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TECHNICAL NOTE

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Development and Evaluation of Preconditioning Protocols for Sand Specimens in Constant-Volume Cyclic Direct Simple Shear Tests

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Reference

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ABSTRACT

Textured platens are often used to improve the transfer of shear stresses from the platens to the soil specimen during direct simple shear (DSS) tests. However, constant-volume DSS tests when textured platens are used can be affected by inadequate engagement of the soil at the platen-soil interface, leading to large reductions in the vertical stress at the start of shearing. The application of a preconditioning sequence involving small-strain drained cycles prior to constant-volume shearing can improve engagement at the platen-soil interface, but when excessively implemented, it can also have adverse effects on the measured soil behavior (e.g., strength, stiffness). A series of constant-volume cyclic DSS tests preceded by different preconditioning sequences was performed to evaluate the effect of preconditioning on the engagement of sand specimens at the platen-soil interface and the stress-strain response of these specimens. Results showed that textured platens that are properly engaged with sand specimens can reduce slippage at the platen-soil interface. This engagement can be achieved by applying a limited number of small-strain drained cycles at a low vertical stress while still obtaining representative soil behavior during the subsequent equivalent undrained constant-volume cyclic loading. Although the preconditioning protocol presented herein is specific to the testing equipment and materials considered, similar procedures may be adopted to develop preconditioning protocols for other soils, platens, and testing devices.

Keywords

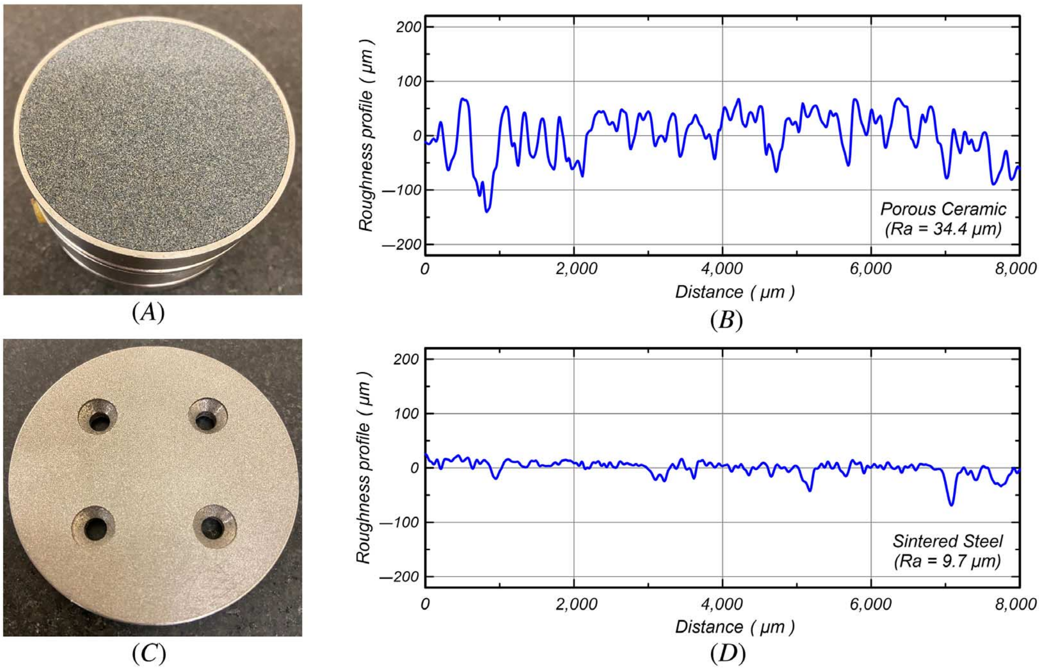
direct simple shear test, testing protocols, textured platens, constant-volume tests, shear transfer, liquefaction, preconditioning

Introduction

ASTM D8296-19, *Standard Test Method for Consolidated Undrained Cyclic Direct Simple Shear Test under Constant Volume with Load Control on Displacement Control*, specifies that constant-volume cyclic direct simple shear (DSS) tests should be performed using flat porous platens, which should have pores that are fine enough to prevent soil intrusion and should provide enough roughness to effectively transmit shear stresses to specimens. Porous ceramic, sintered brass, or sintered steel flat platens of different porosities have been commonly used for this purpose, in all cases demonstrating the ability to provide stiff boundaries in the top and bottom surfaces. The ability of such platens to properly transfer shear stresses to specimens depends on their surface roughness, defined by the surface finishing process during manufacturing. **Figure 1** presents examples of flat platens available for DSS testing, including measurements of their surface roughness. Flat platens with appropriate surface roughness (e.g., **fig. 1*B***) have been shown to effectively transfer shear stresses to both fine-grain soils (e.g., Price, DeJong, and Boulanger 2017) and fine sands (e.g., Morales, Humire, and Ziotopoulou 2021). However, some flat platens (e.g., smooth sintered stainless steel platens) may not be sufficiently rough (e.g., **fig. 1*D***) to prevent slippage at the top-platen and soil-specimen interface. Prevost and Høeg (1976) concluded that the shear stress distribution in the sample can be severely affected as a consequence of slippage along this platen-soil interface. Previous experimental works suggest that such slippages can be reduced by using textured platens such as platens with embedded pins (e.g., Porcino and Diano 2016; Robinson et al. 2019) or protruding ridges (e.g., Kovacs and Leo 1981; Milatz and Grabe 2015).

Despite its ability to limit slippage, the use of textured platens can also lead to improper engagement of soil specimens at the end of the consolidation phase, resulting in excessive voids at the platen-soil interface. If the presence of such voids is not mitigated prior to constant-volume cyclic loading, large and nonrepresentative

FIG. 1 Examples of direct simple shear (DSS) flat porous platens and measurements of their average roughness (*Ra*) with a 3D optical profiling system: (*A*) porous ceramic platens used by Morales, Humire, and Ziotopoulou (2021); (*B*) representative surface roughness profile of the platen shown in (*A*); (*C*) flat sintered stainless steel porous platens used in this study; and (*D*) representative surface roughness profile of the platen shown in (*C*).



reductions in vertical stresses can take place early on during shearing. This can result in both erroneous stress-strain behavior and localization of shear strains at the top platen-soil interface.

Previous research (Andersen 2009; Rees 2016) indicates that engagement of soil specimens at the top platen-soil interface can be improved through the application of a preconditioning sequence consisting of low-amplitude drained cycles prior to shearing. Preconditioning drained cycles are intended to fully engage the top platen with the soil specimen prior to shearing events.

The application of preconditioning sequences may also improve the mobilization of lateral stresses within specimens, therefore creating near K_0 conditions in the specimen prior to shearing (Rune Dyvik, pers. comm., January 17, 2019). These near K_0 conditions were demonstrated by measurements of lateral stresses in DSS specimens by Dyvik (pers. comm., January 17, 2019), which showed that lateral stresses may not be fully mobilized when only vertical stresses (seating and consolidation) are applied because of soil arching effects and the shedding of a portion of the applied vertical stress to specimen sidewalls. The application of preconditioning sequences, however, has been shown to mitigate such stress localizations while increasing the horizontal stresses mobilized in specimens (Finn 1981; Andersen 2009), therefore allowing for more representative and repeatable K_0 conditions to be established prior to undrained cyclic shearing.

Previous research has shown that the application of low-amplitude cycles prior to undrained cyclic shearing can also lead to significant increases in liquefaction resistance (Finn, Bransby, and Pickering 1970; Seed, Mori, and Chan 1977; Finn 1981; Andersen 2009; Nelson and Okamura 2019). This increase not only results from an improved engagement of specimens at end platen interfaces and increases in K_0 coefficients, but also because of changes in the soil fabric caused by pre-straining effects (Finn 1981; Andersen 2009). These past studies have also shown that changes in specimen liquefaction resistances depend on both the number and amplitude of the loading cycles applied before shearing. Therefore, the number and amplitude of preconditioning cycles must be carefully selected to minimize excessive changes in subsequent soil responses.

Although preconditioning sequences are commonly used, procedures to determine the number of drained cycles needed to engage specimens without excessively altering their soil behaviors (e.g., strength, stiffness) remain non-standardized. The objectives of this work are listed as follows: (1) confirm that textured platens can be used as a viable method to prevent slippage at the top platen-sand interface when the sand is incompatible with the flat platens' available roughness; (2) assess the effects of preconditioning loading sequences on the initial relative density (D_R) and stress-strain response of sand specimens; and (3) present a testing plan that can be used to develop lab-specific preconditioning protocols for constant-volume cyclic DSS tests on reconstituted sand specimens. This is achieved by conducting DSS tests with different top platen geometries and preconditioning loading sequences using a fixed cyclic strain amplitude and comparing test results with experimental information available in the literature for the same sand and stress conditions. Although preconditioning is expected to improve both the initial establishment of K_0 conditions within DSS specimens and the transfer of shear stresses during cyclic shearing, only the latter effect was evaluated in this study as it reflects the collective impacts of both factors on specimen behaviors. The engagement issues at the top platen-soil interface presented in this work, as well as the preconditioning protocol identified through this study, are specific to the testing equipment and type of materials considered in this investigation. Recommendations are provided regarding the development of preconditioning procedures for other testing conditions; however, further research is recommended given the numerous factors affecting the engagement at the top-platen interface (e.g., platen geometry, platen roughness). In addition to the specific objectives of this paper, the present study is intended to highlight the sensitivity of results to lab-specific testing protocols and to broadly encourage the dissemination of thorough and complete testing procedures.

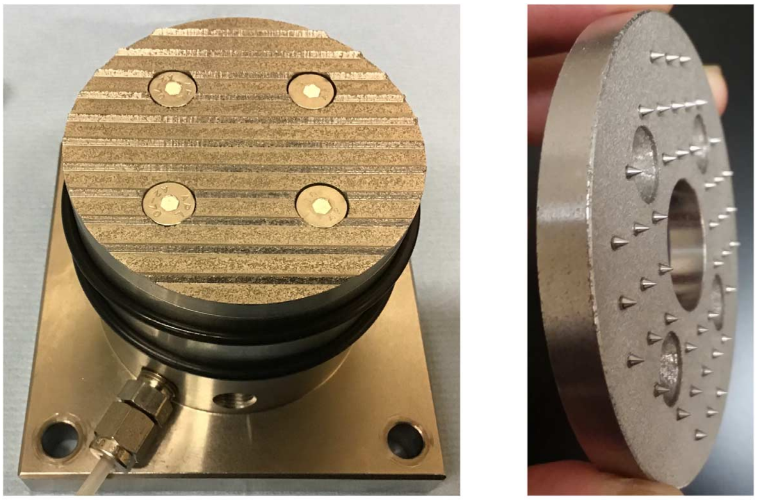
Experimental Setup and Procedures

EQUIPMENT

An Electromechanical Dynamic Cyclic Simple Shear device manufactured by GDS Instruments was used to perform all the constant-volume cyclic DSS tests presented herein. Constant-volume conditions were enforced with

FIG. 2

DSS sintered stainless steel porous platens of 70 mm in diameter with (*A*) protruding ridges and (*B*) embedded pins that were used in this study.



(*A*) (*B*)

the active height control system implemented in the Electromechanical Dynamic Cyclic Simple Shear device, which achieved vertical strain fluctuations of less than 0.01 % in all tests, which met the 0.05 % criterion recommended by ASTM D8296-19 and the 0.025 % threshold recommended by Zekkos et al. (2018). Cylindrical samples near 22 mm in height and 70 mm in diameter were laterally enclosed within stacked Teflon-coated steel rings and a latex membrane of about 0.3 mm in thickness. Three types of sintered stainless steel porous platens were used to transmit the shear forces to the sand specimens: flat platens (fig. 1*C*); platens with protruding ridges of 1 mm in height, 2 mm in width, and with a spacing of about 6 mm between the tip of ridges (fig. 2*A*); and platens with embedded pins of 2 mm in height with a spacing of about 7 mm between pins (fig. 2*B*). During tests involving platens with protruding ridges, platen ridges were oriented perpendicular to the direction of shearing. Gypsum was applied to fill all voids in exposed head screws that secured porous platens to end caps to eliminate the potential for soil migration into screw voids during shearing.

MATERIAL AND PREVIOUS TESTING

Experiments were conducted on specimens of Ottawa F-65 sand, which was the primary soil used in the Liquefaction Experiments and Analysis Projects (LEAP) (Kutter, Manzari, and Zeghal 2020). In the context of LEAP, this soil was classified as a poorly graded sand (SP) with a mean grain size (D_{50}) of 0.20 mm, a coefficient of uniformity (C_u) of 1.47, and no fines (Carey, Stone, and Kutter 2020). A range of values for the maximum and minimum void ratios (e_{max} and e_{min}) have been reported for Ottawa F-65 by different LEAP researchers (Vasko 2015; Parra Bastidas 2016; Carey, Stone, and Kutter 2020). Carey, Stone, and Kutter (2020) concluded that the index properties of the Ottawa F-65 sand used in different research facilities are relatively consistent and that the variability in the index dry densities are associated with operator variability. They recommended the use of an e_{max} of 0.78 and an e_{min} of 0.51 for future analyses on Ottawa F-65 sand for the LEAP project. These values were used for the calculation of relative densities for all tests presented in this study.

The development of preconditioning protocols was guided using two experimental data sets developed through the LEAP project for the same material, including hollow cylinder tests performed by Ueda, Vargas, and Uemura (2018) and DSS tests performed by Morales, Humire, and Ziotopoulou (2021). The high quality and reliability of these data sets is reflected in the detailed documentation of experimental procedures, observations that confirm specimens did not experience slippage, shear localization prior to liquefaction triggering, or both, compliance with ASTM specifications (e.g., vertical strains below ±0.05 % for constant-volume DSS tests), and other procedures followed to maintain a high level of consistency and repeatability in the produced data (El Ghoraiby, Park, and Manzari 2020). All tests presented in these data sets were performed using reconstituted (via air pluviation) Ottawa F-65 specimens, and shear stresses were applied to sand specimens using flat porous ceramic platens (fig. 1A) but without preconditioning. Cyclic stress ratios from hollow cylinder tests (CSR_{HC}) were converted using equation (1) to estimate CSR values expected during simple shear conditions (CSR_{DSS}) while assuming a coefficient of earth pressure at rest (K_0) of 0.5 (Ishihara 1996).

$$CSR_{DSS} = \frac{1 + 2K_0}{3} CSR_{HC} \tag{1}$$

PROCEDURES AND TESTING PLAN

All samples were prepared using air pluviation, which involved raining oven-dried sand from a constant fall height to create soil specimens. The performed testing plan aimed to evaluate the effect of top platen geometries and seating loads during the preconditioning process (Table 1). Prior to preconditioning, samples were subjected to a seating vertical stress of either 25 kPa or 100 kPa and were either saturated with deionized water or remained dry as indicated in Table 1. Then, samples were subjected to a preconditioning protocol wherein identical strain-controlled drained cycles with an amplitude of 0.01 mm (about 0.045 % shear strain) were applied at a frequency of 0.1 Hz (fig. 3A). The number of preconditioning cycles ($N_{pre\text{-}cond}$) varied between 0 and 200 cycles and induced changes in both the measured vertical strains and the secant shear moduli (fig. 3B). After completing the pre-conditioning protocol, the vertical stress was either maintained or increased to the target initial consolidation

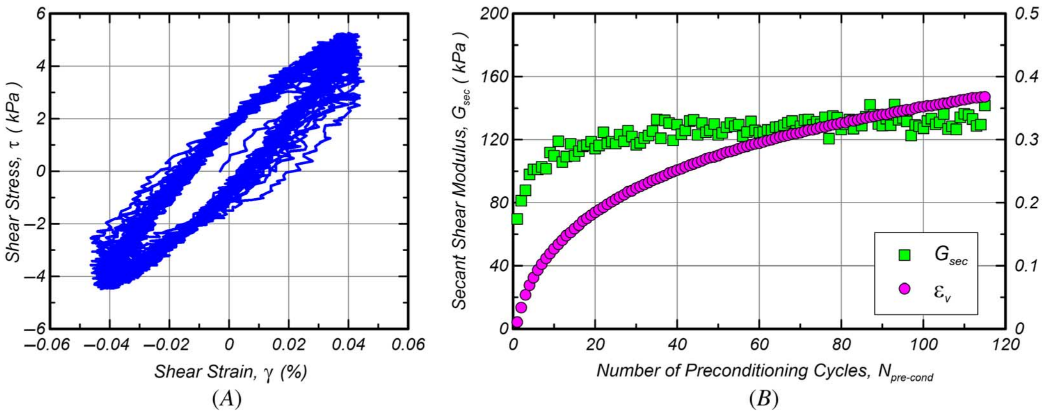
TABLE 1

Summary of direct simple shear (DSS) tests performed to evaluate the effect of preconditioning protocols

Test Group	Number of Tests	Type of Platens	D_R, %	σ'_{vc}, kPa	CSR	σ'_v during preconditioning, kPa	Number of Drained Preconditioning Strain-Controlled Cycles, $N_{pre\text{-}cond}$	Testing Sequence
1	2	Flat	60	100	0.1	25	0	(1) Applied vertical effective stress of 25 kPa;
2	3	Ridged	60	100	0.05, 0.10, 0.15	25	0	(2) Increased vertical effective stress to 100 kPa; (3) Applied undrained cyclic shearing.
3a	12	Ridged	60	100	0.1	25	25, 50 75, 100, 110, 115, 120, 125, 130, 141, 150, 200	(1) Applied vertical effective stress of 25 kPa; (2) Applied drained cycles to
3b	3	Ridged	60	100	0.10, 0.12, 0.15	25	115	precondition specimens; (3) Increased vertical effective stress to 100 kPa; (4) Applied undrained cyclic shearing.
4a	4	Ridged	60	100	0.10, 0.12, 0.15, 0.18	100	50	(1) Applied vertical effective stress of 100 kPa; (2) Applied drained cycles to precondition specimens;
4b [a]	8	Ridged	40	100	0.1	100	0, 10, 20, 30, 40, 50, 75, 150	(3) Applied undrained cyclic shearing.
5 [a]	10	Pinned	40	100	0.1	100	0, 10, 30, 40, 50, 60, 70, 75, 80, 150	

Note: [a] Denotes tests performed on dry sand specimens.

FIG. 3 Preconditioning stage with 115 drained loading cycles of 0.01 mm in amplitude (about 0.045 % shear strain) applied under a seating load of 25 kPa: (*A*) shear stress-strain loops, and (*B*) changes in the secant shear modulus and vertical strain for each drained cycle.



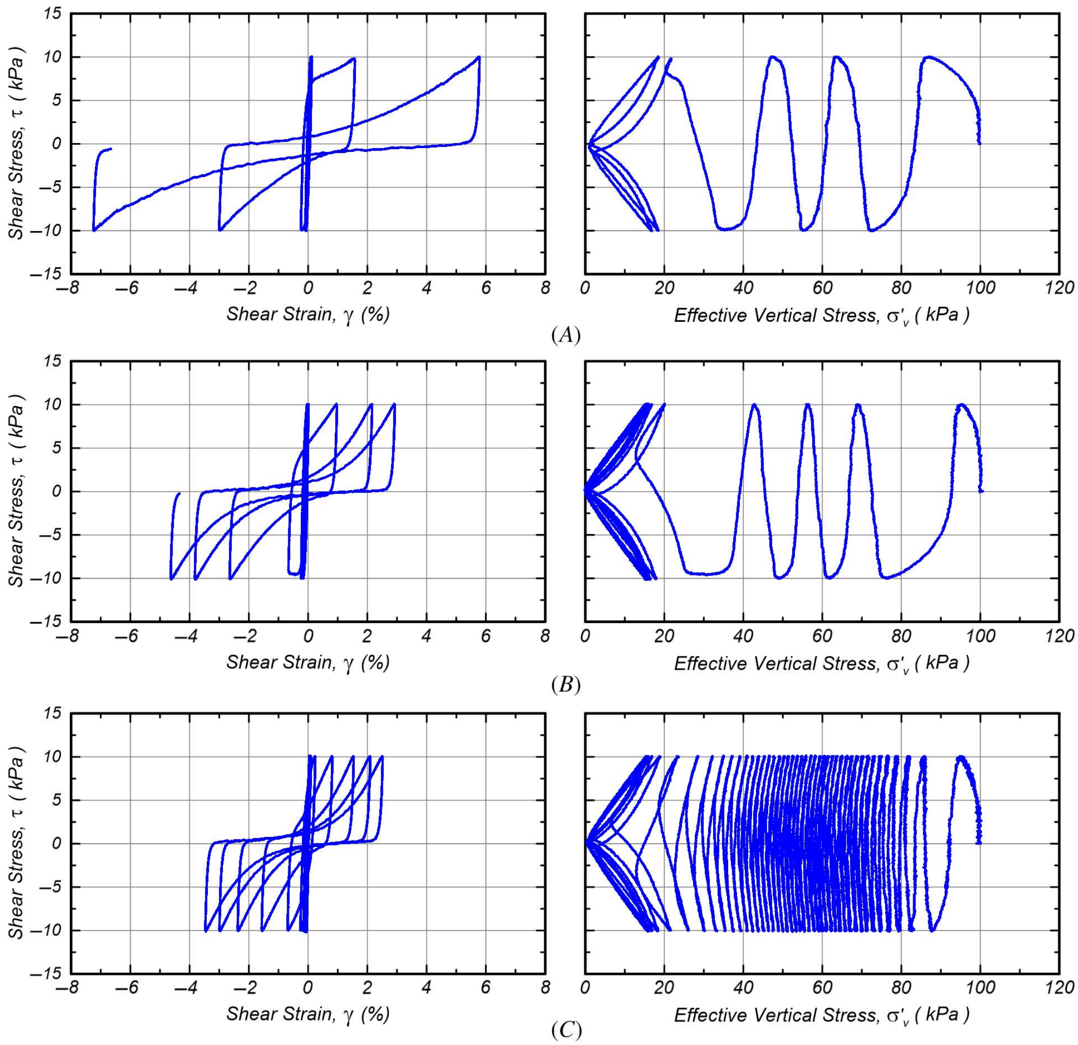
stress (100 kPa) for all specimens. Finally, all samples were subjected to constant-volume cyclic shearing wherein stress-controlled cycles were applied at a frequency of 0.05 Hz.

Test Results and Discussion

EFFECT OF PRECONDITIONING AND PLATEN GEOMETRY

Figure 4 presents the results of three DSS tests prepared to the same relative density ($D_R = 60$ %) and subjected to the same initial consolidation stress ($\sigma'_{vc} = 100$ kPa) and cyclic stress ratio ($CSR = 0.10$) but with different top platens and preconditioning sequences including the following: (1) sintered stainless steel flat platens without preconditioning, (2) ridged platens without preconditioning, and (3) ridged platens with 115 preconditioning drained cycles with an amplitude of about 0.045 % shear strain. As shown in **figure 5**, past tests by Ueda, Vargas, and Uemura (2018) and Morales, Humire, and Ziotopoulou (2021) suggested that approximately 40 loading cycles were needed to trigger liquefaction (defined with a double amplitude strain criterion of $\gamma_{DA} = 6$ %) for similar conditions. For tests conducted with sintered stainless steel flat platens (**fig. 4*A***), liquefaction triggering occurred after only four loading cycles and large shear strains developed immediately post-triggering. These behaviors can be associated with slippage observed at the top platen and soil interface during the application of the undrained cyclic loading, which occurred because of the inadequate roughness of the sintered stainless steel flat platens (**fig. 1*D***) and resulted in shear stresses not being properly mobilized through the sand specimen. When ridged platens were used instead (**fig. 4*B***), a slight increase in the number of cycles required to trigger liquefaction as well as reductions in post-triggering shear strains occurred. Despite some improvement in the transfer of shear stresses when using the ridged platens, the number of cycles needed to trigger liquefaction remained significantly less than similar tests from the literature (**fig. 5**), suggesting that the soil specimen remained poorly engaged at the top platen interface. Observations of arching in the corners of sheared specimens also suggested a poor engagement at the top platen interface. In contrast, when tests were performed using ridged platens and 115 preconditioning drained cycles (**fig. 4*C***), both pre- and post-triggering behaviors agreed well with similar tests from the literature. This result was attributed to the rearrangement of soil particles at the platen-soil interface, which improved contact between the textured porous platen and soil specimen. The improvement of engagement at the platen-soil interface was also supported by observations of more uniform shear deformations along the height of the sheared specimens.

FIG. 4 Results from DSS tests performed on specimens of Ottawa F-65 sand ($D_R = 60$ %) with: (*A*) sintered stainless steel flat platens and no preconditioning, (*B*) ridged platens and no preconditioning, and (*C*) ridged platens with preconditioning consisting of 115 drained cycles.



DEVELOPMENT OF LAB-SPECIFIC PRECONDITIONING PROTOCOLS

A lab-specific preconditioning protocol was developed for specimens with ridged platens by performing tests at identical D_R, σ'_{vc}, and CSR values but with different numbers of drained preconditioning strain-controlled cycles ($N_{pre\text{-}cond}$) applied at a vertical effective stress of 25 kPa (Test Group 3a in **Table 1**). The application of drained preconditioning cycles induced minor changes in specimen heights and, therefore, gradually increased specimen D_R values. **Figure 6*A*** presents changes in specimen D_R values resulting from preconditioning as a function of the number of drained preconditioning cycles applied. As shown, large increases in D_R values resulted from the application of the first 100 drained preconditioning cycles, which was primarily attributed to the elimination of voids initially present at the top platen-soil interface. **Figure 6*A*** also presents changes in D_R values that resulted from increasing vertical stresses from 25 kPa (after preconditioning) to 100 kPa. Such changes were larger for tests with the smaller $N_{pre\text{-}cond}$ because of the existence of voids at the platen-sand interface, which became partially filled when increasing the vertical stress.

FIG. 5 Liquefaction resistance data for Ottawa F-65 sand (D_R = 50–70 %, σ'_{vc} = 100 kPa) including experimental data from Ueda, Vargas, and Uemura (2018) and Morales, Humire, and Ziotopoulou (2021) as well as data obtained in this study using different preconditioning sequences.

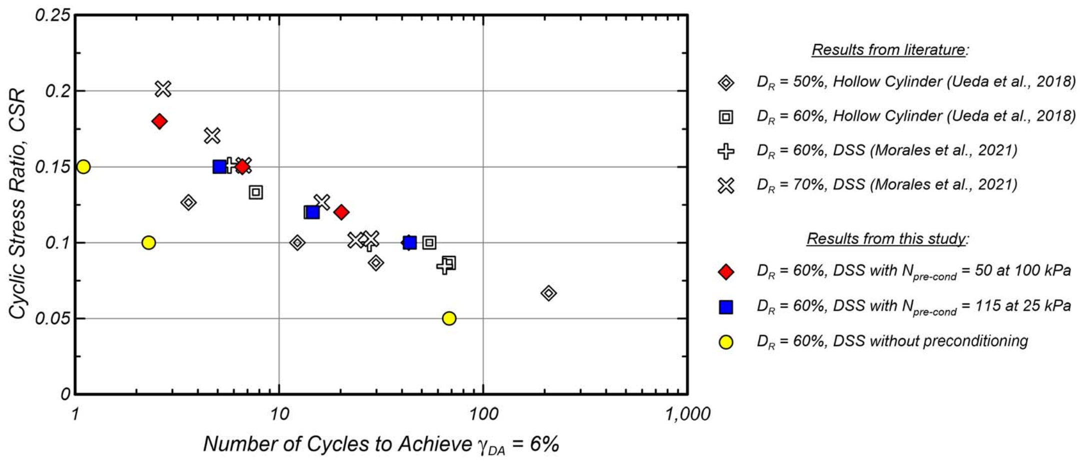


FIG. 6 Effect of the number of preconditioning cycles ($N_{pre\text{-}cond}$) with an amplitude of 0.045 % shear strain on: (*A*) changes in specimen relative densities (D_R) resulting from preconditioning and consolidation and (*B*) the number of cycles required to trigger liquefaction (γ_{DA} = 6 %).

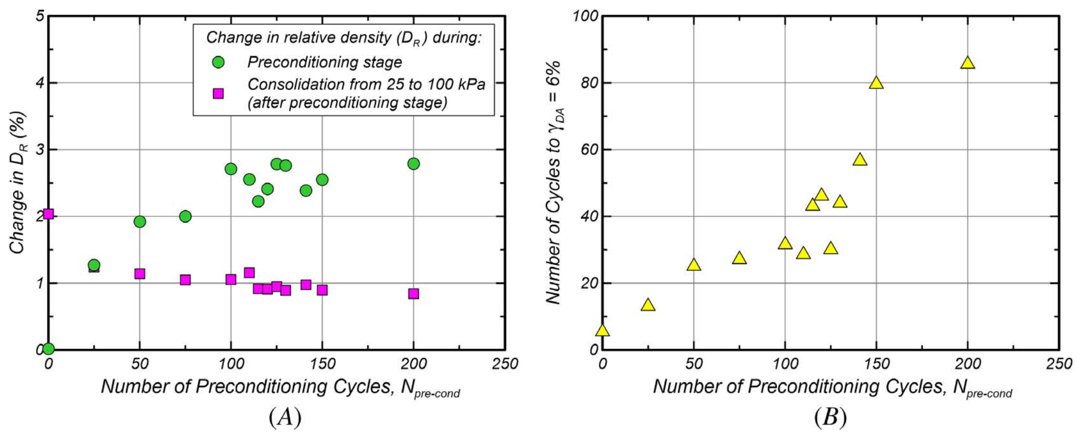


Figure 6*B* presents increases in the number of cycles required to trigger liquefaction as a function of the number of drained preconditioning cycles applied. Apparent increases in specimen triggering resistances again resulted from the improved engagement of specimens at the top platen-soil interface but may have also resulted from an increase in K_0 coefficients and changes in soil fabrics (Finn 1981; Andersen 2009). Large and progressive increases in the number of loading cycles required to trigger liquefaction were observed for specimens receiving over 100 preconditioning cycles. For these specimens, progressive increases in measured secant moduli and relative densities with increasing drained cycles suggested that the majority of voids present at the top platen-soil interface were eliminated during the first 100 preconditioning cycles. Subsequent cycles were found to dramatically increase cyclic resistances, which can likely be attributed to progressive changes in the initial soil fabrics resulting from pre-straining effects (Finn 1981; Andersen 2009). Therefore, preconditioning protocols must be

developed to ensure the engagement of specimens at the top platen-soil interface while minimizing adverse effects on initial soil fabrics and subsequent soil responses.

Independent experimental data from previous studies suggested that for similar conditions, air-pluviated specimens of Ottawa F-65 sand should require about 40 loading cycles to trigger liquefaction for a *CSR* of 0.10 (fig. 5). For the materials, equipment, and procedures used during this testing, it was therefore identified that 115 strain-controlled drained cycles, with an amplitude of about 0.045 % shear strain, should be applied under a vertical effective stress of 25 kPa during preconditioning to prepare specimens that achieve liquefaction triggering after 40 undrained cycles ($CSR = 0.10$, $\sigma'_{vc} = 100$ kPa), which is consistent with similar past studies.

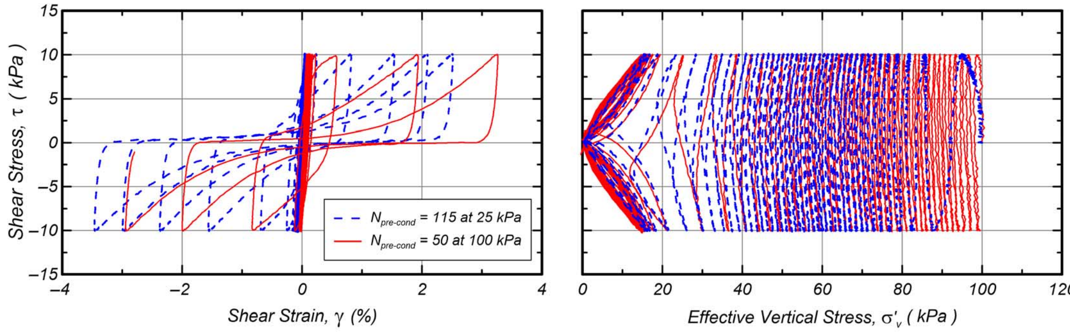
This preconditioning protocol was used to develop liquefaction-triggering plots for specimens with identical D_R and σ'_{vc} values but with different applied cyclic stress ratios (Test Group 3b, Table 1). Liquefaction triggering curves were determined for specimens with ridged platens using both the identified preconditioning protocol as well as no preconditioning (fig. 5). Triggering curve data obtained using the identified preconditioning protocol agreed well with data from similar past studies and exhibited higher liquefaction resistances when compared to similar tests without preconditioning.

CHANGES IN SUBSEQUENT UNDRAINED BEHAVIORS BECAUSE OF PRECONDITIONING

Previously, it was shown that the application of more than 100 preconditioning cycles can lead to a large increase in liquefaction-triggering resistances, which was associated with progressive changes in soil fabrics because of pre-shearing effects. However, the precise number of cycles after which pre-shearing effects begin to alter soil fabrics and subsequent soil behaviors cannot be definitively identified. It is therefore necessary to acknowledge that some changes in soil fabrics may occur during preconditioning sequences, which may alter subsequent soil behaviors. The experimental data presented herein are solely representative of reconstituted specimens subjected to a preconditioning sequence prior to shearing. Still, the described approach for improving platen-soil engagement may be useful for parametric investigations using reconstituted specimens wherein all samples are prepared and preconditioned in identical manners. Although undisturbed sand samples are not commonly used for laboratory testing, the application of preconditioning sequences to such samples is not recommended, as this may induce unknown disturbances and changes in in situ soil fabrics, all of which were not examined in this study.

Changes in subsequent soil behaviors not only depend on the number of drained preconditioning cycles but also on the loading conditions at which preconditioning is performed. Following the identification of a preconditioning protocol, a series of DSS tests was performed to investigate the effect of changes in the vertical effective stress present during preconditioning. Collectively, the results of these tests suggested that when the vertical effective stress present during preconditioning cycles was larger, a smaller number of drained cycles was required to effectively engage specimens. As shown in figure 5, when preconditioning cycles were applied at a vertical effective stress of 100 kPa (rather than 25 kPa used in the previously discussed protocol), only 50 drained cycles were required for specimens to obtain similar liquefaction resistances. While consistency of liquefaction resistances with past studies could be achieved with either protocol, the presence of a vertical effective stress during preconditioning that was identical to the final consolidation stress (i.e., 100 kPa) appeared to significantly affect specimen contractive tendencies during the onset of undrained cyclic loading. As shown in figure 7, much smaller reductions in vertical effective stresses were observed during the first cycle for specimens preconditioned at 100 kPa when compared to similar specimens preconditioned at 25 kPa despite having similar triggering resistances. The greater initial contraction observed in specimens preconditioned at lower vertical effective stresses is more representative of behaviors expected for normally consolidated specimens, which suggests that over-consolidation of specimens may result from preconditioning at a vertical effective stress that is identical to the target consolidation stress. It is recommended that preconditioning therefore be performed at a vertical effective stress level of no more than 25 % of the target consolidation vertical effective stress to reset the stress history of specimens prior to undrained shearing.

FIG. 7 Comparison of DSS tests performed on specimens of Ottawa F-65 sand ($D_R = 60$ %) with preconditioning cycles applied at different vertical stress levels.



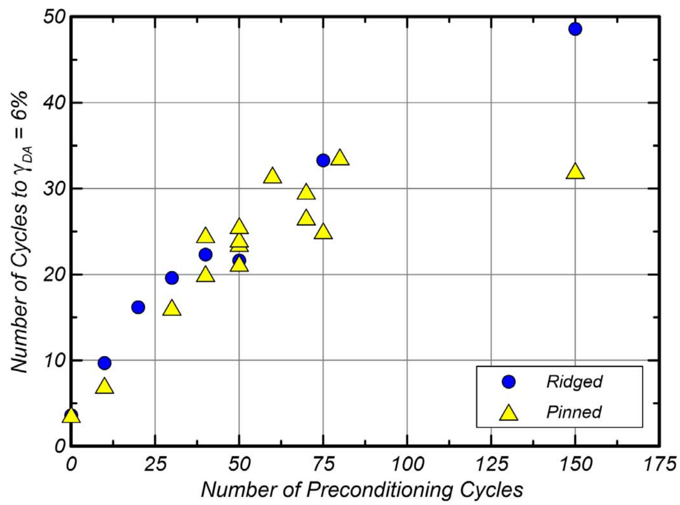
RECOMMENDATIONS FOR DEVELOPING LAB-SPECIFIC PRECONDITIONING PROTOCOLS

While this study presents the rationale and testing processes needed to develop lab-specific preconditioning protocols for constant-volume DSS tests, details regarding applied stresses and cycle numbers are specific to the equipment, materials, and procedures used. Therefore, it is recommended that researchers perform similar experiments involving the application of different numbers of preconditioning cycles to evaluate the appropriate level of preconditioning required for other platen geometries, soil gradations/angularities, preparation procedures, and equipment. For example, figure 8 compares results obtained for loose Ottawa F-65 sand specimens preconditioned under a vertical effective stress of 100 kPa using either ridged or pinned platens with varying numbers of applied preconditioning cycles. As shown, when 0 to 80 preconditioning cycles are applied prior to shearing, specimens with pinned platens exhibited similar liquefaction resistances compared to similar specimens with ridged platens. However, triggering resistances are quite different when 150 preconditioning cycles are applied, suggesting further investigation of the effect of platen geometries is needed. While both platen types can be used, lab-specific testing can help identify the effect of such variables and adjust preconditioning protocols to maintain consistency of testing data with reliable benchmarks from the literature, other testing devices, or both.

The lab-specific protocol identified in this study was guided by past experimental data available for Ottawa F-65 sand. In the absence of such reference tests, it is recommended to perform a testing plan similar to that

FIG. 8

Number of undrained cycles required to trigger liquefaction ($\gamma_{DA} = 6$ %) for similar specimens involving pinned and ridged porous platens and varying numbers of applied preconditioning cycles.



presented herein to examine the effect of the number of preconditioning cycles ($N_{pre\text{-}cond}$) on changes in specimen D_R, secant moduli values, and numbers of loading cycles required to trigger liquefaction. The stabilization of changes in D_R (fig. 6A) and the sudden increase in N_{liq} (fig. 6B) may be used as criteria to define an appropriate $N_{pre\text{-}cond}$ for which engagement at the top platen-soil interface is improved without excessively altering soil responses. Using similar criteria for the tests shown in figure 6, the value of $N_{pre\text{-}cond}$ would be approximately 100, which is very close to the value determined by comparison with reference tests ($N_{pre\text{-}cond} = 115$). Lastly, additional geotechnical testing of similar specimens using alternative testing devices (e.g., triaxial, hollow cylinder) can provide important reference data needed to develop and verify lab-specific preconditioning protocols.

Conclusions

Ensuring the effective transfer of shear stresses to soil specimens is a key requirement for all DSS tests. This transfer can be accomplished using flat platens as recommended by ASTM D8296-19, but care must be taken to ensure that platens have a roughness compatible with the tested soil to avoid slippage at the top platen-soil interface (e.g., Morales, Humire, and Ziotopoulou 2021). If in a given equipment the flat platens are found to not be adequate, the use of porous platens with protrusions (e.g., ridges, pins) can provide the ability to effectively transfer shear stresses within sand specimens without slippage at the top-platen soil interface. Although textured platens alone offer improved engagement, preconditioning consisting of the application of small-strain drained cyclic loading is needed to ensure that voids are removed from the top platen-soil interface.

The preconditioning protocol developed in this study consists of the application of strain-controlled drained cycles prior to consolidation to the target overburden stress. The number of preconditioning drained cycles ($N_{pre\text{-}cond}$) required to ensure specimen engagement was determined by the following methods: (1) analyzing changes in D_R resulting from the application of drained cycles and (2) comparing the number of loading cycles required to trigger liquefaction (N_{liq}) to past experimental data available for the same tested material. A preconditioning phase consisting of the application of 115 strain-controlled drained cycles (0.045 % shear strain amplitude) under a vertical effective stress of 25 kPa was found to effectively engage sand specimens at the top platen-sand interface without significantly affecting the stress-strain response of reconstituted Ottawa F-65 sand specimens as suggested by the consistency between the achieved data and the results of similar past studies. Although the identified preconditioning protocol is specific to the materials, equipment, and procedures used in this study, recommendations are provided, which can be used to develop similar procedures for tests involving other conditions including textured platens with varying geometries, other equipment and preparation procedures, and different sandy soil types.

While preconditioning sequences can improve specimen engagement at platen-sand interfaces, preconditioning can also result in significant changes in subsequent soil responses. These effects can include changes in specimen volumetric tendencies during the onset of undrained cyclic loading, such as the case when preconditioning is applied at a vertical stress similar to the target consolidation stress, as well as dramatic increases in triggering resistances, such as the case when an excessive number of preconditioning drained cycles is applied. The selection of preconditioning procedures should always be evaluated with reference to a testing plan's primary objectives and scope to ensure that its effects on the soil behaviors of interest (e.g., liquefaction resistance) are more fully understood. Although not considered in this study given the complexity of the engagement issues at the platen-soil interface, further work is required to investigate the importance of other variables (e.g., drained preconditioning cycle strain amplitudes, soil grain size, platen geometry and roughness, loading frequency) on preconditioning sequences and their collective effects on behaviors of interest. The sensitivity of tests characterizing liquefaction resistances to both sand-platen engagement and preconditioning sequences also highlights remaining concerns regarding the repeatability of DSS results across different laboratories and research facilities. For that reason, the authors encourage the performance of a collaborative round robin testing program to assess the repeatability of DSS testing results on sandy soils that have no existing reference test data.

Finally, the presented DSS tests were aimed at evaluating the liquefaction behavior of sands, and responses of interest (e.g., cycles required for liquefaction triggering) were shown to depend strongly on the preconditioning protocols followed. Thus, the utility of similar laboratory testing results will strongly rely on the thorough documentation and dissemination of all testing procedures (e.g., preconditioning). This information is valuable for evaluating uncertainties, providing more robust experimental databases, supporting future reexaminations of published data, and promoting progressive improvements in both laboratory equipment and testing protocols.

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