Development of new volume reduction technique for natural cohesive soil ground by disturbing

Yoshio Mitarai ⁱ⁾, Yosuke Tanaka ⁱⁱ⁾, Daisuke Kiuchi ⁱⁱⁱ⁾ & Kohta Nishida ⁱⁱⁱ⁾

i) Deputy General Manager, R & D Center, TOA Corporation, 1-3, Anzen-cho, Tsurumi-Ku, Yokohama 230-0035, Japan.

ii) Senior Researcher, R & D Center, TOA Corporation, 1-3, Anzen-cho, Tsurumi-Ku, Yokohama 230-0035, Japan.

iii) Researcher, R & D Center, TOA Corporation, 1-3, Anzen-cho, Tsurumi-Ku, Yokohama 230-0035, Japan.

ABSTRACT

This paper covers a development of volume reducing method for natural cohesive soil ground by disturbance, generated by mixing machinery as utilized for cement deep mixing method. This method is based on the basic knowledge that compressibility of natural clay will be changed by sample disturbance. This paper summarizes basic effect of compressibility of natural clay on artificial disturbance by a series of laboratory oedometer tests. Through the tests using undisturbed clay samples taken in Japan, effects of disturbance on compressibility is examined. Then, simple estimation of potential settlements due to ground disturbance by mixing machinery is studied using liquid limit of clay sample, as basic clay intrinsic parameter. In addition, effect of coefficient of consolidation due to the disturbance is confirmed to control the consolidation speed in subsequent soil improvement work by pre-fabricated vertical drain. Finally, some probable application of this proposed method is mentioned.

Keywords: volume reduction, disturbance, natural cohesive soil, compressibility, disposal site

1 INTRODUCTION

It is generally known that sample taken from natural cohesive soil ground will induces disturbance of the soil structure due to mechanical disturbance during sampling and sample preparation, with stress release. From past research, the degree of disturbance of a sample is considered to be reflected in strength characteristics (stress-strain curve, strain at failure, modulus of deformation, etc.) and consolidation characteristics (shape of void ratio-consolidation pressure curve, consolidation yield stress, reduction of coefficient of consolidation etc.), and methods to evaluate and compensate for disturbances have been proposed (Schemertman et. al. 1955, Ladd et. al. 1963 and Okumura 1973). Because it is difficult to eliminate such disturbances completely during sampling or disturbances during soil improvement work with vertical drain installation, and disturbances greatly affect design and execution, including prediction of consolidation settlement, stability analysis, etc., they are generally considered undesirable. However, in this research, the effect of disturbance was summarized in laboratory experiments with the aim of proposing a new technique for volume reduction of natural cohesive ground and expansion of the capacity of soil disposal sites by positively utilizing disturbance.

2 MECHANISM OF VOLUME REDUCTION BY POSITIVE DISTURBANCE

Figure 1 shows the general concept of the mechanism of volume reduction by positive disturbance (Mitarai et. al. 2013 & 2014). The blue and green lines in the figure are the compression curves for “Undisturbed” and “100% Disturbed”, respectively. Regarding the behavior of the original ground, it is thought that settlement occurs after compression stress exceeds the consolidation yield stress, as shown by the black broken line.

Fig. 1 Concept of mechanism of volume reduction by disturbance.

If a specimen hypothetically having a certain effective overburden pressure (A) is disturbed, the compression curve of that specimen will perform settlement (ϵ_{vp}), as shown by the red arrow, due to a shift to the “100% Disturbed” compression curve (B). This means that some amount of potential settlement, i.e., “settlement potential,” exists if a volume-reduction-by-disturbance technique is applied to the ground.

3 SPECIMENS AND EXPERIMENTAL METHOD

3.1 Specimen Used in Experiments

The main physical properties of the specimens used in these experiments are shown in Table 1. A plasticity chart is shown in Fig. 2. All specimens were sampled with a stationary piston-type thin-wall sampler. After extraction, the specimens were coated with paraffin and stored in a constant temperature, constant humidity chamber (room temperature: $20 \pm 2^\circ\text{C}$, room humidity: 95% or higher) to prevent drying.

Table 1 soil physical properties of clay

Sample	σ'_v (kN/m^2)	w_n (%)	Atterberg limit		
			w_L (%)	w_P (%)	I_P (%)
Saga Ariake A	47.3	134	62	32	30
Saga Ariake B	77.0	78	64	34	30
Tokyo Bay A	224.2	88	103	45	58
Tokyo Bay B	257.3	43	41	20	21
Tokyo Bay C	270.0	38	31	23	8
Kobe	35.2	101	106	40	66
Osaka bay A	34.2	110	120	34	86
Osaka bay B	95.3	49	57	24	33

Fig. 2. Plasticity chart of clay samples used in this study.

3.2 Experimental Method

Two types of consolidation tests were adopted. One is standard step loading test (STD) in accordance with JIS A 1217, other is constant strain rate consolidation test (CRS) in accordance with JIS A 1227. During CRS test, continuous compression curve and coefficient of consolidation c_v can be obtained quickly. Then some samples are subjected to CRS to obtain continuous compression curve and c_v . Others are subjected to STD

to examine the effect of consolidation curve on disturbance. The strain rate is 0.02%/min in CRS. The test method used with each sample is shown in Table 4.

The specimen preparation method and specimen conditions are shown in Fig. 3 and Table 2, respectively. “Undisturbed” specimens were prepared by extracting the middle 30 mm from the specimen height of approximately 100 mm, and inserting the specimen in a consolidation ring. “100% Disturbed” specimens were prepared by sampling the 30 mm section above the “Undisturbed” specimen, performing complete remolding to eliminate variations in water content, and packing a sample of the same weight as the “Undisturbed” specimen in a consolidation ring. For “50% disturbance” and 75% disturbance”, the 30 mm section under the “Undisturbed” specimen was sampled, and complete remolding was performed in the same manner as with the “100% disturbed” specimens. Dice of specimens with a size of 3-5 mm square were then cut out with a cutter, mixed uniformly at the mass ratios shown in Table 2, and packed in consolidation rings (see bottom of Fig. 3).

Fig. 3. Specimen preparation method.

Table 2. Mixing portion of Undisturbed and Disturbed sample.

Case	Undisturbed sample	Remolded sample
Undisturbed	100%	0%
50% of disturbed	50%	50%
75% of disturbed	25%	75%
100% of disturbed	0%	100%

4 EXPERIMENTAL RESULTS

4.1 Effect of Degree of Disturbance on Results

Figure 4 shows the relationship between the volumetric strain (ϵ_v) and consolidation pressure (p) of Osaka Bay A and B from STD. As reported in past

research, consolidation yield stress (p_c) decreases as a result of disturbance, and the form of the curve becomes gentle. It is noted that 50% and 75% disturbed sample is similar to that of 100% disturbed sample. The reason is due to stress concentrations are generated in the mixture of disturbed and undisturbed sample. Once stress concentration is generated, shear deformation is generated due to high stress occurs preferentially in the dice of undisturbed sample. As a result, the material approaches the remolded condition as 100% disturbed sample. Table 3 summarizes the volumetric strain when the specimens were loaded with the same effective overburden pressure (σ_v') as in the original in-situ condition. From the table, it is noted that the volumetric strain more than 50% disturbed sample is more than 80% of that of 100% disturbed sample. (For example, in the case of Osaka Bay A, $10.0/13.3 = 0.81$.)

Fig. 4. Relationship of ε_v and p .

Table 3. Volumetric strain under effective overburden pressure.

Sample		Osaka Bay A	Osaka Bay B
σ_v' (kN/m ²)		34.2	91.5
ε_v at σ_v' (%)	Undisturbed	4.2	5.6
	50% of disturbed	10.8	15.5
	75% of disturbed	11.9	15.9
	100% of disturbed	13.3	14.6

4.2 Influence of Physical Properties on Volume-Reduction-by-Disturbance Effects

Figures 5 and 6 show the compression curves

(volumetric strain and consolidation stress) obtained from all consolidation tests for the cases of “Undisturbed” sample and “100% disturbed” sample. With all specimens, the compression curve changes and compressibility increases as a result of disturbance. Table 4 shows the results when the “settlement potential” ε_{vp} of the “100% disturbance” specimens under the in-situ effective overburden pressure is read from Fig. 5. From these results, the volumetric strain of 100% disturbed sample tends to become larger as the yield point of the compression curve of the undisturbed specimens becomes clearer. The relationship between ε_{vp} and the liquid limit is arranged in Fig. 6. In this figure, a positive correlation between ε_{vp} and the w_L can be seen. Due to differences in the fine contents of the sample used here and other factors, it is not possible to draw a definitive line from the results presented in this paper alone. However, these results suggest that “settlement potential” becomes greater as the liquid limit increases.

Fig. 5 ε_v - $\log p$ relationship
(Saga Ariake A & B, Tokyo Bay A)

(d) Tokyo Bay B

(e) Tokyo Bay C

(f) Kobe

(g) Osaka Bay A

(h) Osaka Bay B

Fig. 6 $\varepsilon_v - \log p$ relationship
(Tokyo Bay B & C, Kobe, Osaka Bay A & B)

Table 4 Results of consolidation tests

No.	Sample	Testing Method	w_L (%)	Volume strain at in-situ stress level ε_v (%)
1	Saga Ariake A	CRS	62	21.6
2	Saga Ariake	STD	64	15.3
3	Tokyo Bay A	CRS	103	18.2
4	Tokyo Bay B	STD	41	8.0
5	Tokyo Bay C	CRS	31	10.7
6	Kobe	STD	76	15.0
7	Osaka Bay A	CRS	120	17.0
8	Osaka Bay B	STD	57	10.6

Fig. 7. $\varepsilon_{vp} - w_L$ relationship

4.3 Influence of Disturbance on Coefficient of Consolidation

Figures 8 and 9 show the relationship between the coefficient of consolidation and the mean consolidation pressure obtained from the consolidation tests of Osaka Bay A and B. The fact that the coefficient of consolidation decreases due to disturbance can be confirmed. In particular, in the case of “Undisturbed”, the coefficient of consolidation decreases in the stress range of the over-consolidated region. This is considered to be due to a change in compressibility. Thus, in the volume-reduction-by-disturbance technique, it is necessary to determine the coefficient of consolidation by a consolidation test before design of the drain after disturbance.

(a) Osaka Bay A

Fig. 8 $\log c_v - \log p$ relationship (Osaka Bay A)

Fig. 9 $\log c_v - \log p$ relationship (Osaka Bay B)

5 PROPOSALS FOR APPLICATION AT ACTUAL SITES

The following are possible applications of the volume-reduction-by-disturbance technique at actual sites.

- (1) Securing capacity and volume reduction at soil disposal sites (e.g., at newly-constructed sites and at sites where landfill has been completed)
- (2) Securing water area of reservoirs, lakes, and marshes, etc.
- (3) Containment of contaminated soil
- (4) Reduction of excavation and dredging soil and soil disposal (including reduction to zero)

Possible applications are required for all locations including cohesive soil layer in the ground without soil improvement work such as vertical drain. Regarding (1) and (4), in particular, due to the shortage of soil disposal sites in recent years, there is a strong need to increase the capacity of existing soil disposal sites in cases where new construction would be difficult. Where (3) is concerned, when the reclaimed ground at existing landfill sites contains pollutants, the amount of contaminated soil generated by construction work and the amount of soil requiring disposal can be greatly reduced by promoting settlement of the natural sedimentary ground where this is possible.

In implementation of the proposed technique, various methods of disturbing the ground are applicable. However, probable candidate is a method using the equipment of the deep mixing method, in which a stabilizer is mixed with the soil while agitating the ground with an impeller. As the necessary mixing time, including rod installation and withdrawal time, for forming a homogeneous stabilized soil-cement column has already been determined, this is a proven method with a uniform mixing capacity.

6 CONCLUSIONS

As mentioned, the effects of disturbance on soils in laboratory tests and disturbance of the ground during construction were frequently considered to be negative as of now. On the other hand, the proposed technique is the result of, so to speak, a reversal in thinking, in that the effects of positive disturbance are actively utilized. In this study, a series of consolidation tests were carried out using specimens with different degrees of disturbance, and the influence of differences in the degree of disturbance and the physical properties of the specimens on compressibility was studied. The following knowledge was obtained.

- (1) As reported in past study, p_c decreases as a result of disturbance, and the shape of the compression curve also changes greatly. When disturbance is applied, large volumetric strain occurs at the same p in comparison with the case of “undisturbed”.
- (2) With 50% “disturbed”, a compression curve similar to that of 100% disturbed sample was obtained. This means that 100% disturbance of the ground is not required in actual mixing perfectly, and a sufficient volume reduction effect can be obtained with more than 50% of disturbance.
- (3) “Settlement potential” shows a tendency to increase as the liquid limit increases.

REFERENCES

- 1) Schemertman, J.H. (1955): The Undisturbed Consolidation Behavior of Clay, *Trans. ASCE*, Vol. 120, pp. 1201~1233.
- 2) Ladd, C.C. and Lambe, T.W.(1963): The strength of “Undisturbed” Clay Determined from Undrained Tests, *ASTM STP-361, Laboratory Shear Testing of Soils*, pp. 342-371.
- 3) Okumura, T. (1973): Studies on the disturbance of clay soils and improvement of their sampling techniques, *Technical Note of the Port and Harbour Research Institute Ministry of Transport*, No. 193 (in Japanese).
- 4) Mitarai, Y., Tanaka, Y. and Nishida, K. (2013): Influence of disturbance on consolidation properties of natural cohesive soil and its positive utilization, *Proceedings of 68th JSCE annual conference*, Div. III, 419-420, (in Japanese).
- 5) Mitarai, Y., Tanaka, Y., Kiuchi, D. and Nishida, K. (2014): Newly Technique for Reduction of Cohesive Ground by Positive Disturbing, *Geotechnical Engineering Magazine*, 62(5), 28-29 (in Japanese).