ISST : In-Situ Shear Test for Soil Investigations

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Abstract

The importance of reliable soil parameters in geotechnical analyses has been emphasized at every occasion. In the second half of the last century emphasis has been placed on *in situ* determination of strength and deformation properties of soil. The ISST (In-Situ Shear Test) is a new in-situ testing device that is the subject of this study. Basically, a shear failure on the sides of a borehole is induced in order to obtain independent measurements of soil friction, cohesion, and deformation modulii. Results in different soils were obtained, and comparisons to the popular Direct Shear and SPT results have been made, and strength correlations were issued. Recommendations for future research were also presented.

INTRODUCTION

The importance of reliable soil parameters in any geotechnical analysis has been emphasized over and over again at every public occasion and conference. Geotechnical properties such as the gradation, plasticity, compressibility and shear strength, can be assessed by proper laboratory testing or *in situ* testing. Many in situ tests to determine shear strength parameters, were introduced in the second half of the last century; and most were standardized. Such tests include the Standard Penetration Test (SPT) [Ref 1], Plate Load Test (PLT) [Ref 2],Vane Shear Test (VST) [Ref 3], Cone Penetration Test (CPT) [Ref 3], Pressure-Meter Test (PMT) [Ref 4], Dilato-Meter Test (DMT) [Ref 5], & Borehole Shear Test (BST) [Ref 6 & 7].

The ISST (In-Situ Shear Test) is a new device developed in a joint effort by the Lebanese American University and the IGM Institute for Geotechnics & Materials-Research Division. The main purpose of the test is to obtain in-situ strength parameters and properties of the soil (cohesion=c, Friction Angle=ϕ, Elastic Modulus=E, Modulus of Subgrade Reaction=k_s, and Shear Modulus=G). The ISST is similar mostly to the BST; however, it is more rugged and more advanced. It is more rugged which enables handling under rough construction conditions. Ruggedness also allows testing in any direction with large machines such as anchoring drill rigs rather than performing the test vertically by hand like the BST [Ref 6, & 7]. It is more advanced since it allows determinating more parameters in addition to the shear strength parameters. The production, development, results & evaluation of the ISST are all presented and discussed in this paper.

ISST DEVELOPMENT

Theoretical Approach

The idea behind the test is to induce a shear failure *in-situ* on the sides of a borehole in order to obtain independent measurements of soil friction and cohesion, and simultaneously measure the corresponding deformations in order to obtain compressive and shear modulii.

The test consists of applying a known normal stress on two plates against the sides of a borehole, then apply gradually a shear force by pulling to induce and measure the shear stress at failure (see Fig. 1). This is done while measuring compressive and shear deformations, thus respective compressive and shear modulii (see Fig. 1).

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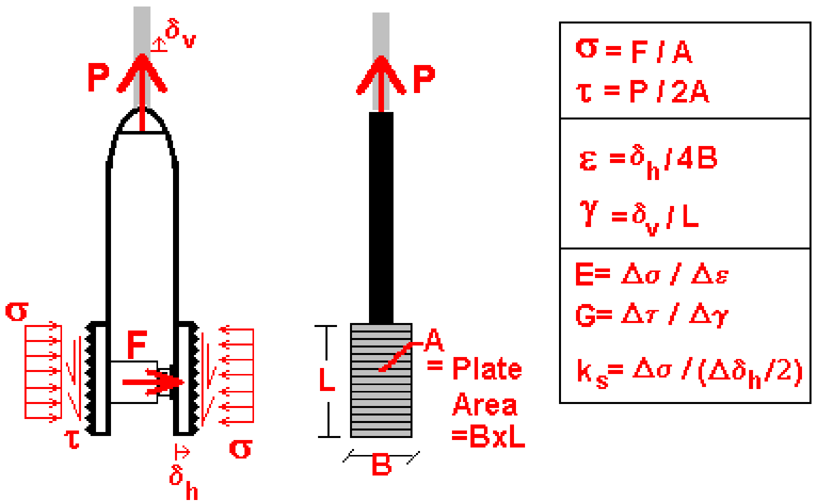


Fig. 1. Device Principle

The test would be repeated at least 3 times at almost the same location, each time by increasing the normal forces F (different σ). Each test is taken to failure (max. P), and the shear (τ) at failure is recorded. Each test gives a point on the τ vs σ graph. Similarly to a direct shear test, three points joined by the best fit line would define the In Situ Mohr-Coulomb failure envelope. Consequently c and ϕ are graphically determined as shown in Fig. 2.

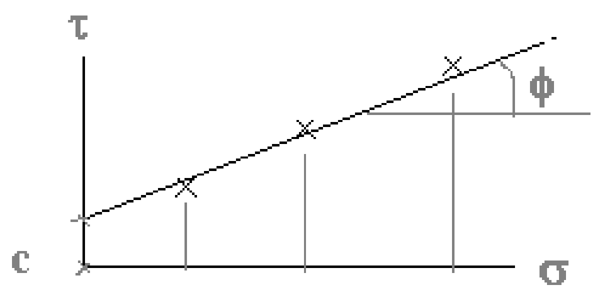


FIG.2- Mohr-Coulomb Failure Envelope .

Device Description

The ISST is a device that include many components that could be assembled together on site. The components are shown in Fig. 3, including:

- Shear Head (or piston): is an expandable piston equipped with diametrically opposed shear plates.
- Shear Plates with Teeth: attached to the sides of the shear head, with individual angular protrusions on the face; forcing shear failure to occur along the soil to soil contact.
- Hydraulic Pump: that applies hydraulic pressure via a control valve to activate the normal force F

- Control valve: allowing the expansion and retraction of the shear head in order to; respectively, engage the borehole walls and later be retrieved out of the hole.
- Dynamometer, a calibrated spring used to measure the pull out force, P
- Lateral displacement gage: is a device transmitting the lateral displacement, δ_h, of the mobile plate on the piston to the ground surface.
- Reference Wire: to measure the uplift vertical displacement, δ_v , during pull out. The measurement is done on the tubes connecting the dynamometer to the shear head, assuming that their elongation is negligeable with respect to movements of the shear head (see Fig. 3).

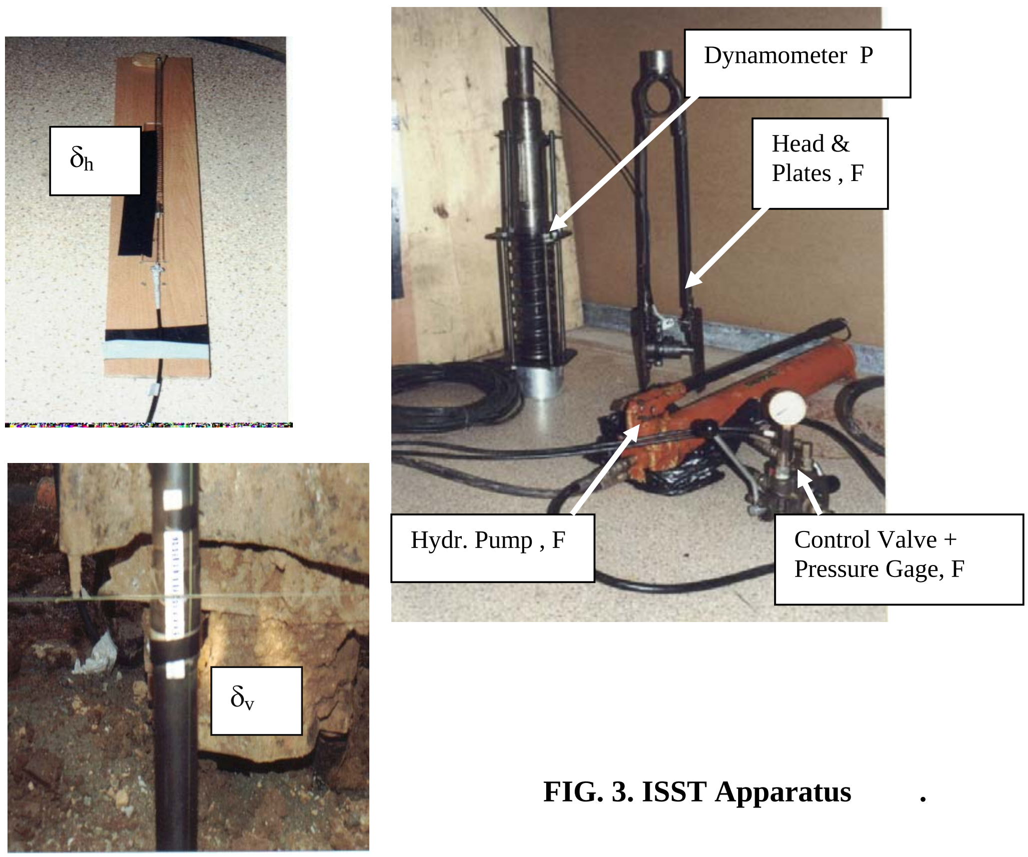


FIG. 3. ISST Apparatus .

Calibration

Prior to a soil investigation campaign, the ISST measuring components must be calibrated; particularly, the dynamometer and the head piston

Dynamometer

The dynamometer would be calibrated in the Lab by determining the force/displacement relationship after assembly. A typical calibration is shown in Fig.4 where 3 trials were performed showing the accuracy of the device after usage on 3 different sites. Differences proved to fall within tolerances.

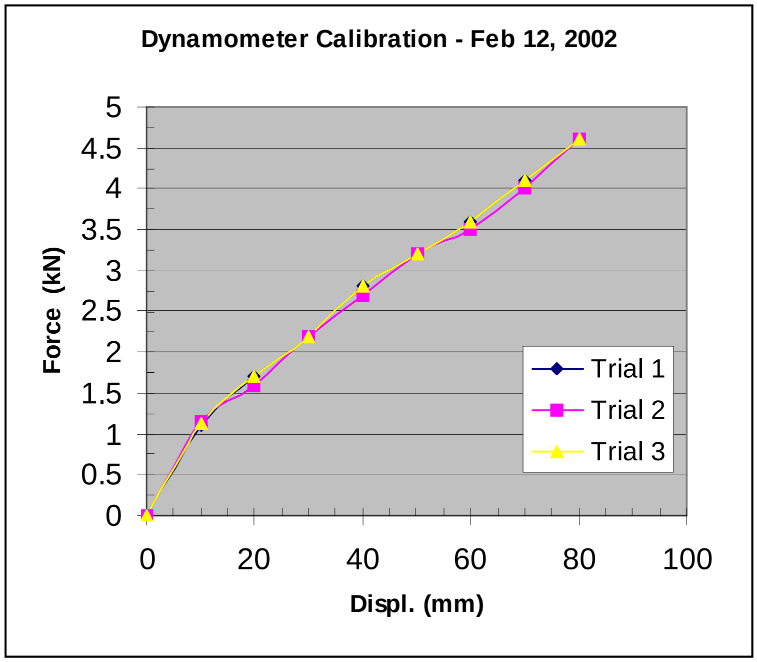
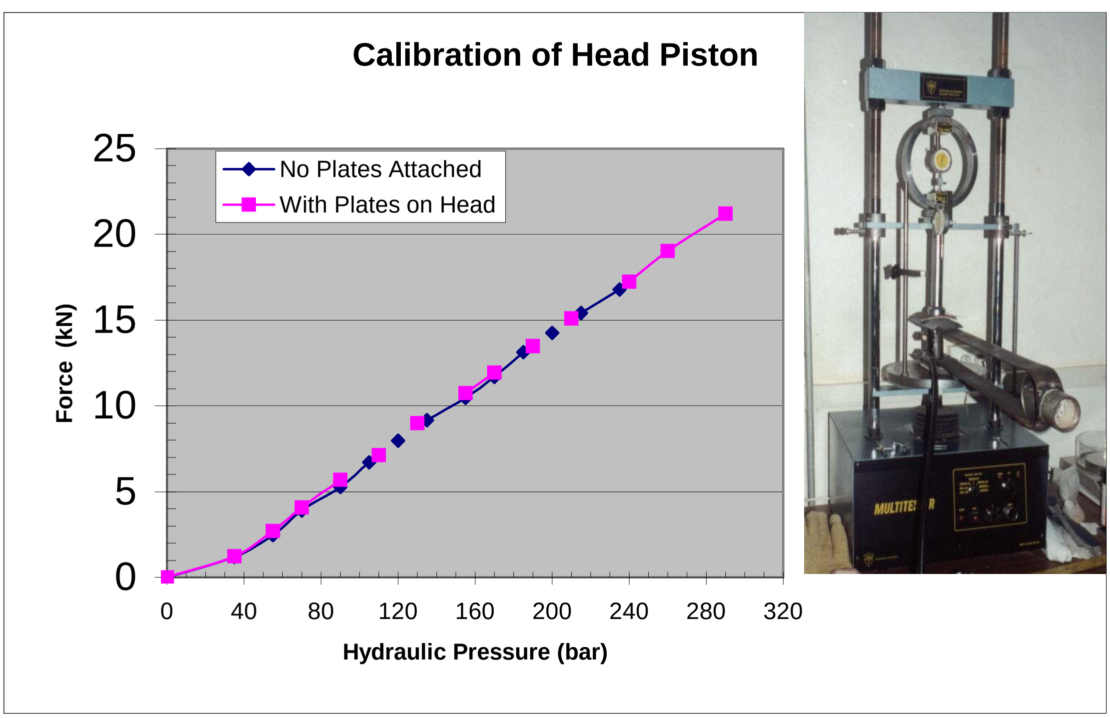


FIG. 4. Dynamometer Typical Calibration

<u>*Piston (or shear head) Calibration*</u>

A calibration was done on the piston with and without the plates being attached to the ISST head. The set-up and the calibration curve are shown in Fig. 5. The 2 curves showed no stiffening effect from the plate attachements.

FIG. 5. Piston Calibration in the IGM Lab.



FIELD APPLICATION

Procedure

The ISST test is performed as shown in Fig. 6, and as described in the following step by step procedure:

1. The apparatus is first assembled as shown in Fig. 3.
2. Drill the investigation borehole to the test depth with a diameter close to device diameter (~ 120mm)
3. Check workability of all Force & Displacement measuring components
4. Lower the shear head to the test depth, and record initial readings
5. Apply the first normal force F_1 (pressure gage) while measuring δ_h (cable displacement); giving σ_1 vs. ε to determine E, and σ_1 vs. δ_h to determine k_s
6. Apply a shear force P_1, by pulling upward and reading the dynamometer, and simultaneously reading the shear displacements δ_v by wire/ruler set up; giving τ vs γ curve to determine G.
7. When failure occurs, the maximum force P_{1f} is recorded corresponding to τ_{1f} for a given σ_1. Actually 2 τ_{1f} may be obtained at failure: one for actual shear and the other for residual shear at large strain.
8. When test is done, 1 point on the τ/σ graph is now obtained. A back-pressure is applied with the control valve and the device head is retracted and retrieved from the ground.
9. The shear plates are then cleaned and the test is repeated (steps 4 to 8)
10. At least two other tests are done for different normal stresses. The failure envelope from these 3 points will determine the in-situ c and ϕ soil parameters. Properties like E, ks, and G modulii, can also be obtained

FIG. 6. Testing Procedure

Test Identification

Shear Tests were performed at different sites ,different boreholes and different depths. A labelling format was adopted in this study in order to identify each sample test based on the location, project name, borehole nbre and depth. This format is presented in Table 1.

TABLE 1 . Test Sample Identification

Site Location	**Project Name**	**Borehole ID BH**	**Depth D (m)**	**Sample ID**
Tripoli (T)	Basatine (B)	1	2	TB1-2
T	B	2	3.5	TB2-3.5
T	B	2	5	TB2-5
T	Pumping Station (P)	1	3	TP1-3
T	P	1	6	TP1-6
Kfarchima (K)	Army (A)	1	3	KA1-3
K	A	2	3	KA2-3

ISST Results

Only one typical ISST set of results is given as an example in this paper, and it corresponds to the TB1-2 sample. These results are presented in Figs. 7, 8, & 9.

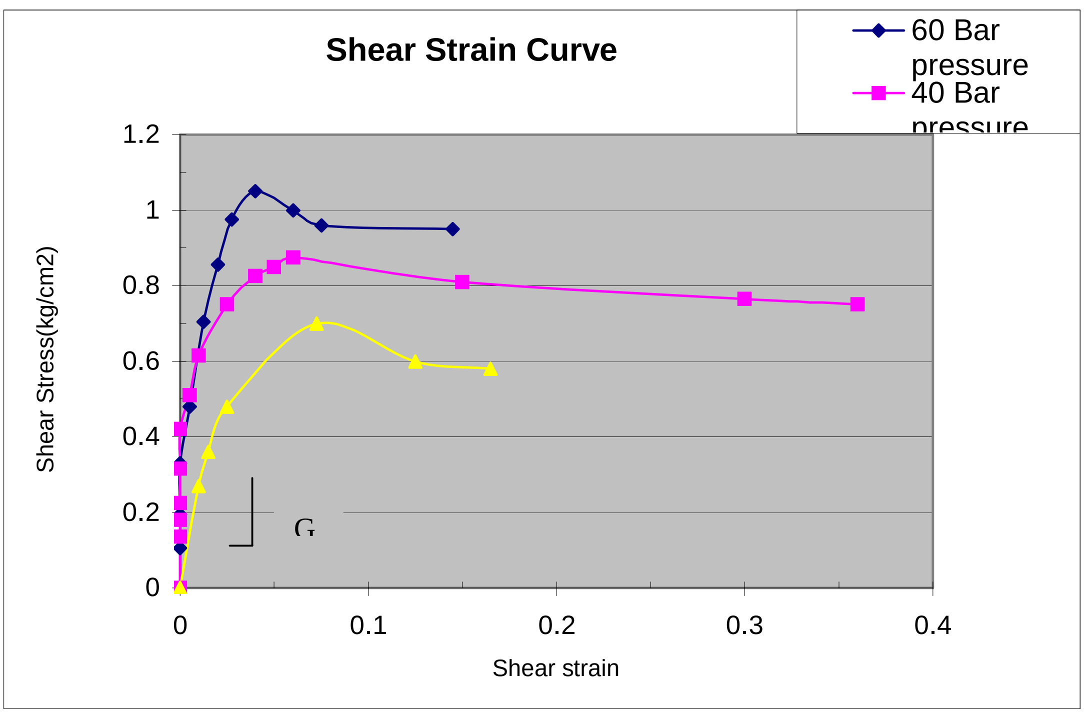


FIG. 7. Shear Strain Curve of Sample TB1-2

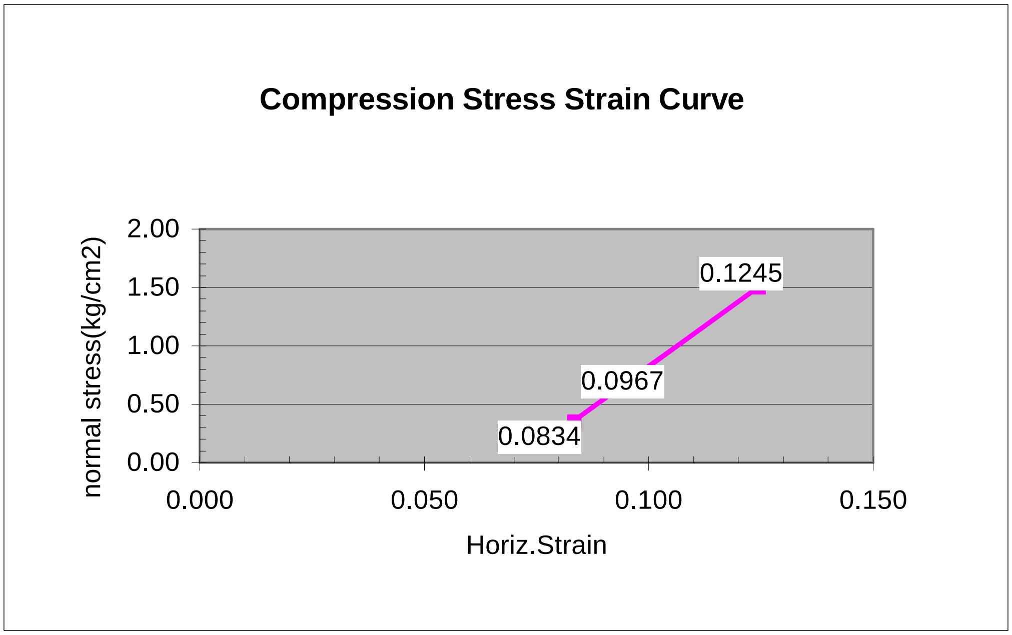


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FIG. 8. Compression Stress Strain Curve of Sample TB1-2

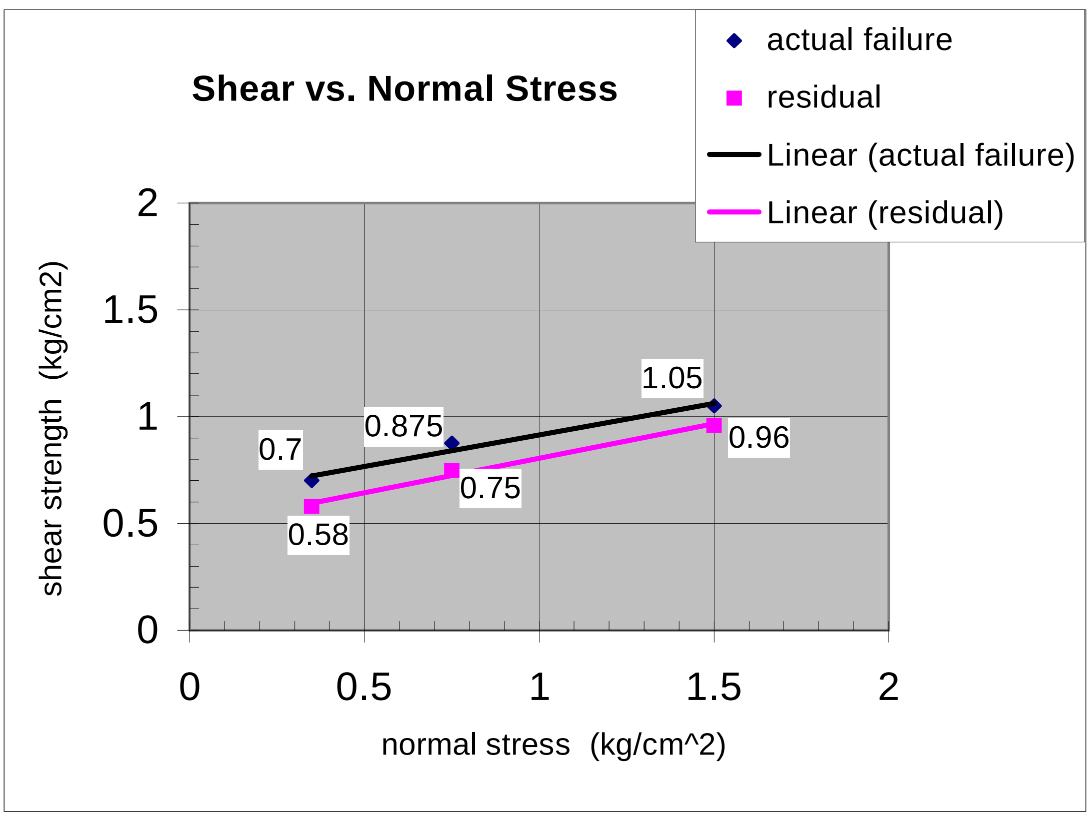

FIG. 9. Mohr-Coulomb envelope representing the Field Failure of Sample TB1-2

For this example, and from Fig. 7, the peak values represent the maximum shear at failure; however, for large strain one could obtain the residual shear (asymptotic portion of the curve). So, in this example, Fig. 9 gives the Mohr-Coulomb Failure Criterion with soil strength parameters :

$$c\ (\text{actual}) = 62\ \text{kPa}$$
$$\phi(\text{actual}) = \tan^{-1}(0.2952) = 16.45^{o}$$

and the residual strength parameters obtained are:

$$c\ (\text{res.}) = 48\ \text{kPa}$$
$$\phi(\text{res.}) = 17.95^{o}$$

Table 2 gives a summary of the results for the samples considered in this paper.

TABLE 2. ISST Results

Sample ID	**Sample Classification (USCS)**	**c,** in kPa	**ϕ,** in degrees	**E,** in kN/m^2	**G** in kN/m^2
TB1-2	CH:Brown silty Clay	62	16.4	11100	2900
TB2-3.5	Brown silty clay with sand	57	20.8	-	1500
TB2-5	Brown silty clay with gravel	59	28	-	2000
TP1-3	SP:sandy soil	46	45.5	10800	3200
TP1-6	SP:sandy soil	56	42	3300	2000
KA1-3	Light brown clayey sand	79	18	7400	2900
KA2-3	Light brown clayey sand	64	42	4000	3000

ISST EVALUATION

Comparison of Results

Tests were conducted on various soils ranging from sand to clay. It should be noted that the comparison analysis was done only on shear strength parameters c & ϕ, since common tests such as the Direct Shear (DS) and the Standard Penetration Test (SPT) cannot give the parameters that ISST is able to determine! The ISST field data were compared to laboratory Direct Shear results done on shelby tube samples, and to in situ SPT samples, taken from the same depth and in the same borehole. This comparison is presented in the following Table 3.

TABLE 3. ISST versus common tests

Sample ID	Sample Classification (USCS)	c, In kPa		ϕ, in degrees		
		ISST	D.S	ISST	D.S	SPT
TB1-2	CH:Brown silty Clay	62	57	16.4	41	42
TB2-3.5	Brown silty clay with sand	57	62	20.8	25	39.5
TB2-5	Brown silty clay with gravel	59	83	28	20	48
TP1-3	SP:sandy soil	46	7	45.5	45	58
TP1-6	SP:sandy soil	56	34	42	40.5	60
KA1-3	Light brown clayey sand	79	65	18	15	45
KA2-3	Light brown clayey sand	64	75	42	35	52

Introducing Correlation Factors Fc and Fϕ

New Correlation Factors were introduced. These are important Factors that help the design Engineer in correlating his findings to results that he is used to deal with. For example, if an engineer is used to deal with SPT, he can apply Fϕ to the ISST results and make his own strength assesment of the soil in question.

Based on the results tabulated in Table 4, correlation factors were established graphically as shown in Figs 10 & 11. These factors can be given by:

$$Fc = c(ISST)/c(DS) = -0.02 \times c(DS) + 2.26 \quad \text{(c in kPa)}$$
$$F\phi = -0.6 \times \tan[\phi(DS)] + 1.42$$
$$F\phi = 0.25 \times \tan[\phi(SPT)] + 0.19$$

Where :
Fc= Correlation factor for the cohesion parameter
Ff = Correlation factor for the friction factor
(ISST)= In Situ Shear Test
(DS) = Direct Shear Test
(SPT)= Standard Penetration Test- using the correlation of Kulhawy and Mayne, 1990, to obtain ϕ from N (SPT blow count number) [Ref 8]

TABLE 4-New Correlation Factors

Sample ID	In-Situ, ISST		LAB, D.S		Correlation Factors		
	c (kPa)	Tan(ϕ)	c (kPa)	Tan(ϕ)	Fc (D.S)	Fϕ (D.S)	Fϕ (SPT)
TB1-2	62	0.295	57	0.87	1.09	0.34	0.33
TB2-3.5	57	0.367	62	0.47	0.92	0.81	0.46
TB2-5	59	0.53	83	0.364	0.71	1.45	0.48
TB1-3	46	1.017	7	1	0.66	1	0.63
TB1-6	56	0.9	34	0.869	1.65	1.04	0.52
KA1-3	79	0.32	65	0.268	1.21	1.19	0.32
KA2-3	64	0.89	75	0.7	0.853	1.28	0.7

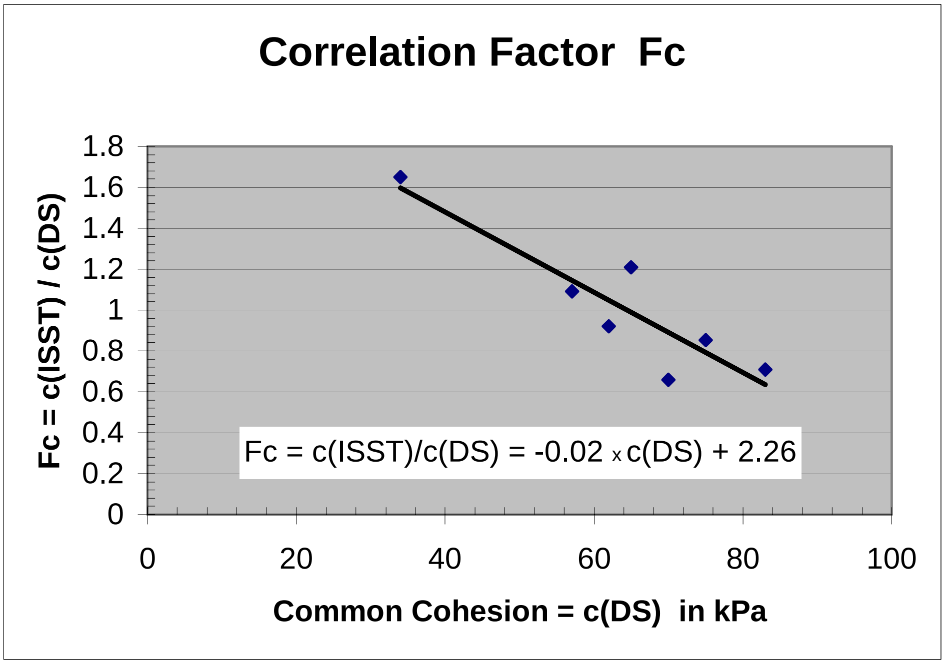

FIG. 10. Fc Correlation Factor

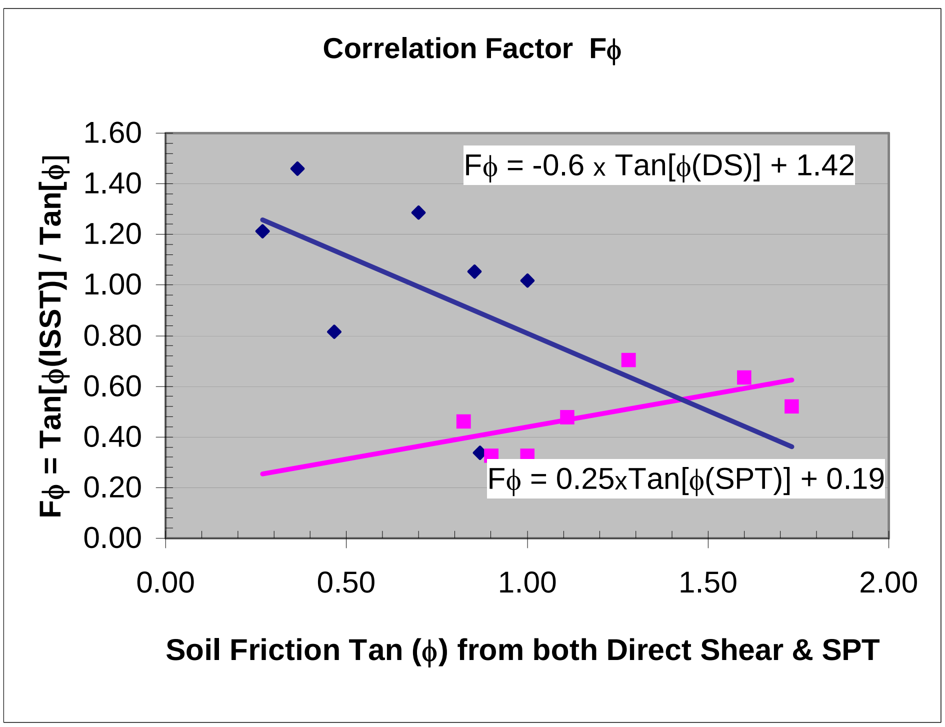

FIG. 11. F(ϕ) Correlation Factor

As can be seen in Fig. 11, the soil friction data is wide spread which leads the author to believe that more testing and comparisons would be needed in order to establish more reliable relationships.

CONCLUSIONS

The ISST(In-Situ Shear Test), a rugged tool that obtain soil parameters directly on site) has been produced, developed, and tested. Preliminary results have shown that the ISST proved to be reliable tool and its results are comparable to commonly used tests with which correlation factors are established. Moreover, ISST offers additional advantages:

- No disturbance of Samples, the soil is not molded in-situ.
- Obtain quickly accurate soil parameters on site specially in cohesionless and unsaturated soils [Ref 9]
- Shear strength measurement could be done by the ISST in any direction since it is rugged and fits on large anchoring drill rigs
- Possibility to perform the test in any direction; which helps determining soil anisotropy. Also Shear strength measurement could be done by the ISST in the expected direction of actual shear like is the case of ground anchors, or slope stability analyses.
- Possibility to measure residual parameters for large strain problems
- Allow performance of value engineering : because ISST data can be collected on a regular basis during construction, thus allowing to optimize the design , check its validity and evaluate its safety continuously

Recommendations for future research could include the following steps:

Further Testing on many other samples, and sensitivity analyses would be needed in order to confirm or modify the findings and correlation factors given in this paper

Possibility of Pore Pressure measurement at the shear plates level to simulate Consolidated Undrained Test (CU) as was attempted for the BST [Ref 10]

Possibility of shearing at very slow rates to simulate Consolidated Drained Test (CD) in saturated clayey soils

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