was introduced. Under seismic loads, the potential soil layer of natural slopes might hold fore possible modes of relative displacement with respect to the bedrock: (1) no relative displacement, (2) downhill sliding mode, (3) uphill sliding mode or (4) the separation mode. The critical state corresponding to all this modes of relative displacement and the method of calculating the relative displacement were determined.

The test apparatus, materials and instrumentation used in the experiments intended to assess the infinite slope model under dynamic loads were reviewed in *Chapter 3*. The experiments led to the following conclusions:

・ For the rigid block model the calculation almost agrees with the experimental result and a combined downhill and uphill modes of relative displacement were shown.

・ The plastic deformation of the soil layer subjected dynamic loads did not happen immediately at the start of shaking. The delay of the sliding was a function of the dimension of the slope model and of the input frequency of shaking.

・ When sliding began the peak shear resistance of the soil layer was mobilized. The transitional and residual shear resistance was mobilized during the remaining time of shaking.

・ The experiments permitted to explain the formation of the cracks within the natural slopes and to show the impoetance of cracks to evaluate natural slope damages sfter an earthquake event.

・ An amount of plastic deformation happened during all the time the shaking continues.

Chapter 4 aimed to illustrate the theoretical extension of the proposed approach, for modeling the Finite Slope. Basing on the newly discovered continuity condition of acceleration the author extended the theory of rigid plasticity to be applied for dynamic plastic problems. Generalized Limit Equilibrium Method (GLEM), which is one of the limit equilibrium methods providing an approximate solution for Kotter' s equation in static atability problems, was extended to treat the dynamic atability of finite slopes. Two formulations of the dynamic GLEM were done. The first formulation uses force field (Force equilibrium), and the second formulation uses displacement rate field (Energy equilibrium or Upper Bound Method). The calculation of slope motion during earthquake based on D-GLEM was done through a Fortran program including minimization routine. The program was applied using the physical model's parameters.

Chapter 5 presents the background information for the small-scale slope experimental program. A gap between the theoretical and experimental results still exists. However, interesting observations were made and still warrant additional research. Similar to the findings of the inclined plane studies, The test results made in a small scale slope, also , indicate that the accuracy of the proposed procedures would be improved by accounting the elastic deformation, implementing the degrading strength parameters and taking into consideration the delay of the plastic deformation response of the sliding soil mass.

Application of the Method Using Earthquake Records was presented in *Chapter 6*. The proposed approach was applied to natural slopes damaged after Tottori western earthquake. The relation between the slope orientation and its susceptibility to slide under earthquake shaking was clarified through calculations and graphs. The existence, for every earthquake event and at every locality, of the most dangerous and the safest directions was shown using acceleration records of several earthquakes. For the same earthquake event, the dangerous direction might change from place to place. The sensitivity of the slopes and the relative displacement affecting it during an earthquake depend on the space-time distribution and magnitude of the accelerations.

The proposed method, which is easily applicable provide more or less accurate procedure for estimating the seismically induced displacements in slopes. The findings gotten through this work are for great importance and might form a base for further development of the proposed method. The method presented herein could be applied to more complicated boundary conditions to resolve the dynamic plastic deformation of any kind of earth structures when exposed to any kind of dynamic loads.

論文審査の結果の要旨

土木工学においては「耐震」についての考え方が、それまでの「壊れないものを造る」から、兵庫県南部地震以降には「少しは壊れても大変形しないものを造る」に変化している。これは経済性から考えて当然のことであるが、このためには、地震後の土木構造物等の残留変形・残留変位を推定する解析方法が必要となる。

本論文は、地震時の山腹斜面表層土の運動を論じ、地震後の残留変位の解析方法を提案するものである。まず、山腹の基岩上にある薄い表層土は、力学的に無限斜面と同様の孤立土塊として扱えることを利用して、地震時に表層土は基岩に対して相対的に、「運動しない（基岩と一体となって運動する)」、「すべり落ちる」、「すべり上がる」、「飛び上がる」の４種類のモードの運動をすることを示し、これらの運動モードの存在条件を示した。そして、通常の地震では前２者の運動が卓越することことを示した。次に、土を剛塑性体と仮定して、地震時の斜面表層土の運動を塑

性論的に明確にし、残留変位の解析方法を示した。この方法により、榎らが鳥取県西部地震の震央近くの鎌倉山調査で発見した「山腹や稜線に生じた多数のクラック」の発生理由を示すことができた。また、解析結果と実測値を比較するとともに、振動台を用いた模型実験でその妥当性を確認した。さらに、地震動に方向性がある地震の場合には、特定の向きの斜面に被害が集中する傾向があることを推定した。なお、塑性論的に同様の手法を用いて、盛土などの有限斜面が地震動を受ける場合の解析方法の原理も検討した。

本研究の成果の第一は、地震時に起こりえる斜面表層土の４種類の運動モードの存在とその存在条件を明確にしたことである。第二は、地震時の斜面表層土の運動に対して、Newmark 法などと比べてより塑性論的に合理的な、鉛直加速度も考慮できる解析法を提案していることである。第三は、基岩上を滑っている土塊の運動を決定するための、「すべり面に垂直な加速度成分はすべり面の両側で等しい」という加速度の連続条件の重要性を指摘したことである。この連続条件は、その後の動的塑性理論の展開に不可欠と考えられる。

以上から、本論文は実用的・理論的価値が高く、今後の地盤工学・耐震工学の発展に寄与するところが大きい。したがって、本論文は博士（工学）の学位に値するものと認められる。