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Shuying Wang

Ronaldo Luna
Missouri University of Science and Technology, rluna@mst.edu

Richard Wesley Stephenson
Missouri University of Science and Technology, rwstephenson@mst.edu

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Shuying Wang,[1] *Ronaldo Luna,*[1] *and Richard W. Stephenson*[1]

A Slurry Consolidation Approach to Reconstitute Low-Plasticity Silt Specimens for Laboratory Triaxial Testing

ABSTRACT: Silt specimen reconstitution using a slurry consolidation approach is commonly used for laboratory testing. This paper presents a new slurry consolidation approach to reconstitute silt specimens for use in triaxial testing. Silt specimens were reconstituted in a split vacuum mold mounted on a special experimental setup. The uniformity of the reconstituted specimens was verified by measuring the water content and grain size distribution throughout the specimens. The testing program was expedited using a special sample handling technique to move the specimen from the special experimental setup to the triaxial chamber base platen. The handling process did not disturb the specimens to a measurable degree. Further, the replicas of the reconstituted specimens were verified by submitting them to basic volumetric measurements followed by static and cyclic triaxial tests. The triaxial test results reported very small differences.

KEYWORDS: low-plasticity silt, reconstituted specimens, specimen translation, slurry consolidation, specimen uniformity, testing replicas

Introduction

Low-plasticity silt occupies the uppermost stratigraphic position over extensive areas of the Central United States. It has different shear strength when compared to sands and clays and can liquefy during earthquakes, changing its mechanical properties. There is a continued need for experimental investigation of the unique static, cyclic, and postcyclic behavior of low-plasticity silt. One of the important aspects is how to prepare specimens for laboratory testing, because the specimen preparation technique strongly impacts testing results (Kuerbis and Vaid 1988).

The preferred way to conduct laboratory testing of natural soil deposits is to use undisturbed soil sampling. However, it is very difficult to recover undisturbed samples of low-plasticity silt and sand, because they are disturbed easily and are difficult to recover. One approach to recover undisturbed specimens is the freezing method, but it has a high cost and is of limited availability. Another method is to inject a gel or similar material to solidify the soil, which is then cored. The gel is then removed in the laboratory under controlled conditions. However, this process is very difficult to do with low permeable soils and suffers from potentially high disturbance as well. Consequently, the most common technique is to reconstitute the specimen in the laboratory. The key objective for specimen reconstitution is to obtain properties identical or at least very close to those in situ. As said by Kuerbis and Vaid (1988), a reconstituted sand sample preparation technique must follow five criteria: The ability to prepare the desired density, uniformity in void ratio, full saturation, no particle size segregation, and simulation of natural soil deposition. These criteria should also be applicable to the preparation of silt specimens. Herein, the full saturation can be achieved using high back pressure.

Low-plasticity silt is a difficult soil material to test in the laboratory. There are limited laboratory testing studies available in the literature (e.g., Yasuhara et al. 2003; Hyde et al. 2006; and others). Slurry consolidation (or deposition) has been used to prepare reconstituted specimen for silt. However, the uniformity of specimen was not reported well; the techniques of specimen preparation were complicated; or the testing process was too time consuming. Although silt specimens may be consolidated similarly to clay specimens, they cannot stand alone and can be disturbed during trimming because they cannot hold suction over a longer period of time.

This paper presents a new approach of slurry consolidation to reconstitute low-plasticity silt specimens in a split mold without trimming and techniques of specimen transfer to expedite a triaxial testing program. The specimen uniformity was verified with measurements of water content and grain size distribution throughout the specimen. This specimen preparation was developed within an experimental program to study the static and cyclic behavior of silts. The preparation of replicas was needed so that the effects of different cyclic stress ratios (CSRs) and confining stresses could be isolated from soil specimen variations. It was found early on that the specimen preparation technique affected testing dramatically and the procedure presented herein is the one that produced superior results, according to the replicas of static and cyclic triaxial tests.

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[1]Missouri Univ. of Science and Technology, Rolla, MO 65409.

Research Background

The common methods to reconstitute soil specimens include moist tamping (MT), water pluviation, air pluviation (AP), and slurry consolidation methods. These different methods can yield different soil properties for the same materials under identical test conditions due to different fabrics produced by the specimen preparation method (Ladd 1977; Mulilis et al. 1977; Kuerbis and Vaid 1988; Murthy et al. 2007). Soil specimens prepared by wet tamping could have a cyclic strength as much as 100 % greater than those prepared by dry deposition (Ladd 1977). The specimens prepared by the MT method have considerably higher undrained shear strength and a slightly smaller flow potential than those prepared by the slurry deposition (SD) method (Murthy et al. 2007). However, at large

strain, these differences in fabric vanish, leading to a unique fabric at the critical state. Wood et al. (2008) reported that the effect of the depositional method on the undrained response decreased with an increase in soil density, and this effect became more significant with increased silt content, particularly at lower densities. The effect of silt content on the change of the microstructure due to the depositional method was reported by Yamamuro et al. (2008). Dry funnel deposition yielded a higher percentage of potential unstable grain contacts than water sedimentation (or pluviation), and this effect was pronounced as silt content increased.

The MT method best models the soil fabric of compacted construction fills, for which the method was originally designed (Kuerbis and Vaid 1988). Water tension forces exist in the specimen and a honeycomb structure easily forms (Guo and Wang 2009). Vaid (1994) stated that the MT technique neither simulates the fabric of alluvial soil deposits nor guarantees specimen uniformity. Bradshaw and Baxter (2007) presented a new modified MT method and stated that the samples using this method could give comparable cyclic strengths to the slurry sample and the in situ block samples. They compared the new modified MT method with the slurry method for the Wellington Ave. Silt and with the block sample method for the Olneyville Silt, respectively. Making a direct comparison with the same silt material would be preferred.

The AP method models the natural deposition process of windblown Aeolian deposits, which generally consist of either well-sorted sand or well-sorted silt (Kuerbis and Vaid 1988). Well-graded sand is not suitable for the AP method. It is easily segregated, since the process of sample saturation may disrupt the initial sand fabric and fines are washed out from the sample (Kuerbis and Vaid 1988; Carraro and Prezzi 2007).

The water pluviation method simulates the deposition of sand through water as it occurs in many natural environments and mechanically placed hydraulic fills (Kuerbis and Vaid 1988). It produces uniform samples of poorly-graded sand, but particle size segregation is a problem. Water pluviation of a well-graded soil results in a larger maximum void ratio comparable to that of a more poorly-graded soil. Vaid et al. (1999) carried out an experimental program to study the influence of reconstituted methods for sand. They concluded that water-deposited specimens were very uniform compared to the large non-uniformities that usually occur on MT. Vaid et al. (1999) compared the shear resistance of undisturbed frozen sand with that of other sample preparation methods and presented that water pluviation could closely simulate the fabric of the natural alluvial and hydraulic fill sands. Høeg et al. (2000) finally stated that the method of water pluviation seems promising, although there are difficulties with segregation for sands with high fines content.

It is well-known that a silt specimen is difficult to densify using vibration to achieve the desired density. The SD method is a common technique to prepare silt specimens, and even sandy silt and silty sand specimens, although the SD method only yields loose specimens compared to the silt deposit in the field. Using the SD method, specimens easily reach saturation under back pressure compared to the MT and AP methods because specimens are essentially prepared saturated (Carraro and Prezzi 2007). Ishihara et al. (1978) developed the SD technique for silty sand and sandy silt but their specimens were not very homogeneous when the fine content was between 30 % and 80 %. Kuerbis and Vaid (1988) presented a new SD method to prepare sand specimens. The specimens were exceptionally homogeneous with respect to void ratio and particle size distribution, regardless of gradation and fines content. This method simulated well the soil fabric found within a natural fluvial or hydraulic fill deposit, yet created homogenous samples that can be easily replicated as required. Carraro and Prezzi (2007) carried out another slurry method for silty sands. The homogeneous specimens of sand containing fines were prepared and the characteristic strain-softening response associated with the usually collapsible fabric obtained by the AP and MT techniques was not observed. Yasuhara et al. (2003) used the silt SD method to prepare specimens and study the postcyclic degradation of strength and stiffness. Hyde et al. (2006) also prepared a silt specimen using the SD method. The samples were not highly uniform due to the friction in the consolidation tubes and sample disturbance during preparation. They stated that this method of preparation did not produce samples that were representative of silt placed as a coastal fill material, which would often be pluviated under water and then consolidated by an overburden. Instead, they applied a simple sedimentation technique to consolidate the slurry under a negative head of water. Hyde et al. (2006) did not report the verification of uniformity within the specimen. In addition to the above-mentioned SD methods for silt, sandy silt, and silty sand, Khalili and Wijewickreme (2008) presented a new slurry displacement method to reconstitute specimens of mixtures of waste rock and tailings and overcame the difficulties in the preparation of highly gap-graded specimens.

It can be concluded from the recent published results that the SD method is the preferred method to reconstitute slit specimens. However, the problems shown by other researchers' work include the complexity and duration of specimen preparation. This paper presents a new approach to prepare low-plasticity silt specimens for triaxial testing.

TABLE 1—*Index properties of MRV silt.*

Index Properties	Values
Clay content (<2 μm)	14.5 %
Liquid limit	28
Plastic limit	22
Plasticity index	6
Specific gravity	2.71
Maximum void ratio	1.604
Minimum void ratio	0.436
Compression index (C_c)	0.0896
Recompression index (C_r)	0.0090

Subject Soil

The soil material used in this study consists of silt originally from Collinsville, IL, about 13 miles east of the Mississippi River. The index properties of the Mississippi River valley (MRV) silt were determined using multiple laboratory tests and are summarized in Table 1. The Atterberg limits were determined following the standard ASTM D 4318-10 (2010) and further details on the determination of the liquid limit will be provided later in this section. The specific gravity was measured based on the standard ASTM D 854-10 (2010). The maximum void ratio and minimum void ratio were obtained according to the SD approach and modified compaction approach, respectively (Polito and Martin 2001; Bradshaw and Baxter 2007; ASTM D 1557-09 2009). Consolidation parameters were determined using isotropic consolidation pressure in the triaxial chamber. According to the Unified Soil Classification Sys-

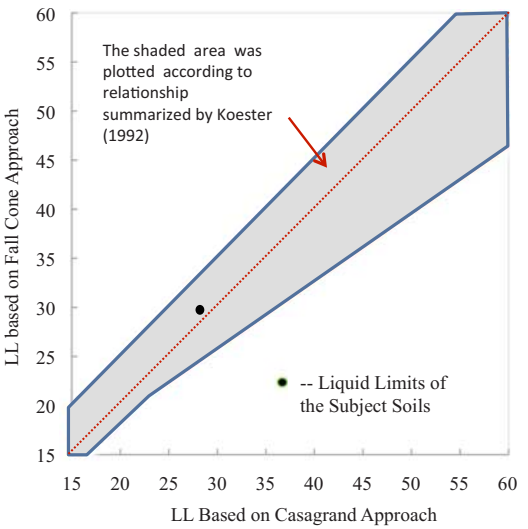


FIG. 1—*Relationship between liquid limits determined by Casagrande and Fall Cone approaches.*

tems, ASTM D 2487-10 (2010), the MRV silt was classified with a group name: "Silt" and symbol: ML.

It is difficult to determine the liquid limit of low-plasticity silt. There are two common approaches to measure the liquid limit: The Casagrande approach (ASTM D 4318-10 2010) and the Fall Cone approach (BS 1377-2 1990). Other researchers have compared the two approaches comprehensively. For the upper range of liquid limits, the Casagrande method results in a slightly higher value when compared to the Fall Cone method; conversely the opposite is true for the lower range (Koester 1992; Sridharan and Prakash 2000; Prakash and Sridharan 2006). The Casagrande approach is popular in the United States; however, its procedure is much more elaborate than the Fall Cone approach for low-plasticity silt. This is mainly because the silt easily cracks when cutting the silt paste using the grooving tool in the Casagrande cup. Thus, the test results for low-plasticity silt using the Casagrande approach are more questionable and have low reproducibility.

The Fall Cone approach was used to check the validity of the liquid limit obtained from the Casagrande approach. The liquid limit for the silt was 28 using the Casagrande approach and 30 using the Fall Cone method. The data point for the subject silt material used was placed on Fig. 1, which shows the plotted relationships summarized by Koester (1992). The point falls within the range of the relationships made by many researchers. The liquid limit of 28 was used here to facilitate comparison with other soils, whose liquid limits have also been determined using the more common Casagrande approach.

Specimen Reconstitution

Reconstitution Procedures

The silt specimens were reconstituted using a slurry consolidation method in a 71.1 mm diameter split vacuum mold. The target dimensions of the specimen were 71.1 × 142.2 mm to accommodate static and dynamic triaxial testing. The silt slurry was consolidated under incremental dead weights and vacuum. The procedure to prepare specimens was presented as follows.

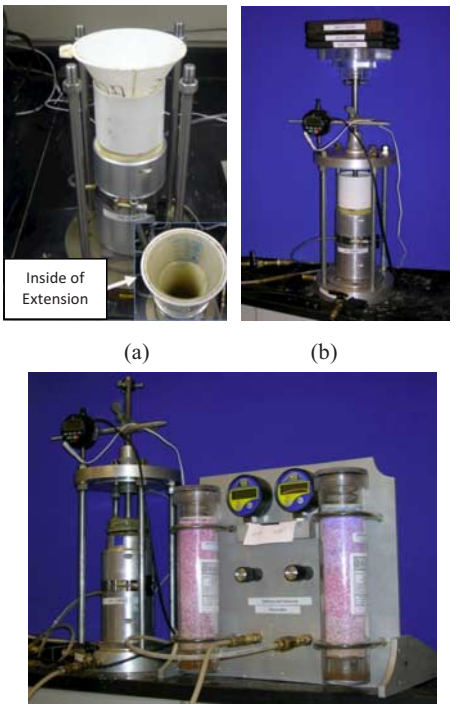


FIG. 2—*Experimental setup used for reconstituted silt specimens: (a) Slurry holder; (b) slurry consolidated under incremental dead weight; (c) specimen consolidated under the vacuum.*

Preparation of Silt Slurry—The portion of the silt that passed through the No. 40 sieve (0.425 mm) was selected for the slurry. 1 kg of dry silt was mixed with deaired water, resulting in a water content of 44 %. The slurry was then covered with plastic wrap to prevent water from evaporating and left to soak overnight (for about 10 h) to ensure complete absorption of the water. Finally, the slurry was mixed thoroughly for 15 min using an industrial Hobart electric mixer (Model: N-50) with a flat paddle. To avoid air entrapment during mixing, the slurry was mixed at a low speed (60 rpm).

Pouring of Slurry into Split Vacuum Mold—After the silt slurry was mixed, it was poured into a split vacuum mold. Because the volume of the slurry was larger than the split vacuum mold, an extension tube with internal graduated marks was placed on the top of split mold (Fig. 2(*a*)). The slurry was poured into the split vacuum mold through a funnel to the desired height so that the specimen target height (142.2 mm) was obtained after consolidation under weights and vacuum. The desired slurry height was determined through several trials. The excess slurry was collected in a bowl so that the mass of the soil specimen could be determined accurately.

Consolidation of the Silt Slurry in the Split Mold—The slurry was left to settle under its own weight for 3 h to prevent the slurry from squeezing out under the dead weights. A plastic cap was placed on the slurry for 2 h, and a loading rod was placed overnight. The loading times were determined based on several trials in order to avoid squeezing the slurry out of the mold during incremental weight placement. As shown in Fig. 2(*b*), weights were then

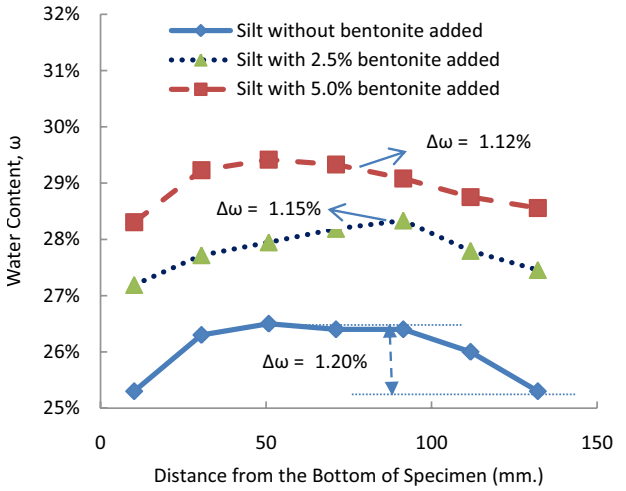


FIG. 3—*Variation in water content from top to bottom of specimen.*

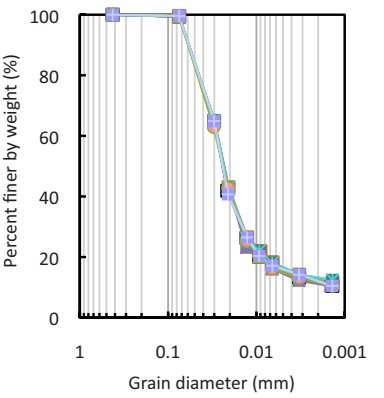
added, and primary consolidation was achieved under each load increment before the next weight was added. The consolidation progress was monitored using a digital dial gauge on the loading rod to monitor specimen deformation. The vertical stress (less than 32.3 kPa) imposed by all the weights added was less than the desired effective minimum consolidation pressure of 50 kPa.

Use of Vacuum to Improve Consolidation Pressure—Due to the friction that develops between the membrane liner and the consolidating soil in the mold, the effective vertical consolidation pressure tends to decrease from the top (loading) face of the specimen to the bottom of the specimen, resulting in a non-uniform void ratio. To improve the uniformity of the specimen, identical vacuum pressures (less than effective consolidation pressure) were applied simultaneously at the top and bottom of the specimen. The vacuum was applied using a unique differential vacuum control apparatus, which collects the water drained from the specimen and dries the air with a gas drying unit to avoid the drained water being sucked into the vacuum regulator and pump when the slurry consolidates under vacuum. In this way, the specimen consolidated under the same top and bottom pressures. Before applying the vacuum, the weights were removed, the top porous stone and filter paper were replaced with clean ones, the membrane was folded over the top cap, and o-rings were placed around the membrane. The consolidation process under the vacuum was also monitored using the digital dial gauge (Fig. 2(*c*)). The specimen was then ready for triaxial testing.

The soil adhering to the porous stone and filter paper was cleaned. After the soil particles settled out of suspension, the surface water was removed, and the excess soil was dried and weighed to obtain the total weight of the silt solids in the specimen. Each incremental pressure took about 8 h to consolidate. Preparation of one specimen under all loads took a total of about two days.

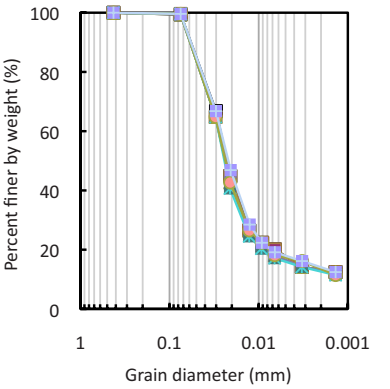
Specimen Uniformity

The uniformity of the silt specimen was verified by measuring the variation in water content and particle size distribution throughout the specimen. Assuming that the degree of saturation was identical throughout the specimen, water content is a measure of void ratio. The grain size distribution indicated whether particles had been segregated by size.



Average	
Diameter (mm)	% finer
0.425	100.00
0.075	99.51
0.030	64.72
0.021	42.48
0.013	25.76
0.009	20.88
0.007	17.15
0.003	13.61
0.001	11.04

(a)



Average	
Diameter (mm)	% finer
0.425	100.00
0.075	99.51
0.030	65.37
0.021	43.62
0.013	26.49
0.009	21.77
0.007	18.70
0.003	14.74
0.001	12.15

(b)

FIG. 4—*Variation in grain size distribution of silt specimen reconstituted by SD for each of the seven slices: (a) Natural silt; (b) silt with 2.5 % bentonite added.*

The silt specimens were cut into seven slices, and the water content of each slice was measured. Figure 3 shows the variation in water content versus the height of the specimen. As expected, the water content was lower towards the top and bottom ends of the specimen where the vacuum was applied and the pressure gradients were the highest. The maximum difference in water content (Δw) throughout the specimen was just 1.20 %.

To verify that the specimen preparation was not dependent on the fines content, two other silt specimens were prepared with 2.5 % and 5 % bentonite added. With the added bentonite, the variation in water content ($\Delta\omega$) was even smaller, as seen in Fig. 3. These results make it reasonable to conclude that the void ratio was essentially uniform throughout the specimen.

Once the water content was determined, 50 g were cut from each silt slice and placed in a 250 mL beaker mixed with 125 mL of sodium hexametaphosphate solution (40 g/L) for hydrometer analysis (ASTM D 422-63 (Reapproved 2007) 2010). The dry silt slices were easily disaggregated into the solution. Figure 4 shows the particle size distributions, which were very consistent. Actually, the deposition of silt slurry is different from that of sand. For sand, the larger sand particles settle easily and quickly so that segregation may be more common. However, for silt slurry, the water content is only about 1.6 times the liquid limit. Voids among the silt particles are insufficient to allow the larger particles to pass and settle down to induce segregation.

The distribution of water content and particle size in the reconstituted specimens of natural silt and silt with bentonite indicated that the specimens were quite uniform and could be used to prepare relatively identical reconstituted silt specimen.

Specimen Preparation for Testing

Specimens can be prepared directly on the triaxial base platen. Saturation, consolidation, and shearing can then be completed with the specimen in the same position. This process, however, makes a complete test sequence time consuming. To expedite the testing process, this research developed a special procedure. The specimen was prepared on another base platen, which was then moved to the triaxial base platen. A key requirement of this process was that the specimen be moved with as little disturbance as possible. The following procedure was developed to accomplish this:

(1) The split vacuum mold was removed while the vacuum was kept on the specimen. A split miter sample mold with a diameter of 71.0 mm was used to hold the specimen. A clamp was used to hold the split mold together (Fig. 5(*a*)).
(2) The vacuum was then reduced to zero. After waiting for a 30 min period to dissipate the vacuum and avoid entrapment of air in the specimen, the o-rings and the membrane were stretched around the bottom of the split miter sample mold (Fig. 5(*b*)).
(3) The top porous stone and cap were left attached to the specimen, and the specimen with the bottom porous stone was slid onto a metal plate. Before this, the plate was placed next to the base so that the specimen could be moved onto the metal plate with the bottom porous stone level (Fig. 5(*c*)).
(4) The specimen, with the porous stones and cap, was moved onto the triaxial base platen and fixed with another clamp (Fig. 5(*d*)).
(5) The membrane and o-rings were stretched down to the triaxial base platens (Fig. 5(*e*)).
(6) The plastic cap was removed, and the triaxial top cap was carefully placed. The membrane was folded over the triaxial top cap, and the o-rings were placed around the membrane (Fig. 5(*f*)).
(7) A 45 kPa vacuum was applied at the ports connected to the top and bottom ends of the specimen with tubing and was left for 8 h to remove any air in the specimen, porous stones, and lines. The vacuum system allowed the vacuum to be increased as necessary to remove more air bubbles out of the specimen to achieve good saturation. However, the vacuum was always smaller than the effective consolidation pressure (Fig. 5(*g*)).
(8) The split miter mold was removed and specimen dimensions were measured (Fig. 5(*h*)). The cell chamber was mounted and secured, and then deaired water was filled in the chamber. After a low cell pressure was applied to hold the specimen, the vacuum was removed and the specimen was then connected with tubing to the top and bottom burettes on the pressure panel to allow access of deaired water into the specimen under back pressure (air bubbles in the tubing should be drained out with deaired water from the burettes). At this time, the specimen was ready for triaxial testing.

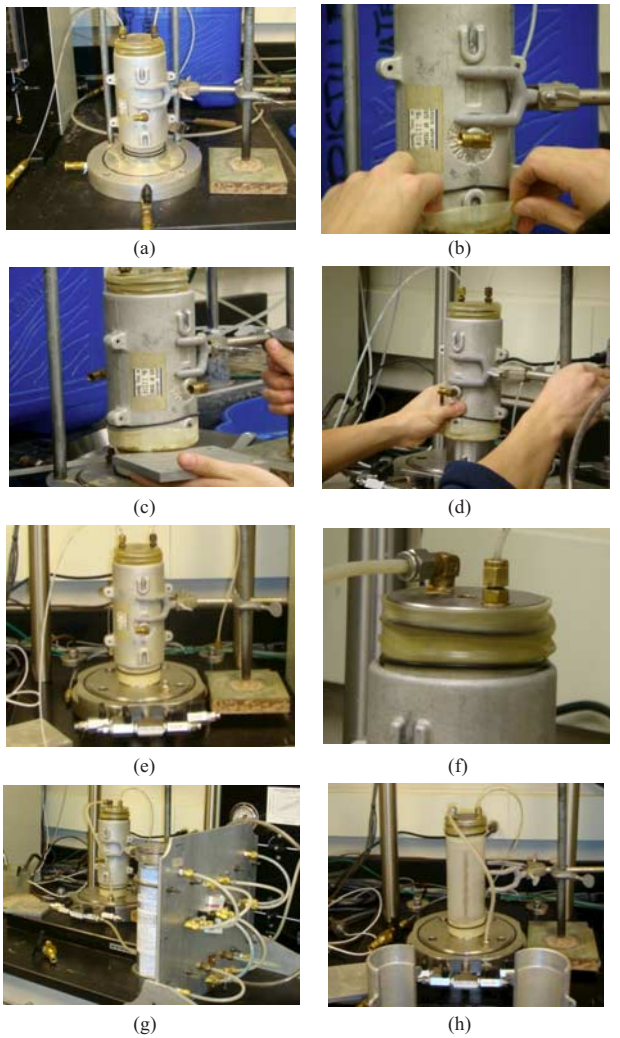


FIG. 5—*Specimen translation from preparation location to triaxial chamber on load frame pedestal: (a) Remove the split vacuum mold and use a split miter box to hold the silt specimen; (b) Move o-rings up and stretch the membrane upwards; (c) slide silt specimen onto a metal plate; (d) move silt specimen to a triaxial base platen and fix it with a clamp; (e) stretch membrane down and move o-rings down to the triaxial base; (f) set triaxial cap with screw; (g) place vacuum at top and bottom of specimen for 8 h to remove air in the specimen; (h) remove split miter mold.*

While testing was conducted on the specimen in the triaxial chamber, another specimen was prepared on the special experimental setup simultaneously. Since the time to prepare a specimen was almost equal to that required for the saturation, consolidation, and shearing, this process reduced the time for the whole testing program by at least 50 %.

Disturbance During Handling and Moving of the Specimen

Observations of the specimen indicated that there was very little disturbance during movement as long as the specimen remained vertical. This technique required no direct handling to trim the specimen. Trimming is normally required if silt sedimentation occurs in a large-scale consolidometer, into which sampling tubes are pushed to sub-sample the silt specimen. In particular, the membrane was kept so that it helps hold the specimen during handling and moving of the specimen.

TABLE 2—*Change of diameter (mm) of specimen due to specimen translation.*

Location	Before Translation	After Translation	Difference
Top	70.45	70.40	−0.05
Middle	69.06	68.95	−0.11
Bottom	69.40	69.50	0.10

To verify that there was very little disturbance of the specimens during movement from the special experimental setup to the triaxial base platen, the resulting size of a specimen under a 45 kPa vacuum was measured with a Pi tape before and after movement (Table 2). This value was recorded as an initial diameter before the vacuum was removed. Removal of the vacuum unloads the specimen and can cause swelling. The vacuum of 45 kPa was left on the specimen for 8 h to remove the air out of the specimen after movement. This process behaved as a recompression and the size of the specimen may recover. The diameter at this time was recorded at the same location and compared to the original measurement (Table 2). If handling and movement had disturbed the specimen, the two diameters before and after movement would have varied. The difference, however, was very small, confirming that the handling and moving process created only minimal disturbance on the specimen.

Replication

The ability to produce identical specimens was verified by conducting triaxial tests under identical conditions. The objective was to quantify the reproducibility of the testing protocols and assess their quality. For this purpose, two static triaxial compression tests and several cyclic triaxial tests were conducted.

Monotonic Triaxial Tests

Two normally consolidated undrained triaxial tests with an effective consolidation stress (σ_c') of 50.0 kPa were conducted to verify the repeatability of monotonic triaxial testing under the same conditions. After the specimens were moved to the triaxial base platen from the specimen preparation location, vacuum and then back pressure were applied to saturate the specimens, resulting in a Skempton B-value higher than 0.98.

Figure 6 shows the testing results. The stress-strain curves are nearly identical in shape at the initial phase of shearing; they become dissimilar at large strains. The differences in deviator stress and excess pore pressure between the tests were insignificant under large strain. The percent differences are 5.9 % and 10.4 % of the average values of deviator stresses and excess pore pressures, respectively. Further, the reliability of stress and strain computations at large strain values (>10 %) are inherently unreliable because of the area corrections at these levels. These small differences, however, are acceptable and can be attributable to unavoidable variations in testing and to human factors. These results confirm the repeatability of monotonic triaxial compression testing on specimens prepared as described here.

Cyclic Triaxial Test

Cyclic triaxial tests were conducted at two CSRs of 0.18 and 0.35, normally consolidated to an effective confining stress of 90 kPa (Fig. 7). For a CSR of 0.18, the specimens MD2 and MD2R required 35.2 and 32.2 cycles of loading, respectively, to liquefy. The

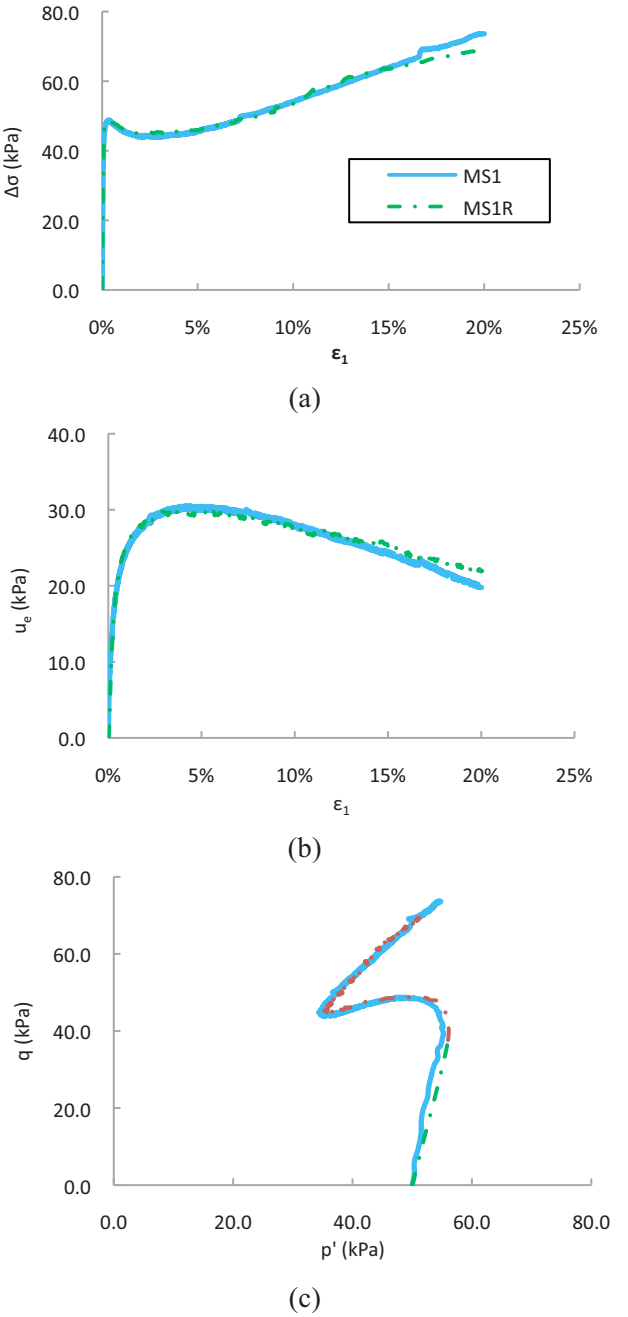


FIG. 6—*Repeatability of static testing: (a) Deviator stress versus axial strain; (b) excess pore water pressure versus axial strain; (c) stress path, $p' = (\sigma_1' + \sigma_2' + \sigma_3')/3$, $q = \sigma_1 - \sigma_3$.*

average number of cycles is 33.7. The difference between the average value and 35.2 or 32.2 is 1.5, which is only 4.5 % of the average number of 33.7. Thus, the difference of number of cycles between the two tests is small. For the higher CSR = 0.35, the tests MD4 and MD4R yielded even smaller differences, as shown in Fig. 8. Both liquefied at only 1.2 cycles of loads. The excess pore water pressure and stress paths were nearly identical. Thus, the replicated reconstituted specimens produced nearly identical dynamic failure conditions of liquefaction.

In addition to the above testing program, this specimen preparation technique was used for studying the postcyclic behavior of silt soils. Seven cyclic triaxial tests were conducted, each with CSR

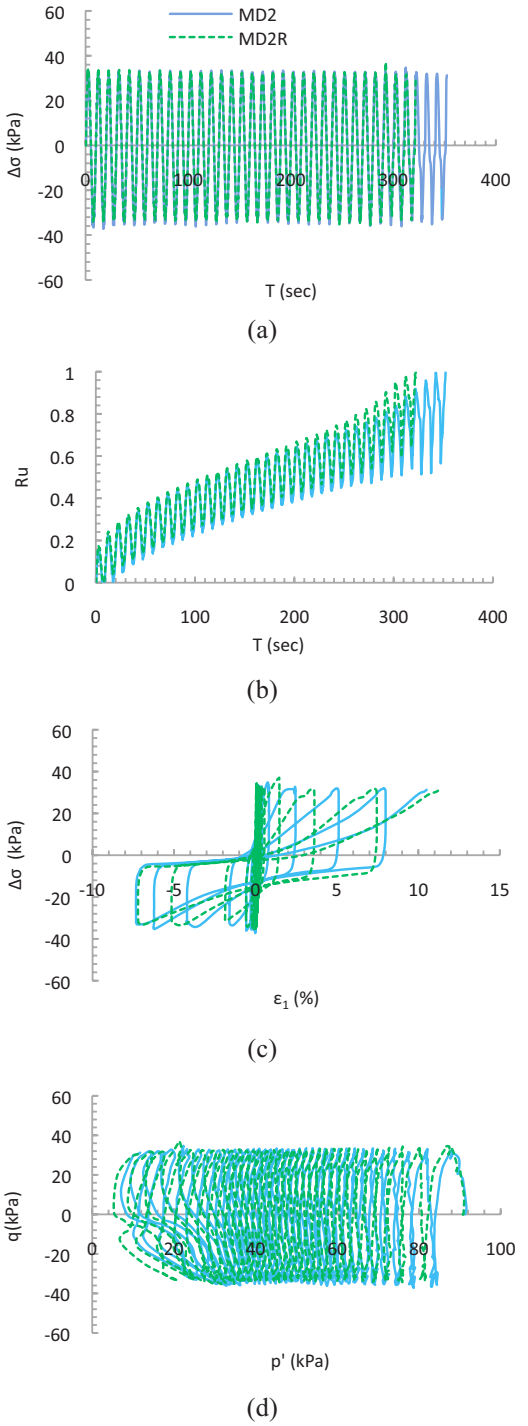


FIG. 7—*Repeatability of cyclic testing with CSR of 0.18: (a) Deviator stress versus time; (b) R_u versus time; (c) deviator stress versus axial strain; (d) q versus p′.*

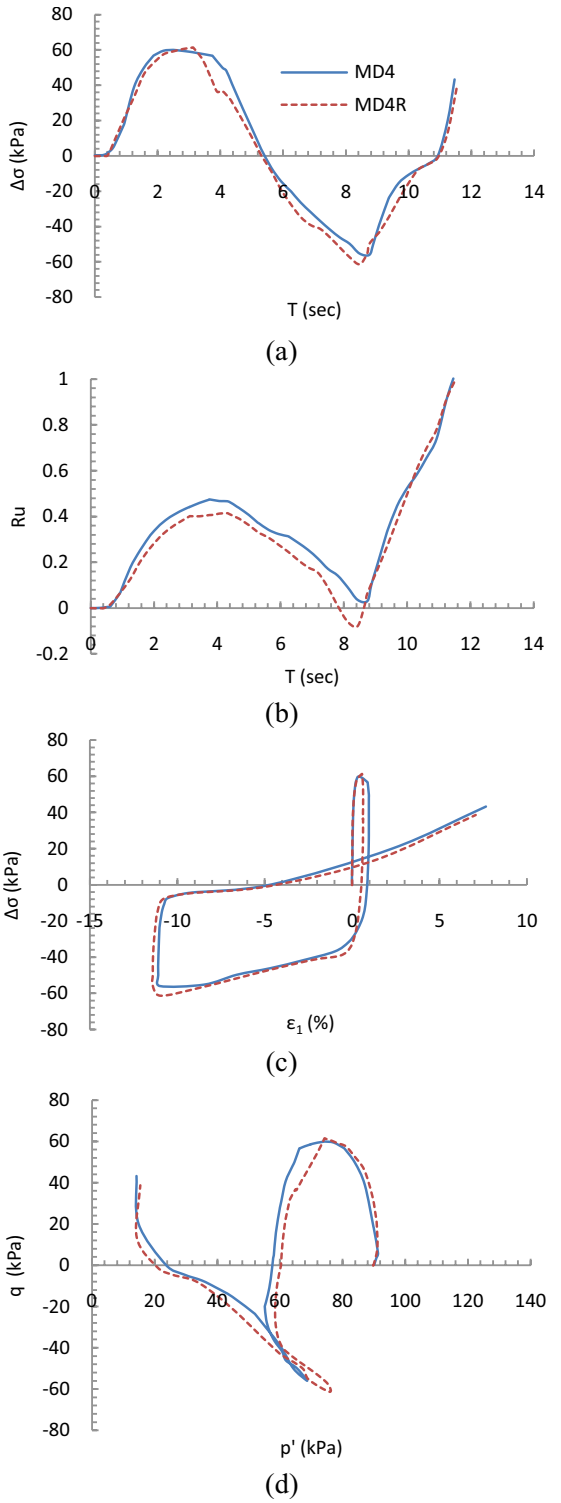


FIG. 8—*Repeatability of cyclic testing with CSR of 0.35: (a) Deviator stress versus time; (b) R_u versus time; (c) deviator stress versus axial strain; (d) q versus p′.*

=0.18 and σ_c'=90 kPa. Table 3 shows the void ratio (e) after normal consolidation and the number of loading cycles (N_c) to liquefy the specimens. The MD and MF tests were used to study liquefaction resistance and postliquefaction behavior, respectively. The coefficient of variation of the void ratio is 0.0125, and that of the number of loading cycles is 0.1023. These small coefficients of variation were considered acceptable for a research quality testing program.

The liquefaction resistance of the tested silt is shown in Fig. 9 with two more cyclic tests under the CSRs of 0.25 and 0.10. The testing showed that the specimen with a CSR of 0.10 did not liquefy. The curve of CSR versus number of cycles is comparable to the liquefaction resistance of other silty soils (Boulanger et al. 1998; Guo and Prakash 1999).

TABLE 3—*Statistics of cycles of loading to liquefy specimens with* CSR=0.18.

Specimen ID	MD2	MD2R	MF1R1	MF1R2	MF2	MF3	MF4	Mean	Standard Deviation	Coefficient of Variation
e	0.661	0.681	0.660	0.669	0.657	0.663	0.659	0.664	0.008	0.0125
N_c	35.2	33.2	27.1	31.1	27.2	30.1	28.1	30.3	3.1	0.1023

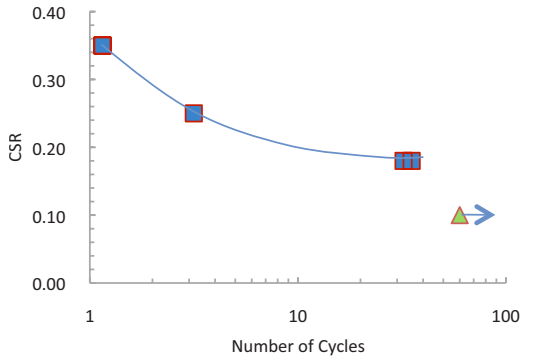


FIG. 9—*Liquefaction resistance of the MRV silt normally consolidated to effective confining pressure of 90 kPa.*

Conclusion

This paper presented a new SD (or consolidation) method with a procedure using MRV silt. Specimen uniformity was verified by measuring the water content and particle size distribution in seven slices of the silt specimens. These measurements showed very little variation throughout the length of the specimens. The testing program was expedited with a special handling and moving technique to permit simultaneous specimen preparation and triaxial testing. The reliability of this technique was verified by confirming minimal disturbance of the specimen during movement. To further verify the validity this approach, tests were repeated for both static and cyclic triaxial conditions, and the results were compared. The differences in the testing results of replicated specimens using identical testing parameters were minimal. Thus, this new approach can be used to reconstitute specimens of low-plasticity silt.

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References

ASTM D 422-63 (Reapproved 2007), 2010, "Standard Test Method for Particle-Size Analysis of Soils," *Annual Book of ASTM Standards*, Vol. 4.08, ASTM International, West Conshohocken, PA.

ASTM D 4318-10, 2010, "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils," *Annual Book of ASTM Standards*, Vol. 8.04, ASTM International, West Conshohocken, PA.

ASTM D 854-10, 2010, "Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer," *Annual Book of ASTM Standards*, Vol. 8.04, ASTM International, West Conshohocken, PA.

ASTM D 2487-10, 2010, "Standard Practice for Classification of Soils for Engineering Purposes (USCS)," *Annual Book of ASTM Standards*, Vol. 8.04, ASTM International, West Conshohocken, PA.

ASTM D 1557-09, 2009, "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))," *Annual Book of ASTM Standards*, Vol. 4.08, ASTM International, West Conshohocken, PA.

Boulanger, R. W., Meyers, M. W., Mejia, L. H., and Idriss, I. M., 1998, "Behavior of a Fine-Grained Soil During the Loma Prieta Earthquake," *Can. Geotech. J.*, Vol. 35, pp. 146–158.

Bradshaw, A. S. and Baxter, C. D. P., 2007, "Sample Preparation of Silts for Liquefaction Testing," *Geotech. Test. J.*, Vol. 30, No. 4, pp. 1–9.

BS 1377-2, 1990, "Methods of Test for Soils for Civil Engineering Purposes–Part 2: Classification Tests," British Standards Institution, United Kingdom, pp. 5–8.

Carraro, J. A. H. and Prezzi, M., 2007, "A New Slurry-Based Method of Preparation of Specimen of Sand Containing Fines," *Geotech. Test. J.*, Vol. 31, No. 1, pp. 1–11.

Guo, T. and Prakash, S., 1999, "Liquefaction of Silts and Silt-Clay Mixtures," *J. Geotech. Geoenviron. Eng.*, Vol. 125, No. 8, pp. 706–710.

Guo, Y. and Wang, Y. X., 2009, "Experimental Study About the Influence of Initial Water Content in Wet Tamping Method on Static Triaxial Test Results of Silt," *Electron. J. Geotech. Eng.*, Vol. 14.

Høeg, K., Dyvik, R., and Sandbækken, G., 2000, "Strength of Undisturbed Versus Reconstituted Silt and Silty Sand Specimens," *J. Geotech. Geoenviron. Eng.*, Vol. 126, No. 7, pp. 606–617.

Hyde, A. F. L., Higuchi, T., and Yasuhara, K., 2006, "Liquefaction, Cyclic Mobility, and Failure of Silt," *J. Geotech. Geoenviron. Eng.*, Vol. 132, No. 6, pp. 716–735.

Ishihara, K., Sodekawa, M., and Tanaka, Y., 1978, "Effects of Overconsolidation on Liquefaction Characteristics of Sands Containing Fines," *Dynamic Geotechnical Testing*, ASTM, West Conshohocken, PA, pp. 246–264.

Khalili, A. and Wijewickreme, D., 2008, "New Slurry Displacement Method for Reconstitution of Highly Gap-Graded Specimens for Laboratory Element Testing," *Geotech. Test. J.*, Vol. 31, No. 5, pp. 1–9.

Koester, J. P., 1992, "The Influence of Test Procedure on Correlation of Atterberg Limits with Liquefaction in Fine-Grained Soils," *Geotech. Test. J.*, Vol. 15, No. 4, pp. 352–361.

Kuerbis, R. H. and Vaid, Y. P., 1988, "Sand Sample Preparation—The Slurry Deposition Method," *Soils Found.*, Vol. 28, No. 4, pp. 107–118.

Ladd, R. S., 1977, "Specimen Preparation and Cyclic Stability of Sands," *J. Geotech. Engrg. Div.*, Vol. 103, No. 6, pp. 535–547.

Mulilis, J. P., Seed, H. B., Chan, C. K., Mitchell, J. K., and Arulanandan, K., 1977, "Effects of Sample Preparation on Sand

Liquefaction," *J. Geotech. Engrg. Div.*, Vol. 103, No. 2, pp. 91–108.

Murthy, T. G., Loukidis, D., Carraro, J. A. H., Prezzi, M., and Salgado, R., 2007, "Undrained Monotonic Response of Clean and Silty Sands," *Geotechnique*, Vol. 57, No. 3, pp. 273–288.

Polito, C. P. and Martin, J. R., 2001, "Effects of Nonplastic Fines on the Liquefaction Resistance of Sands," *J. Geotech. Geoenviron. Eng.*, Vol. 127, No. 5, pp. 408–415.

Prakash, K. and Sridharan, A., 2006, "Critical Appraisal of the Cone Penetration Method of Determining Soil Plasticity," *Can. Geotech. J.*, Vol. 43, pp. 884–888.

Sridharan, A. and Prakash, K., 2000, "Percussion and Cone Methods of Determining the Liquid Limit of Soils: Controlling Mechanisms," *Geotech. Test. J.*, Vol. 23, No. 2, pp. 242–250.

Vaid, Y. P., 1994, "Liquefaction of Silty Soils," *Ground Failures Under Seismic Conditions, Geotechnical Special Publication*, ASCE, New York, No. 44, pp. 1–16.

Vaid, Y. P., Sivathayalan, S., and Stedman, D., 1999, "Influence of Specimen Reconstituting Method on the Undrained Response of Sand," *Geotech. Test. J.*, Vol. 22, No. 3, pp. 187–195.

Wood, F. M., Yamamuro, J. A., and Lade, P. V., 2008, "Effect of Depositional Method on the Undrained Response of Silty Sand," *Can. Geotech. J.*, Vol. 45, pp. 1525–1537.

Yamamuro, J. A., Wood, F. M., and Lade, P. V., 2008, "Effect of Depositional Method on the Microstructure of Silty Sand," *Can. Geotech. J.*, Vol. 45, pp. 1538–1555.

Yasuhara, K., Murakami, S., Song, B. W., Yokokawa, S., and Hyde, A. F. L., 2003, "Postcyclic Degradation of Strength and Stiffness for Low Plasticity Silt," *J. Geotech. Geoenviron. Eng.*, Vol. 129, No. 8, pp. 756–769.