学 位 論 文 内 容 の 要 旨

DISSERTATION ABSTRACT

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学 位 論 文 題 名

Title of dissertation submitted for the degree

Development of sustainable ground improvement methods using biochemical techniques

(生物化学的手法による持続可能な地盤改良工法の開発)

Human activities increased with the increase of population. Therefore, people move to undeveloped areas and try to construct buildings and structures in the poor ground conditions. This is a major issue to improve the ground conditions and liquefaction is another big issues for countermeasure these problems. As discussed above, sustainable construction practices rely on the use of environmentally friendly alternative building methods and materials where possible. This research investigates the sustainability and cost effective techniques for ground improvement. Biochemical methods are introduced in this thesis. This thesis consists of two major sections; soil improvement with calcium phosphate compound (CPC) and soil improvement with microbially induced calcite precipitation (MICP). Chapters of this thesis are described as follows.

In Chapter 1, research background, objectives, and originality of thesis were described. Chapter 2 consisted with soil improvement using CPC-Chem method and soil improvement using CPC-Powder method was viewed in Chapter 3. In Chapter 4, under MICP process, syringe solidification test using MICP method was detailed. Chapter 5 consisted of model test for sand solidification using MICP method and finally, in Chapter 6 summarized and provided a conclusion that may guide future work.

Novel grout using CPC has been used for countermeasures for liquefaction by increasing soil strength. In Chapter 2, the condition for CPC precipitation by using different mixtures of calcium and phosphate stock solutions were investigated and analyzed. For that, Toyoura sand test pieces were cemented by CPC solutions and cured up to 28 days and carried out unconfined compressive strength (UCS) test. The strength of the samples was large for 1.5 M CA: 3.0 M DPP and 1.5 M CN: 3.0 M DPP mixtures with the concentration of Ca/P ratio is 0.5. The UCS values of Toyoura sand test piece cemented with CA: DPP and CN: DPP were 144.65 kPa and 143.60 kPa respectively. Furthermore, pH measurement and scanning electron microscope (SEM) observation were conducted. The results indicate that the pH value was increased with the curing time for the calcium to phosphate molar ratio was 0.5. Whisker-like crystal formation showed the only sample prepared with CA: DPP=0.5 mixtures. Therefore, it is concluded that the best CPC mixture is 1.5 M CA: 3.0 M DPP with the concentration of Ca/P ratio is 0.5.

In Chapter 3, the aim was to improve strength by adding CPC with $CaCO_3$ (commercially found) and scallop shell (naturally found) powder and exceed a maximum UCS of 100 kPa after 28 days of curing, which is the strength required as a countermeasure against soil liquefaction during an earth-

quake. For that, initially, Toyoura sand test pieces were cemented by CPC solutions only and cured up to 56 days and carried out UCS test. Moreover, Toyoura sand test pieces were cemented by CPCs with $CaCO_3$ (CC) powder and CPCs with scallop shell (SS) powder and cured and these specimens also analyzed with UCS tests. The UCS of the sand test pieces cemented by CPC with SS powder and CC powder was higher than that of the test pieces with no added powders. In addition, a series of laboratory experiments were conducted, including pH measurement, SEM observation in order to examine the microscopic structure, density before and after curing etc. The results indicate that the density and the pH of the sand test pieces cemented by CPC with SS powder and CC powder were higher than that of the test pieces with no added powders.

Chapter 4 and Chapter 5 described MICP process. MICP process is a complex biochemical process which has two main key steps; urea hydrolysis and calcite precipitation. The precipitation of calcite takes place between sand particles and improve the soil engineering properties. There are many factors that may affect for the MICP process. Some of these factors reported in Chapter 4 using syringe solidification test. Those are bacteria concentration, re-injection of bacteria, sand type and particle size of the sample, injection interval of the cementation media, concentration of the cementation media, curing time, temperature, and viscosity of the bacterial solution. From the results of syringe solidification test, estimated UCS value shows that all the studied factors have an obvious effect on the MICP treated sand. More than 3 MPa of estimated UCS value obtained from the solidified samples and also it was obtained more than 10 MPa of estimated UCS value for the testing cases of changing concentration of cementation media and re-injection of the bacterial solution after 7 days of curing period. Multiple regression analysis showed that the relevant conditions for estimated UCS, q_{eu} (MPa), was experimentally determined to be q_{eu}=13.99C_{ca}+0.37D–0.09 (where; C_{ca}=concentration of cementation media (M) and D=curing time (days)).

For obtaining a uniformly homogenous sample and getting the several MPa of average strength from the solidified sample, the small size lab model tests were conducted and it is described in Chapter 5. UCS, SEM-EDX, X-CT, primary and secondary wave velocity of the sample (V_p and V_s), $CaCO_3$ content of the sample and color measurements were conducted. Completely solidified samples were obtained by changing different testing conditions; height of the sample (2 cm and 9 cm), particle size of the sand material (mean diameter: 0.6 mm (Mikawa sand) and 1.3 mm (Mizunami sand), curing time (14 days and 21 days) and re-injection of bacterial solution. The average estimated UCS value varied from 3.1 to 4.4 MPa. The results indicate that UCS was closely related to $CaCO_3$ weight (g/ g sand) of the sample which means UCS value was increased with the increase of weight of $CaCO_3$ (g/ g sand). From this study, the relationship between $CaCO_3$ content and the UCS values can be derived by q_u=66.6x^2 + 3.5287x; where q_u is UCS of the sample (MPa) and x is amount $CaCO_3$ (g / g sand). Moreover, estimated UCS and color (L^*) shows a correlation between the parameters. The equation is q_{eu}=0.7669L^*–33.921 (where; q_{eu}= estimated UCS (MPa) and L^*=color (L^*)). This correlation is valid for Mizunami sand sample only.

The results obtain from each chapter point out that the solidification using CPC method and MICP method stand as promising techniques for soil improvement.