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Shear strength evaluations of river embankment soils under low confinement pressure using water absorption softening test

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ABSTRACT

In this paper, we discuss a new testing method for determining the strength parameters of river embankment soils. Our proposed water absorption softening test is a kind of triaxial test conducted under drained conditions that utilizes low effective stress states to determine soil strength parameters. In order to evaluate our proposed method, samples from three actual river embankment levees were extracted and prepared for use. From the results of a series of tests conducted using these samples, it was confirmed that our new testing method is suitable for use in evaluating the seepage resistance of embankment soils and determining their strength parameters under the same low-level effective stress states that could be assumed to exist during actual levee flood conditions.

Keywords: river embankment; triaxial test; strength parameters; water absorption softening test; seepage failure

1 INTRODUCTION

In recent years, levee collapses caused by unexpectedly heavy floods have occurred frequently in Japan, making it increasingly clear that the ability to precisely evaluate river embankment stability is a crucial issue of levee management. The authors carried out a series of triaxial tests on river embankment soils under various test conditions (e.g. Kodaka et al., 2013, 2015, 2017). Through these studies, they identified and proposed the use of effective stresses at the phase transformation state as an effective way to determine the strength parameters of tested samples.

Because soils reach maximum deviator stress levels under relative high strain levels, those stress levels are unsuited for determining the potential for river embankment failures that might occur due to seepage force under either undrained or drained conditions. In fact, since the deviator stress of dense sandy soils obtained via consolidated undrained shear triaxial tests increases continuously due to the positive dilatancy restriction, this method is particularly unsuitable for determining the physical behaviors of soils in actual river embankments. In contrast, a strength parameter determination method that uses effective stresses at phase transformation states is easy to implement and more suitable for use when evaluating the potential of river embankment seepage failures under relatively low strain levels. However, a more precise testing method is required for determining strength parameters under low levels of effective strain.

In the present paper, we report on a new water absorption softening test that utilizes very low effective stress states as well as the results of its use in determining the strength parameters.

2 WATER ABSORPTION SOFTENING TEST

Our proposed test is a kind of triaxial compression test that is applied under drained conditions. First, conventional drained shear testing is conducted until the prescribed deviator stress is reached in order to induce an anisotropic stress state in the soil specimen that simulates the slope of an embankment. Next, the pore water pressure is gradually increased while constant deviator stress is maintained. In the case of a sample consisting of fine rich soils, the rate of water absorption must be limited in order to maintain a uniform pore pressure distribution within the specimen.

In this study, the water absorption softening test is applied to both clean silica sand samples and medium grained soil samples with rich fine contents.

3 CLEAN SILICA SAND

3.1 Test Conditions

In this test, Mikawa silica sand No. 6 is used to evaluate the effect of specimen density on strength parameters under low confining stress conditions. An air pluviation (AP) method is used to produce the

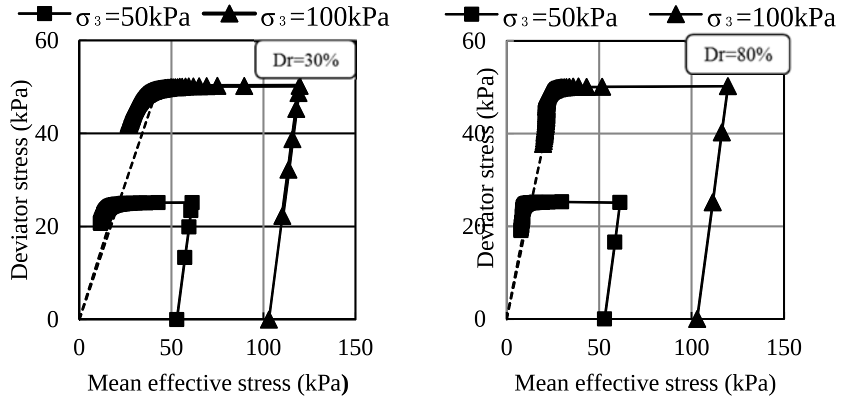

Fig. 1. Effective stress paths of clean silica sand by water absorption softening test.

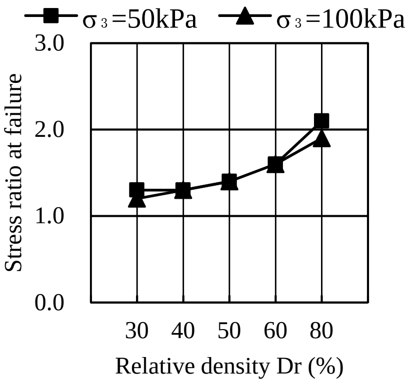

Fig. 3. q/p′ – Dr relations.

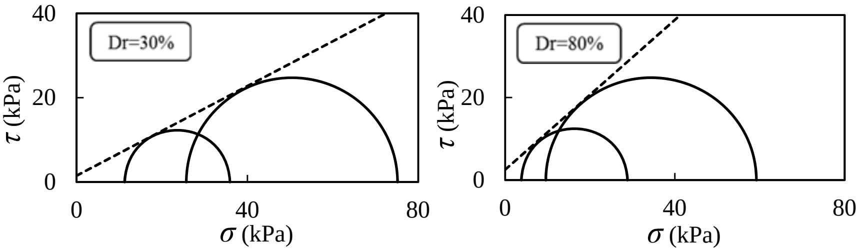

Fig. 2. Mohr's stress circles of clean silica sand by water absorption softening test.

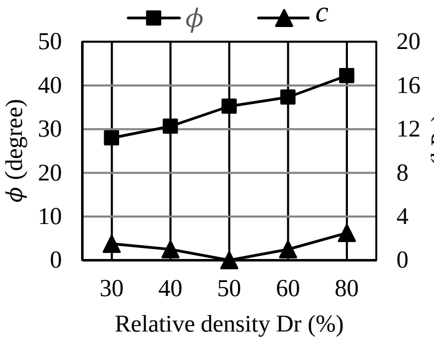

Fig. 4. ϕ and c – Dr relations.

various relative specimen densities, Dr=30, 40, 50, 60 and 80%. After being placed in the triaxial chamber, the specimens were fully saturated via the double-vacuum method and the application of 200 kPa back pressure (i.e., B value of over 0.95).

In all of our tests, isotropic consolidation was performed by applying predetermined effective confining pressures (50 and 100 kPa). First, axial compression was performed using a loading rate of 0.1%/min. under a fully drained condition and constant cell pressure until the prescribed deviator stresses (25 and 50 kPa) were reached. Next, the pore water pressure was gradually increased at a rate of 5 kPa/min. while maintaining constant deviator stress mentioned above until specimen failure was observed.

3.2 Test results

Figure 1 shows the effective stress paths obtained by applying the water absorption softening test. The dashed straight lines show the critical stress ratio produced by the conventional triaxial test performed for comparison purpose. The effective stress paths consist of two parts. One is a line that inclines at a rate of 1:3, and the other is a nearly horizontal line. The inclined line indicates the path of drained shear under constant confining pressure in which stress moves from the isotropic to anisotropic state. The horizontal line shows the process of mean effective stress decreasing due to increasing pore water pressure under constant deviator stress conditions.

The failure state is expressed as inflection on the left side of the horizontal line. In the case of loose sand, (Dr=30%), the deviator stress gently drops after reaching the failure state. In contrast, the stress paths of dense sand (Dr=80%) drop catastrophically. This indicates that the denser sand has a higher stress ratio at failure (defined as the maximum inflection point of the stress path) that exceeds the critical stress ratio obtained by the conventional triaxial test. Figure 2 shows the Mohr's stress circles defined by the effective stress states at the maximum inflection points in Fig. 1.

Figure 3 shows the stress ratio relations at failure and relative density of the specimens. Here, it can be seen that the stress ratio at failure increases with increases in the relative density. Furthermore, the stress ratio can be seen slightly high in the lower case of confining pressure. As a result, we can infer that a dense soil embankment would have higher resistance to flood-related seepage failure. This result can be also seen from the strength parameters at various relative densities that were determined by the stress state at failure when using the water absorption softening test, as shown as Fig. 4.

4 ACTUAL MEDIUM GRAINED LEVEE SOILS

4.1 Test Conditions

The water absorption softening test was carried out using the three kinds of medium grained soils samples extracted from actual Japanese levees: the Shibui River, in Miyagi Prefecture, the Kakehashi River at Ishikawa Prefecture, and the Koyoshi River in Akita Prefecture.

The soil samples were collected in an undisturbed state. Thin-walled tube sampling using a boring

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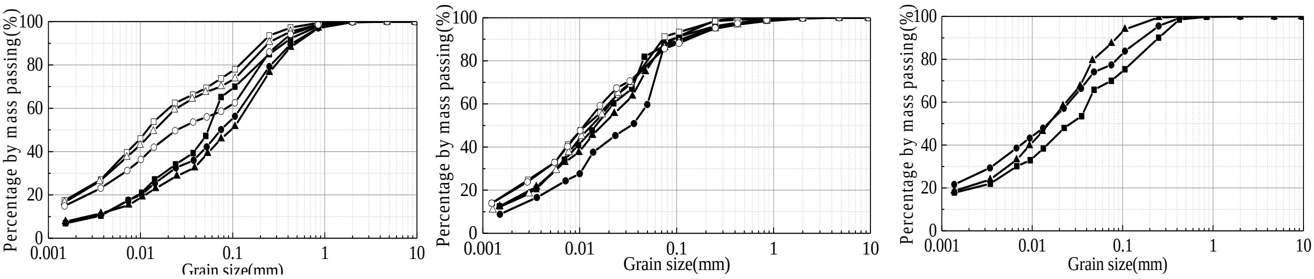
(a) Shibui River (b) Kakehashi River (c) Developed driving sampler

Photo 1. Situations of field sampling of embankment soils at actual levees by the simple sampling method.



(a) Shibui River (b) Kakehashi River (c) Koyoshi River

Fig. 5. Grain size distributions of river embankments soils used in this study

Table 1. Water absorption softening test conditions.

Samples	Initial mean effective stress/ Cell pressure (kPa)	Deviator stress during water absorption (kPa)	Initial water content (%)	Initial void ratio	Void ratio at shearing
Kakehashi	50	25	35.0	1.00	1.02
	100	50	-	-	-
	100	75	35.4	1.00	0.96
Shibui	50	25	33.3	1.85	1.71
	100	50	26.1	1.53	1.39
	100	75	30.5	1.76	1.53
Koyoshi	50	25	50	1.38	1.36
	100	50	52.7	1.49	1.36
	100	75	53.1	1.47	1.32

machine was employed to collect the Koyoshi River embankment sample, whereas the Shibui River and Kakehashi River soil samples were collected via the simple sampling method newly proposed by Kodaka et al. (2017). Photo 1 shows the simple sampling method being used in the field along with the newly developed driving sampler. The sampler has an inner tube made by polyvinyl chloride pipe to avoid sample disturbance.

All specimens were fully saturated via the double-vacuum method after being placed in the triaxial chamber. A series of water absorption softening tests as well as conventional triaxial test were then conducted using these soil samples. The confinement pressures used were 50 and 100 kPa, and the constant deviator stress levels used were 25, 50, and 75 kPa. Figure 5 shows the grain size distributions of the soils measured after the test. Here, it can be seen that each soil has rich fine-grained fraction contents. The test conditions used in these measurements are listed in Table 1.

4.2 Test results

Figures 6, 7, and 8 show the test results for the sampled soils extracted from the Shibui, Kakehashi, and Koyoshi River embankments, respectively. Each figure shows the effective stress paths and the relationship between the stress ratio and axial strain as observed by the water absorption softening test. In the stress paths of each figure, the conventional triaxial test results are also shown for comparison. The dashed lines express the critical stress ratio assumed by the effective stress path of the conventional triaxial test.

In the case of the Shibui River soil, as shown in Fig. 6, the effective stress paths produced by the conventional triaxial test express the shear behavior of relative loose sand, which can be seen in the simple decrease of mean effective stress due to plastic compression. The stress ratios at failure that were observed by the water absorption softening test are around the critical stress ratio. The Shibui River levee ruptured in 2015 during heavy rains in the Kanto-Tohoku region. Since the overflow was not observed there, it was presumed that the embankment collapsed due to piping of the body of the embankment. Furthermore, from the results of this study, the Shibui River embankment soil can be considered to be a geomaterial that has relatively low seepage resistance.

In contrast, when water the absorption softening test was applied to the Kakehashi River soil in a lower deviator stress case, the stress ratio approached 3, which is relative high, as shown in Fig. 7. Since the axial strain at failure is around 1%, it is likely that the Kakehashi River soil has the potential to fail suddenly due to water absorption. On the other hand, since stress ratios at failure are lower when higher deviator stress is applied, the results also indicate that the seepage resistance of Kakehashi River soil is high under low confining pressure conditions.

In the case of Koyoshi River soil, as shown in Fig. 8, the stress ratios at failure reach the value of 3 in spite of the deviator stress, which means the effective confining stress reaches zero. From this result, it can be stated that the Koyoshi River soil has high resistance to seepage failure.

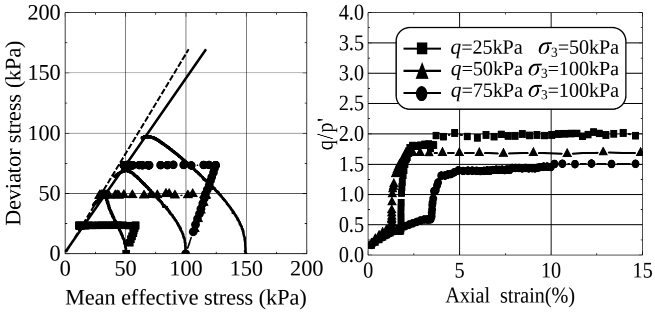


Fig. 6. Shibui River soil test results.

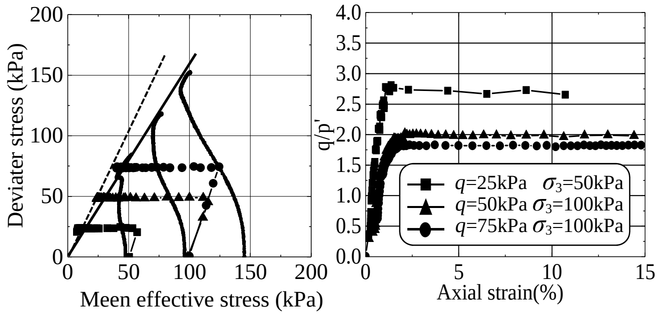


Fig. 7. Kakehashi River soil test results.

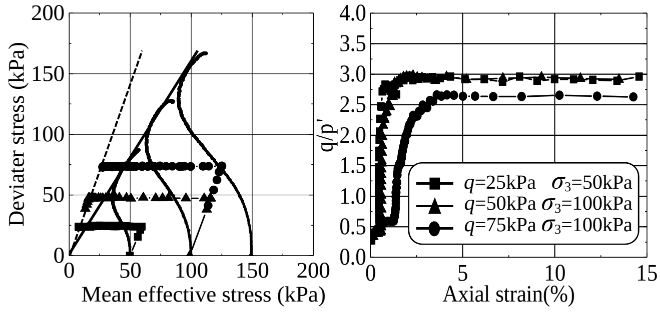


Fig. 8. Koyoshi River soil test results.

Figure 9 shows schematic diagrams in which three effective stress path patterns obtained by the water absorption softening tests are displayed. Pattern 1 shows that the stress ratio at failure reaches 3. Pattern 2 shows that the stress ratio approaches 3 only in the case of low confinement pressure. Pattern 3 shows that the stress ratios are almost the same as the critical stress ratio of the conventional triaxial test. The embankment soil categorized as Pattern 3 should be evaluated as low resistance due to seepage, even if the soils are classified as cohesive due to their rich fine contents.

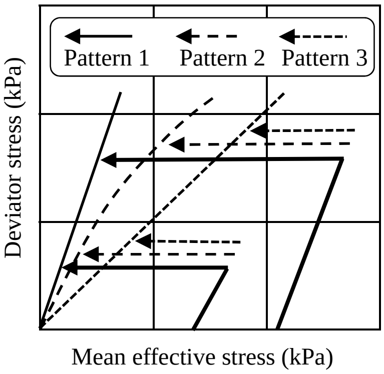


Fig. 9. Schematic diagrams of three typical patterns observed via water absorption softening testing.

5 CONCLUSION

Herein, we proposed a water absorption softening test and showed how it can be used to evaluate the seepage resistance of the river embankment soils under very low effective stress states. Based on the results of tests using clean silica sand, it was determined that higher stress ratios at failure could be measured with increases in the relative density. Large strength parameter values were also obtained during these tests.

From the test results of actual river embankment soils that contained rich fine contents, it was found that effective stress paths followed three typical patterns during the water absorption process. Of particular note, the results indicate that river embankments whose soils are categorized by Pattern 3 during the water absorption softening test should be evaluated as having low resistance to seepage failure.

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