EVALUATION OF SHEAR STRENGTH CHARACTERISTICS OF UNSATURATED UNDISTURBED VOLCANIC ASH SOIL SUBJECTED TO STATIC AND CYCLIC LOADING FOR SLOPE STABILITY ANALYSIS

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（静的および繰返し載荷条件下での不飽和・不攪乱火山灰質土のせん断強度特性の評価と斜面安定への適用）

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論 文 内 容 の 要 旨

Major direct triggering factors of slope failures are rainfall and earthquake load which change pore pressure or stress in the slope and directly reduce the soil shear strength. There is a possibility for a combination of rainfall and earthquake load attack the same area especially Indonesia and Japan which has high annual precipitation and high intensity of earthquake event. However, a few studies discussed the combined factor between rainfall and earthquake load induced slope failures.

Recently in April 2016 an earthquake with a magnitude of 7.0 has struck the Kumamoto area and induced several slope cracks and failures. Where one of the massive failures occurred around the Aso mountain area. In addition, after the Kumamoto earthquake, the rainy season followed. Consequently, it will trigger a secondary disaster. Therefore, the investigation of soil shear strength behavior around the Aso mountain area is strongly needed. It was reported that orange-colored pumice deposits and the black volcanic ash soil are dominant in the affected area. Many researchers have studied the Kumamoto slope failures especially the orange-colored pumice. However, small attention was given to the black volcanic ash soil. In Japan, the black volcanic ash soil which is also known as Kuro-boku soil is a problematic type of soil and generally located in the top layer of the natural slopes above the groundwater table with degrees of saturation less than 100 %, which can be classified as an unsaturated state. In addition, for simplicity, the black volcanic ash in this research will be referred to as volcanic ash.

A key parameter in the soil slope stability analysis is estimating the strength of the soil. Reliable analysis can only be performed if the provided shear strength properties are reliable for the considered soil and representative for the investigated location. Extensive and detailed analysis for both the soil mechanical and hydrological properties is required to acquire a better understanding of slope stability when considering rainfall infiltration. Generally, the existing conventional approaches for soil mechanics are not enough to analyze such kind of complex problem. The limitations can be generally attributed to the simplified assumptions where the soil pore is assumed to be fully saturated with water. Adopting those methods lead to inaccurate estimation of the safety factor and the slip surface location. Therefore, an advanced analysis that incorporates unsaturated soil mechanics is strongly needed. Several approaches and techniques to obtain unsaturated shear strength properties of soil were developed. Laboratory testing for unsaturated soils is difficult, high cost, and time-consuming. Consequently, researchers have been trying to propose empirical and theoretical formulas to predict the unsaturated shear strength properties. However, the accuracy of the obtained data is relatively low in comparison to the data directly determined in the laboratory.

This thesis aims at evaluating the shear strength characteristics of unsaturated undisturbed volcanic ash subjected to static and cyclic loading for slope stability analysis. In order to achieve the aim of this thesis, four main objectives were delineated, starting with identifying the shear strength behavior of the collected unsaturated undisturbed volcanic ash soil under static and cyclic loading. To identify the effect of the soil structure disturbance on the shear strength of the volcanic ash soil by reflecting the pore size distribution differences of undisturbed and disturbed samples. To develop a new suction controlled unsaturated direct shear box apparatus. The developed apparatus differs in its features and testing procedure in comparison to the conventional testing apparatus. Finally, application of the experimental results in the unsaturated slopes stability analysis subjected to rainfall infiltration and earthquake loading. The thesis was divided into 7 chapters as follows:

Chapter 1 provides an introduction to this research, the current problems, and the motivation to conduct this research. The proposed aim, objectives, and scopes of this thesis are illustrated.

Chapter 2 includes a brief literature review illustrating the research that has been carried out in relation to the scopes considered in this thesis. This chapter starts with the elements of unsaturated soils, and methods to impose the suction before reviewing the existing laboratory testing techniques of unsaturated shear strength of soils. Next, a review of the conventional slope stability analysis is presented.

Chapter 3 presents the shear strength behavior of unsaturated undisturbed volcanic ash soil subjected to static and cyclic loading using the conventional direct shear box apparatus. It was found that under static shearing, unsaturated undisturbed volcanic ash soil samples exhibit a higher apparent cohesion and friction angle in comparison to the saturated samples. Furthermore, the normalized shear stress under cyclic loading of the unsaturated undisturbed sample was found to be relatively larger.

Chapter 4 provides the necessity to evaluate the effect of degree of disturbance on the volcanic ash soil which is directly related to the soil structure characteristics. It was found that the chemical composition of the volcanic ash soil is comprised mainly from allophane which accounts for as high as about 94%. The undisturbed samples exhibit a unimodal pore structure, while the disturbed samples exhibit a bimodal pore structure. Since the pore structure of the disturbed sample is unstable, the static shear strength tends to be lower, and the degradation index value is around 20 % higher than that of the undisturbed sample. It can be said that disturbed samples do not properly represent the field conditions with significant discrepancies that should be carefully considered when conducting slope stability analysis.

Chapter 5 focuses on the development of a new suction controlled unsaturated direct shear box apparatus. Using the standard soil, the suction-controlled system was confirmed. Furthermore, the shear strength and stiffness of the volcanic ash soil increase with the increase in the soil suction. The soil exhibits more dilative volumetric behavior as the suction increases. The internal friction angle (ϕ) of the volcanic ash soil is relatively constant, and the apparent cohesion (c) increases with increasing the suction value.

Chapter 6 presents the slope stability analysis considering reflecting the obtained experimental results. It was found that the discrepancies of the soil shear strength between undisturbed and disturbed samples affected the safety factor of slope. Furthermore, the obtained results show that the safety factor of the slope decreases with increasing the soil layer thickness. However, during precipitation events, the smaller the layer's thickness results in a higher average reduction in the safety factor. In addition, the safety factor of slope in the higher suction value significantly larger in comparison to the lower suction value. It can be concluded that the suction value provides more resistance to the slope stability.

Chapter 7 summarizes the main findings of this dissertation and delineates the future work.