Soil structure in gravel-mixed sand specimen and its influence on mechanical behavior

Structure du sol des échantillons de sable avec gravier et son influence sur le comportement mécanique

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ABSTRACT: Soil parameters are very important to conducting stability inspections of earth structures, e.g., river levees. However, the results of triaxial tests using reconstituted sand specimens change easily depending on the specimen preparation method. In the present paper, a series of conventional undrained triaxial tests is performed using specimens with the same void ratio, but different initial water contents. Even though the specimens are fully saturated before the consolidation process, the shear behavior varies remarkably with the different initial water contents. It is first assumed that the initial suction in the soil sample during the specimen preparation may produce various soil structures. Next, a numerical simulation by the SYS Cam-clay model is carried out to confirm this assumption. It is seen that the numerical simulation can reproduce the various types of experimental shear behaviors of the gravel-mixed sand derived from the different soil structures.

RÉSUMÉ : Les paramètres du sol sont très importants pour effectuer le contrôle de stabilité des structures en terre (ex : digue). Cependant, les résultats des essais triaxiaux utilisant des échantillons de sable reconstitués changent facilement en fonction de la méthode de préparation de ces échantillons. Dans cet article, une série d'essais triaxiaux non drainés conventionnels sont réalisés en utilisant des échantillons de même indice des vides mais avec une différente teneur initiale en eau. Bien que les échantillons aient été complètement saturés avant la phase de consolidation, le comportement des cisaillements change en fonction de la teneur en eau initiale. On peut supposer que la succion initiale lors de la préparation de l'échantillon peut induire des structures de sol différentes. Ensuite, une simulation numérique par modèle de SYS Cam-Clay est réalisée pour confirmer cette hypothèse. La simulation numérique peut reproduire les différents comportements en cisaillement des échantillons de sable avec gravier dérivés de différentes structures de sols.

KEYWORDS: soil structure, gravel-mixed sand, strengh coefficient, triaxial test, numerical simulation, river levee.

1 INTRODUCTION

Soil parameters, e.g., strength coefficients c and ϕ, are very important to the design and the inspection of earth structures. However, practicing engineers do not necessarily note the reliability of the soil parameters. In the stability inspections of river levees consisting of gravel-mixed soils, the required soil parameters have to be obtained through laboratory triaxial tests using specimens reconstituted with mechanically stabilized soil and without large-sized gravel. In such cases, the test results change easily depending on the specimen preparation methods, even when the specimens are reconstituted to have the same common void ratio. In practice, however, there are no rules regarding the specimen preparation methods. The first aim of the present paper is to show the difference in the results obtained by triaxial tests using specimens of reconstituted gravel-mixed sand. Dry and wet soil samples, with various water contents, were tamped in steel molds to the prescribed degree of compaction. Specimens with the same void ratio, but different initial water contents, are prepared. These specimens are then fully saturated to conduct conventional triaxial tests under undrained conditions. Ishihara (1993) showed that each type of undrained shear behavior of the Toyoura sand specimens, made by various specimen preparation methods, is different from the others. In his study, the void ratios of all the specimens are different due to the initial structure of the sand particles. However, since the specimens in this study are reconstituted using well-graded natural gravel-mixed sand, it is possible for the initial void ratios of all the specimens to be the same. This point is quite different from the results of Ishihara's experiment.

A series of the triaxial tests is performed using the specimens, with three degrees of compaction and five initial water contents for each degree of compaction. The shear behavior, including both stress-strain and dilatancy relations, is seen to vary remarkably with the different initial water contents. The authors assume that the soil structure in the specimen causes this difference in shear behavior. Namely, the initial suction in the soil sample during the specimen preparation may produce the various soil structures. The second aim of this paper is to confirm the assumption using a numerical simulation by the SYS Cam-clay model (Asaoka et al. 2002).

2 TEST PROCEDURE

Figure 1 shows the grain size distributions of the gravel-mixed sand samples. The natural soil was taken from a real river levee. Mechanically stabilized soil is used in this study, which involved the removing of over 9.5mm gravels from the natural soil.

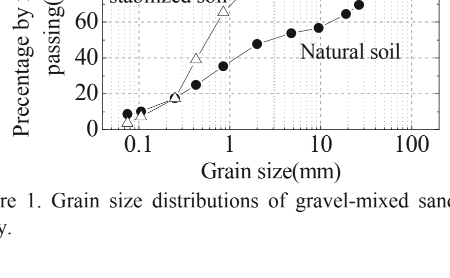


Figure 1. Grain size distributions of gravel-mixed sand used for this study.

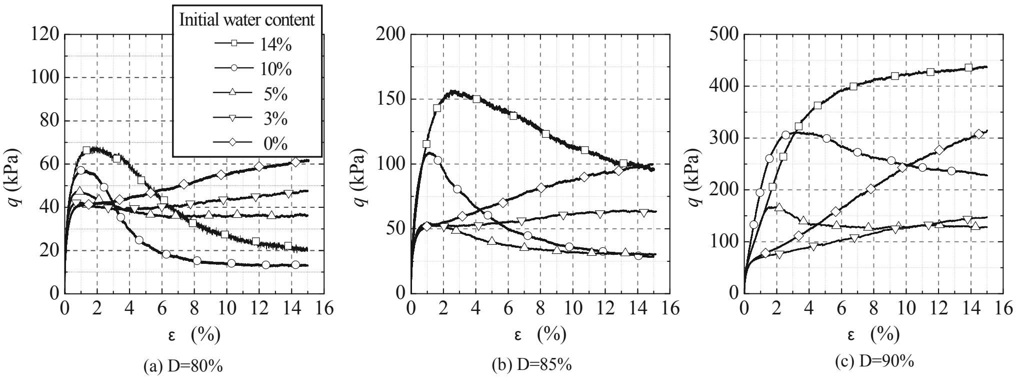


Figure 2. Deviator stress – axial strain relations of gravel-mixed sand with various initial water contents.

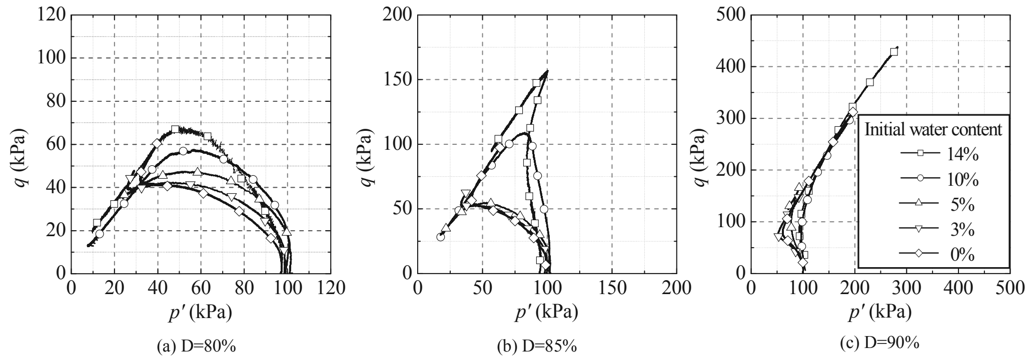


Figure 3. Effective stress paths of gravel-mixed sand with various initial water contents.

The specimens are 5cm in diameter and 10cm in height. The maximum dry density and the optimum water content of the mechanically stabilized soil were 2.0g/cm^3 and 10.5%, respectively. Three degrees of compaction are adopted, i.e., D = 80, 85 and 90%, in which the dry densities are 1.6, 1.7 and 1.8g/cm^3. The test sample was mixed well by adding water to be the prescribed initial water contents. Then, the moisture-controlled sample was compacted to reconstitute it to the prescribed degree of compaction. The compaction was carried out by dividing the sample into five layers to make homogeneous specimens. In this study, 'initial water content' denotes the water content of the sample during the specimen preparation. All the specimens in this test were fully saturated, i.e., a B value of over 0.95, after setting them in a triaxial chamber by the double-vacuum method. Therefore, the effects of suction in the specimens are negligible in the evaluation of the test results.

In all the test cases, an isotropic consolidation was performed by applying an effective confining pressure of 100kPa, and then an undrained shear was conducted using the loading speed of 0.1%/min.

3 TEST RESULTS

Figures 2 and 3 illustrate the stress-strain relations and the effective stress paths, respectively. For each degree of compaction, strain-softening behavior can be observed in the cases of high initial water content. On the other hand, only the strain-hardening behavior can be seen in the cases of low initial water content. In particular, this tendency is very clear in the case of the degree of compaction of D=85%. The specimens with 10% and 14% initial water contents show remarkable elastic characteristics in the early loading stage, i.e., large shear rigidity and p'=constant behavior. Then, significant strain softening, accompanied by plastic volumetric compression, occurs.

Photos 1 and 2 show views of the reconstituted specimens with initial water contents of 10% and 0%, respectively. An overview of the specimen and a surface image observed by a

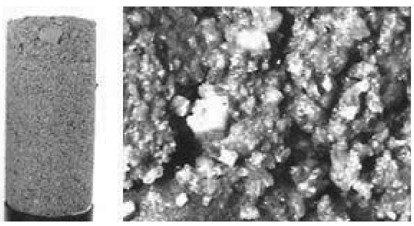


Photo 1. Overview of the specimen (left) and a surface image observed by a microscope (right) for initial water content 10%.

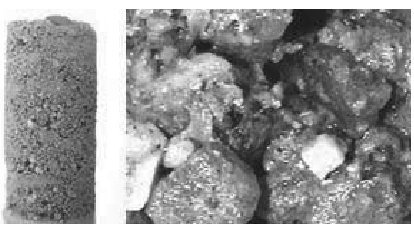


Photo 2 Overview of the specimen (left) and a surface image observed by a microscope (right) for initial water content 0%.

microscope are exhibited in each case. The degree of compaction for both specimens is D=90%. From the overviews, the specimen with the 10% initial water content looks homogeneous. On the other hand, the specimen with the 0% initial water content looks uneven. In other words, there are two areas which containing rich coarse particles or rich fine particles. From the enlarged surface images, many fine particles sticking to coarse particles can be observed in the specimen with the 10% initial water content. Since relatively high suction existed in the specimen with 10% initial water content during the specimen preparation, the fine particles must be uniformly distributed around the coarse particles. This distribution may cause a highly structured soil skeleton. In the case of the initial water content of 0%, since dry particles without suction were used for the specimen preparation, the classification of coarse and fine particles may have occurred during the compaction.

The specimens with the 10% and 14% initial water contents, and a high soil structure, exhibit relatively rigid elastic behavior at the early stage of loading and show brittle behavior at the following stage. Plastic behavior can be observed from the early stage for the specimens with the 0% and 3% initial water contents without a high soil structure.

4 . SIMULATION BY SYS CAM-CLAY MODEL

It can be assumed that the difference in the test results due to the initial water contents is caused by the soil structures that form in the specimens during the specimen preparation. In this study, a numerical simulation is performed to confirm this assumption using the superloading and subloading Cam-clay model named SYS Cam-clay model (Asaoka et al. 2002), which can describe the effects of the soil structure. The SYS Cam-clay model incorporates the concepts of the soil stucture, over-consolidation and anisotropy into the modified Cam-clay model. In e SYS Cam-clay model, the soil structure is assumed to deteriorate with an increasing the plastic shear strain.

Figure 4 illustrates the simulation results with the values of the parameters for the soil structure used in each case. In this analysis, the initial values for the degree of soil structure $1/R_0^*$, initial overconsolidation ratio $1/R_0$ and soil structure degradation parameter a are defined as variables in order to explain the various complicated types of behavior of the structured soil. From the triaxial test results, it is assumed in this study that higher soil structures are generated in the specimens with higher initial water contents. Therefore, a higher the initial value for the degree of soil structure $1/R_0^*$ is set in the case of a higher initial water content. Furthermore, a smaller a value is adopted in that case, since the high soil structure may not be easily deteriorated due to shearing. Thus, parameter a expresses the rate of degradation of the soil structure and the larger value for a describes faster degradation of the soil structure. The other parameters used in this study, i.e., elasto-plastic parameters, evolution law parameters and initial conditions, are in common and are listed in Table 1. Since $1/R_0^*$and $1/R_0$ are dependent on each other, when $1/R_0^*$ is set first, $1/R_0$ is automatically determined from the values of an initial specific volume v_0 and

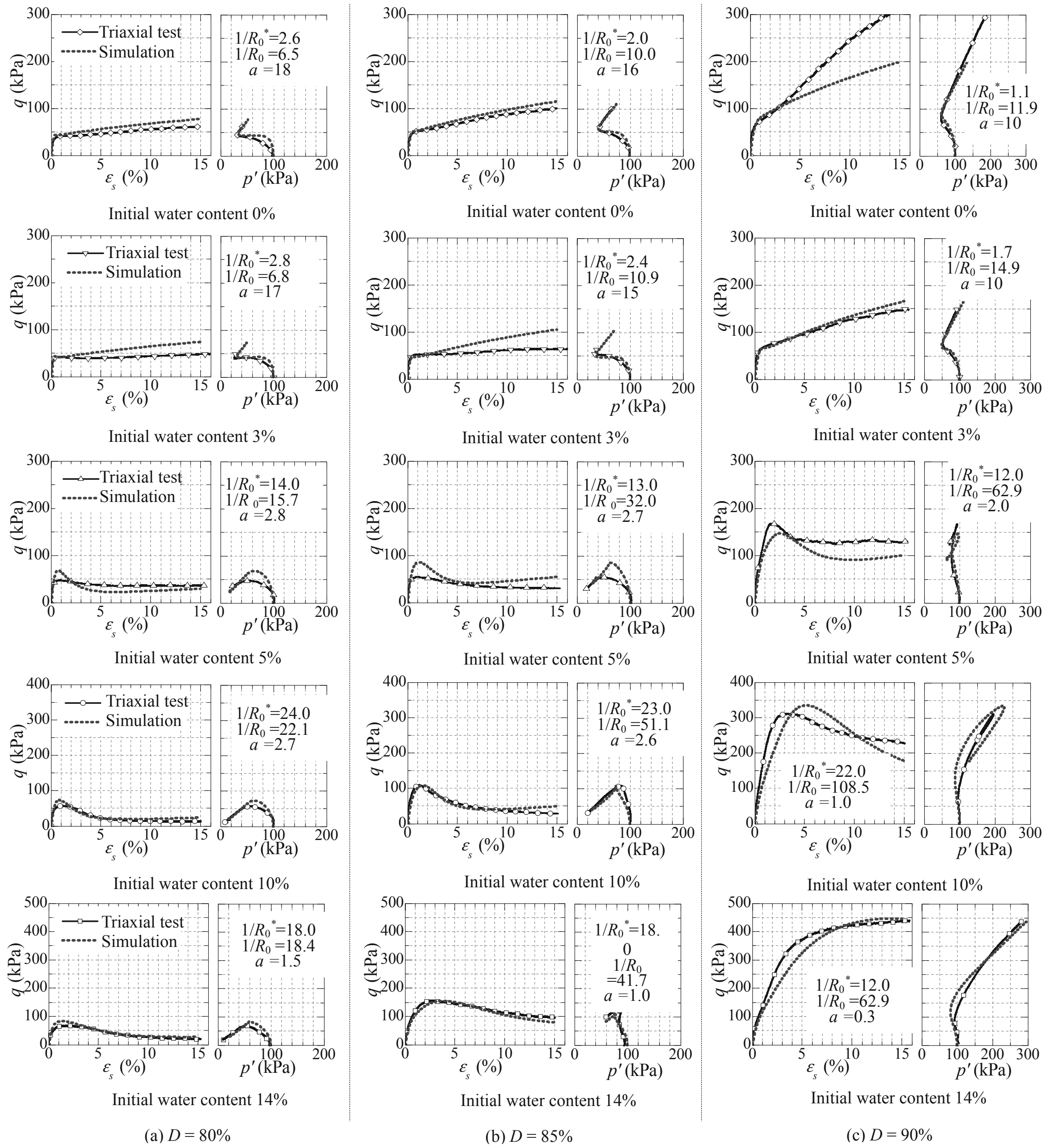
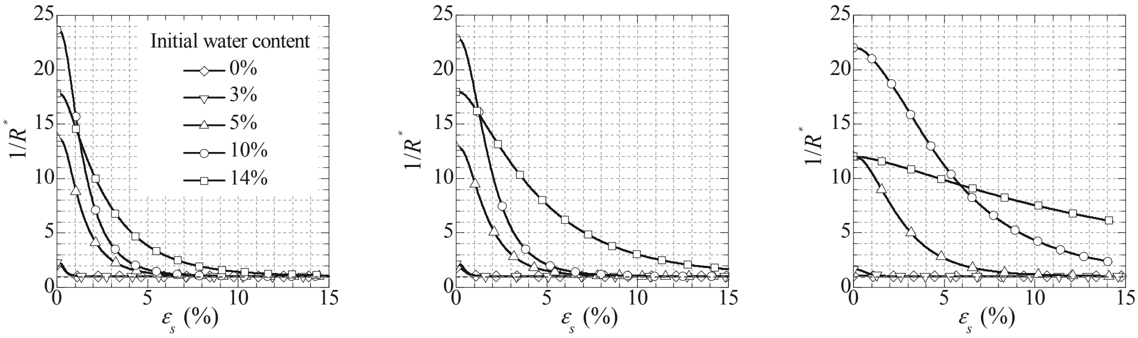


Figure 4. Numerically simulated stress- strain relations and effective stress paths with various initial water contents.



(a) D = 80% (b) D = 85% (c) D = 90%

Figure 5. Degradation of degree of soil structure with increasing shear strain.

Table 1. Soil parameters used in the numerical simulation.

Elasto-plastic parameters	
Compression index $\tilde{\lambda}$	0.100
Swelling index $\tilde{\kappa}$	0.011
Critical state constant M	1.46
Intersect of NCL N (v at q=0, p'=98.1kPa)	1.570
Poisson's ratio ν	0.300
Evolution parameters	
Degradation parameter of soil structure a (b=c=1.0)	*see* Fig.5
Degradation parameter of overconsolidated state m	0.030
Evolution parameter of β b_r	1.00
Limit of rotation m_b	0.001
Initial conditions	
Initial specific ratio v_0=1+e_0	1.637 (D=80%) 1.536 (D=85%) 1.457 (D=90%)
Initial degree of structure $1/R_0^*$	*see* Fig.5
Initial overconsolidation ratio $1/R_0$	*see* Fig.5
Initial anisotropy $\zeta=\sqrt{2/3(\beta_0\cdot\beta_0)}$	0.01
Initial mean effective stress p_0'	9.80 (kPa)

an intercept of normal consolidation line N. Although soil structure degradation parameters a, b and c are material coefficients, b=c=1.0 is adopted in this analysis for simplicity. The values for initial specific volumes v_0 are determined as the representative values from the specimens with a 10% initial water content. Compression index $\tilde{\lambda}$ is obtained from the oedometer tests, while critical state constant M and swelling index $\tilde{\kappa}$ are determined from the typical triaxial test results.

In each simulation, the initial effective stress p_0' is 9.8kPa and the isotropic consolidation is 100kPa; then the following undrained shearing is numerically performed.

In general, the simulation explains the triaxial test results well. Namely, basic parameters are used in common for all cases. Only the parameters for the soil structure are changed in order to reasonably explain the effects of the initial water content and the degree of compaction on the shear behavior. Therefore, the assumption that the initial water content of the specimen leads to generation of a high soil structure is considered to be valid.

Figure 5 illustrates the history of $1/R^*$, which describes how the soil structure deteriorates with an increasing the shear strain ε_s. In all the analytical cases, the degrees of soil structure $1/R^*$ gradually decrease and come closer to 1.0. Here, $1/R^*$=1.0 means the disappearance of the soil structure. Since $1/R_0^*$ and a are assumed in this analysis, the $1/R^*$ and ε_s relations are kinds of installed functions, as shown in Figure 5. Using these relations dor the soil structure, the triaxial test results can be simulated well.

5. SUMMARY

When performing triaxial tests using specimens consisting of reconstructed gravel-mixed sand, the initial water content of the sample during the specimen preparation greatly influences the results of the tests. Various degrees of soil structures were generated with various values of sample suction in the specimen preparation. Although the specimens were fully saturated before the tests, the soil structure generated by the compaction under unsaturated conditions was probably maintained during the triaxial tests.

The numerical simulation conducted in this study with the SYS Cam-clay model, which can describe the effects of the soil structure on the mechanical characteristics of soils, has verified the reason for the difference in the shear behavior of the gravel-mixed sand due to the difference in the initial water contents. By increasing the initial water content until the optimum water content is reached, a higher soil structure seems to be generated in the specimen. On the other hand, the specimen reconstituted by the lower initial water content sample has a lower soil structure and easily loses it. By incorporating the above-mentioned concept, the complicated test results for the relation between the soil structure and the initial water content can be explained well.

In practice, when the triaxial tests are performed using reconstituted sand specimens, a dry deposition method is usually adopted for the specimen preparation for convenience. However, it is difficult to generate the soil structure in the specimen with dry sand. Therefore, the triaxial test results using reconstituted specimens, made by the dry deposition method, may not express the real behavior of earth structures.

6 ACKNOWLEDGEMENTS

The authors would like to express their sincere thanks to Dr. Noda, a professor at Nagoya University, for his useful advice on the numerical simulation performed in this study.

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