学 位 論 文 要 旨

Study on earthquake resistance of fill dam using centrifuge shaking model tests

遠心振動模型実験によるフィルダムの耐震性に関する研究

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Most studies investigating the effect of cyclic loading on soil properties have been conducted for saturated soils. Embankments such as fill dams, roads, and railways are usually constructed by unsaturated geo-materials and retained under unsaturated conditions during their in-service periods. Then when the stabilities of the embankments against dynamic motions such as earthquakes and traffic loads are evaluated, it is necessary to investigate seismic properties of unsaturated soils. However, there are few studies investigating mechanical properties of unsaturated soils under cyclic loadings. The objective of this study is to clarify seismic properties of fill dams by using element and model tests. One objective is to investigate cyclic properties of an unsaturated silt under various cyclic loading conditions, while the other is to investigate the stress-dilatancy relationships; the relation of plastic strain increment ratio, $-d\varepsilon_v^p/d\gamma^p$ vs. stress ratio: q/p' and derive the plastic potential function of the unsaturated silt by conducting cyclic triaxial compression tests. The third objective is to clarify how differences of water contents and frequencies affect to failures and behaviors of pore pressure of the fill dam models during earthquake shaking.

Cyclic triaxial compression tests under various loading conditions were conducted to identify the properties in the element test level. The material used is an artificial silty soil named DL clay. The sample was prepared with water content 17 % and dry density 1.3 g/cm^3. The tests were performed under the single net confining pressure $\sigma_{3net} = \sigma_3 - u_a = 100$ kPa and five different values of the constant suction $s = 0$, 10, 30, 60, and 90 kPa. Cyclic shear loadings were applied under three different stress conditions: constant stress ratio, constant axial strain and increased shear strain by controlling a constant shearing strain rate of 0.05 %/min. It was found that the stiffness of the soil increased with an increase in suction and the number of cyclic loadings. The application of higher suction values inhibited the plastic deformations. The amounts of volume reduction decreased with an increased in suction. When the numbers of cyclic loading and suction increased, the dilation also increased. Each unique stress-dilatancy

relation could be found in each loading and unloading for an unsaturated soil. The relations were similar to those of saturated soils under cyclic loadings. Plastic potential functions for the unsaturated soil could be identified by the stress-dilatancy relations. The proposed plastic potential functions will be used in the estimation of permanent deformation of embankments.

Centrifuge shaking model tests for fill dams under a different water content and frequency were conducted by using the different soil particle as DL clay, silty soil and silica sand No.6, sandy soil and different slope gradient as 1:1.5 and 1:2.5. Models were constructed under the same compaction degree for each soil sample. Centrifugal acceleration was applied 30 G. Input acceleration was gradually increased until the collapsed of the dam model. During the experiment, the acceleration, the displacement and the pore pressures were measured. In the models using DL clay, the differences of failure situations between the different water contents was very large. There was not found the big failure in the model with lower water content which is less than the optimum water content. During the centrifuge dynamic loading, the negative pore water pressure was gradually increased inside the dam model with acceleration. On the other hand, the fill dam model with higher than the optimum water content exhibited the large failure near the toes and on the slopes. The positive pore water pressure was increased at the bottom of the model with acceleration. The acceleration response was amplified at the upper part of the model with low water content.

In the models using silica sand No.6, the higher water content of the model, the greater the amount of deformations, such as the cracks on the crest and both slopes, the vertical settlement at the crest and the size of the slip line. The acceleration response was amplified in the upper part and the part close to surface of the slope. The deeper slip lines had occurred on both slopes of the model for frequency 4 Hz than those for frequency 10 Hz. The mount of vertical settlement was also lager in the model for frequency 4 Hz. Larger acceleration response was occurred at the upper part of the model in the lower shaking stage for frequency, 10 Hz. However, when the input acceleration was increased, the lower acceleration response was observed. The largest amount of positive pore water pressure was observed at the bottom of the model with high water content and low frequency 4 Hz. The negative pore water pressure was increased near the slopes and the crest. But, the amount of pore air pressures remained small values. After the shaking they almost disappeared. Thus, the fundamental seismic behavior of fill dams was clarified.