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Effect of Sample Reconstitution Methods on the Behaviors of Sand under Shearing

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Abstract

The effect of sample reconstitution methods on the behavior of sand under shearing is investigated by using the first commercially available Variable Direction Dynamic Cyclic Simple Shear System. Three sample reconstitution methods are used in this study, the dry funnel method, air pluviation, and dried wet tamping. Because only dry specimens can be tested in many simple shear apparatuses, a new method called the dried wet tamping is used in this study, in which the soil sample prepared by the wet tamping is dried before being tested. Leighton buzzard sand at various relative densities is tested in monotonic, one-directional cyclic and two-dimensional circular cyclic simple shear tests. Experimental results show that different sample reconstitution methods have limited effects on the shear behavior in monotonic loading tests. On the contrary, the sample reconstitution methods greatly influence the dynamic responses of sand, including the undrained one-dimensional cyclic and two-dimensional circular cyclic loading. The liquefaction resistance is the greatest by using the dried wet tamping method, followed by the dry funnel method and air pluviation method. These test results are also compared with previous studies on sample reconstitution methods, and their similarities and differences are analyzed.

Keywords

Simple shear tests, stress-strain responses, sample reconstitution methods, fabric of soil, liquefaction

Introduction

In almost all soil experiments, stress-strain responses are greatly influenced by different sample reconstitution methods, which generate different fabrics and structures in soil samples [1-3]. Although there have been numerous studies on this aspect, many findings are contradictory. For example, Yang et al. [4] indicate that the dry funnel method leads to stronger samples under monotonic loadings than the wet tamping method, but Sze and Yang [5] indicates the opposite. In addition, most studies on sample reconstitution methods are carried out by using triaxial apparatuses [2,5-7].

In many occasions, triaxial stress conditions are different from in-situ stress conditions [8-12], and triaxial stress path cannot simulate the rotation of principal stress [13-15]. Simple shear tests involving a continuous rotation of principal stress can better duplicate in-situ stress conditions [16-18]. Especially the bi-directional direct simple shear test can study soil responses under multiple shear stresses, which often occurs in geotechnical engineering applications.

In this study, the effect of sample reconstitution methods on the behaviors of sand under shearing will be studied using the first commercially available Variable Direction Dynamic Cyclic Simple Shear System (VDDCSS).Two-dimensional circular cyclic loading paths will be tested using the VDDCSS, together with conventional monotonic and one-dimensional cyclic loading tests. This paper selects three most commonly used sample reconstitution methods, which are the dry funnel, air pluviation, and dried wet damping methods.

Experimentation

Testing facility and testing material

The first commercially available bi-directional direct simple shear apparatus VDDCSS, manufactured by GDS (Global Digital Systems) Instruments Ltd. UK, is used in this study. The stress control and strain control are available for both static and cyclic loading tests, with user defined specifications. Figure 1 shows the apparatus in which two orthogonal actuators can independently apply shear stresses on a soil specimen, which enables the VDDCSS to perform simple shear tests in any horizontal direction. The VDDCSS minimized the potential for rocking and pinching problems by using a larger diameter to height sample and an improved loading frame (track bearing system, similar as the one described by Kammerer [19]). More details of this apparatus are described by Li et al. [20,21].

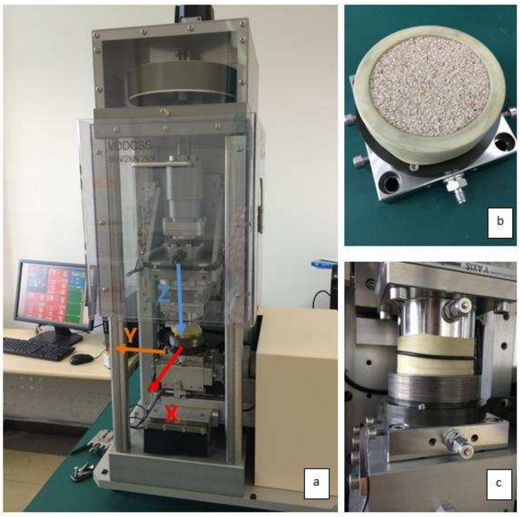

Figure 1 The Variable Direction Dynamic Cyclic Simple Shear (VDDCSS) (a: apparatus; b: a prepared specimen; c: a specimen under undrained shear)

A cylindrical specimen with 70 mm in diameter and 17 mm in height is tested. The high diameter to height ratio minimizes the non-uniformity of stress and strain in the specimen [22-24]. A stack of low-friction Teflon coated rings with 1.16 mm high each is placed outside membrane of the specimen. The sectional details of a specimen are shown in the Figure 2. In drained tests, the vertical stress is held constant, and the volume (height) of a specimen is allowed to change. In undrained tests, the volume (height) of a specimen is held constant, and vertical stress is allowed to change. The change of vertical stress in a dry specimen is assumed equivalent to the excess pore water pressure generated when a saturated specimen is tested under true undrained conditions [25-27]. Dyvik et al. [26] found that the vertical stress changes of samples in a simple shear apparatus without pore water pressure measurements are equal to the measured excess pore water pressures in a simple shear apparatus with pore water pressure measurements. All tests are terminated after the pore water pressure increases to 90% of the initial vertical stress, and this state is defines as liquefaction in this study. This is because the existence of shear stress prevents the pore water pressure from reaching 100% of the initial vertical stress [19,28].

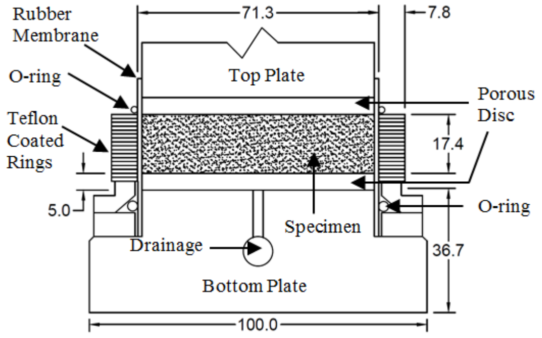

Figure 2 Sectional details of a specimen

Leighton Buzzard sand (Fraction B) is used in this study. The grading curve of the soil is shown in Figure 3. Its maximum and minimum void ratios are 0.79 and 0.46, respectively [29]. Its mean diameter (D_{50}) is 0.82 mm, and its effective grain size (D_{10}) is 0.65 mm with a uniformity coefficient (D_{60}/D_{10}) at 1.38. It is British standard sand and has been extensively studied by numerous research institutes including Nottingham Centre for Geomechanics (NCG) [30,31].

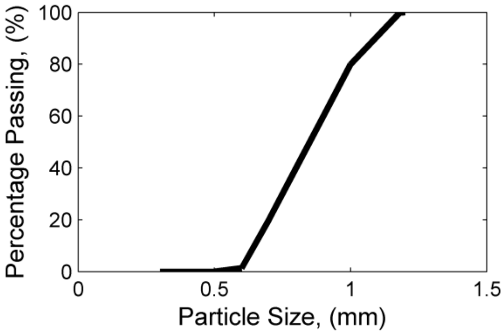

Figure 3 Grading curve of Leighton Buzzard sand (Fraction B)

Sample preparation and loading conditions

Three commonly used sample preparations methods are employed, which are the dry funnel (DF), air pluviation (AP) and dried wet tamping methods (DWT). These three methods use different densification techniques, which are vibration, dropping and tamping, respectively.

The dry funnel method best models the soil densified by vibration, such as soil in earthquake regions. In the dry funnel method, a funnel with a nozzle about 5mm in diameter is first placed in the centre of an empty mould, and then oven dried sand at a predetermined weight is poured into the funnel. Sand is spread into the membrane without drop height through the funnel, and then the funnel is slowly raised close to the surface of a specimen along the axis of symmetry of the specimen. A higher relative density is obtained by applying a low energy and high frequency vibration on samples using a small magnetic shaking table, in which the amplitude of the vibration is 0.5mm and the frequency of the vibration is 2 Hz. The time of the vibration is used to control the relative densities of samples. For example, 10 seconds are taken for samples with a relative density of 48%, and 30 seconds for samples with a relative density of 68%.

The air pluviation method best simulates the deposition process of wind blown aeolian deposits [32]. In the air pluviation method, weighted sand is placed in a funnel with a nozzle about 5mm in diameter fixed at a certain height above the center of an empty mould, and the specimen is made by raining sand through the funnel into the mould. Flow rate of the raining is fixed by using the same funnel for all samples. The height of the funnel and weight of sand are predetermined by trial and error to achieve a specified relative density. A higher relative density is achieved by increasing the mass of sand and the height of the funnel. For example, 105g sand and 25cm drop height are used for samples with a relative density of 48%, and 110g sand and 55cm drop height are used for samples with a relative density of 68%.

The moist tamping method is designed to model the soil fabric of rolled construction fills [32]. In the VDDCSS, only dry specimens can be tested. A new method called dried wet tamping is used to model the soil fabric generated by the widely used wet tamping method. A subsequent drying step is required for the dried wet tamping method compared with the wet tamping method. In the dried wet tamping method, weighted sand portions are divided into five groups with the same mass and then mixed with deaired water at a water content of 5 %. Each portion of the sand is strewn by a spoon to a predetermined height, and then tamping is applied using a tamper with a diameter of 4 mm and a mass of 320 g. The height of each lift is predetermined using the calculation of required height in the undercompaction method [33]. Different relative densities are achieved by adjusting the number of tamping at each stage of the lift, and the height of the tamper is fixed to 20 cm. Finally, the sample is dried in an oven at around 50°C overnight and cooled to room temperature before testing. Hence, it is referred to as the dried wet tamping method. The low temperature is used to avoid damaging the membrane, and the volume of the specimen is unchanged after drying. Only medium dense and dense sands are tested as denser sand has a more stable fabric. Leighton Buzzard sand (Fraction B) has a relatively large particle size, and the change of the water conditions in the samples does not affect its fabric.

Table 1 Tests conducted with various sample reconstitution methods, relative densities and loading conditions (AP: air pluviation; DF: dry funnel; DWT: dried wet tamping)

Test series	Test condition	Relative density , %	Preparation method
Monotonic	Undrained	30	DF&AP
		47-49	DF,AP,DWT
		67-68	DF,AP,DWT
	Drained	27	DF&AP
		48	DF,AP,DWT
		68	DF,AP,DWT

Cyclic	Undrained	28	DF&AP
		47-48	DF,AP,DWT
		67-68	DF,AP,DWT
Circular	Undrained	28	DF&AP
		47-48	DF,AP,DWT
		67-68	DF,AP,DWT

Different loading conditions are used in this study, including monotonic, one-dimensional cyclic and two-dimensional circular cyclic loading paths, as shown in Figure 4. In the monotonic loading tests, prepared samples are consolidated under the vertical stress of 200 kPa for 30 minutes, and then monotonically sheared in drained or undrained condition along the x direction of the VDDCSS with a fixed shear speed of 0.01mm/min until soil failure occurs. In the one-dimensional cyclic and two-dimensional circular cyclic tests, prepared samples are firstly consolidated under the vertical stress of 200 kPa for 30 minutes. Then, cyclic shear loadings are applied in undrained condition at a low frequency of 0.1 Hz until liquefaction occurs. Stress controlled method is used in cyclic tests, and cyclic shear amplitude is 5.2 kPa in all these cyclic tests. Table 1 summarizes tests performed. Relative density is calculated after the consolidation, three relative densities are tested in this study, which are 30%, 48% and 68%.

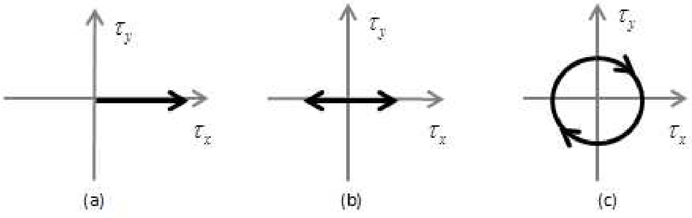

Figure 4 Loading paths in (a) monotonic tests (b) one-dimensional cyclic tests (c) two-dimensional circular tests.

Experimental Results

Monotonic loading tests

Figure 5 shows the undrained shear stress-strain responses for different relative densities, and Figure 6 shows the development of equivalent pore water pressure. The test is stopped when the pore water pressure reaches 90% of the initial vertical stress. It should be noted that the relative density of 30% is the loosest state of specimen, in which the air pluviation method with zero drop height is the same as the dry funnel method without vibration. Figure 5 and Figure 6 show that the responses with different reconstitution methods at a given relative density are similar, indicating very limited influence of different sample reconstitution methods.

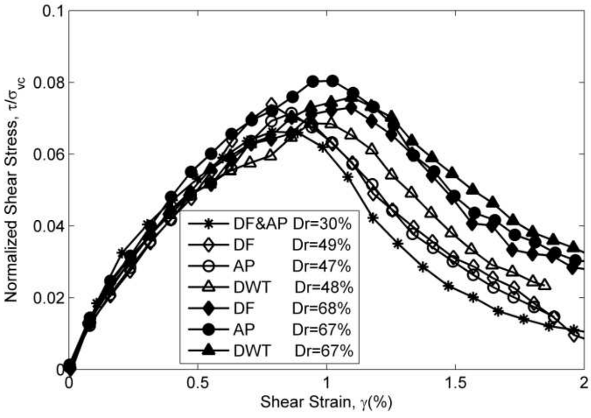

Figure 5 Shear stress-strain responses in undrained monotonic loading tests

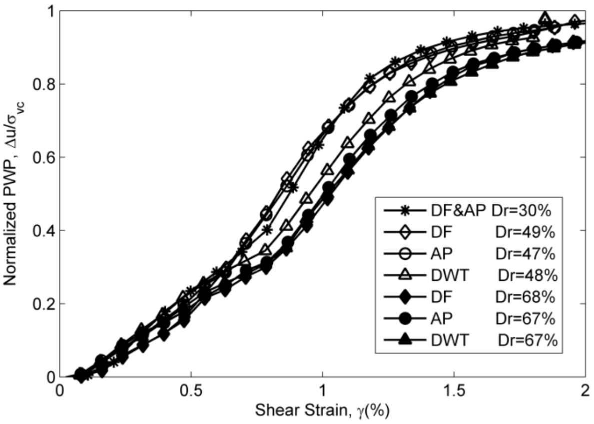

Figure 6 The generation of normalized PWP in undrained monotonic loading tests

Drained tests with the air pluviation , dry funnel and wet dried tamping methods are also conducted to validate the effects of sample reconstitution methods. Figure 7 shows the shear stress-strain responses and Figure 8 shows the vertical displacements corresponding to volumetric strains. They indicate that different sample reconstitution methods have little impact on the responses, similar to the findings in the undrained tests.

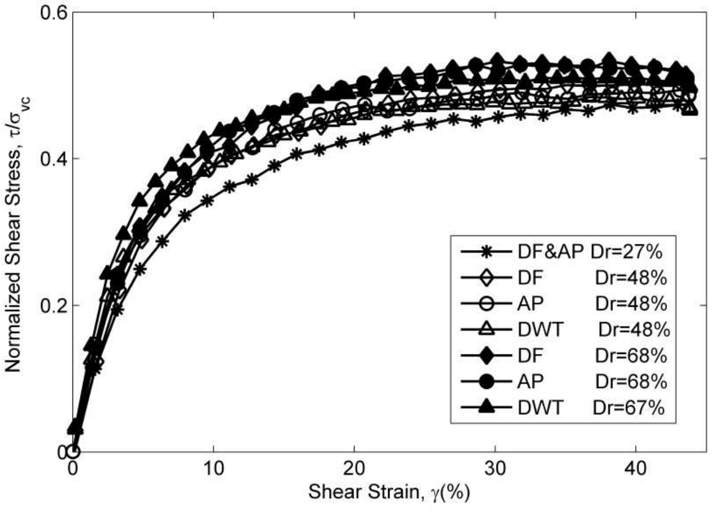

Figure 7 Shear stress-strain responses in drained monotonic loading tests

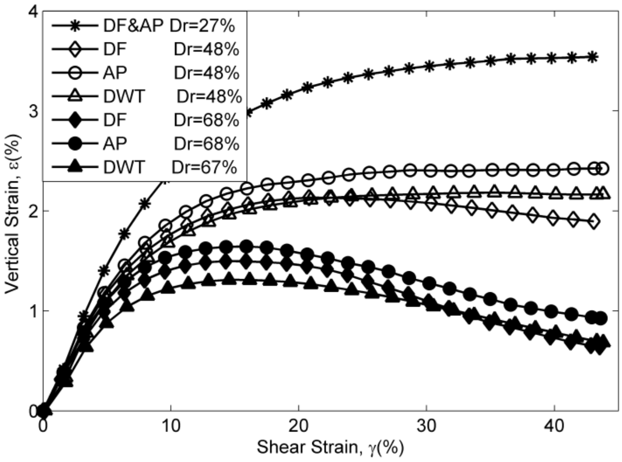

Figure 8 The development of vertical strain in drained monotonic loading tests

Cyclic loading tests

Figure 9 shows a typical shear strain response in one-dimensional cyclic loading test for the medium dense sand, and the strain development pattern is similar to all other tests. Figure 10 shows the generation of pore water pressure, in which its rate is the lowest in the dried wet tamping method and takes the largest number of cycles to reach liquefaction, followed by the dry funnel method. The air pluviation method gives the least liquefaction resistance. The impact of different sample reconstitution methods is the most obvious for the dense sand. While it takes 62 cycles to reach liquefaction in the dried wet tamping method, it takes 43 and 22 cycles for the dry funnel and air pluviation methods to reach liquefaction, respectively.

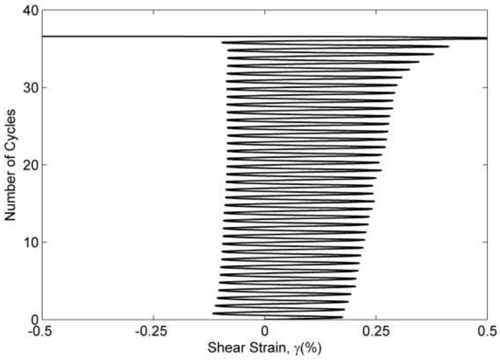

Figure 9 The development of shear strain in a typical one-dimensional cyclic loading test (DWT, Dr=47%).

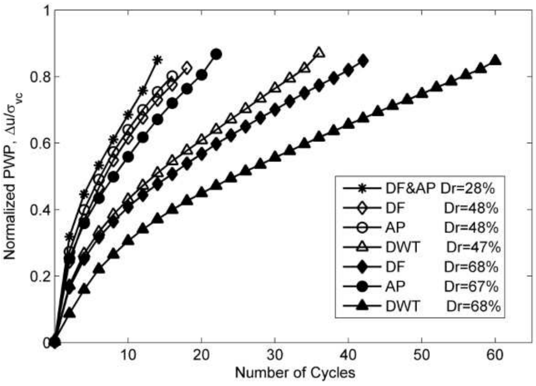

Figure 10 The generation of normalized PWP in one-dimensional cyclic loading tests.

Figure 11 shows a typical shear strain path in the two-dimensional circular cyclic loading test for the dense sand. Figure 12 shows the generation of pore water pressures for different relative densities until the liquefaction. Compared with the one-dimensional cyclic loading tests, it takes fewer cycles for the two-dimensional circular cyclic loading tests to reach the liquefaction. This is evident as there is an additional loading along the orthogonal direction. On the other hand, the impact of different sample reconstitution methods is the same between the one-dimensional and two-dimensional tests. Figure 12 indicates that the dried wet tamping method leads to the greatest liquefaction resistance, followed by the dry funnel method, and the air pluviation method gives the least liquefaction resistance. In addition, similar to the one-dimensional cyclic loading tests, the impact is the larger for denser sands.

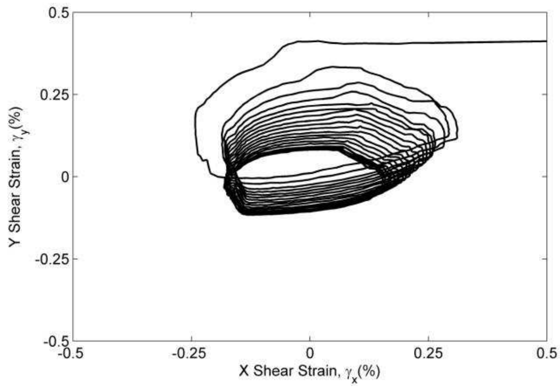

Figure 11 The development of shear strains in a typical two-dimensional circular cyclic loading test (DWT, Dr=68%)

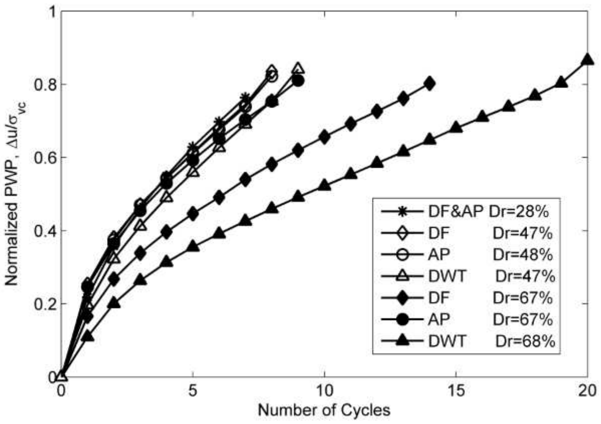

Figure 12 The generation of normalized PWP in two-dimensional circular cyclic loading tests

Discussion and conclusion

The test results under one-dimensional cyclic loading and twodimensional circular cyclic loading paths in this study using the bidirectional simple shear apparatus are in agreement with previous triaxial test results [1–3,5]. Samples prepared by the wet tamping method are stronger than those prepared by the dry funnel and air pluviation methods.

A well-established explanation concerns the soil fabric [4,5,19]. By using an image-analysis-based technique, Yang et al. [4] measured, quantified, and compared the fabric anisotropy of granular soil samples prepared by different reconstitution methods. It was found that a sand sample prepared by the air pluviation method is more anisotropic in its fabric, and the preferential contact of sand particles is vertical. The dry funnel method can be considered similar to the air pluviation method on the aspect of fabric anisotropy as they both involve dropping sand into a mould. The difference of the dry funnel method from the air pluviation method is zero drop height and use of vibration which reduce the anisotropy. During the triaxial cyclic loading, the orientation of major principal stress repeatedly alternates between vertical and horizontal directions, and it is a sudden change of 90°. When the major principal stress is along the horizontal direction equivalent to the triaxial extension, a sand sample with the vertical preferential contact is the weakest. In contrast, sand samples prepared by the wet tamping method are more isotropic in their fabrics [4], and the impact of principal stress reversal is not as great as in the sample by the air pluviation method. As a result, samples prepared by the wet tamping are stronger than those by the air pluviation under the triaxial cyclic loading.

Similar to the triaxial cyclic loading, the simple shear cyclic loading also generates repeated principal stress reversal. However, there are differences between them. While the triaxial cyclic loading features a sudden change of major principal stress orientation and the magnitude of the change is 90°, the simple shear cyclic loading features a gradual change of major principal stress orientation, and the magnitude of the change is smaller than 90°. Therefore, the intensity of principal stress reversal in the former is greater than in the latter. However, the principal stress reversal in the simple shear cyclic loading is still great enough to generate sufficient influence on sand sample fabric, so that the sample that uses the air pluviation and dry funnel methods is weaker than that using the dried wet tamping method. The test results under the monotonic loading path in this study indicate that the sample reconstitution methods don't have marked influence on the shear behavior. This is because the principal stress rotation is mild and smooth in the process of monotonic loading, and its impact is limited. This study shows the importance of accounting for the effect of the sample reconstitution method in simple shear tests, especially in cyclic simple shear tests. In addition, when comparing results with previous studies, it is necessary to ensure that the same sample reconstitution methods are used.

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Figure and Table Captions

Table 1: Tests conducted with various sample reconstitution methods, relative densities and loading conditions (AP: air pluviation; DF: dry funnel; DWT: dried wet tamping)

Figure 1: The Variable Direction Dynamic Cyclic Simple Shear (VDDCSS) (a: apparatus; b: a prepared specimen; c: a specimen under undrained shear)

Figure 2: Sectional details of a specimen

Figure 3: Grading curve of Leighton Buzzard sand (Fraction B)

Figure 4: Loading paths in (a) monotonic tests (b) one-dimensional cyclic tests (c) two-dimensional circular tests.

Figure 5: Shear stress-strain responses in undrained monotonic loading tests

Figure 6: The generation of normalized PWP in undrained monotonic loading tests

Figure 7: Shear stress-strain responses in drained monotonic loading tests

Figure 8: The development of vertical strain in drained monotonic loading tests

Figure 9: The development of shear strain in a typical one-dimensional cyclic loading test (DWT, Dr=47%).

Figure 10: The generation of normalized PWP in one-dimensional cyclic loading tests.

Figure 11: The development of shear strains in a typical two-dimensional circular cyclic loading test (DWT, Dr=68%)

Figure 12: The generation of normalized PWP in two-dimensional circular cyclic loading tests