Characterizations of Secondary Deformation Behaviors of Cement-Treated Granulate Soil

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1. Introduction

The utilization of dredging materials for construction material has been increasingly attended for economical and environmental purposes. To improve effectiveness of conventionally treated methods, a granular material named as Cement-Treated Granulate Soil (CTGS) has been developed recently (Takahashi et al., 2010). In this approach, the high water content and low workability dredged clays can be treated to become a coarse grain size granular material by mixing with proper amounts of cement and polymer. CTGS is considered as a promising material for reclamation, backfill or subgrade soils, since it has a lightweight, good drainage, and can be produced from lean-mixture for cost reduction. This paper discusses the secondary deformation behaviors of CTGS produced from lean-mixed amount of cement and polymer by a series of one-dimensional consolidation tests.

2. Materials

In this study, we selected Kawasaki clay (Fig. 1) to produce the testing material. Some physical properties of this soft clay are shown in Table 1. The clay was first mixed with Aqupaana polymer (partially neutralized polyacrylic acid) then mixed with Portland cement by using a small blade mixing machine. The material after mixing was cured in airtight condition for more than 28 days. The detailed production method can refer to Takahashi et al. (2010). We herein considered two types of treated soils, which were produced from lean-mixed amounts of cement and polymer and named as C_1 and C_2 (Fig. 1.b). The physical properties of these soils are given in Table 2.

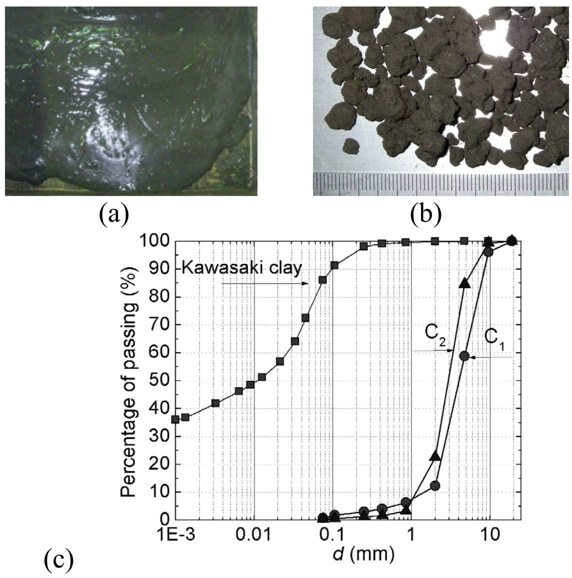

Fig. 1. (a) Kawasaki clay; (b) CTGS (C_1 type) and (c) grading curves of the materials

Table 1. Physical properties of Kawasaki Clay

Properties	Value
Water content, w (%)	48.6
Limited Liquid, w_L (%)	60.0
Specific density ρ_s (g/cm^3)	2.676
Percentage of sand (%)	14.0
Percentage of silt (%)	42.0
Percentage of clay (%)	44.0

Table 2. Physical properties of GCTS

Properties	C_1	C_2
Cement (%)	5	15
Polymer (%)	0.1	0.3
Particle density ρ_s (g/cm^3)	2.69	2.71
Natural water content, w (%)	44.82	39.2
pH	10.64	11.34
Maximum void ratio, e_{max}	3.35	2.98
Minimum void ratio, e_{min}	2.44	2.23

3. Experiments

The tests were carried out on loose and dense C_1 and C_2 specimens. It can be seen from Fig. 1.c that the maximum CTGS particle size is about 10 mm, so the tests were herein conducted on specimens having 20 cm diameter and about 8 cm height to avoid the scale effect. Figure 2 shows the apparatus that consists of a cylindrical box, 20 cm internal diameter and 30 cm height, is equipped one valve at the top for pressure supply and two drainage tubes at the bottom and the top. The compressive piston can move vertically, and its movement can be monitored by a displacement gauge during loading. The loose specimens were prepared by pouring the materials into cell with zero drop height, where dense specimens were prepared by directly compacting in the cell. The dry density values of C_1 and C_2 specimens in loose state are 0.702 g/cm^3 and 0.690 g/cm^3, and those in dense state are 0.926 g/cm^3 and 0.957 g/cm^3, respectively. The specimens were first saturated by passing de-air water through bottom drainage to top drainage and using a vacuum pressure. Subsequently, the specimens were subjected to load increments of 9.8, 19.6, 39.2, 78.5, 157, 314 and 628 kPa and analyzed according to JIS A1217 (2009).

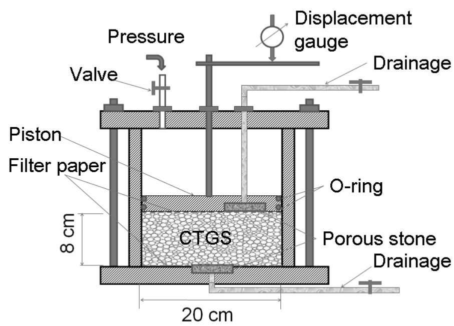

Fig.2. the model of one-dimensional consolidation test

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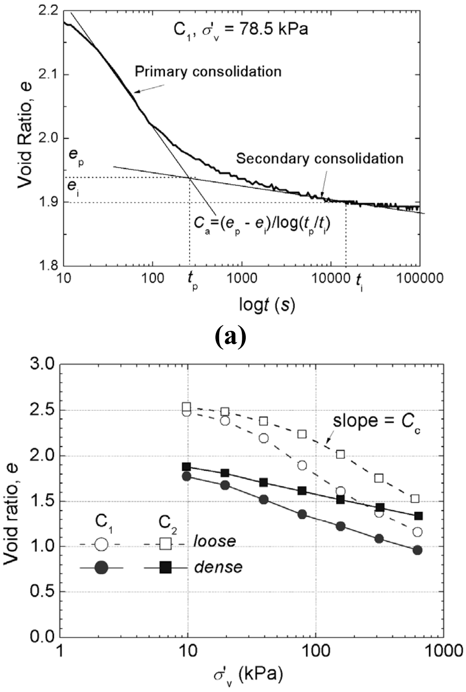

Fig. 3: (a) typical e-log$t$ curve; (b) relations of e-logσ'_v

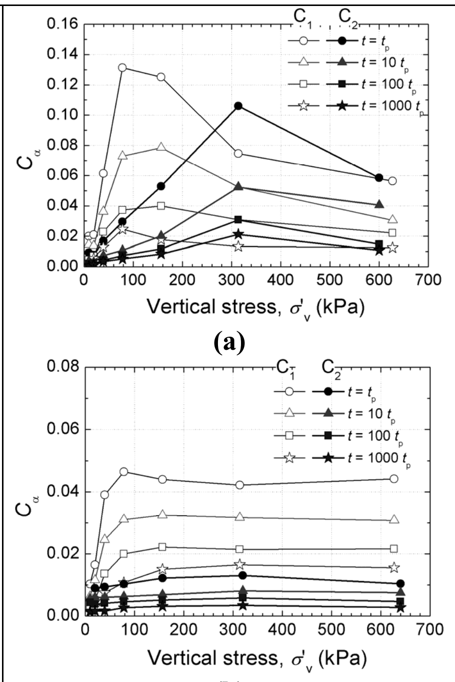

Fig. 4. secondary deformation index, C_α vs. vertical stress: (a) loose; (b)dense

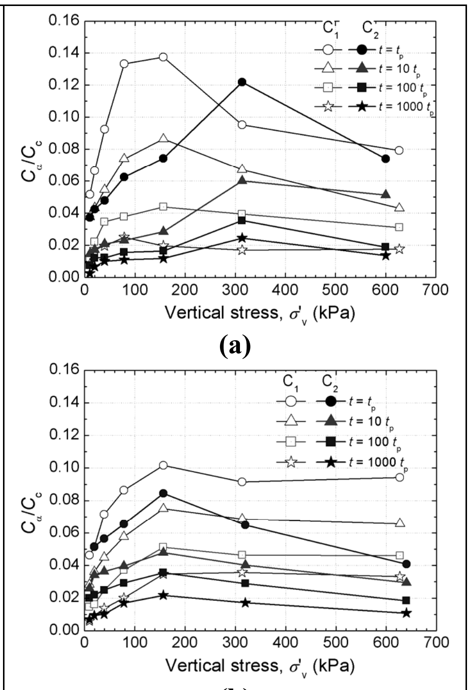

Fig. 5: normalized ratio C_α/C_c vs. σ'_v: (a) loose; (b) dense

Figure 3.a shows a typical e-log$t$ curve in case of C_1 specimen subjected to a vertical load of σ'_v = 78.5 kPa. From these curves, the duration of primary consolidation and secondary consolidation are determined. It was observed in most cases that the primary consolidation was completed for a short time, t_p is in term of minutes, which implies that secondary deformation of CTGS occurs very soon, just after loading.

In Fig. 3.b presents the relations of e-logσ'_v, based on which the compression index is calculated, $C_c = -\Delta e/\Delta log\ \sigma'_v$. It is seen in both C_1 and C_2 types that void ratio of loose specimen decreases and approaches to the one of dense state as vertical stress increases. The curvature of e-logσ'_v curves at dense state could be explained that dense specimens were compacted to over-consolidated condition before loading. However, similar non-linear behavior of the compression lines e-logσ'_v is also found in loose C_1 and C_2 specimens whilst these loose specimens were virginally compressed. This distinct feature of CTGS from conventional soils, which normally shows straight compression line, could be due to the effect of particle crushing when imposed stress grows.

Based on the relation of e-log$t$ for each loading increment in Fig.3.a, the secondary deformation index can be determined, $C_\alpha = (e_p - e_{ti})/\log(t_p/t_i)$, where C_α was determined at time t_i equals some interval cycles of time t_p, at which the primary consolidation was completed. Figures 4.a and 4.b show the relations of C_α - σ'_v in loose and dense specimens, respectively. It is observed that the relations of C_α - σ'_v of C_1 and C_2 show almost similar tendency though C_2 shows relatively lower C_α than C_1, especially at high stress level or dense state. And also, the stress level at which C_α exhibits maximum value in case of C_2 is also larger than that in case of C_1. These behaviors could be due to effect of higher stiffness of the C_2 particles than the C_1 particles. In addition, it can be seen that C_α index of CTGS in loose state (Fig.4.a) is relative large that is comparative with soft clay. However, C_α is considerably decreased at dense state (Fig. 4.b) and is quickly diminished with consolidation time.

Figures 5.a and 5.b plot the relations of normalized ratio of C_α/C_c vs. σ'_v. The relation C_α/C_c vs. σ'_v shows almost similar manner to that of C_α vs. σ'_v (Figs. 4). The average values of C_α/C_c measured at time t = 100 t_p in cases of loose and dense C_1 are 0.032 and 0.034, respectively, whereas those value in case of loose and dense of C_2 are 0.019 and 0.021. These values of C_1 and C_2 are correlative with those reported for mudstone and good granular soil JIS A1217 (2009).

4. Conclusions

The comprehensive understanding on secondary consolidation behaviour is necessary for practical design in order to predict the long-term settlement of ground using CTGS. The test results obtained from this study conclude that although C_α of CTGS exhibits quite high value, relatively with that reported for soft clay or peat soil. However, the secondary deformation starts very soon, during or just after construction. It quickly reduces with consolidation time and can be effectively reduced in dense state. Therefore, the long-term deformation of CTGS ground should be taken into account for practical design but it seems not to be severe matter, especially in compacted condition.

References

Takahashi, H., Morikawa, Y., Ichikawa, E., Hayano, K. and Okusa Y. (2010). Model tests on compressibility and bearing capacity of lean-mixed granular cement treated soil, *Journal of JSCE, C,* **66**(2), 236-249.