Simplified sampling method for river embankment soils and strength property evaluations of the sampled soils

Méthode simplifiée d'échantillonnage des sols de remblai de rivière et évaluation de la prorpiété de résistance des sols échantillonnés

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ABSTRACT: In this study, two different sampling methods for river embankments were investigated. In the first, hereinafter referred to as Method-A, short length and large diameter polyvinyl chloride (PVC) pipes are driven into embankments by handheld wooden hammers. In the other, hereafter referred to as Method-B, newly developed double-tube samplers with long length and small diameter PVC inner tubes are driven into embankments by handheld hammers. *In-situ* sampling was conducted at a river embankment consisting primarily of relatively homogenous decomposed granite sand, after which a series of consolidated-undrained triaxial tests was performed to study the quality of the sampling methods. The test results indicate that the specimens obtained by Method-A show typical loosen sand tendencies whereas the specimens obtained by Method-B show typical medium dense sand tendencies. The differences seem to be derived from disturbances that occurred during sampling, and it is difficult to determine which method is more sensitive to such disturbances. However, by evaluating strength parameters using the effective stress state at phase transformation, which is newly proposed in this study, the difference effect can be suppressed and rational strength parameters can be obtained.

RÉSUMÉ : Dans cette étude, deux méthodes d'échantillonnage des berges de rivières ont été étudiées. Dans la première, ci-après appelée méthode A, des tubes de polychlorure de vinyle (PVC) courts en longueur et à grand diamètre sont enfoncés dans les remblais avec des marteaux de poche. Dans l'autre, ci-après appelée méthode-B, des doubles tubes à prélèvement dernièrement développés, avec des tubes intérieurs en PVC longs et à petit diamètre, sont plantés avec un marteau. L'échantillonnage in situ a été effectué sur un remblai de rivière constitué principalement de sable de granit décomposé relativement homogène, sur lequel une série de tests triaxiaux consolidé-non drainé ont été effectués pour étudier la qualité des méthodes d'échantillonnage. Les résultats des essais indiquent que les prélèvements obtenus par la méthode A montrent des tendances typiques d'un sol brassé, tandis que les prélèvements obtenus par la Méthode-B montrent des tendances typiques d'un sable moyen et dense. Cependant, en évaluant les paramètres de résistance via l'état de contrainte efficace lors de la transformation de phase, qui est nouvellement proposé dans cette étude, l'effet de différence peut être supprimé et des paramètres de résistance logiques peuvent être obtenus.

KEYWORDS: River embankment, Sampling method, Triaxial test, Strength parameter, Phase transformation.

1 INTRODUCTION

Recently in Japan, many open-cut river embankment reconstruction works are underway nationally as part of efforts to renovate aging river structures. These open-cut construction periods provide ample opportunities for levee soil sampling. However, at such times, an efficient and high quality sampling method is required.

In the past, the authors carried out a series of triaxial tests under various test conditions on river embankment soils to investigate their mechanical behavior (Kodaka et al., 2010, 2012, 2013a, 2013b, 2014 and 2015). Those soil samples were collected using a double-tube sampling method during boring, or via a simple sampling method, hereinafter referred to as Method-A, in which short length and large diameter polyvinyl chloride (PVC) pipe sections were driven into embankments by handheld wooden hammers.

However, in this paper, we propose a new method, hereafter referred to as Method-B, in which newly developed double-tube samplers with long length and small diameter PVC inner tubes are driven into embankments by handheld hammers. River embankment soil samples were obtained by both methods, after which a series of consolidated-undrained triaxial tests was performed to study the effects of the sampling method on the mechanical properties of the obtained soil samples.

Figure 1: Sluiceway reconstruction and soil sampling

2 OUTLINE OF THE SAMPLING METHODS

Samples were collected from the sluiceway reconstruction site shown in Fig. 1 using the two sampling methods described as Method-A and Method-B above. The river embankment was constructed using sandy soil consisting primarily of relatively homogenous decomposed granite. Figure 2 shows the Method A sampling procedure, in which a single PVC pipe section with an inner diameter of 100 mm and a height of 190 mm was used.

(a) Driving in the pipes (b) Excavating the samples

Figure 2: Sampling Method-A

(a) Double tube sampler (b) Driving in the pipes

(c) Pulling out the sampler (b) Protecting the sample

Figure 3: Sampling Method-B

(a) Driving in the pipes (b) Pulling out the sampler

Figure 4: Sampling Method-B-i

However, when this sampling method is used, only one specimen can be prepared for triaxial tests for each section of PVC pipe.

The Method-B sampling procedure is shown in Fig. 3. Here, the inner PVC tube is 71 mm in inner diameter and 500 mm in height. Unlike Method-A, at least three, and sometimes four, specimens can be prepared for triaxial tests when this sampling method is used.

It should be noted that another method was used to collect a sample from the embankment slope near the Method-A and Method-B sampling points. Here, the double-tube sampler was driven to the embankment at an oblique angle (i.e., not vertically), as shown in Figure 4. Hereafter, this method is referred to as Method-B-i.

3 LABORATORY TEST RESULTS

3.1 *Shear properties*

The collected soil samples were transported to our laboratory and frozen inside the pipe, after which they were trimmed to the predetermined size in the frozen state. Thereafter, the samples were preserved by freezing and set in the triaxial chamber in frozen state. All specimens were fully saturated (i.e., B value of over 0.95) via the double-vacuum method after being placed in the triaxial chamber. The specimens are maintained in the triaxial chamber for 15 hours after saturation in order to make sure they had thawed completely.

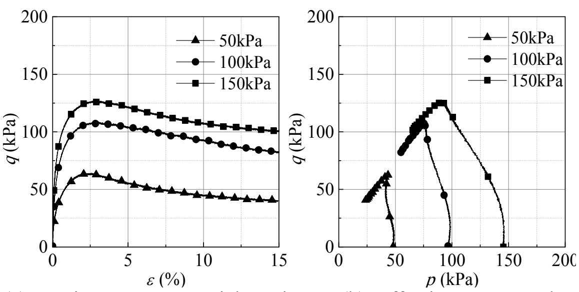
In all the tests, isotropic consolidation was performed by applying a predetermined effective confining pressure. Thereafter, consolidated undrained triaxial testing was conducted using a loading rate of 0.1%/min. The tests were conducted under initial effective confinement pressures of 50, 100, and 150 kPa. Figures 5 - 7 show the stress-strain relations, the effective stress paths, and the pore pressure - strain relations of the soil samples.

In the soils collected by Method-A, the stress-strain relations indicate the existence of strain-softening behavior when the axial strain is larger than 2.5%, irrespective of the confining pressure. This result reflects the tendencies typically associated with loosened sand. In the soils collected by Method-B, the stress-strain relations indicate the presence of strain-hardening behavior.

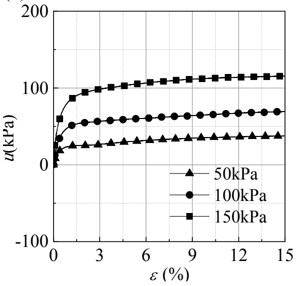
From the effective stress paths, plastic volumetric compression behavior can be seen in the early loading stage, after which volumetric expansion occurs under all the effective confinement pressures. This result reflects the typical tendencies of medium dense sand. For the soils collected via Method-B-i, the stress-strain relations indicate strain-hardening behavior under 50 kPa of confining pressure, whereas the specimens confined under pressures of 100 and 150 kPa exhibit strain-softening behavior when the axial strain exceeds 3.0%.

While the test results for the stress-strain relations and effective stress paths for the specimen collected via Method-A reflect the tendencies of typical loosened sand, the specimens collected via Method-B reflect the tendencies of typical medium dense sand. However, the densities of specimens collected by Method-A and Method-B do not show any notable differences.

Assuming the samples obtained by Method-B indicate the actual mechanical behavior of the embankment soil, one possible reason for the mechanical behavior differences for the samples collected by Method-A could be sampling disturbances. However, if it is assumed that the samples collected by Method-A reflect the embankment soil well, the reason of the difference might be related to the soil compaction that occurs during sampling Method-B when the pipes are driven into the soil.

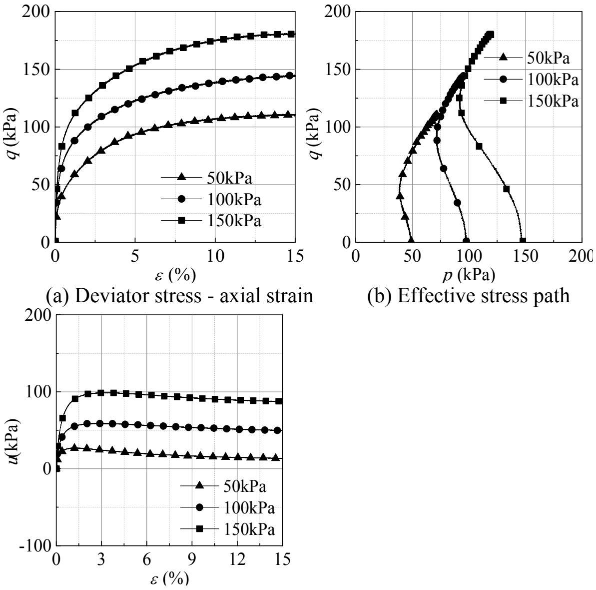


(a) Deviator stress - axial strain (b) Effective stress path



(c) Pore pressure - axial strain

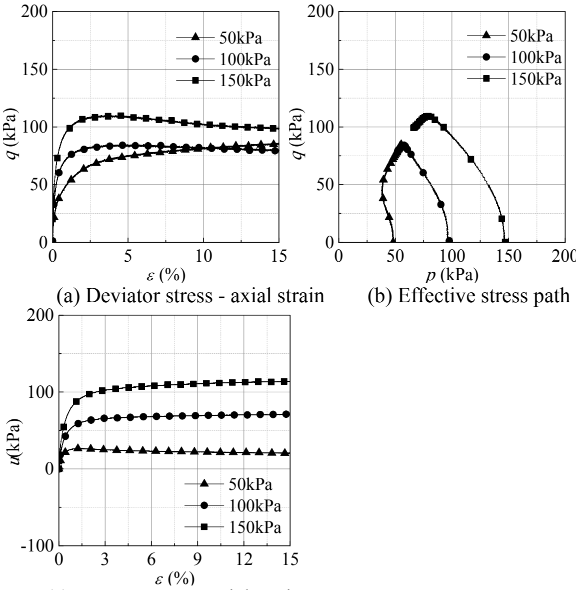
Figure 5: Triaxial test results of the soils collected by Method-A



(a) Deviator stress - axial strain (b) Effective stress path

(c) Pore pressure - axial strain

Figure 6: Triaxial test results of the soils collected by Method-B



(a) Deviator stress - axial strain (b) Effective stress path

(c) Pore pressure - axial strain

Figure 7: Triaxial test results of the soils collected by Method-B-i

At this moment, it is difficult to determine which sampling method produces more accurate results. In contrast, the density of the specimen collected by Method-B-i was significantly less than that of the specimens collected by Method-A and -B. This is because the double-tube sampler is unstable during hammering since the sampler driven into the embankment at an oblique angle.

Based on the stress-strain relations and the effective stress path, the curves shows almost the same shapes for sampling Methods-A, -B, and -B-i. The large sampling method differences appeared when the axial strain became larger. In other words, the soils collected by Method-A and -B exhibit the same mechanical properties when the axial stress is less than 1%.

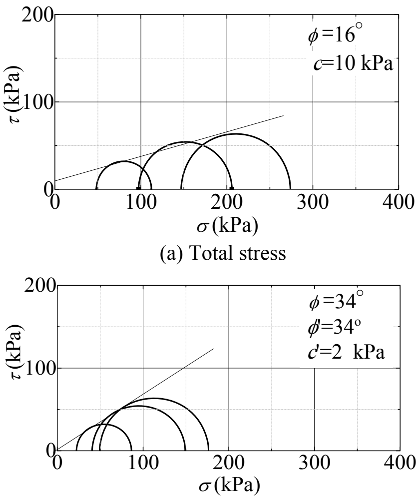
3.2 *Strength parameters by Mohr's stress circles*

Figures 8-10 show Mohr's stress circles and the failure criterion obtained from Figures 5-7. In addition, strength parameters of cohesion c and internal friction angle ϕ for each sample are also included in the figures. Strength parameters such as ϕ and c were calculated using the total stress obtained from the consolidated-undrained tests while ϕ' and c' were calculated using the effective stress obtained from the same consolidated-undrained tests.

In both Method-A and Method-B, when calculating the strength parameters using the total stress, the apparent cohesion c are observed as a result the internal friction angle ϕ declining significantly in relation to ϕ'. Moreover, for the different sampling methods, different apparent cohesion c values were obtained.

When evaluating the mechanical properties of the soil using total stress, the "undrained shear strength" is the same as the maximum deviator stress. For sandy soil that exhibits positive dilatancy during shearing, restraining the volume under undrained conditions will cause large deviator stress. This large deviator stress is directly reflected in the total stress cohesion increase.

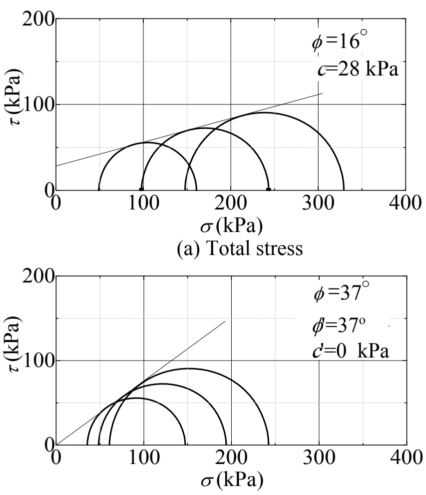
Furthermore, from experience gained through the author's



(a) Total stress

(b) Effective stress

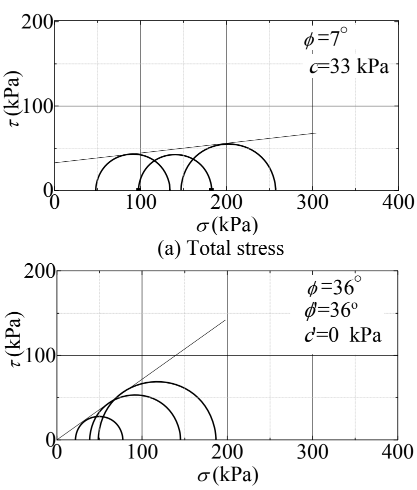
Figure 8. Mohr's stress circle (Method-A)



(a) Total stress

(b) Effective stress

Figure 9. Mohr's stress circle (Method-B)

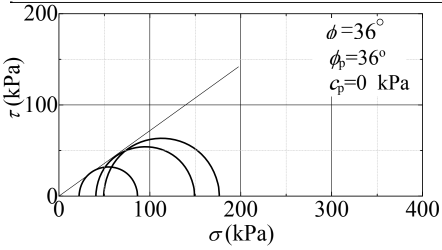


(a) Total stress

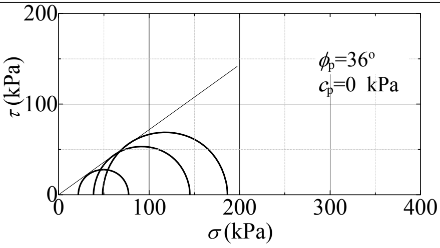
(b) Effective stress

Figure 10. Mohr's stress circle (Method-B-i)

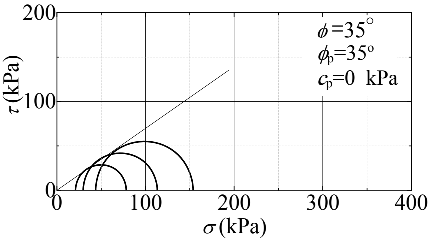
experimental studies, it can be said that the development of



(a) Method-A



(b) Method-B



(c) Method-B-i

Figure 11. Evaluation at the phase transformation state

deviator stress in dilative sands under undrained conditions is easily affected by sample disturbances. Therefore, the cohesion of relatively dense sand, in terms of total stress, is not unique and changes with the strain level used for determination. Between Method-A and Method-B, mechanical property differences appear primarily in the later stage of shearing. As a result, the cohesion c changes.

The above results suggest that strength parameter determination methods that use the maximum deviator stress are easily affected by sample conditions, and that these uncertain strength parameters are inappropriate for use during the design of a river embankment. Therefore, the following new strength parameter determination method is proposed.

4 EVALUATION OF THE STRENGTH PARAMETERS AT THE PHASE TRANSFORMATION STATE

For strength parameter determinations, the Laboratory Testing Standards of Geomaterials published by Japanese Geotechnical Society states that when the deviator stress achieves its peak value, soil failure occurs. On the other hand, when there is no peak in the stress-strain relations, the strength parameters are calculated using the stress values at the axial strain of 15%. However, the effective stress in the embankment decreases when a seepage failure occurs, and the strains are thought to be smaller than 15%.

Additionally, in general, the deviator stress obtained for dense sandy soil from the consolidated-undrained triaxial test increases continuously due to the positive dilatancy restriction. This phenomenon is different for the undrained shear strength of the actual embankment soil. Therefore, a new strength parameter determination method that utilizes the effective stress state at phase transformation is proposed. The phase transformation state is defined in the following paragraphs.

When the stress-strain relation reaches a peak, as shown in Figure 5, the state where deviator stress has the maximum value is the phase transformation state. On the other hand, when the deviator stress increases continuously, as shown in Figure 6, the state where the pore pressure has the maximum value is considered to be the phase transformation condition.

Mohr's stress circle and the failure criterion that are evaluated using the effective stress state at the phase transformation are shown in Figure 11. The cohesion and internal friction angle calculated using the proposed method are defined as c_p and ϕ_p. For Method-A samples, which show typical loosened sand tendencies, ϕ_p is slightly larger than ϕ'. For Method-B samples, which show typical dense sand tendencies, ϕ_p is smaller than ϕ'. Moreover, the c_p and ϕ_p values that were obtained by different sampling methods were almost the same. This result is due to the phenomenon that occurs when the axial strain for the different samples is small enough to prevent the specimens from reaching the phase transformation state. Therefore, use of the proposed method is reasonable for determining the strength parameters for a river embankment assuming the seepage failure at flood.

5 CONCLUSION

In the present study, in-situ sampling was conducted at a river embankment constructed of homogenous decomposed granite sand, after which a series of the consolidated-undrained triaxial tests was performed to study the quality of the different sampling methods used. The triaxial test results show different tendencies for each sampling method. However, the unique strength parameters of each sample could be obtained without considering the sampling method by evaluating the effective stress state at the phase transformation state.

Differences in the test results seem to be due to disturbances that occur at soil sampling. We believe the effects of such disturbances can be decreased by improvements in sampler handling. Method-B, which utilizes a newly developed double tube sampler, provides a high level of mobility and is very effective for soil sampling at open-cut fields in river embankments.

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7 REFERENCES

Kodaka T., Itabashi K., Nakashima K., Makita Y., Lee K.-T., Uemura T., Tsubota K. and Kato M. 2010. Evaluation of deformation and strength characteristics of sandy gravel in river embankments. *Japanese Geotechnical Journal* 5(2), 193-205. (in Japanese)

Kodaka T., Cui Y., Lee K.-T., Mori S. and Kanematsu Y. 2012. Effects of soil structure on mechanical properties of sand in river embankment. *Advances in river engineering* 18, 339-344. (in Japanese)

Kodaka T., Cui Y., Lee K.-T., Kanematsu Y. and Kobayashi Y. 2013a. Effects of test conditions of triaxial test on the strength parameters of river levee soils. *Advances in river engineering* 19, 81-87. (in Japanese)

Kodaka, T., Cui, Y., Lee, K.-T., Mori, S. and Kanematsu, Y. 2013b. Soil structure in gravel-mixed sand specimen and its influence on mechanical behavior, *Proc. of the 18th Int. Conf. on Soil Mechanics and Geotechnical Engineering*, Paris, 1691-1694.

Kodaka T., Cui Y., Kobayashi Y., Wu Y. and Lee K.-T. 2014. Appropriate strength coefficients of sandy soils for stability inspection of river levees, *Proceedings of 59th symposium on geotechnical engineering*. 145-150. (in Japanese)

Kodaka, T., Cui, Y., Lee, K.-T., Kobayashi, Y. and Wu, Y. 2015. Evaluation of strength coefficients of sandy levee soils under various triaxial test conditions, *Proc. of the 15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering*, Fukuoka, JPN-088.