Rock and Soil Mechanics

Volume 42 | Issue 1 Article 5

5-26-2021

On influencing factors of quick consolidated-drained triaxial tests of widely-graded gravelly soils

Zhi-bo CHEN
Fujian Provincial Universities Engineering Research Center of Geological Engineering, Fuzhou University, Fuzhou, Fujian 350116, China

Cong-ming HUANG
Fujian Provincial Universities Engineering Research Center of Geological Engineering, Fuzhou University, Fuzhou, Fujian 350116, China

Jun-gao ZHU
Key Laboratory of Ministry of Education for Geomechanics and Embankment Engineering, Hohai University, Nanjing, Jiangsu 210098, China

Jun-jie WANG
Diagnostic Technology on Health of Hydraulic Structures Engineering Research Center of Chongqing Education Commission of China, Chongqing Jiaotong University, Chongqing 400074, China

Custom Citation
CHEN Zhi-bo, HUANG Cong-ming, ZHU Jun-gao, WANG Jun-jie. On influencing factors of quick consolidated-drained triaxial tests of widely-graded gravelly soils[J]. Rock and Soil Mechanics, 2021, 42(1): 160-167.

Rock and Soil Mechanics 2021 42(1): 160−167
https: //doi.org/10.16285/j.rsm.2020.5556
ISSN 1000−7598
rocksoilmech.researchcommons.org/journal

On influencing factors of quick consolidated-drained triaxial tests of widely-graded gravelly soils

CHEN Zhi-bo[1, 2], HUANG Cong-ming[1, 2], ZHU Jun-gao[3], WANG Jun-jie[4]

1. Department of Geotechnical Engineering, College of Environment and Resources, Fuzhou University, Fuzhou, Fujian 350116, China
2. Fujian Provincial Universities Engineering Research Center of Geological Engineering, Fuzhou University, Fuzhou, Fujian 350116, China
3. Key Laboratory of Ministry of Education for Geomechanics and Embankment Engineering, Hohai University, Nanjing, Jiangsu 210098, China
4. Diagnostic Technology on Health of Hydraulic Structures Engineering Research Center of Chongqing Education Commission of China, Chongqing Jiaotong University, Chongqing 400074, China

Abstract: Widely-graded gravelly soil is composed of gravelly and clayey material in a certain proportion. It has the characteristics of low compressibility and high shear strength. At present, it is widely used as the core material for embankment dams and subgrade filling. Due to the low permeability of well-graded gravelly soil, the consolidation process is slow in conventional consolidated-drained (CD) triaxial tests, resulting in a long test period. In order to improve the efficiency of consolidation process, a quick triaxial CD test method with cylindrical sand core in the center of specimen is proposed in this paper. A comprehensive study on the influence of various factors on the quick triaxial CD test of well-graded gravelly soils is performed by changing types of sand cores, diameters of core sand cylinder and gravel contents. Results show that the proposed quick triaxial CD test method can effectively accelerate the consolidation process of the specimen, thus speeding up the whole test. Various factors including type of sand core, diameter of core sand cylinderand gravel content show different levels of influence on the speed of consolidation process and the stress-strain curve in the subsequent shearing stage. The smaller the diameter of the sand core is, the closer the test results are to those of specimens without sand cores.

Keywords: widely-graded gravelly soil; quick triaxial CD test; sand core cylinder specimen; type of sand cores; gravel content

1 Introduction

Widely-graded gravelly soil is a soil-rock mixture that is composed of a wide range of particle grading. Its particle sizes range from clayed particle (particle size $d \leqslant 0.005$ mm) to coarse gravel (20 mm $< d \leqslant 60$ mm) and even cobble (60 mm$< d \leqslant 200$ mm). It includes all soil-rock mixtures with an intermediate particle size and with a coefficient of uniformity from 100 to 1,000. Such mixtures have mechanical properties such as low permeability, low compressibility and high shear strength. Widely-graded gravelly soil has been widely adopted as impervious material for core wall in some high earth- rock dams in China and other parts of the world. For example, it was used in the Nuozhadu high-core rockfill dam (dam height is 261.5 m) in China, the Nurek high-core earth-rock dam (the height of the dam is 300.0 m) and the Rogun high-core earth-rock dam (the highest dam in the world with a height of 335.0 m), etc.

Up to date, the mechanical properties of widely-graded gravelly soils have been studied by many researchers all over the world. These mechanical properties include the compaction properties[1−4], permeability[5−7] and shear strength[8−11]. Some researchers also came up with constitutive models[12−14] to obtain a more comprehensive understanding of the mechanical properties of widely-graded gravelly soils.

Triaxial test is considered as an important means of understanding the mechanical properties of soil and obtaining its mechanical parameters. However, for widely-graded gravelly soils, due to their low permeability (for example, as the core material of earth-rock dams, the permeability is generally lower than 1×10^{-6} cm/s), the consolidation efficiency is low, leading to long period for triaxial tests, which is very unfavorable for laboratory testing for research purposes and also in practical engineering applications. At present, a couple of researchers have made some useful explorations in accelerating the drainage process of triaxial tests. Sivakumar et al.[15] conducted consolidated-undrained (CU) triaxial tests by adding sand columns of different lengths to the center of soft soil specimens to study their consolidation and stress−strain characteristics. Xu et al.[16] carried out drilling

Received: 3 May 2020 Revised: 24 September 2020
This work was supported by the Natural Science Foundation of Fujian Province, China(2017J01481), the Open Fund of Key Laboratory of Geohazard Prevention of Hilly Mountains, Ministry of Natural Resources (FJKLGH2017K005) and the Scientific Research Project of Huadong Engineering (Fujian) Corporation Limited (FH2018-KY003).
First author: CHEN Zhi-bo, male, born in 1977, PhD, Professor, research interests: basic characteristics of soil, geotechnical numerical simulation. E-mail: czb@fzu.edu.cn

and sand filling on the triaxial specimens of gravelly soil and tested three specimens with different sand well replacement ratios, namely, 0-hole, 5-hole, and 1-hole in consolidated-drained (CD) tests. In the test, the drainage effects in both consolidation and shearing stages of specimens with and without sand wells were compared, and the influence of sand wells with low replacement ratio on the stress−ingstrain curve was evaluated. We proposed a quick method for triaxial CD tests[17−18], which is to reserve a slender cylindrical space in the center of the specimen during sample preparation, and then fill it with standard sand with better permeability to form a cylindrical sand core drainage channel. This method speeds up the drainage of the specimen and achieves the purpose of quick testing.

The consolidation curves, stress−strain curves and Duncan-Chang model parameters of specimens with and without sand cores in the fast triaxial CD tests [18] are compared. Results preliminarily confirmed the effectiveness of the method. However, some aspects remain to be unclear and require further study. These include the specific impact of different types and sizes of sand cores on the quick triaxial CD tests, and how to choose these factors in the actual application.

This paper intends to present a series of quick triaxial CD comparison tests to analyze the impact of different influencing factors such as the types and sizes of sand cores and gravel contents, on the completion time and mechanical properties of the quick triaxial CD tests of wide grading gravelly soils. Results will work as a reference for practical industrial applications.

2 Introduction to the quick triaxial CD test method

In the quick triaxial CD test method[18], the cylindrical specimen in conventional triaxial tests is modified to a cylindrical specimen with a slender cylindrical sand core in the center, as shown in Fig. 1. With the high permeability of sand, the core forms a good drainage channel to speed up the drainage process and accelerates the whole process of triaxial CD test including consolidation and shearing.

In the quick triaxial CD test, the confining pressure is still applied to the sand core cylindrical specimen in consolidation process as in the conventional triaxial test method. After the consolidation is completed, the shear rate of the shearing process is determined according to the consolidation curve. Since the sand core in the center of the specimen can effectively accelerate drainage and the dissipation of pore water pressure, the shear rate in the shearing process can also be greatly increased. As a result, triaxial tests can be completed more quickly. Studies have shown that the stress−strain curves measured in quick triaxial CD tests are in good agreement with those in conventional triaxial tests. Shear strength indexes and Duncan-Chang model parameters of the two are also very close [19].

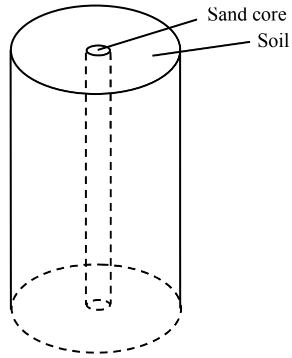

Fig. 1 Schematics of sand-core cylindrical specimen for quick CD test

3 Quick triaxial CD tests under different influencing factors

3.1 Tested soil

The soil material used in the experiment is widely-grading gravelly soil, which is a mixture of clayey and gravelly materials. The amount of gravel mixed in this paper is represented by P_5 (referring to the content of particles larger than 5 mm). The clayey material was taken from the cohesive residual soil in granite in Pingtan comprehensive test area, Fujian Province. The particles larger than 5 mm were remove from clayey material first prior to test. Its fundamental physical properties are shown in Table 1. The gravelly material was artificially mined crushed stone from granite. Its original particle size distribution is shown in Table 2. The maximum allowable particle size of the medium triaxial specimen (diameter D=101 mm, height H=200 mm) is 20 mm, and the allowable maximum particle size of the small triaxial specimen (diameter D=61.8 mm, height H= 125 mm) is 5 mm. The amount of the oversized material in the triaxial specimens in this paper is not more than 50%, and the equal amount substitution method is used directly for treatment of oversized materials. The equivalent substitution method[19] is to replace the oversized materials by equal weight with coarse materials from the allowable maximum particle size d_{max} to 5 mm, by weighted average method according to the content of each particle size fraction. However, if the amount of the oversized material in the small triaxial specimen is greater than 50%, the equal-quantity substitution method cannot be directly used for treatment of oversized materials. Instead, the hybrid method [19] can be used. In this method, the similar grading method is used for scaling first, and then the equal amount substitution is used to treat the remaining oversized materials. After the oversized material is processed, the particle size distribution of the gravelly material used in this experiment is shown in Table 2.

Table 1 Fundamental physical properties of clay

Specific gravity G_s	Density ρ /(g • cm^{-3})	Water content w /%	Void ratio e	Liquid limit w_L /%	Plastic limit w_p /%
2.67	1.88	35.1	0.929	46.1	31.2

Table 2 Grain size distribution of gravel

Particle size /mm	Percentage in the original soil /%	Percentage used in medium triaxial tests /%	Percentage used in small triaxial tests /%
40−20	0.49	0	0
20−10	5.79	5.83	0
10−5	60.85	61.30	0
5−2	25.85	25.85	74.30
2−1	2.33	2.33	18.45
1.0−0.5	2.69	2.69	2.49
<0.5	2.00	2.00	4.76

3.2 Sample preparation

The sample preparation method of the quick triaxial CD test is different from that of the conventional triaxial CD test. When preparing the sample, a vertical rod must be added to the center of the sample to leave space for filling the cylindrical sand core later. In order to minimize the influence of the central sand core on the test, it should be ensured that the diameter of the round rod is less than or equal to D/5. When preparing the soil samples, weigh the clayey and gravelly materials required for each sample in 5 equal parts, mix the clayey and gravelly materials one by one, add water to achieve the required water content and stir evenly to prepare 5 mixture in the same way. Samples should be always kept warm and moisturized. When preparing the sample, the sample is compacted in 5 layers. Each part of the mixture is put into the sample preparation cylinder in 3 times to ensure the uniform distribution of large gravelly particles before it is compacted into 1 layer. A steel ruler is used for measurement to ensure that the height of each layer is equal after compaction. During the entire sample preparation process, efforts should be made to ensure the uniformity of the sample and the large gravelly particles. After compacting the first layer of soil around the round rod, pull out the vertical round rod, fill a thin layer of clay at the bottom of the round hole to ensure that the center sand core does not leak out, then fill the round hole with sand and press to achieve the required dry density. Scrape the surface of the first layer of soil with a scraper, then place the round rod vertically again back to the center of the sample, after that, pour the second layer of soil and compact the second layer, pull out the vertical round rod, fill the round hole with sand and press to achieve the required dry density, and so on. In the end, a sample with a cylindrical sand core is created as shown in Fig.2. Finally, put the sample into the saturator, and then put it into the pumping cylinder for vacuum saturation. The pumping time is more than 2 hours and the underwater standing time is more than 10 hours [20].

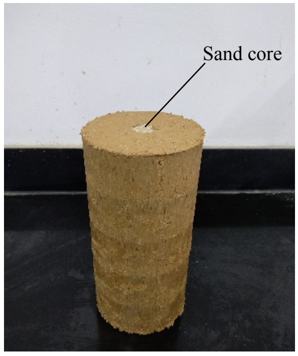

Fig. 2 Triaxial specimen with cylindrical drainage sand core

3.3 Testing method

The quick triaxial CD test of widely-graded gravelly soil is mainly affected by the sample size, sand core, gravel content and other factors. Therefore, the research plan mainly considers the influence of four factors on the consolidation speed in quick triaxial CD tests of widely-graded gravelly soils. These four factors are sample sizes, types of sand cores, sand core diameters and gravel contents. At the same time, the conventional triaxial CD tests with different sample sizes and different gravel contents were carried out to compare with the quick triaxial CD tests. The specific test plan is shown in Table 3. During the test, quick triaxial CD tests were performed on the medium-sized triaxial samples, coarse sand core, sand core diameter D/5 and gravel content of 30% as the benchmark test. When analyzing the impact of a certain influencing factor, only the test conditions related to that factor were changed, while other factors remained unchanged for controlling variables. For instance, when considering the influence of different gravel contents, only the gravel content was changed, while other benchmark test conditions such as medium-sized sample, coarse sand core and sand core diameter of D/5 were used for comparative tests. The same applies for other testing conditions as well. The sand cores used in the test are divided into two types, namely, coarse and fine sand.

The grain size of coarse sand is 0.2−0.5 cm, and the grain size of fine sand is 0.075−0.25 cm. The permeability coefficients of the two types of sand are 2.492×10^{-1} and 3.146×10^{-3} cm/s, respectively. The dry density of the coarse sand core and the fine sand core are controlled to be consistent, with the dry density of both sand cores equal to 1.6 g/cm^3. In order to facilitate the comparative study, this article does not consider the influence of different shear rates. The same shear rate is used in all triaxial tests performed in this research. The chosen shear rate is determined based on the consolidation and drainage process, using the empirical formula of duration of shearing stage proposed by Gibson[18, 20]. The value of shear rate in this research is chosen to be 0.012%/min. Tests are terminated when the axial strain reaches 15%.

Table 3 Testing schedules of triaxial CD test on widely-graded gravelly soil

Type of test	Type of triaxial test	Sample size		Type of sand cores	Diameter of sand cores d_s	Gravel contents P_5 /%	Confining pressure σ_3 /kPa
		Diameter D /mm	Height H /mm				
Quick triaxial CD test	Small triaxial test	61.8	125	Fine sand, coarse sand	D/12，D/10，D/8，D/5	20，30，40，50	200，400，600，800
	Medium sized triaxial test	101.0	200	Fine sand, coarse sand	D/12，D/10，D/8，D/5	20，30，40，50	200，400，600，800
Conventional triaxial CD test	Small triaxial test	61.8	125	No sand core	0	20，30，40，50	200，400，600，800
	Medium sized triaxial test	101.0	200	No sand core	0	20，30，40，50	200，400，600，800

4 Analysis of test results

4.1 The influence of types of sand core

Taking the medium-sized triaxial tests with 30% gravel contents as an example, quick triaxial CD tests were performed on medium-sized triaxial samples with different types of sand cores (coarse sand, fine sand) under different confining pressures. The corresponding consolidation curves are shown in Fig. 3. It can be seen from Fig. 3 that under the same confining pressure, the consolidation time (in Fig. 3, the time when the consolidation displacement reaches a steady value [20]) for middle-sized triaxial tests with coarse sand cores is shorter than that of tests with the same sample size but fine sand cores. In other words, if other conditions are kept to be the same, consolidation occurs more quickly when coarse sand cores are used. For the same type of sand core, as the confining pressure increases, the water volume V that needs to be drained out increases, the consolidation time t becomes longer accordingly.

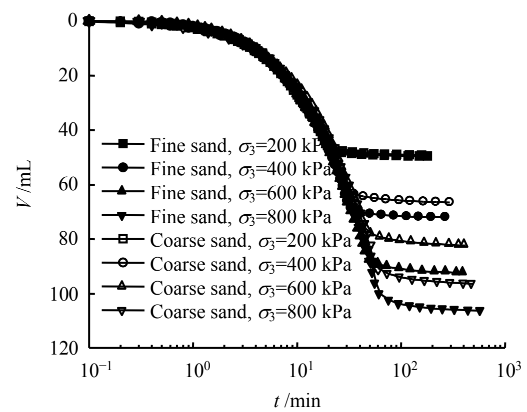

Fig. 3 V-t curves of medium-sized consolidated-drained triaxial tests with different types of sand cores（P_5=30%）

Table 4 lists the consolidation completion time of samples with different sand cores. It can be seen from Table 4 that as the confining pressure increases, the consolidation completion time of samples with different sand cores increases. By comparing the consolidation completion time of samples with two different sand cores (expressed as $t_{\text{fine sand}}/t_{\text{coarse sand}}$), it can be seen that the consolidation completion time of samples with fine sand cores $t_{\text{fine sand}}$ is longer than that of samples with coarse sand cores $t_{\text{coarse sand}}$, and the ratio between the two values is about 1.20. Figures 4 and 5 show the stress−strain, volumetric deformation−axial deformation curves of medium-sized triaxial tests with different types of sand cores, with 30% gravel content. It can be seen from Fig.4 that with the continuous increase of axial strain, the greater the confining pressure, the greater the deviatoric stress. Curves of the medium-sized triaxial CD tests with coarse and fine sand cores basically coincide. Figure 5 illustrates that for tests with either coarse or fine sand cores, the volumetric strain increases with the increase of axial strain under the same confining pressure, and the sample exhibits contraction under shearing. The greater the confining pressure, the more obvious the contraction. The volumetric strain of the medium-sized triaxial samples with coarse and fine sand cores are roughly the same.

Based on the above analysis, it can be inferred that different sand cores have significant effects on the consolidation process in triaxial tests, but if the same shear rate is used in the shearing process, the difference in stress−strain curves is small.

DOI: 10.16285/j.rsm.2020.5556

Table 4 Consolidation time of triaxial tests on specimens with different sand cores

Confining pressure /kPa	Consolidation completion time /mm		$t_{\text{fine sand}}/t_{\text{coarse sand}}$
	$t_{\text{fine sand}}$ /min	$t_{\text{coarse sand}}$ /min	
200	40	35	1.14
400	60	50	1.20
600	100	80	1.25
800	150	130	1.15

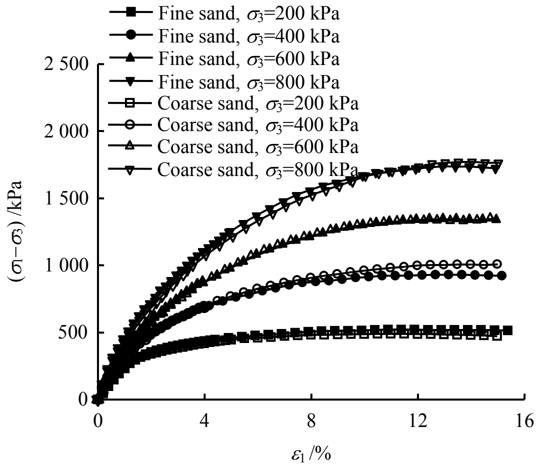

Fig. 4 Stress−strain curves of medium-sized triaxial CD tests with different types of sand cores

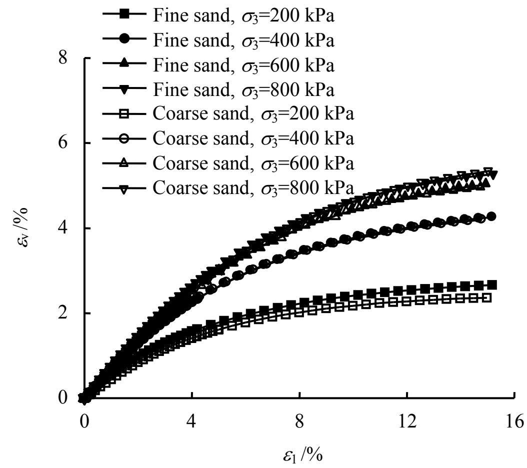

Fig. 5 Volumetric strain−axial strain curves of medium-sized triaxial CD tests with different types of sand cores

4.2 The influence of core diameters

In order to investigate the effect of different sand core diameters on sample consolidation, consolidation curves of medium-sized and small triaxial samples with different sand core diameters (*D*/5, *D*/8, *D*/10, *D*/12, 0) are plotted. The tests with confining pressure of 600 kPa are analyzed as examples, and consolidation curves are shown in Figs. 6 and 7. It can be observed from the figures that the larger the diameters of the sand core in the medium-sized and small triaxial specimens, the shorter the consolidation completion time, that is, the faster the consolidation. In order to compare the effect of different sand core diameters on the speed of consolidation, consolidation completion time of samples with different sand core diameters is plotted in Fig. 8. Without sand cores, the consolidation completion time of medium-sized triaxial samples is much longer than that of the small triaxial samples. With the increase of sand core diameter, the difference in the consolidation completion time between the medium-sized and small triaxial tests is significantly reduced. However, the consolidation completion time of the medium-sized triaxial tests is still longer than that of the small triaxial tests.

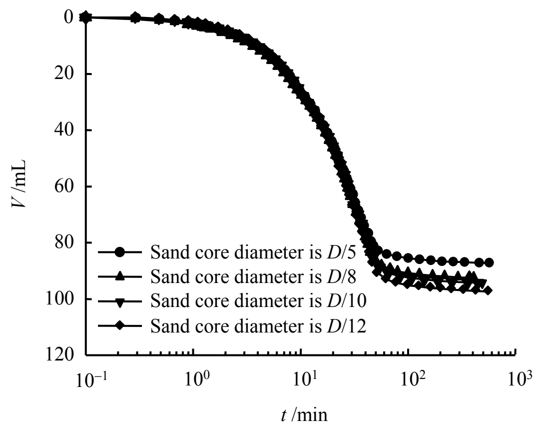

Fig. 6 *V-t* curves of medium-sized triaxial (CD) tests with different sand core diameters (σ_3 =600 kPa)

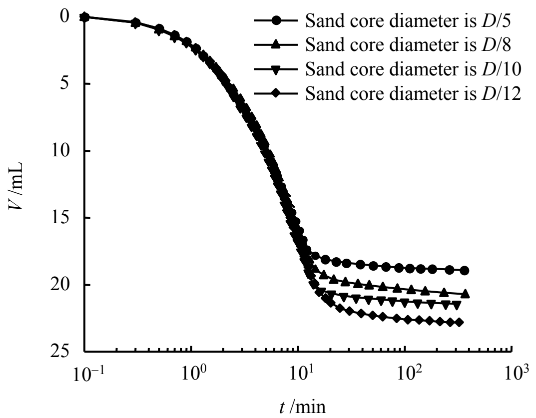

Fig. 7 *V-t* curves of small triaxial (CD) tests with different sand core diameters (σ_3 =600 kPa)

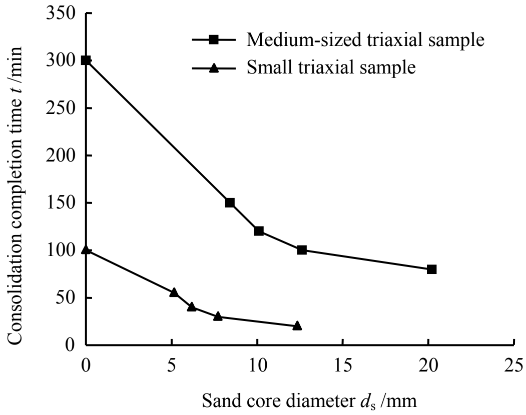

Fig. 8 Consolidation time for specimens with different sand core diameters

Figures 9 and 10 show the stress−strain, volume deformation and axial deformation curves of the medium-sized triaxial CD tests with different sand core diameters. Figures 9 and 10 illustrate that the stress−strain curves of the medium-sized triaxial specimens with different sand core diameters exhibit strain hardening behavior. From no sand core to sand core diameter of *D*/12 to sand core diameter of *D*/5, the larger the sand core diameter, the larger the peak deviatoric stress of the sample. This shows that as the diameter of the sand core increases, that is, more sand particles are filled in the core, the impact on the overall mechanical strength of the sample increases, resulting in a larger peak deviator stress. As for the volumetric strain of the test, as the sand core gradually increases, the corresponding volumetric strain becomes smaller and smaller. This suggests that the sand core used in this paper is different from the experimentally used widely-graded gravelly soil in terms of their performance in mechanical deformation. Its existence affects the deformation of the original soil. The larger the sand core diameter, the greater the impact on the test results. The differences in Figs. 9 and 10 show that the larger the diameter of the sand core, the greater the impact on the deviatoric stress and volume deformation. Sand cores used in this research work as a type of ‘reinforcement’ in the shearing stage. The larger the volume of sand cores, the larger the peak deviator stress, and the smaller the volume change. Therefore, in practical applications, the diameter of the sand core should be reduced as much as possible. At the same time, it can also be considered to reasonably reduce the dry density of soils used for sand cores to reduce their ‘reinforcement’ effect. In addition, it is advised to try to find the ideal sand core with its properties close to the tested soil. The stress−strain and volume change curves of the small triaxial specimens are roughly the same as those of the medium-sized triaxial specimens. The results are not repeated again in this paper.

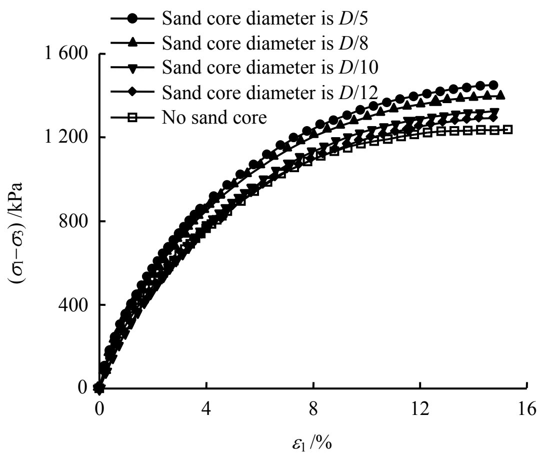

Fig. 9 Stress−strain curves of medium-sized triaxial CD tests with different sand core diameters

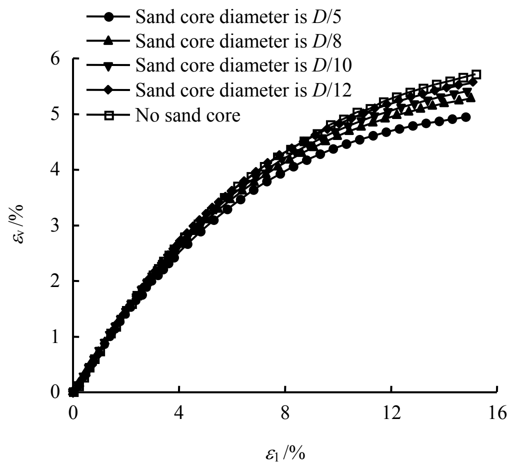

Fig. 10 Volumetric strain−axial strain curves of medium-sized triaxial CD tests with different sand core diameters

4.3 The influence of gravel contents

In this section, the test of =600 kPa is still taken as an example for analysis. The consolidation curves of the medium-sized triaxial tests are summarized and shown in Fig. 11. It can be observed from the figure that whether it is a triaxial sample with or without a sand core, the consolidation completion time in the triaxial test decreases with the increase of the gravel content in the sample. The reason is that the widely-graded gravelly soil has three structures, namely, suspended−compact, compact−skeleton and skeleton−void structures[17]. When the gravel content is 20%, the widely graded gravelly soil has a suspended−compact structure. In other words, there is considerably amount of fine-grained soil but a little coarse-grained soil in the sample. The coarse-grained soil is "suspended" in and wrapped by fine particles. The sample’s engineering properties are biased towards fine-grained soils, showing low permeability. Under such circumstances, it takes about 400 minutes to complete the consolidation stage in the triaxial test. As the amount of gravel increases to 30%−40%, the wide-graded gravelly soil presents a compact−skeleton structure. In micro scale, the coarse particles show point to surface contact, the coarse particles begin to act as the skeleton of the soil and the fine-grained soil can fill the pores. As a result, permeability of the soil becomes larger. The consolidation completion time in the triaxial test is about 200−300 min. As the gravel content continues to increase and reaches 50%, voids between coarse particles cannot be completely filled by fine-grained soil particles. At this time, the widely-graded gravelly soil has a skeleton−void structure, and it only takes about 100 minutes to complete the consolidation stage in the triaxial test.

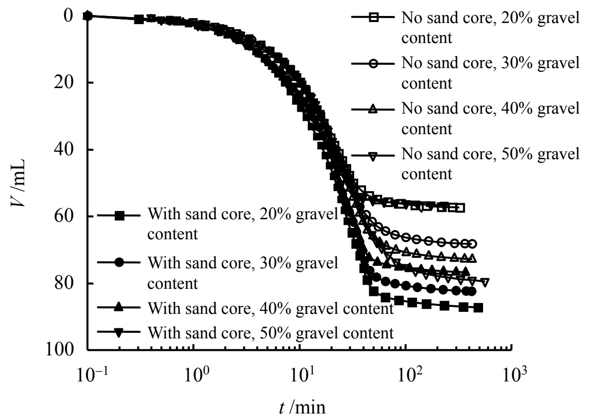

Fig. 11 *V-t* curves of medium-sized triaxial (CD) tests with different gravel contents (σ_3 =600 kPa)

Table 5 gives the comparison of the consolidation completion time in triaxial tests with different gravel contents. As shown in the table, when the amount of gravel in the sample increases, the ratio of the consolidation completion time of samples without sand cores to samples with sand cores $t_{\text{without sand core}}/t_{\text{with sand core}}$ first increases and then decreases. When the gravel content is 20%–30%, the consolidation completion time of samples with sand cores accounts for about 1/3 of that of samples without sand cores. However, with the increase of gravel content, the difference gradually becomes smaller. It shows that the sand core has an obvious effect of accelerating consolidation when the gravel content is low. With the increase of gravel content, the sand core's accelerating effect during consolidation stage gradually weakens.

Table 5 Comparison of consolidation time of triaxial tests with different gravel contents

Gravel content /%	Consolidation completion time for samples		$t_{\text{without sand core}}$ / $t_{\text{with sand core}}$
	$t_{\text{without sand core}}$ /min	$t_{\text{with sand core}}$ /min	
20	400	150	2.67
30	300	80	3.75
40	200	70	2.86
50	100	50	2.00

From the deviator stress–strain curve in Fig. 12, it can be seen that with the increase of gravel content, the deviator stress of the sample increases. In general, under the same gravel content, the peak deviator stress of samples without sand cores is slightly greater than that of samples with sand cores. At small strain, the peak deviator stress of samples without sand core is approximately equal to that of samples with sand cores. It can be seen from the curve in Fig. 13 that with the increase of gravel content, the volumetric strain decreases. Under the same gravel content, the volumetric strain of samples without sand cores in medium-sized triaxial tests is slightly larger than that of samples with sand cores. At small strain, the volumetric strain of samples without sand cores and that of samples with sand cores is roughly equal.

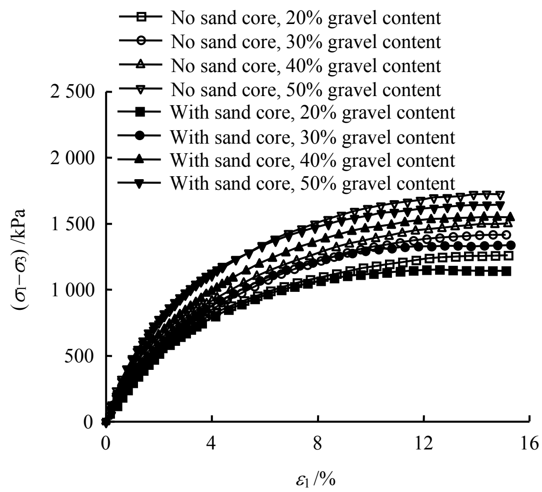

Fig. 12 Stress−strain curves of medium-sized triaxial CD tests with different gravel contents

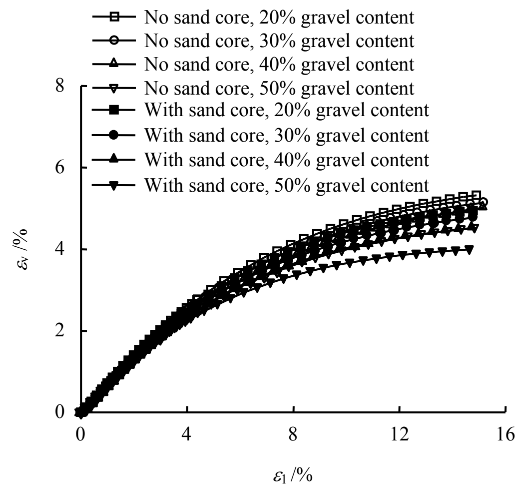

Fig. 13 Volumetric strain−axial strain curves of medium-sized triaxial CD tests with different gravel contents

5 Conclusion

By adding a cylindrical sand core to the center of the triaxial sample, the sample preparation method of the conventional triaxial CD test was improved. The effect of different factors, including types of sand cores, diameter of sand cores and gravel contents on triaxial tests of widely-graded gravel soil was studied. Conclusions are summarized as follows.

(1) Under the same confining pressure, the consolidation completion time of samples using coarse sand as sand

cores is shorter than that of samples with fine sand as sand cores. In other words, consolidation is faster in the former samples. The larger the diameter of the sand core in the triaxial specimen, the shorter the consolidation time. Consolidation is also faster in the small triaxial tests than in the medium-sized triaxial tests. The larger the gravel content in the widely-graded gravelly soil, the shorter the consolidation completion time in the triaxial test. The effect of sand cores in accelerating drainage is more prominent in soil samples with low gravel content.

(2) Factors such as type of sand core, diameter of sand core, and the gravel content have certain effects on the stress−strain, volumetric strain−axial strain relationship of triaxial CD tests. The test results of samples with small-diameter coarse sand cores are more consistent with results of those samples without sand cores.

(3) The existence of sand cores speeds up the consolidation stage in triaxial tests, but it also shows the effect of 'reinforcement'. In other words, the larger the diameter of sand core, the greater the peak deviatoric stress during the shearing stage of the triaxial test and smaller the volumetric strain. In practical applications, the diameter of sand core should be as small as possible and the density of sand core should be properly controlled.

References

[1] QIAO Lan, PANG Lin-xiang, LI Yuan, et al. Experimental study of compaction characteristics of oversized clay mixed with gravels[J]. Chinese Journal of Rock Mechanics and Engineering, 2014, 33(3): 484−492.

[2] XU Xi-chang, ZHOU Wei, HAN Zhuo, et al. Research on compaction properties of soil-aggregate mixture[J]. Rock and Soil Mechanics, 2010, 31(Suppl. 2): 115−118.

[3] CHEN Zhi-bo, ZHU Jun-gao, WANG Qiang. Compaction property of wide grading gravelly soil[J]. Chinese Journal of Geotechnical Engineering, 2008, 30(3): 446−449.

[4] AVIRUT C, EKACHAI M K, ANUCHIT U, et al. Compaction characteristics of non-gravel and gravelly soils using a small compaction apparatus[J]. Journal of ASTM International, 2010, 7(7): 1−15.

[5] SHI Xin, PANG Kang, LI Xu, et al. Hydraulic conductivity of widely-graded gravelly soils[J]. Chinese Journal of Geotechnical Engineering, 2018, 40(Suppl. 2): 189−193.

[6] CHEN L, ZHAO J, ZHANG H, et al. Experimental study on suffusion of gravelly soil[J]. Soil Mechanics and Foundation Engineering, 2015, 52(3): 135−143.

[7] LIU Jie, XIE Ding-song. Research on seepage stability experiment of gravelly soil[J]. Rock and Soil Mechanics, 2012, 33(9): 2632−2638.

[8] CHANG W J, PHANTACHANG T. Effects of gravel content on shear resistance of gravelly soils[J]. Engineering Geology, 2016, 207(1): 78−90.

[9] ZHAO H F, ZHANG L M, CHANG D S. Behavior of coarse widely graded soils under low confining pressures[J]. Journal of Geotechnical and Geoenvironmental Engineering, 2013, 139(1): 35−48.

[10] WENJONG C, THITIBHORN P. Effects of gravel content on shear resistance of gravelly soils[J]. Engineering Geology, 2016, 207(6): 78−90.

[11] JI En-yue, CHEN Sheng-shui, FU Zhong-zhi. Experimental investigations on tensile cracking mechanical characteristics of gravelly core material[J]. Rock and Soil Mechanics, 2019, 40(12): 4777−4782.

[12] DING Shu-yun, BI Qing-tao, YIN Zong-ze. Simplified method for measuring the Duncan model parameters of gravel-mixed core materials by means of triaxial tests[J]. Chinese Journal of Geotechnical Engineering, 2014, 36(4):763−767.

[13] ZHANG Y, CHEN Y L. A constitutive relationship for gravelly soil considering fine particle suffusion[J]. Materials, 2017, 10(1217): 1−13.

[14] CHEN Zhi-bo, ZHU Jun-gao. A modified ellipse-parabola double yield surfaces model on gravelly soil[J]. Journal of Fuzhou University (Natural Science Edition), 2016, 44(6): 874−880.

[15] SIVAKUMAR V, MCKELVEY D, GRAHAM J, et al. Triaxial tests on model sand columns in clay[J]. Canadian Geotechnical Journal, 2004, 41(2): 299−312.

[16] XU Han, HUANG Bin, RAO Xi-bao, et al. Consolidation and drainage effect of drilling and sand replacement samples in consolidated drained triaxial tests[J]. Rock and Soil Mechanics, 2007, 30(4): 333−336.

[17] CHEN Zhi-bo. Study on engineering properties and quick triaxial CD test of wide grading gravelly soil[D]. Nanjing: Hohai University, 2008.

[18] CHEN Z B, ZHU J G, JIAN W B. Quick triaxial consolidated drained test on gravelly soil[J]. Geotechnical Testing Journal, 2015, 38(6): 985−995.

[19] GUO Qing-guo. Engineering characteristics and application of coarse grained soil[M]. Zhengzhou: Yellow River Water Conservancy Press, 1998.

[20] Ministry of Water Resources of the People's Republic of China. GB/T50123 — 2019 Standard for soil test method[S]. Beijing: China Planning Press, 2019.

https://rocksoilmech.researchcommons.org/journal/vol42/iss1/5
DOI: 10.16285/j.rsm.2020.5556