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Geogrid reinforcement for cement stabilized soil

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ABSTRACT: This paper examined geogrid reinforcing effects for stabilized soil based on laboratory model test. In a series of the tests, influence of consolidation stress, drainage condition during loading, and loading speed on the strength properties of reinforced-stabilized soil are investigated. Main conclusions are as follows. 1) Geogrid prevents the propagation of cracks in stabilized soil. 2) Limit load resistance value increases by geogrid reinforcement. 3) Reinforcing effects can be expected as regardless of the consolidation pressure. 4) Reinforcing effects becomes larger according to the loading speed.

1 INTRODUCTION

In the construction of marine structure, utilization of dredged soil is important to reduce environmental impact due to construction. A popular utilizing method is to mix dredged soil with stabilizing material such as cement. However, the stabilized soil is generally brittle material. Improving method of ductility of the stabilized soil has been needed.

Authors and members in same project team in Port and Airport Research Institute, Japan have proposed a construction method of marine structure with dredged soil. This is combining method of geogrid reinforcement with cement stabilization. In this paper, influences of consolidation stress, drainage condition during loading, and loading speed on the strength properties of reinforced-stabilized soil are discussed.

2 CONCEPT OF GEOGRID REINFORCEMENT FOR CEMENT STABILIZED SOIL AND RESEARCH PROJECT

The invented method; SG-Wall method is combing technology of cement stabilization (S) of dredged soil and geogrid (G) reinforcement for quay wall (Wall). Typical cross section of the SG-wall is shown in Figure 1. The wall consists of cement stabilized soil, geogrid and sheet pile facing. Geogrid is used to reduce the tensile strain of stabilized soil and to prevent the propagation of cracks in the stabilized soil. Facing of the SG-wall is sheet pile. It is connected to geogrid directly. Sheet pile has high axial, shear and bending rigidity. The sheet pile is installed into base ground to fix the toe of facing. Tatsuoka (1992) noted that rule of facing rigidity on the stability of geosynthetics reinforced soil. El-Emam & Bathurst (2005) reported the effect of facing toe condition on response of geogrid reinforced soil wall. This facing system will make a rule in increasing of stability. In the first stage of this project, its feasibility was studied by performing 1/24-scale model shaking table tests (Miyata et al., 2006). In this test, high seismic performance of SG-wall was observed. In order to put this technology in practical use, the further examination has been required about design and construction method. Our project is now in second stage to investigate reinforcing mechanism in physical model test for the reduced–scale model.

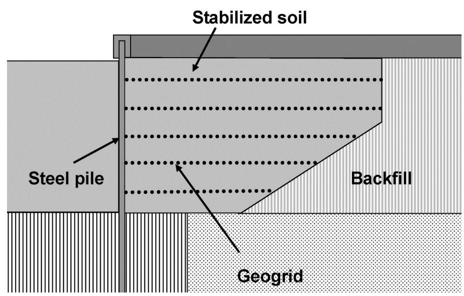


Figure 1. Outline of the SG-wall method.

3 LABORATORY TEST

In the case of cement stabilization of soft soil having high water content, overburden pressure will affect on the strength properties of the stabilized soil. The other

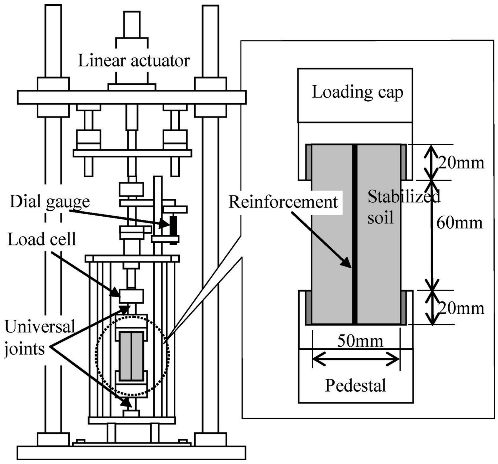


Figure 2. Laboratory test setup.

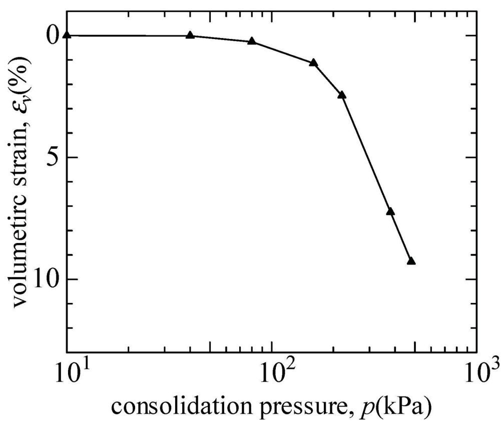


Figure 3. Triaxial test result of the stabilized soil used.

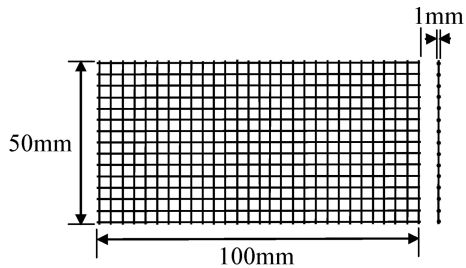


Figure 4. Outline of the geogrid used.

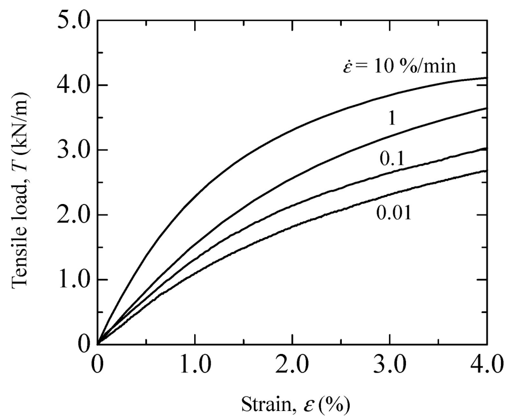


Figure 5. Tensile strength test results of the geogrid used.

side, strength of geogrid depends on strain rate. This paper considers the rule of consolidation pressure and loading speed on the effect of geogrid reinforcement.

Performed test was loading test for reduced model with triaxial testing apparatus. The laboratory test setup is shown in Figure 2. The shape of the specimen resembled that of a square pillar (50 mm × 50 mm × 100 mm). Geogrid was placed at center of specimen vertically. After curing of sample, the sample was fixed to the loading cap with gypsum. The loading was performed by making the cap move at fixed speed. A series of isotropic consolidation and triaxial tensile loading were performed by referencing the JGS-0523. Consolidation time was determined by the 3t method.

The stabilized soil sample was prepare by mixing cement with Kibushi clay ($w_L = 92\%$, PI = 59, $D_{50} = 0.0025$ mm) under the condition of high water content ($w = 135\%$). Cement content, which is the weight ration of cement to dried soil, a_w, was 17.3%. The result of triaxial consolidation test of this stabilized soil is shown in Figure 3. The consolidation yield stress, p_y can be estimated as $p_y = 150$ kPa. In a series of test, reduced-scale model of geogrid was used as shown in Figure 4. Tensile force per unit width – strain relations are shown in Figure 5. Curing of the sample was conducted in the mold. All of the test specimens were cured for 7 days in a humid room under atmospheric pressure at a temperature of 20 ± 3 °C.

In a series of laboratory test, the influence of confining pressure was investigated in the CD and the CU test. The range of investigated pressure was 0 kPa to a maximum of 196 kPa. The strain rate of loading was set to 0.1 %/min to the CU test, and 0.01%/min to the CD test, respectively. The influence of loading speed was investigated by the CU test. The CU tests were conducted at two kinds of consolidation stress as 0 kPa and 147 kPa. Range of investigated strain rates was 10^{-2} %/min to 10^1 %/min.

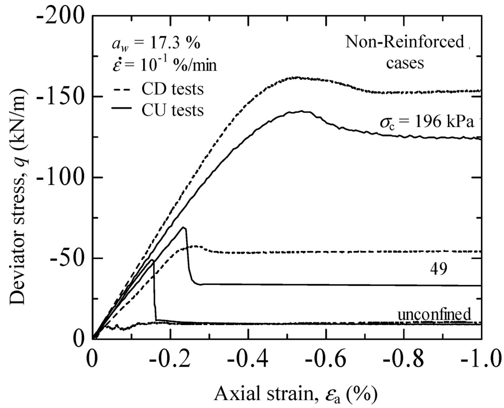


Figure 6. Stress – strain relations. (Non-reinforced cases).

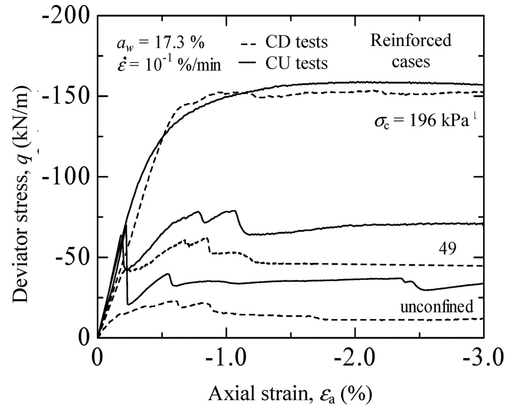


Figure 8. Stress – strain relations. (Reinforced cases).

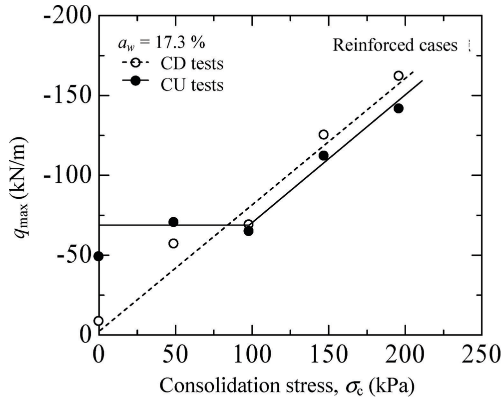


Figure 7. Peak deviator stress – consolidation pressure relations. (Non-reinforced cases).

4 TEST RESULTS AND CONSIDERATIONS

4.1 *Strength property of stabilized soil without reinforcement*

Figure 6 shows the relation between deviator stress, $q = \sigma_a - \sigma_r$, and averaged axial strain, ε_a. Where σ_a is axial stress, σ_r is lateral pressure respectively. In a series of tests, local deformation such as propagation of cracks was observed. However both the stress and strain were calculated by using typical length or area of samples. In the case of that consolidation pressure, σ_c is relatively smaller, stress-strain relations in the CU tests showed the peak value in each test. In the CD tests, such behavior was not observed. In the case of that σ_c is relatively larger, the difference between peak and residual strength was lower than one at that σ_c is relatively smaller. This does not depend on drainage condition during loading. The relations between peak deviator stress, q_{max} and σ_c are shown in Figure 7. The $q_{max} - \sigma_c$ relations at the CD tests can be evaluated as follows.

$$q_{max} = a \cdot \sigma_c \tag{1}$$

The $q_{max} - \sigma_c$ relations at the CU test can be evaluated as follows.

$$q_{max} = q_0,\ \sigma_c < \sigma_y \tag{2}$$

$$q_{max} = a' \cdot \sigma_c,\ \sigma_c < \sigma_y \tag{3}$$

Where σ_y is a certain stress that strength properties changes.

4.2 *Strength property of reinforced-stabilized soil*

Figure 8 shows the relation between q and ε_a. The q_{max} and residual values, q_r of reinforced cases are smaller than one of non-reinforced case. By geogrid reinforcement, ductility of stabilized soil was improved. The q_{max} of reinforced cases is almost same as one of non-reinforced case. However q_r of reinforced case is higher than one of non-reinforced case. The relations between residual strength, q_r and consolidation stress, σ_c are shown in Figure 9. The relation of CU test and one of CD test are almost same. From this result, it can be concluded that drainage condition does not affect on residual strength of reinforced stabilized soil.

The effect of loading speed on the peak strength of non-reinforced can be summarized in Figure 10. Influence of loading speed on the strength of stabilized soil can be almost omitted. The effect of loading speed on the residual strength of reinforced sample can be summarized in Figure 11. In the case that $\sigma_c = 0$, the effect of loading speed is same as non-reinforced case. However, In the case that $\sigma_c = 147$ kPa, strain rate effect is more remarkable when $\dot{\varepsilon} > 10^{-1}$(%). As shown in Figure 5, strength properties of the geogrid

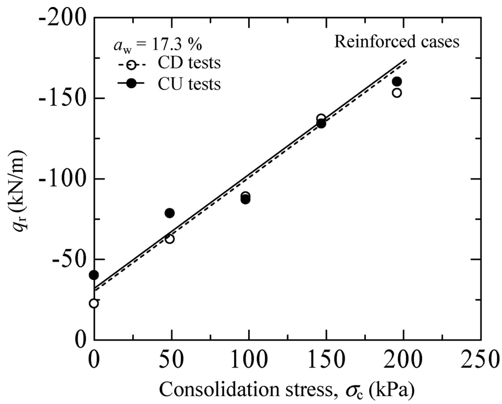


Figure 9. Peak deviator stress – consolidation pressure relations. (Reinforced cases).

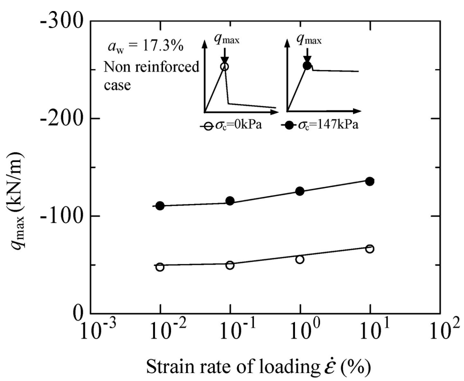


Figure 10. The effect of strain rate on the peak strength of non-reinforced sample.

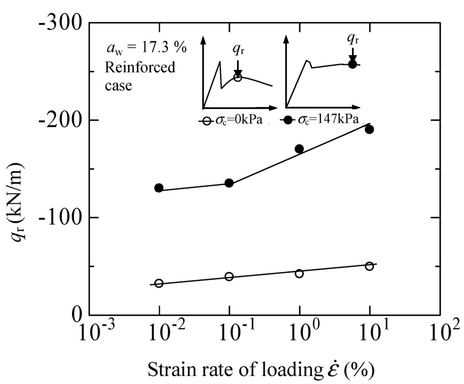
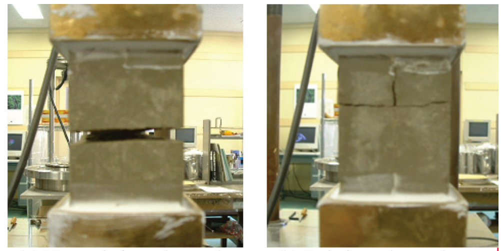


Figure 11. The effect of strain rate on the residual strength of reinforced sample.

depends on strain rate. This mean that geogrid resist to the applied load in reinforced cases.

The states at the end of testing for non-reinforced or reinforced sample are shown in Figure 12 (a), (b)



(a) Non-reinforced sample. (b) Reinforced sample.

Figure 12. The state at the end of test of no reinforced or reinforced sample.

respectively. Those results were obtained from unconfined test. In the case of un-reinforced case, failure plane was observed at the middle at of specimen. The other side, in the case of reinforced case, complicated failure mode was observed. Geogrid prevented the progressing of crack in stabilized soil.

5 CONCLUSION

Main conclusions are as follows. 1) Geogrid prevents the progressing of crack in stabilized soil. 2) Limit load resistance value of reinforced-stabilized soil increases. 3) Effect of the geogrid reinforcement can be expected as regardless of the consolidation pressure. 4) Effect of the geogrid reinforcement becomes larger according to the loading speed.

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