論 文 の 内 容 の 要 旨

論文題目 Long term behavior of improved surplus soils with low binder contents under groundwater
(水浸した低改良率改良土の長期挙動)

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In Japan, it is promoted to reutilize surplus soils which are generated by earthworks such as cutting and excavations due to the limitation of reclamation sites and their capacities. All the surplus soils are not suitable for direct use in earthworks. The surplus soils with less strength or trafficability which are categorized under type 3, 4 or muddy (according to surplus soil classification) need to be improved with special installation or stabilization technique due to high water content and fine content. Generally, the engineering properties of those low-quality surplus soils are improved using cement or lime with low binder contents considering cost-effectiveness and the feasibility of the project and those improved soils are frequently used as fill materials of road embankments. In such a case, those embankments are susceptible to penetration of rainwater or groundwater due to low strength. Mechanism of strength gaining/ reduction of improved surplus soils with low binder contents under groundwater is not clearly understood up to date. This study was organized to increase the awareness of long-term behavior of those improved soils.

There were several objectives in this study. First was to discuss the influential factors on the progression of deterioration under soaking curing. The second was to identify the deterioration mechanism under each exposure condition. Finally, to propose a prediction methodology on long term tendency of deterioration of improved surplus soils under groundwater.

In this study, an actual surplus soil called Miho sand which contained fines around 50 % and natural water content of 31 % was improved by using cement or lime. The contents of lime were set to 1.2, 2.5 and 3.8 % by dried weight of Miho sand, while those of the cement was set to 1.7, 3.5 and 5.3 %. Cylindrical specimens with 50 mm in diameter and 100mm in height were prepared by setting dry density as of 1.4 g/cm^3. All specimens were cured under two different curing

conditions as sealed and soaked. In sealed curing, specimens were cured under constant temperature room tested under saturated condition by applying saturation one day before testing. To evaluate the effect of soaking from early curing period on the strength, the second set of specimens were cured under artificially made acidic water (immature) with pH of 4.5, after applying sealed curing for initial 3 days. In addition to that additional two sets of specimens were prepared for each cement 3.5 % and lime 2.5 % contents. First sets of specimens were soaked under pure water (immature) after 3 days of their preparation to see the effect of acidity and the second sets of specimens were cured under sealed condition for initial 6 months (168 days) and soaked under the acidic water (mature) to see the effect of maturity before soaking on the strength. Unconfined compression tests and needle penetration tests were conducted periodically for up to 2 years. To understand the mechanism of long-term behavior in the aspect of chemistry X-ray Fluorescence spectrometer (XRF), Electron probe microanalyzer (EPMA) and X-ray diffractometer (XRD) were applied to the improved soil. In addition to that soaking water was analyzed.

From the unconfined compression test results, it was found a clear reduction in unconfined compressive strength, q_u, in all the cases under soaked conditions compared to the strength of specimens cured under sealed condition. Under the sealed condition, q_u values were gradually increased with curing time. Therefore, in this study, the "deterioration" at a given curing period was defined as the reduction in strength of soaked specimen with respect to the sealed specimen. In order to quantify the deterioration, strength ratio was defined as the ratio of the averaged q_u value in each soaked condition to the averaged q_u value in sealed condition. When plot the strength ratio against soaking period, it was found that there are two stages in deterioration of cement-treated soil soaked in the immature state as primary deterioration (0-25 days) and secondary deterioration (25- 672 days). Deterioration due to primary deterioration was reduced when increasing the cement content. When increasing the maturity before soaking primary deterioration did not appear. In the case of lime treatment, no primary deterioration appeared in any of the cases. Further, it was found that there was no effect of acidity on the deterioration in both cement and lime treated soil. In the cases of cement 1.7 % and lime 1.2 % cases, it was difficult to evaluate the reason for deterioration accurately due to changes in the physical properties and further analysis were not conducted.

In order to find out the reason for the appearance of two stages in deterioration, localized strength distribution along the radius of the specimen was evaluated based on needle penetration test results for each soaking case. From that analysis, it could observe two actions which were appeared in the specimen along the radius as internal deterioration and the deterioration driven from the exposed surface in cement-treated soil soaked in the immature state. In all other cases, deterioration appeared only from the action deterioration driven from the surface. In cement-treated immature case, it was understood that primary deterioration appeared as a result of the internal deterioration. Secondary deterioration was a combined result of deterioration driven from exposed surface and recovery of internal deterioration. In the case of all lime treated soils and the cement-treated mature case secondary deterioration was due to deterioration driven from the exposed surface.

In order to find out the mechanism of appearing internal deterioration and the deterioration driven from the surface in the aspect of chemical behavior calcium ion distributions were evaluated from XRF and EPMA analysis. It was observed a clear reduction in Ca ions near the exposed surface of the specimens. However, it could not be explained the internal deterioration with Ca leaching as there was a clear reduction in strength ratio while there was a slight reduction in Ca ratio. It was suggested that internal deterioration was a result of the mobilization of ions from pore water to soaking water. However, the deterioration observed near the surface of cement-treated immature specimens were due to leaching of calcium ions. In the case of cement-treated soil in a mature state and all cases of lime treated soil, Ca leaching was identified as the reason for the deterioration driven from the surface. Ca ratio and the strength ratio throughout the specimen showed a polynomial relationship. From XRD analysis on cement-treated soil under soaked condition, it was observed the disappearance of ettringite near the exposed surface while they remained in the center. It was suggested that Ca leaching from ettringite also contributed to strength reduction.

A methodology was developed to predict strength distribution along with the specimen after a given soaking period based on five parameters (i.e. upper bound deterioration depth, lower bound deterioration depth, upper bound localized strength ratio, lower bound strength ratio and q_u of the sealed specimen at the given time). From detailed analysis on each parameter, it was found all parameters behaved similarly against time in logarithmically and could express by a general equation.