Direct and simple shear tests: A comparative study of geomaterials

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ABSTRACT: This study presents a comprehensive comparison between Direct Shear Tests (DST) and Direct Simple Shear Tests (DSST) for assessing the shear strength parameters of geomaterials. Laboratory experiments were conducted on representative soil specimens to quantify differences in the measured angle of internal friction and cohesion. Results reveal that DST consistently yields higher values for these parameters compared to DSST. The elevated values in DST are primarily attributed to its controlled stress path, more rigid boundary constraints, and the rapid mobilization of shear resistance along a predetermined failure plane. In contrast, DSST better reproduces in-situ conditions by allowing progressive shear deformations and accommodating lateral displacements, thus capturing a more distributed failure mechanism. Detailed instrumentation and monitoring during testing enabled precise measurement of deformation and stress responses. The findings underscore the critical need for selecting appropriate shear testing protocols that align with specific geotechnical conditions and design requirements. This research contributes to the optimization of laboratory testing procedures, ensuring that design parameters more accurately reflect field behavior and improve the reliability of geotechnical design practices. Future studies should investigate the influence of sample preparation and in-situ stress variations on the comparative strength parameters, thereby further refining predictive soil behaviour models in depth.

1 INTRODUCTION

Shear strength is one of the most important properties for the design of engineering structures and is also difficult to evaluate (Nagendra et al. 2013). The shear strength of soils is necessary for many foundation problems, such as the bearing capacity of shallow foundations, the stability of dam slopes and lateral earth pressure on retaining walls (Yilmazoglu & Ozocak 2023). The safety of geotechnical structures depends on soil's strength properties; therefore, a proper understanding of soil strength parameters is essential. The limited ability of soil to resist shear can result in structural failure when shear stresses exceed the shear resistance mobilized by the soil.

Laboratory and field tests are conducted to determine the strength parameters that govern shear strength, such as the angle of internal friction and cohesion. Many types and variations of laboratory shear tests have been developed. In most of these tests, the deformation rates are controlled, and the resulting loads are measured. The tests employed in the laboratory may include ring shear, torsional shear, triaxial shear, direct shear and simple shear. The direct shear test is a simple and relatively cheap method for determining the soil shear strength parameters. The apparatus is easy to use, and the output data can be relatively quickly processed to obtain the necessary parameters. Therefore, direct shear apparatuses are widely applied in engineering practice suitable/practicable for cohesionless (drained) soils and research purposes (Amsiejus et al. 2013, Ikechukwu et al. 2021). The direct, simple shear device was developed to improve the direct shear box. In 1936, the Swedish Geotechnical Institute (SGI) built the first direct, simple shear device to uniformly deform a soil specimen in pure shear (Kjellam, 1951). The direct shear device suffers from a non-uniformity of the applied stresses and resultant strains. However, these are alleviated in the direct, simple shear device, where stresses are applied more uniformly.

In both devices, shear is applied directly to a soil sample, unlike the triaxial device in which shear develops from a difference of applied principal stresses (Matthieu 2011, Boukpeti & White 2017). The direct application of shear stress closely mimics many shear modes in practice. Based on this, only direct shear and direct simple shear tests were considered for this study. Silver & Seed (1971) reported that the direct, simple shear testing gave results closer to those deduced from back analysis of some field failures than those of other shear tests, but it depends on drainage conditions. A direct, simple shear test (DSST) is commonly used in practice (Dinesh 2010). The device is easy to set up, and the output can be processed. Compared to the direct shear test (DST), Detailed knowledge of the methodology, boundary conditions, and stress paths in direct, simple shear tests is essential to optimize their application for assessing soil shear behaviour. Therefore, this study's main objective was to investigate the correlation between the test results from direct shear and direct, simple shear tests conducted on selected South African soils under the same conditions.

The question arises regarding how direct shear test data relates to the results of direct simple shear tests. This is interesting because the design procedures for many problems are based on direct shear tests, but soil response often resembles direct, simple shear. The study, therefore, endeavours to establish the relationship between the results generated from a direct shear and a direct, simple shear test.

2 RESEARCH MATERIALS AND METHODS

2.1 *Klipheuwel sand*

Klipheuwel sand is reddish-brown, as shown in Figure 1, was locally sourced and was selected due to availability and abundance in Cape Town. It was clean and easy to work with, thus making it possible for the results to be repeatable.

2.2 *Kaolin*

The Kaolin clay used herein is shown in Figure 1. It is a naturally occurring, fine-grained clay mineral predominantly composed of kaolinite, with a chemical formula of $Al_2Si_2O_5(OH)_4$. It forms through the chemical weathering of aluminium-rich silicate minerals, such as feldspar, and is classified as a dioctahedral phyllosilicate. Its structure consists of a layered arrangement where a tetrahedral silica sheet is bonded to an octahedral alumina sheet, which accounts for its distinctive properties.

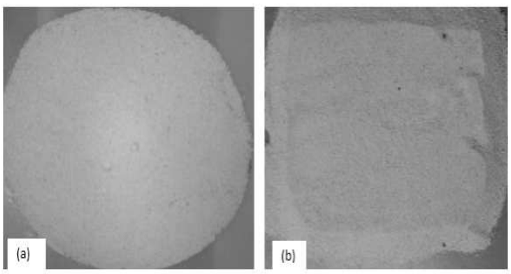


Figure 1. a) Klipheuwel and b) Kaolin

2.3 *Classification*

Different classification tests were conducted on Klipheuwel sand and Kaolinite clay, and the results are summarised in Table 1.

Table 1. Tests for Kaolin and Klipheuwel sand

Soil Properties	Kaolin	Klipheuwel
Specific Gravity, Gs	2.6	2.65
Natural Moisture Content	1.7%	2.63%
Optimum Moisture Content	23%	10.7%
Maximum Dry Density	1.65 Mg/m^3	1.82Mg/m^3
Particle Range	0.045-3.35 mm	
Coefficient of Uniformity, Cu	1.5	3.25
Coefficient of Curvature, Cc	-	0.89
Liquid Limit	36%	[N/A]
Plastic Limit	21.4%	-
Plastic Index	14.6%	-

3 RESEARCH METHODOLOGY

3.1 *Universal Shear Device*

The universal shear device used in this study can run the shear tests and is fully automated with consolidated and shear phases. It uses the Shartar-II option for a DST and ShearTrac-II-DSS for a DSST (Fig. 2). Direct and simple shear tests were undertaken on Klipheuwel and Kaolinite soils and the composite soil comprising 50% sand and 50% clay. The DST and DSST follow the ASTM D3080/D3080M (2023) and ASTM D3080 (2011) protocols, respectively. All specimens were fabricated using Optimum moisture contents. Additionally, the specimens were prepared and sheared in an unsaturated manner.

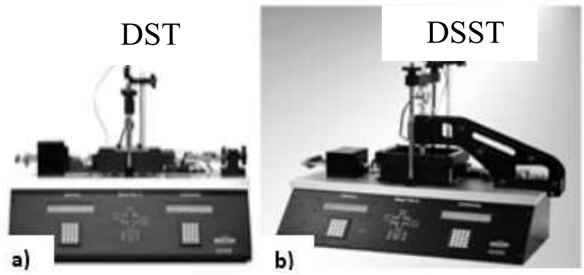


Figure 2. a) ShearTrac-II (DS) and b) ShearTrac-II-DSS (Geocomp, 2015)

A circular shear box was selected for a direct shear test, and a circular ring was chosen for a direct, simple shear test. The circular shear box and the circular ring share a diameter of 64mm and the same height of 31 mm, while the same pre-estimated mass (400g) of the sample was used for both tests.

The soil samples for both tests were sheared at the same 1mm/min displacement rate. The 1 mm/min displacement rate was established after carefully considering prior research and preliminary consolidation tests. Although sands and clays exhibit distinct pore pressure dissipation behaviours, sands dissipate pore pressures rapidly due to high permeability, while clays do so slowly. This rate was selected as a compromise to ensure consistency with the testing conditions and comparability across specimens.

Preliminary tests indicated that at 1 mm/min, sandy soils have sufficient time for excess pore pressures to dissipate, thereby reflecting their actual shear strength. For clays, even though a slower rate might allow a complete dissipation of pore pressures, the selected rate still provided a stable consolidation environment under quasi-static conditions. This compromise allows the test to capture the essential shear response without inducing excessive dynamic effects related to rapid loading or unrealistic long-term deformation behaviour (Aneke et al. 2021, Hu et al. 2025).

In summary, the 1 mm/min rate was determined based on: This approach ensures that the shear performance of both soil types is evaluated under a consistent and controlled testing environment at normal pressures of 50kPa, 100kPa and 200kPa. Thus, the fabricated and tested are presented in Figure 3 for DST and DSST test methods. The specimen is confined laterally using flexible membranes. The direct shear test setup and specimen samples after the test are presented in Figure 4.

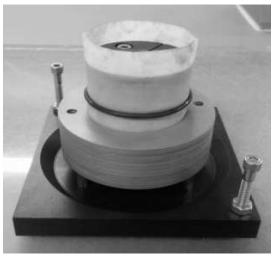
a)  b) 

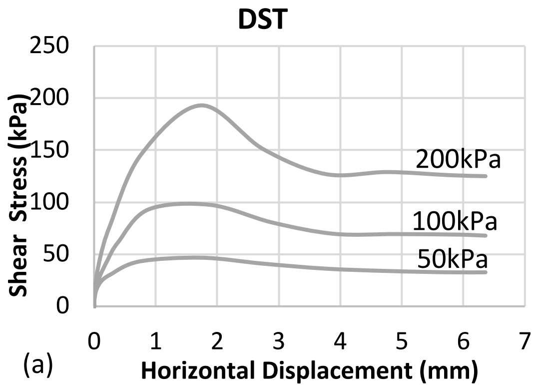
Figure 3 DSST a) Sample ready for testing and b) Sample after test (sand-clay composite)

a)  b) 

Figure 4 DST a) test setup and b) Sample after test (sand-clay composite)

4 RESULTS AND ANALYSIS

The graphs of shear stress against horizontal displacement obtained from direct, simple shear and direct shear tests for sand are shown in Figures 5 (a) and (b). In direct shear tests, the shear stress increases continuously based on the increment of the normal stresses. However, there are slight differences in the strains from each stress. This is because the direct shear box's failure plane is at the specimen's centre and thus may not be the weakest plane. In a direct, simple shear test, the stresses within the sample are likely to be relatively uniform and give more realistic values. The peak shear stresses generated for all the soil samples tested from direct shear are higher than those from the direct, simple shear test. This could be attributed to the Shear strength values obtained from the Direct Shear Test (DST) are often higher than those from the Direct Simple Shear Test (DSST) primarily due to differences in boundary conditions, stress paths, and failure mechanisms of the two tests (Aneke et al. 2019, Ikechukwu et al. 2021).



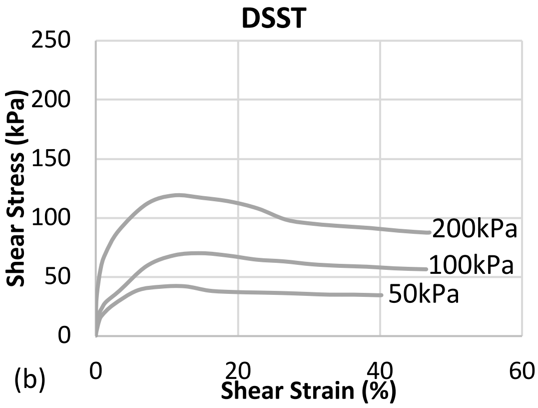


Figure 5 a) Direct shear and b) Direct simple shear test results for sand

4.1 *Shear stress versus normal stress*

The peak shear stress obtained for each test was plotted against applied normal pressures of 50kPa, 100kPa and 200kPa for all the soil samples. The relationship between the stresses for both tests is shown in Figures 6a, b and c graphs. The sand recorded internal friction angles of 44.2^0 and 27.0^0 for the DST and DSST testing methods, respectively. Meanwhile, the sand recorded a cohesion value 0kPa for both testing methods. The kaolinite soil recorded cohesion values of 25.8kPa and 18.3kPa, respectively, for DST and DSST testing conditions.

Furthermore, the composite geomaterial recorded an angle of internal friction of 26.4^0 and $14.3^{0,}$ respectively, for DST and DSST testing conditions. The determined values of cohesion and angle of internal friction were achieved in the following graphs as per (Gundersen et al. 2019; Aneke et al. 2022) recommendation. The results revealed that the direct shear test has a higher internal friction angle than the direct, simple shear test, with all the samples tested at almost the same density. The friction values are lower than those of dry sand in the composite geomaterial's DST and DSST. The shear parameters and density obtained for sand, clay, and composite are presented in Table 2.

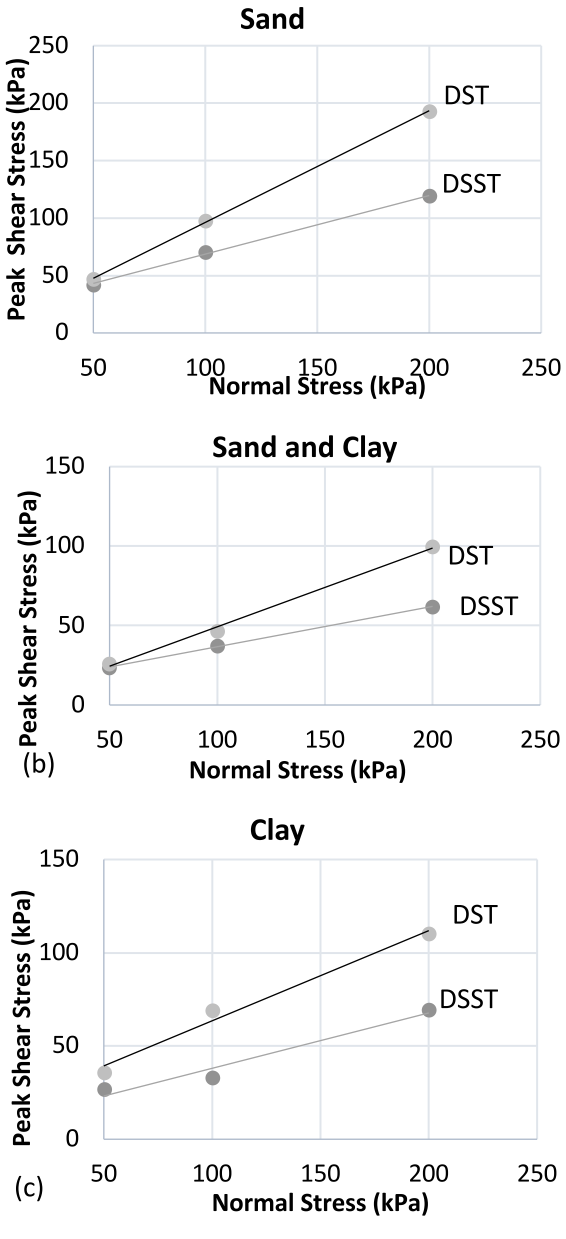


Figure 6. Relationship between the stresses for (a) Sand, (b) Sand + 50% Clay and (c) Clay

Several factors may contribute to the observed differences in shear strength parameters. These may include sample disturbance, shearing mechanism, different consolidation times, shear rate, and testing rate as supported by (Hanzawa et al., 2007; Aneke et al. 2023). Similar testing procedures were observed for both tests, with all the samples tested under the same conditions. There was no offset time input for the T100 parameter at the consolidation stage for both tests because all soil samples must be fully consolidated before shear testing. The effect of consolidation time was studied by Berre (1985), who concluded that consolidation times are less significant in assessing differences. Similar results were obtained by Aneke et al. (2023), Hanzawa et al. (1990), and Hideo et al. (2007), who concluded that the differences between direct, simple shear and direct shear tests could be attributed to different shearing mechanisms.

Table 2 Shear parameters and density (Mg/m^3)

	ϕ (°)		c (kPa)		Density	
	Dst	Dsst	Dst	Dsst	Dst	Dsst
Sand	44.2	27.0	0	0	1.66	1.64
Clay	19.3	16.5	25.8	18.3	1.62	1.64
Sand + 50% clay	26.4	14.3	15.0	11.3	1.56	1.61

5 SUMMARY AND CONCLUSIONS

A series of direct shear and direct, simple shear tests were conducted to establish the correlation between the results of the two tests, considering the differences in the application of shear stresses and strains on the specimen in the tests. The difference in strain in DSST may be due to increased shear strain homogeneity in the samples. DSST can shear soil to unlimited displacement without creating non-uniformity in stress and strain distributions. Saada & Townsend (1981) criticized the direct shear box of non-uniformity of stress-strain throughout the specimen. Based on the results, the direct shear box test gives higher estimates of strengths than a direct, simple shear test. This difference was almost identical for all the soil samples tested. This observation is consistent in dry samples, but a slight deviation was observed in moist samples. The difference in the results could be attributed to their different shear modes. Half of the soil specimen in a DST is sheared, and high strength is obtained; the DST is a quasi-bearing capacity failure that mobilizes increased resistance due to the bearing interface. However, in DSST, the whole soil sample is sheared uniformly, and low strength is achieved. Furthermore, a direct, simple shear helps determine the shear strength of soil because of the broader shearing mechanism, and it is more realistic than a direct shear box. It is anticipated that using the direct, simple shear test to determine the shear strength of soils will produce more accurate results.

In the Direct Shear Test (DST), the soil specimen is divided along a predetermined shear plane, effectively confining shear deformation to one-half of the sample. There is non-uniform stress distribution due to rigid top and bottom plates, and stress is not indeed plane strain. Particles tend to dilate more due to restrained deformation, increasing resistance. Stress concentration near box edges may also lead to higher peak strength. This test geometry creates a localized region where the soil is forced to mobilize its shear resistance rapidly. The imposed displacement on a limited section of the specimen accelerates interparticle friction and interlocking, often resulting in a peak shear strength that appears artificially high compared to more distributed shear processes.

In contrast, the Direct Simple Shear Test (DSST) subjects the entire soil specimen to shear deformation, which leads to a more uniform distribution of strains and stresses throughout the sample. Because the shearing action is not confined to a narrow plane, the DSST captures a response closer to the soil's in-situ behaviour. This distributed deformation allows for progressive mobilization of the shear resistance, including gradual development and redistribution of pore pressures and a more realistic representation of dilation characteristics. As a result, the DSST typically yields lower (arguably more realistic) shear strength values.

Thus, the fundamental difference in shear modes—localized versus distributed deformation—accounts for the discrepancies in observed shear strength between DST and DSST. In a DSST, more uniform shear distribution and no rigid boundaries allow freer soil deformation. There is less dilation than in DST due to less constraint on movement.

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