# Free Head Shear Test on Decomposed Granite Soil

**Dr.Haider Mohammed Mekkiyah**
Lecturer
College of Engineering
University of Baghdad
E-mail:hydmekk@yahoo.com

**Abbas Malik Khallawi**
Asst. Lecturer
Management of Dormitories
University of Baghdad
E-mail:amkhfar@yahoo.com

## ABSTRACT

The study presents the test results of Completely Decomposed Granite (CDG) soil tested under drained triaxial compression, direct shear and simple shear tests. Special attention was focused on the modification of the upper halve of conventional Direct Shear Test (DST) to behave as free head in movement along with vertical strain control during shear stage by using Geotechnical Digital System (GDS). The results show that Free Direct Shear Test (FDST) has clear effect on the measured shear stress and vertical strain during the test. It has been found that shear strength parameters measured from FDST were closer to those measured from simple shear and drained triaxial compression test. This study also provides an independent check on the consistency of the data by providing an interpretation for angle of dilation together with shearing resistance by using flow rule analysis.

**Keywords: decomposed granite soil, free direct shear test, simple shear, triaxial test, angle of internal friction**

# فحص القص الحر لتربة الكرانيت المتفككة

## الخلاصة

الدراسة تقدم نتائج الفحوص على تربة الكرانيت المتعرية التي تم فحصها من خلال الفحوص التالية( triaxial compression، direct shear، simple shear). تم التركيز على تحوير صندوق القص المباشر لجزئه العلوي ليسمح له بالحركة بشكل حر مع سيطرة على الانفعال الراسي باستخدام جهاز (GDS). اظهرت نتائج الفحص التاثير المباشرللقص الحرعلى نتائج اجهاد القص عند الفشل ومقدار الانفعال خلال الفحص. كذلك لوحظ معاملات المقاومة المحسوبة من خلال القص الحر هي اقرب من مثيلاتها في فحص القص البسيط والثلاثي(simple shear، triaxial compression). الدراسة ايضا اعطت تدقيق غير مباشر لتوافق النتائج من خلال دراسة زاوية التمدد(angle of dilation) ومقاومة القص باستخدام مبدأ تحليل الانسياب (flow rule).

**الكلمات الرئيسيه: تربة الكرانيت المتفككة،فحص القص الحر،القص البسيط، الفحص الثلاثي،زاوية الاحتكاك الداخلي**

## 1- INTRODUCTION

The conventional Direct Shear Test (DST) has been used to determine the residual strength parameters, since the direction of defined failure planes, the magnitude and direction and/or rotation of the principle stresses and pore pressure measures are not determined in DST. The DST analysis can open the results to various interpretations (Hill, 1990) and this test is rarely used to determine the undrained or peak effective strength parameters. Simple shear and/or triaxial compression test may be performed more conveniently with better control and finally provide best understanding for shear strength parameters and stress-strain behavior. The direct shear box is only suitable for measuring the shear strength parameters because of non-uniformity of stress and strain on the central plane of soil (Hvorslev, 1960 and Sowers, 1964) and also may be due to the restraints of box ends that can create an even more markedly non uniform shear surface as shown in Figure (1). Nevertheless the DST remains popular in practice due its simplicity and different sample preparation procedure. This test can be used per standards in order to minimize or even eliminate the influence of the upper shear box-soil sample friction. This can be achieved by adding lubrication or smooth material such Teflon plate at the points where the upper shear box is in contact with the bearing ring that measure the shear surface (Nithiaraj et al., 1996).

The Completely Decomposed Granite (CDG) soil is the product of in-situ for measuring the shear strength parameters because of non-uniformity of stress and strain weathering of rocks due to the warm and wet climate in South East Asia. In peninsular of Malaysia for example this type of soil has covered a large area of (Matsuoko and Liu, 1998).

The soil used in this study was CDG soil, the conventional DST has been modified to minimize the friction of the upper shear box and to investigate the stress-strain behavior with FDST. The results obtained from FDST are compared with those measured from DST [ASTM D3080/3080M-11], simple shear test [ASTM D6528-07] and triaxial compression test [ASTM D 7181-11].

## 2- DATA ANALYSIS

Two angles were interpreted from conventional DST and/or FDST test. Firstly is friction angle of direct shear by using Mohr Coulomb failure criteria as follows:

$$\tau = c + \sigma \tan\phi_{DST} \qquad (1)$$

where $\tau$ and $\sigma$ are the shear and normal stress at failure plane; c is the soil cohesion and $\phi_{DST}$ the direct shear angle of friction which refers to the shearing resistance on the planes along where there is no extension (i.e. no linear increment strain). Secondly the plain strain angle of friction is $\phi_{PS}$ of soil. The two angles can be written as:

$$\sin\phi_{PS} = \frac{\tan\phi_{DST}}{\cos\varphi + \sin\varphi \tan\phi_{DST}} \qquad (2)$$

where $\varphi$ is the dilation angle of soil.

The analysis through the critical state can support the data consistency by using flow rule expressed in terms of shearing resistance and the incremental strain on a plane along where there is no linear incremental strain can occur by using Taylors flow rule (1948) as:

$$\tan\phi_{PS} - \tan\varphi = \sin\phi_{CV} \qquad (3)$$

where $\phi_{CV}$ is the critical friction angle of soil.
Another flow rule was used proposed by Bolton (1986) as:

$$\phi_{PS} - 0.8\varphi = \phi_{CV} \qquad (4)$$

In case of simple shear apparatus the test should mobilize the $\phi_{DST}$ in the soil on the central plane similar to DST test.

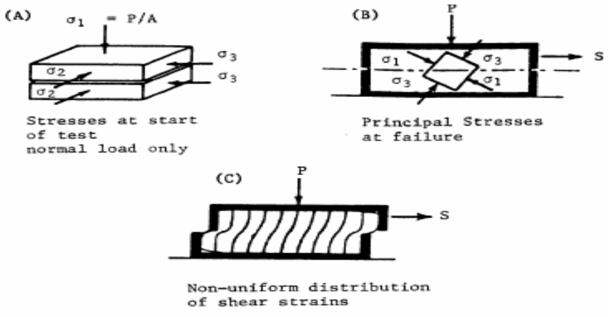

**Figure (1): Rotational of Principal Stresses and Non Uniform Shear Stresses on Horizontal Surfaces at Failure in DST (Sowers, 1964)**

## 3-MATERIAL USED

The soil used in this study was obtained from Serdang area, Kuala Lumpur, Malaysia. The CDG soils consist mainly of sand-silt mixture. The physical properties of CDG soil are listed in Table (1).

**Table (1): Physical Geotechnical Properties of CDG soil.**

| Soil Parameter | Symbol | Value |
|---|---|---|
| Specific Gravity | $G_s$ | 2.68 |
| Liquid Limit, (%) | L.L | 52 |
| Plastic Limit, (%) | P.L | 22 |
| Plasticity Index, (%) | P.I | 30 |
| Max. Dry Unit Weight, (kPa) | $\gamma_d$ | 15.4 |
| Optimum Water Content, (%) | $w_c$ | 21.4 |
| pH | pH | 4.8 |
| Compression Index | $c_c$ | 0.087 |
| Swelling Index | $c_s$ | 0.027 |

## 4- SYSTEM DESCRIPTION

The schematic diagram for the FDST is shown in Figure (2). The upper shear box was modified using a metal rod with a flexible head connected with the proving ring. The free rod movement is not restricted and can rotate freely in any direction from the center line with a maximum angle of 35 degree. The flexible connection of the rod allows the upper shear box to move vertically and horizontally without restriction during shear stage while the lower shear box is fixed in both directions.

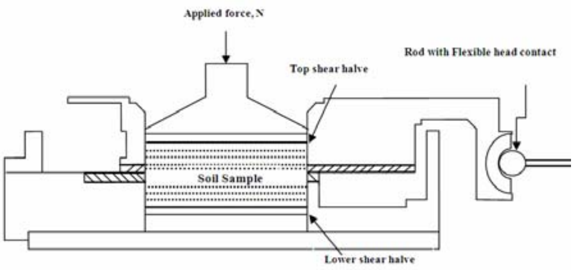

**Figure (2): Schematic Diagram of Free Direct Shear Test**

## 5- DIRECT SHEAR TEST

In this series of test the soil samples were tested under direct shear test setup that was fully computerized by using Geotechnical Digital System (GDS), the detailed description of the system elements were given by GDS laboratory manual (GDS Instruments Ltd, 2002).The GDSLAB control and acquisition software was highly developed, flexible software platform to run different types of modules. The CDG soil was tested under conventional DST and FDST with applied normal stress of 85 kPa, 165 kPa and 250 kPa. The saturated soil samples of 60 mm (i.e. square box) were tested under drained conditions with a unit weight of 17.6 kPa prepared by using moist tamping method. Figure (3) shows the Shear stress versus horizontal strain relationship under DST and FDST with different normal stresses. As expected, higher shear stress developed under higher normal stress. The results obtained from FDST had lower shear stresses compared to those obtained from DST, and this may be due to the free head modification that allows the movement without any restraints at the end of the box. Without this modification higher measured shear stresses can be developed at box ends. Figure (4) shows the relationship between the vertical and horizontal strains (85 kPa, 165 kPa and 250 kPa) the vertical strains measured by FDST were lower than those measured by DST. It further indicates that the vertical soil movement in DST was restricted to one direction while the soil was allowed to move freely in FDST within the flexibility of upper shear box. The free-interface soil movement in FDST may be similar to the movement of soil sample in simple shear test where the soil movement of soil sample was not restricted to one direction. Figure (4) also shows the contractive soil behavior during shear stage.

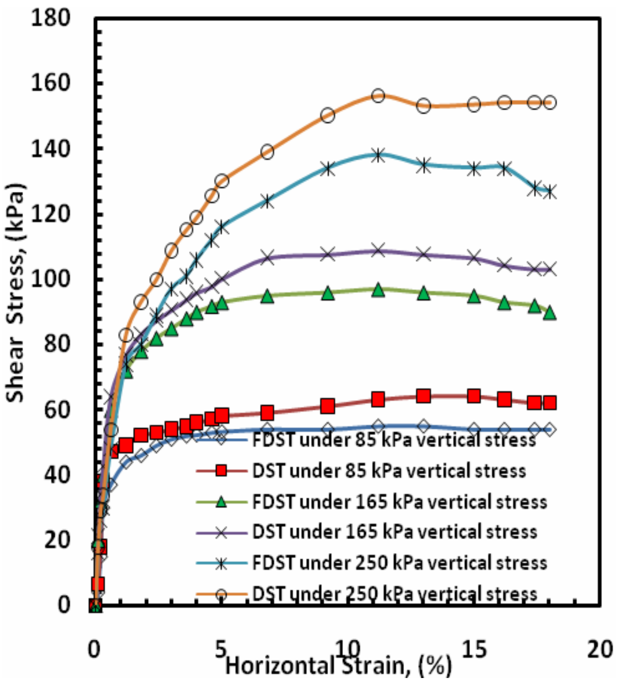

Figure (3): Shear Stress vs. Horizontal Strain for both DST and FDST.

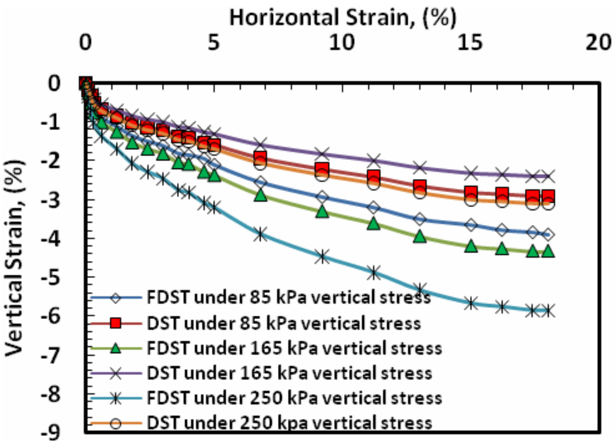

Figure (4): Vertical Strain vs. Horizontal Strain for both DST and FDST under 85 kPa, 165 kPa and 250 kPa.

## 6- SIMPLE SHEAR TEST

In this series of test the soil samples were tested under Simple Shear (SS) test setup that was fully computerized by using GDS-system under 92 kPa, 170 kPa and 265 kPa. The saturated soil samples of 70 mm diameter were tested under drained conditions with a unit weight of 17.6 kPa prepared by using moist tamping method. Figure (5) shows shear stress versus horizontal strain relationship of CDG soil under simple shearing. Figure (6) shows the contractive behavior of CDG soil especially at low horizontal strains, which were similar to the soil in FDST and DST.

## 7- TRIAXIAL COMPRESSION TEST

In this series of tests the triaxial setup was fully computerized by using GDS-system. Specimens of 50 mm in diameter and 100 mm in height with a unit weight of 17.6 kPa were prepared by using the moist-tamping technique tested under triaxial Compression (TC) with a confining stress of 100 kPa, 200 kPa and 300 kPa. Figure (7) indicates the relationship between the deviator stress and axial strain. The results illustrate that hardening soil behavior of weathered granite. Figure (8) shows the contractive tendency of CDG soil under low axial strain similar to the behavior of soil under simple shear test.

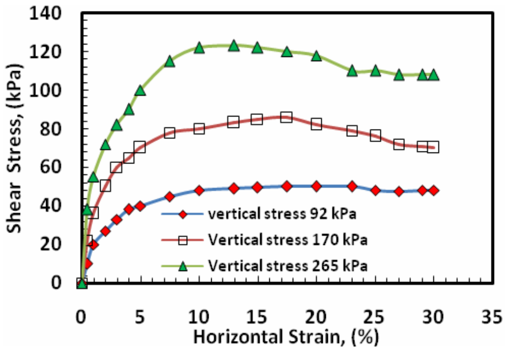

**Figure (5) Shear Stress vs. Horizontal Strain for Simple Shear Test.**

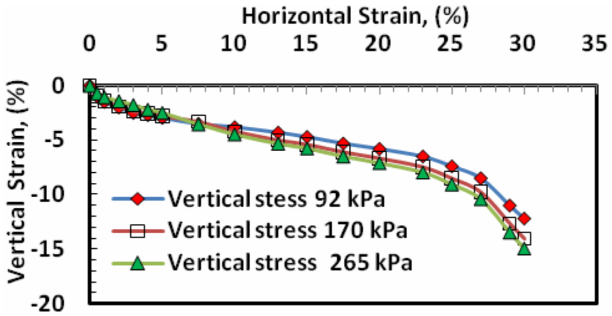

**Figure (6): Vertical Strain vs. Horizontal Strain for Simple Shear Test**

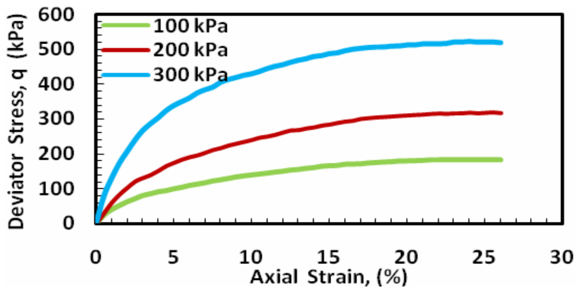

**Figure (7): Deviator Stress vs. Axial Strain for Triaxial Compression Test.**

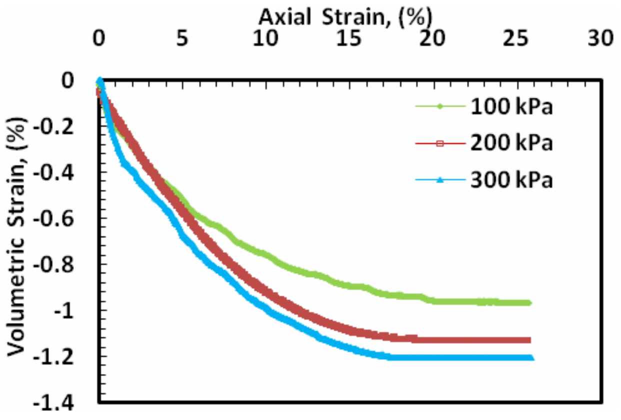

**Figure (8): Volumetric Strain vs. Axial Strain for Triaxial Compression Test**

## 8- DISCUSSION

From the above presented results the shear strength parameters of CDG soil were calculated and shown in Table 2. The shear strength parameters obtained from DST were higher than those obtained from FDST, simple shear and triaxial compression tests. It appears from Table (2) that FDST results were closer to those measured by simple shear and triaxial compression tests. In general the shear strength parameters measured by the DST does not agree completely with those measured by triaxial compression test, due to predetermined failure plane in DST (Liu and Mastuok, 2005). This is also may be due to restraints at the ends of box that create zone of complex and higher principal stress ratio at failure ($\sigma'_1/\sigma'_3$) compared with FDST, simple shear or triaxial test and as shown inTable(3).

**Table (2): Comparison of Shear Strength Parameters of CDG soil measured from Different tests.**

| Test Type | C′ (kPa) | ϕ′$_{DST}$ (Degree) |
|---|---|---|
| DST | 26.5 | 27.1 |
| FDST | 23.1 | 24.0 |
| SS | 18.5 | 20.1 |
| TC | 17.2 | 23.8 |

**Table (3): Principal Stress Ratio at Failure of CDG soil for all Tests.**

| Test Type | $\sigma'_1/\sigma'_3$ |
|---|---|
| DST 1 | 4.02 |
| DST 2 | 3.07 |
| DST 3 | 2.89 |
| FDST 1 | 3.67 |
| FDST 2 | 2.88 |
| FDST 3 | 2.66 |
| SS1 | 2.67 |
| SS2 | 2.16 |
| SS3 | 2.03 |
| TC 1 | 2.86 |
| TC2 | 2.62 |
| TC3 | 2.61 |

The soil friction angle from FDST were found to be lower than the results obtained from DST, similar observation were reported on Toyoura sand as shown in Table (4).

**Table (4): Soil Friction Angle for Toyoura Sand from DST and improved DST (Liu et al., 2005)**

| Test type | ϕ′$_{DST}$ (Degree) |
|---|---|
| DST | 44.8 |
| Improved DST (I) | 41.1 |
| Improved DST (II) | 41.8 |
| Triaxial Test (Matsuoka and Liu, 1998) | 40.0 |

The trend behavior of vertical strains was found to be affected by test type as shown in Figures (4), (6) and (8). Both DST and FDST show the same trend but with different vertical strains level, while these vertical strains are less in case of simple shear test and found to be varied under different normal stress with high dilation angle as measured and shown in Table (5). The vertical strain levels in FDST were found to be closer to those measured in triaxial compression test. Figure (9) indicates the relationship between shear stiffness ($K_s$) and normal stress for (DST and FDST)/or confining stress for TC. The $K_s$ value increased as the normal and/or confining stress increased. Shear stiffness $K_s$ in DST shows higher response compared with those from FDST and simple shear test. Shear stiffness from simple shear shows similar level value obtained from triaxial test as shown in Figure (9b). Table (5) illustrates the shear resistance analysis for 165 kPa and 170 kPa normal stress were carried for (DST, FDST) and SS tests respectively; the analysis show also that dilation angle was high in SS test while it was less in case of DST or FDST. These reflected by the measured direct shear angle and/or plain angle of friction. Low variations were observed between critical flow rule analysis and conventional analysis, which provided support for the data accuracy to the measured stresses and strain during the shearing stage.

**Table (5): Analysis for Peak Shearing Resistance of CDG Soil Measured from DST, FDST and SS.**

| Criteria | DST | FDST | SS |
|---|---|---|---|
| Vertical Stress, kPa | 165 | 165 | 170 |
| $(\tau'/\sigma')_{max}$ | 0.57 | 0.66 | 0.5 |
| $(dy/dx)_{max}$ | 0.0133 | 0.008 | 0.36 |
| $\varphi=\tan^{-1}(dy/dx)_{max}$, (Deg) | 0.76° | 0.45° | 19.8° |
| Direct Shear Angle of Friction $\phi_{DST}$ | | | |
| Measured in Simple Shear | | | 20.1° |
| Conventional Analysis (Eq.1) | 24.0° | 27.1° | |
| Flow Rule Analysis (Eq.3) | (22.8°-25.7°) | (22.5°-25.5°) | |
| Plain Strain Angle of Friction $\phi_{ps}$ | | | |
| Measured in Simple Shear | | | (39.8°-43.84°) |
| Conventional Analysis (Eq.2) | 26.3° | 30.6° | |
| Flow Rule Analysis (Eq.4) | (24.6°-28.6°) | (24.4°-28.4°) | |

Note: the range of critical friction angle assumed in flow rule analysis $\phi_{cv}$=(24.0°- 28.0°)

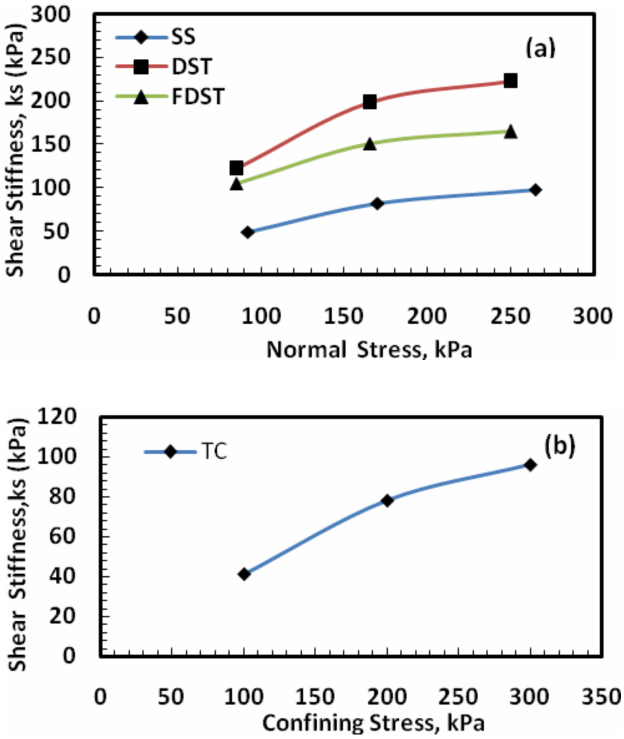

**Figure (9): (a) Shear Stiffness vs. Normal Stress for DST and FDST, (b) Shear Stiffness vs. Normal Stress for TC Test.**

Figures (10 and 11) indicate the shear displacement corresponding maximum stress increased with normal stress, in terms of rate of dilation, the soil exhibits moderate Dilation Ratio (DR) at the beginning of shear stage then a lower dilation ratio observed at the end of shearing stage and gradually increases as the normal stress increases. Contraction soil behavior was more pronounced.

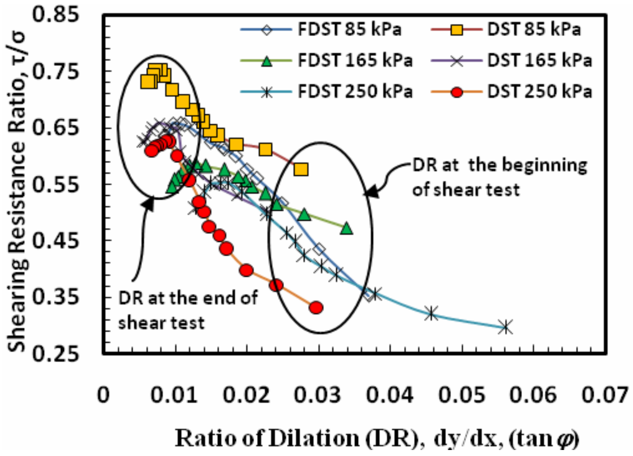

**Figure (10): Direst Shear Test on CDG Soil showing the Influence of Boundary Condition in DST and FDST**

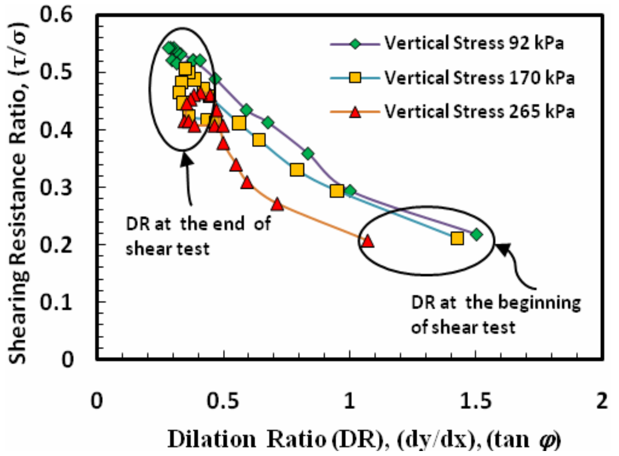

**Figure (11): Direst Shear Test on CDG Soil showing the Influence of Boundary Condition in SS Test**

## 9-CONCLUSIONS

From the series of tests carried on CDG soil using DST, FDST, SS and TC, the shear strength parameters were found in FDST to be closer to those obtained from triaxial and simple shear test.

In general the defined failure planes in DST along with end restraints in the upper box halve cause increase in shear strength parameters and shear stiffness when compared with other tests values. The free movement of the upper box half had similar behavior of soil sample in simple shear test.

The vertical shear strains in DST were closer to those measured in triaxial test while these values were less in case of SS and FDST tests. Rate of dilation at failure increased with increasing normal stress. The soil showed contractive behavior for DST, FDST, SS and TC tests. Both friction angles $\phi_{DST}$ and $\phi_{ps}$ showed in conventional DST test more conservative values compared with FDST, similar behavior in flow rule analysis. The test results of SS showed underestimation of friction angles in conventional analysis $\phi_{DST}$ while overestimation of$\phi_{ps}$ it was in plain strain analysis. The lower limit of friction angles from conventional analysis and /or plain strain analysis can be estimated from DST test, while the upper respective limit of friction angles can be estimated from FDST test since the direction of failure planes are not defined.

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