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A comparison of results for the effective angle of friction using small and large shear box testing.

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Summarg: Reinforced soil walls are finding increasing application in Australian civil engineering infrastructure. The commonly applied Q181C (2002) 'Test Method' of determining the 'Effective angle of internal friction at constant volume conditions for granular (coarse grained) materials' is commonly applied to assess the suitability of backfill soils for compliance with design specifications. This paper presents the results of a coinparison between the results of two series of shear box tests on a typical ripped rock material that might be considered as a possible backfill material. One set of tests is performed using a 300mm shear box, on a sub 19mm fraction of the soil sample. The second set of tests is carried out using a standard small 60mm shear box on a sub 4.75mm fraction of the same soil. Tests were performed at two different shearing ratei. The results show that there is a substantial and coiisisteiit difference in the values obtained fsoni each apparatus. They suggest that the small shear box is unlikely to be a suitable alternative to the large shear box for materials containing a coarse gravel fraction.

INTRODUCTION

Assessment of the stability of slopes, earth pressures on retaining walls and the bearing capacity of foundations is often carried out using a Mohr-Coulomb strength model, based on the strength parameters c and φ. In situations where the rate of soil failure is likely to be slow, the effective strength parameters, c' and φ' are used specifically. These strength parameters are usually acquired from laboratory testing of representative samples, where the material type, method of preparation and stress conditions are chosen to simulate those that are expected to exist under service conditions. Where the conditions during testing differ from those that are likely to exist in service, it is important that the results of testing are interpreted accordingly.

Direct shear testing is a commonly employed testing method for the determination of soil shear strength parameters. On advantage of this test is that it is possible to test relatively large soil samples with ease, and so. soils with large particle sizes can be tested.

Methods for carrying out direct shear tests for geotechnical engineering purposes are well established in practice. These methods have formalised into testing standard documents such as AS1289-6.2.2 *Soil strength and consolidation tests - Determination of the shear strength of a soil - Direct shear test using a shear box* and ASTM D 3080-98 (1998) *Standard Test Methodfor Direct Shear Test of Soils Under Consolidated Drained Conditions.*

In the past 20 years or so. there has been an increasing use of reinforced earth retaining stsuctures (RE walls) in Australian geotechnical practice. Much of this has been associated with the constsuction of transportation infiastsucture. The effective friction angle is a key parameter used in the design of RE walls. In many cases, walls are designed prior to the letting of constsuction contracts, or the formulation of constsuction methodologies, and the exact nature of the backfill soils is unknown at the time of design. In order to accommodate this, walls are designed on the basis of an assumed effective friction angle, and this value is then prescribed as a minimum in subsequent construction specifications.

The materials commonly used in RE wall construction are often won from the sites of large construction projects. As such, they are often poorly processed materials of 'marginal' quality that only just comply with the specifications. Due to their potential to contain large particle sizes, the size of the test sample becomes an issue. Although the testing standards noted above have sufficient scope for application to large shear box tests, there are issues in regard to sample preparation difficulties in large boxes and the determination of shearing rates. Simplified routine testing of

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RE wall backfill soils using large shear boxes was facilitated by the drafting of a standard for that specific purpose by the Queensland Department of Main Roads. The standard, Q181C (2002). *Effective Angle of Internal Friction at Constant Volume Conditionsfor Granular (Coarse Grained) Materials,* was described in a draft form in 1994, and revised in 2002. In its 2002 form, it provides for testing using shear box sizes of a minimum dimension of 300mm x 300mm. However, such devices are relatively uncommon throughout the Australian geotechnical industry. It has been suggested that, in lieu of large box testing, adequate results might be achieved using a small shear box, where the sample has been modified to contain only the finer particle fraction, below an appropriately specified maximum size. Evidence in the literature to support (or otherwise) this idea is scarce. Palmeira and Milligan (1989) cairied out a series of direct shear tests on Leighton Buzzard Sand using shear boxes of small, medium and large size. They determined that the friction angles measured using each box did not vary significantly as a function of the size of the box, for the relatively fine granular material that was used.

The second author has conducted many large shear box tests in accordance with Q181C (1994;draft and 2002). A research program is now underway to explore aspects such as the selection of an appropriate shearing rate, the effects of retesting samples and the effect of shear box size. The aim of this paper is to present and discuss the findings of an assessment of the effects of shear box size, so that the idea of testing using a small box can be evaluated.

METHODOLOGY

This assessment of shear box size effects was simply carried out by performing two series of direct shear tests on the same material; one using a 300x300mm box, and the other using the more common 60x60mm box.

In each case tests were carried out two different shearing rates, to allow the consistency of the results to be assessed.

Also, for each box, and for each shearing rate, a minimum of 4 individual shearing tests was performed, under imposed normal stresses ranging from about 100 to 400kPa. Specific details are presented in following sub-sections.

Shear strength envelopes for similar tests using the large and small boxes are compared in the results section. Comparison is made in terms of both peak and residual shear strengths.

Apparatus

Testing was cairied out using multi-speed direct shear equipment. Two devices were employed, one device with a shear box of 300mmx300mmx140mm and one device with a shear box of 60mmx60mmx42mm. In both cases the equipment was instrumented for automatic logging of both shear load and shear displacement

Materials

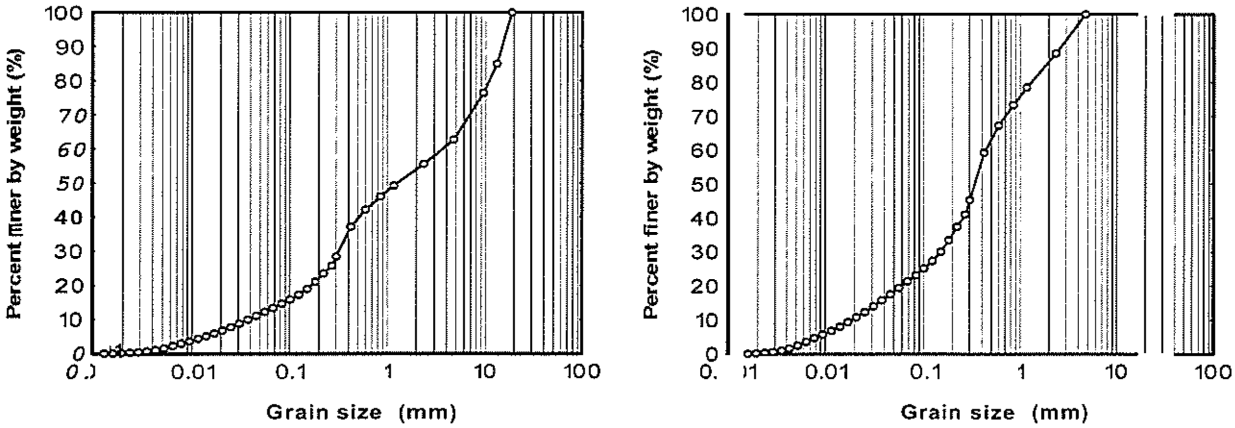
The material employed in this testing program was a ripped siltstone rock, slightly weathered, taken from the excavated overburden of an open-cut coalmine in the Hunter Valley. It was selected because a similar material had previously been tested from the same mine, after it was proposed to use it as RE wall backfill in an infrastructure development at the mine. This gave it particular relevance for the broader aims of the research project (beyond the aims of the work presented here).

In its delivered state, the sample was described as a silty sandy GRAVEL, and it contained gravels up to cobble size. Before testing commenced, the sample was screened to remove all particles greater than 19mm (about 10% of the raw sample). These were ciushed to pass the 19mm sieve, and they were then returned to, and blended evenly through the sample. At the completion of this process, the sample was tested and classified as a *(GM) silty sandy GRAVEL,fine to medium, pale grey siltstone gravels,fine to coarse sand, low liquid limit silt and a trace ofpale grey clay of lowplasticity.* The basic soil properties are given in Table 1.

Table.1. Physical properties of the tested sample

USCS classification	Atterberg Limits (-4.75μm fraction)			Standard Compaction (whole soil)	
	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Maximum Dry Density (g/m^3)	Optimum Water Content (%)
ML	28.7	19.4	9.3	1.86	14.8

ASTM D 3080 (1998) gives some guidance as to the maximum particle sizes of samples that may be tested in a shear box of a given size. It suggests that the width of the shear box should not be less than 10 times the maximum particle size, and that the initial thickness of the sample should not be less than 6 times the maximum particle size. Q181C (2002) specifies that the sample thickness prior to testing should be at least 7 times the maximum particle size. For the large shear box (300mmx300mmx140mm). a maximum particle size up to 19mm was considered permissible, noting that consolidation of the sample often results in a reduction in the sample height of to around 130mm. The bulk sample, prepared to a maximum size of 19mm, could thus be tested directly. For the small shear box (60mmx60mmx42mm). a maximum particle size up to 6mm was permissible. It was decided, for convenience, that testing should be carried out on a sample that had been modified by the removal of all material retained on the standard 4.75mm sieve. The particle size distribution curves for the tested samples are shown in Figure 1. Laser diffraction particle sizing was used to determine particle sizes below 75 µm.



a). <19mm sample, tested in large shear box **b).** <4.75mm sample tested in small shear box

Figure 1. Particle size distribution of tested samples

Note from Figure 1a) that only about 9% of the total sample was in the size range 4.75mm to 19mm. and was removed to create the sample tested in the small box.

Procedures

In as far as was possible, the test procedure of Q181C (2002) was followed in all tests. This includes:

- Initial filling of the box in a loose state, taking care to avoid segregation within the placed sample material.
- Positioning the top plate, and applying a small, nominal vertical stress
- Inundation of the loose sample and allowed it to saturate for one hour.
- Application of the required normal stress for testing, and monitoring of the settlement for a minimum of 2 hours, or until primary consolidation is substantially complete.
- Shearing of the saturated, consolidated sample at an appropriate speed, determined using the method described in the standard.

Although the sample is dominated by fine fractions, primary consolidation of the sample under the applied normal load was rapid. Using the method of Q181C. a maximum shearing speeds of between 8 and 130mm/min determined. The shearing rates adopted are all below this value. For the large shear box, two different speeds were chosen: 7.06mm/min and 0.63mm/min. The nearest equivalent speeds that were available for the small box were 6.70mm/min and 0.44mm/min. Although these are not identical to the values use for the large box tests, they are considered to be sufficiently similar so as not to produce significant differences in the measured strengths.

Minor deviations from the method of Q181C are reported as follows.

- Q181C specifies that 'the minimum specimen width after consolidation to thickness ratio shall be 2:1.' In the small box tests, the consolidated sample was of the order of 40mm thick and 60mm wide, and so, the ratio was around 1.5:1.
- Sample splitting and handling was carried out using good laboratory practice but not necessarily in accordance with test method Q101.

- Tap water was used to inundate the sample instead of de-mineralised water.

These are considered to be only small deviations from the specified method, and unlikely to have a significant result on the results obtained.

RESULTS

Details of the prepared samples prior to testing are presented in Tables 2a) and 2b).

Table 2a) Details of tested samples: Small shear box tests.

Specimen Number	Normal Stress (kPa)	Shearing Rate (mm/min)	Pre consolidation		After consolidation/Prior to shearing			
			Initial dry density (t/m^3)	Initial void ratio e_0	Bulk density prior to shear (t/m^3)	Dry density prior to shear (t/m^3)	Void ratio e_f	Water Content
S1	124	6.70	1.40	0.89	1.92	1.58	0.68	21.1
s2	124	0.44	1.40	0.89	1.94	1.62	0.64	19.9
s3	195	6.70	1.40	0.89	1.94	1.62	0.63	19.3
s4	195	0.44	1.40	0.89	1.94	1.62	0.63	19.3
S5	265	6.70	1.40	0.89	1.97	1.66	0.60	18.6
S6	265	0.44	1.40	0.89	1.99	1.68	0.58	18.1
S7	406	6.70	1.40	0.89	2.02	1.69	0.57	19.1
S8	406	0.44	1.40	0.89	2.02	1.70	0.55	18.4

Specimen Number	Normal Stress (kPa)	Shearing Rate (mm/min)	Pre consolidation		After consolidation/Prior to shearing			
			Initial dry density (t/m^3)	Initial void ratio e_0	Bulk density prior to shear (t/m^3)	Dry density prior to shear (t/m^3)	Void ratio e_f	Water Content (%)
L1	100	7.06	1.40	0.90	1.90	1.62	0.64	17.3
L2	100	0.63	1.40	0.89	1.95	1.63	0.62	19.4
L3	200	7.06	1.37	0.93	2.06	1.70	0.56	21.1
L4	200	0.63	1.38	0.92	1.95	1.65	0.61	18.1
L5	300	7.06	1.42	0.87	2.07	1.73	0.53	20.0
L6	300	0.63	1.41	0.88	2.01	1.74	0.52	15.7
L7	400	7.06	1.41	0.88	2.08	1.74	0.53	20.0

Tables 2a) and 2b) indicate that in all cases, the samples undergo significant densification after consolidation under the applied normal stress. In both cases, the dry density of the loosely placed samples is about 1.4t/m3, but after consolidation, there is a tendency for the large box samples to attain slightly higher dry density values. Whilst there are many possible reasons for this, there is nothing that stands out as a likely cause. Also, when compared with the value of 1.86t/m3 given in Table 1 for the maximum dry density achievable under standard compaction, it is apparent that in all cases, consolidation has failed to achieve this value. The results in Table 2)a and 2b) suggest that the relative density of the prepared samples ranges from about 86% under a consolidation stress of 100kPa, to 94% under a consolidation stress of 400kPa.

Figures 2a) to d) show the shear stress-shear strain curves for each of the tested samples. At both fast and slow shearing speeds, the results for the small box tests show a peak shear stress value being reached by around 10% strain. For shearing from 10% strain to 15% strain, the shear stress remains more or less constant, with only a slight suggestion in two of the results in Figure 2a) that this stress value might begin to decrease after the peak has been reached. In contrast, the results for the large shear box show a tendency to attain a peak strength at a strain of between 7 and 10%, and then, a decrease in the measured shear strength to approach a lower residual strength. This behaviour was most evident in the tests with the slower shear speed. The peak strength characteristic of the large box tests suggests that the slightly higher *dry* densities of these samples had some significant effect. This is discussed further in the context of the following results.

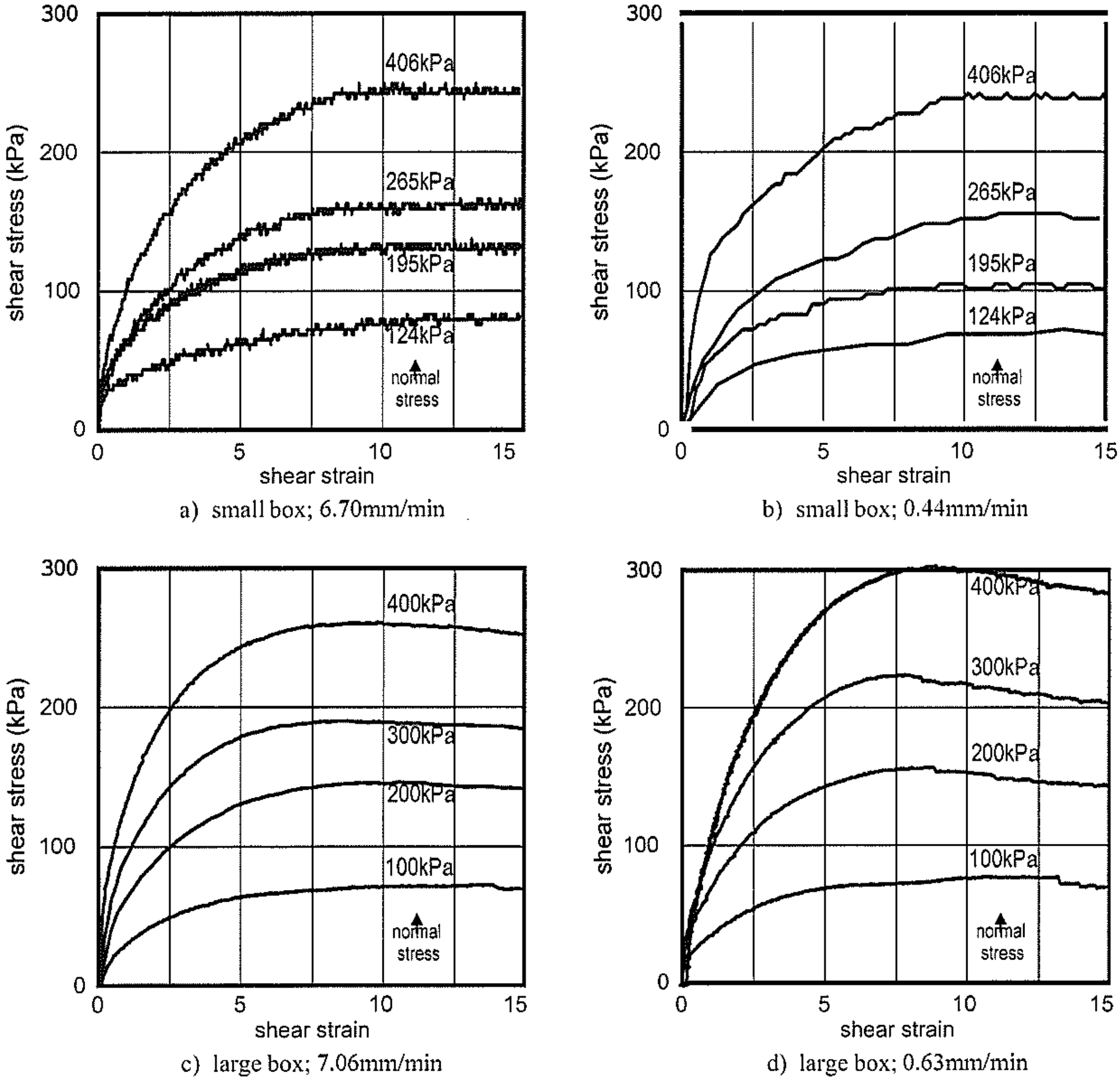


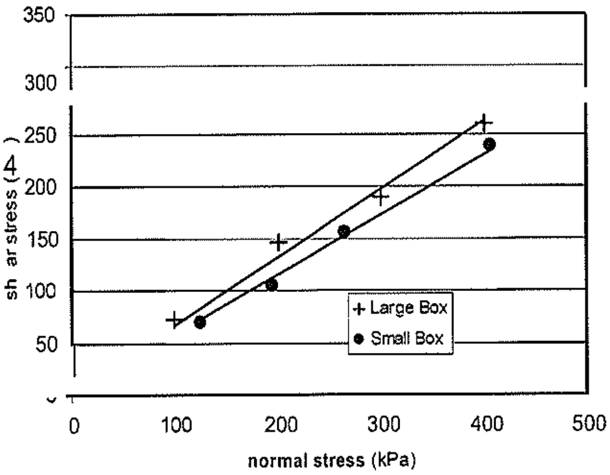
Figure *2*. Shear stress – shear strain results for the tests reported in this study.

The peak and residual shear strength values for each test have been interpreted from the results shown in Figure *2*. They are summarised in Table 3 and plotted as a function of normal stress in Figures 3a) to 3d). In almost all cases, the large box results indicate higher shear strength values than the small box, even when the differences in the normal stress are taken into account. From the plotted results (Figure 3), it is evident that reliable linear tends, passing through the origin, can be fitted to each data set, despite some small scatter in the results. In general, the results suggest that the large shear box gives consistently higher strength values than the small box.

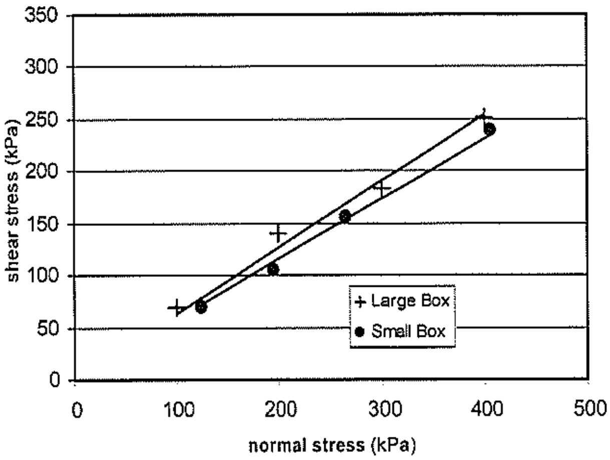
The differences in the shear strength can be quantified by determining the slopes of the trendlines, and hence, estimating the effective friction angles (peak and residual/constant volume). These are given in Table 4.

Table 3. Summary of peak and residual shear strength values

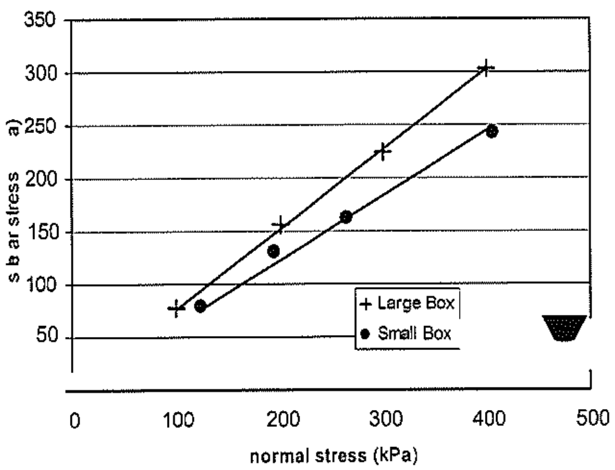
Small shear box test results					Large shear box test results				
Specimen Number	Normal Stress (kPa)	Shearing Rate (mm/min)	Peak Shear Strength (kPa)	Residual Shear Strength (kPa)	Specimen Number	Normal Stress (kPa)	Shearing Rate (mm/min)	Peak Shear Strength (kPa)	Residual Shear Strength (kPa)
S1	124	6.70	68.6	68.6	L1	100	7.06	72.1	69.2
S2	124	0.44	79.5	79.5	L2	100	0.63	77.2	70.6
S3	195	6.70	104.7	104.7	L3	200	7.06	146.1	140.4
S4	195	0.44	130.0	130.0	L4	200	0.63	156.8	140.4
S5	265	6.70	155.3	155.3	L5	300	7.06	190.3	183.3
S6	265	0.44	162.5	162.5	L6	300	0.63	223.7	197.0
S7	406	6.70	238.4	238.4	L7	400	7.06	261.2	250.8
S8	406	0.44	242.0	242.0	L8	400	0.63	302.9	275.5



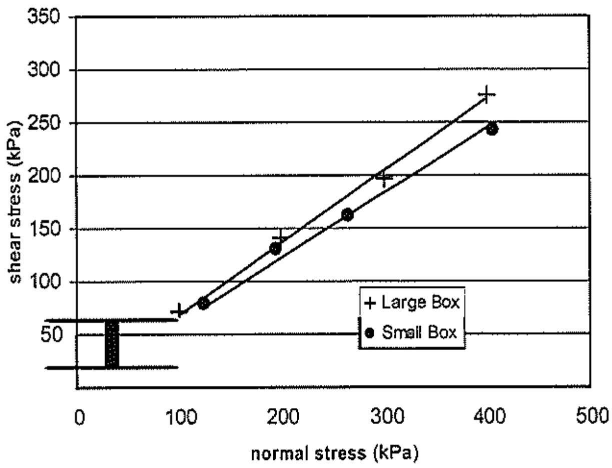
a) Peak Strengths, (fast shear)



b) Residual Strengths, (fast shear)



c) Peak Strengths, (slow shear)



d) Residual Strengths, (slow shear)

Figure 3. Comparison of measured shear strengths for large and small box apparatus.

Table 4. Comparison of determined effective friction angles determined using the small and large shear boxes.

test type	Effective internal friction angle φ'(°)			
	Peak		Residual/Constant Volume	
	Large shear box	Small shear box	Large shear box	Small shear box
Fast shear	**32.5** (7.06 mmimin)	**29.8** (6.70 mm/min)	**31.5** (7.06 mm/min)	**29.8** (6.70 mm/min)
Slow shear	**37.1** (0.63 mmimin)	**30.5** (0.44 mm/min)	**34.2** (0.63 mm/min)	**30.5** (0.44 mm/min)

The effective friction angle results for the tested material suggest that the small shear box underestimates the effective friction angle when sheared at both fast and slow speeds, and when considered in terms of both peak and residual strengths. For the faster shearing speeds, the effective friction angle was underestimated by 1.5 to 2.5 degrees; for the slower shearing speeds the underestimation was even greater: 4 to 6 degrees. In both cases, the underestimation is likely to be significant when assessing the compliance of marginal materials (similar to those used here) to some prescribed value.

The reasons for the difference are not entirely clear. Certainly, the density of the samples prepared in the large box were slightly, though consistently, larger than the small box samples. However, as they were prepared using essentially the same procedure, there is no reason why this should be so. Also, the large box sample contained large particles that would be expected to increase the measured effective friction. The magnitude of the difference is surprising, however, given that this coarser gravel fraction made up only 9% of the large box samples.

Also evident from the results is the outcome that a slower shearing speed seems to give a higher shear strength. Discussion of this is beyond the scope of this paper, but is being considered in some detail in the broader scope of this work.

CONCLUSIONS

The results presented here indicate that, for the material tested in this study, the measured effective friction angle is affected by the size of the box used to measure it. They suggest that use of a small shear box, and a sample modified by the removal of an appropriately selected coarse fraction, will significantly underestimate the measured constant volume effective friction angle by as much as 2.5 degrees.

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