Relation between porosity and strength attained by enzymatic calcium carbonate precipitation in sand

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1. Introduction

Precipitation of calcium carbonate in soil with urease as a hydrolyser may be adopted as a new method for soil improvement. Improvement of sandy loose soil in coastal area and reclaimed land is very important for reducing liquefaction susceptibility during earthquakes. A series of tests carried out in different sized sand samples show noticeable increase in strength with corresponding decrease in porosity. An attempt is made to develop a correlation between change in porosity and strength. Calcium carbonate can be produced in soil by injecting the solution of calcium chloride and urea in the presence of an enzyme called urease. The expected reaction taking place to obtain the precipitation of calcium carbonate is expressed as follows,

$$(NH_2)_2CO + 2H_2O \xrightarrow{\text{urease}} 2NH_4^{+} + CO_3^{2-} \quad [1]$$

$$CaCl_2 \longrightarrow Ca^{2+} + 2Cl^{-} \quad [2]$$

$$Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3\downarrow \quad [3]$$

The reaction takes place in two steps. The first step is an enzymatic reaction, in which urea is hydrolyzed in the presence of specific enzyme of urease. The second step is a chemical reaction, in which calcium precipitates to form calcium carbonate [Van der Ruyt and van der Zon., 2009]. The produced calcium carbonate deposits in the void of soil causing the reduction in porosity. The calcium carbonate may serve as bridges between the sand grains restricting their movement hence improving strength and stiffness of the material [Harkes et al., 2010], and subsequently reducing the liquefaction susceptibility.

2. Materials and methods

2.1. Small Cylinder Test

Small cylinders with a diameter of 5 cm and height of 10 cm are homogenously packed with silica sand (Keisa sand) to obtain relative density of 60% (porosity of 0.42). The solution of urease, urea and calcium chloride is injected into the sand samples from the top at the rate of 5 mL/min. Concentrations of the reagent solution and urease range from 0.5-1.5 mol/L and from 2.0-12.0 g/L respectively. The volume of injection is limited to one pore volume. The samples treated are carefully removed from the cylinder 24 hrs after the solution injections, and dried in oven at 100 °C for 24 hrs. The oven-dried samples are subjected to unconfined compression tests to obtain the stiffness and strength. Finally the amount of $CaCO_3$ precipitated is evaluated by acid leaching, and the evolution of the porosity of sand is calculated.

2.2. Mid Cylinder Test

Cylinders with a diameter of 10 cm and a height of 20 cm are homogenously packed with silica sand (Keisa sand) to obtain relative density of 60% (porosity of 0.42), which is congruent with the small cylinder tests. A injection pipe is inserted at the center and a weight of 400g is placed at the top of the sand sample to prevent liquefaction during injection (hydraulic head applied for the injection is relatively high). 0.5 molar solutions of urea and $CaCl_2$ is blended with 2g/L urease and injected into the sand with the application of external pressure upto 30 kPa. The solution volume was limited to 800 mL and injected two times 400 mL each, at an interval of 2 hrs. The specimen treated is washed gently with water spray from the top 24 hrs after the solution injections. The improved sample was recovered carefully after washing the outer unimproved portion of sand.

3. Results

The relations between amount of precipitated $CaCO_3$, gain in *UCS* and change in porosity for small cylinder test are plotted in

Fig.1- Fig.3. The relation between *UCS* and porosity (Fig.1) shows, a noticeable increase in strength after a small change in porosity. The change in porosity and amount of $CaCO_3$ precipitated shows almost linear relationship as shown in Fig.2. The amount of $CaCO_3$ precipitated ranges from 1-6 % by weight of sand while the corresponding gain in strength ranges from several tens kPa to 2.0 MPa as shown in Fig.3. The maximum E_{50} of 190.3 MPa is achieved. Fig.3 shows a roughly linear relation between strength and amount of $CaCO_3$ with several exceptions. From the mid-cylinder test, almost spherical improved portion of sand with approximate diameter upto 9 cm, as shown in Fig.4, is obtained.

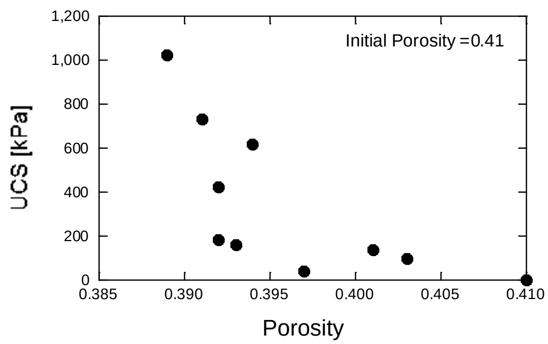

Fig.1. Relation between reduction in porosity and gain in *UCS*

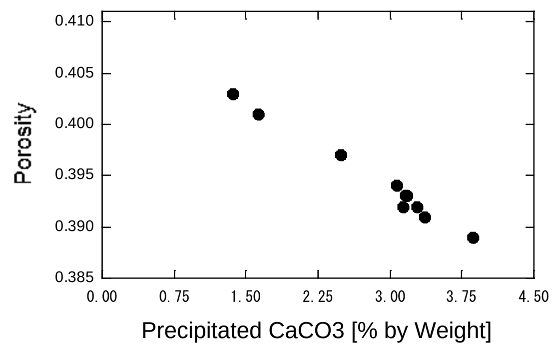

Fig.2. Relation between $CaCO_3$ precipitated and reduction in porosity

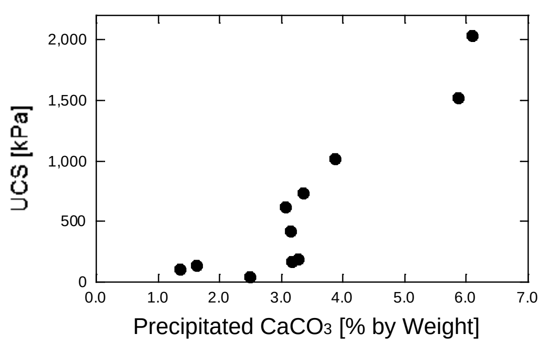

Fig.3. Relation between $CaCO_3$ precipitated and gain in *UCS*

Fig.4. Improved sand sample with mid-cylinder arrangement

4. Conclusions

The results of small cylinder test have shown that this technique of soil modification may be applicable to increase the strength of loose sand. Attempt was made to develop a relationship between gain in *UCS* and change in porosity attained by enzymatic $CaCO_3$ precipitation. Once the correlation between the *UCS* and the porosity change is established the UCS may be estimated by determining the change in porosity. Mid-cylinder test has been conducted to examine its applicability to larger domain and evaluate whether or not this method can be used in field, where the solution is to be injected at the point of interest usually under the ground. Almost spherical shapes of improved sand having diameter of 7-9 cm was obtained inside the cylinder of diameter 10 cm. This result implies that the current method is applicable in real fields.

5. References

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Van der Ruyt, M., van der Zon, W. (2009) “Biological in-situ reinforcement of sand in near-shore areas”, Geotechnical Engineering, 162, 81-83