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Use of in-situ tests for evaluation of shear modulus for hard clays in Sudan

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ABSTRACT: The central clay plain in Sudan is covered by hard partially saturated clays. Most of these clays are highly plastic with medium to high swell potential. As the collection of undisturbed samples is sometimes very difficult, in-situ tests were carried out. The in-situ tests conducted at a site situated in the central clay plain comprised of Menard pressuremeter test, plate load test and geophysical refraction test. The dynamic shear modulus G value was determined from the different tests and compared with each other.

The dependence of dynamic shear modulus on the shear strain was investigated. It was found that results are comparable to these previously reported in the literature. The modulus degradation ratio is used to estimate materials properties needed in analysis and design for different substructures.

1 INTRODUCTION

The generalized soils map of the Sudan shows five different regions of soils. Desert sands in the north and west of Sudan, semi-desert soils in the low mountain range along the Red Sea, alkaline clay soils in the central Sudan and along the Ethiopian border, and stabilized sand in the central and west of Sudan. In addition, alluvial deposits occur along the White Nile, Blue Nile and River Nile. The area dominated by alkaline clay soils is termed the Clay Plain (Charlie et al. 1984). Figure 1 shows the different regions of soils in Sudan.

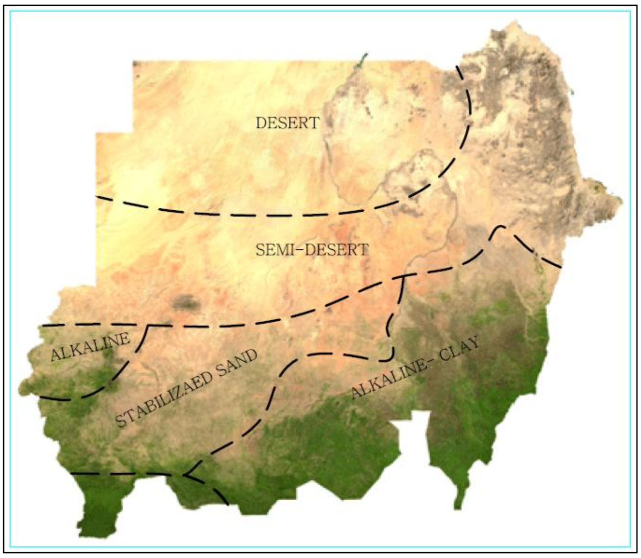

Figure 1. Generalized soil map of Sudan

The Clay Plain region is covered by partially saturated stiff to hard clays of high plasticity with medium to high swell potential. These clays usually followed by medium dense to very dense clayey to silty sands extended to the Nubian formations which includes sedimentary weak rocks of completely weathered to slightly weathered sandstones and mudstones. The top clays sometimes reveal very stiff to hard density and low natural moisture content which makes the undisturbed sampling of these clays is very difficult. Sufficient rock samples also cannot be obtained from the bottom weak Nubian formations due to the high degree of rock weathering. Therefore, in-situ testing is useful in such clays and sedimentary formations to obtain the necessary geotechnical parameters required for foundations design. Different in-situ tests were conducted at a site located in the central clay plain at about 300 km southern Khartoum. Traditional boreholes accompanied by standard penetration test (SPT), pre-bored Menard pressuremeter tests, geophysical seismic tests as well as plate load tests were performed in the investigated site. This paper presents the results of these in-situ tests and comparison of the obtained soil parameters - specifically the shear modulus - calculated from the results of different tests.

2 SITE INVESTIGATIONS AND RESULTS

2.1 Soil Characteristization

Considerable number of boreholes were drilled in the investigated site to an average depth of about 15.0m to 25.0m depth. Standard Penetration Test (SPT) was carried out at 1.0m to 2.0m intervals in cohesion-less soils or wherever it is difficult to get undisturbed samples. Two holes of 20.0m depth and suitable diameter were drilled for pressuremeter testing. Two other holes of 150mm diameter were drilled for seismic testing. Six open test pits of 2.5 to 3.0m depth were also excavated in different locations for plate load testing. The general soil profile revealed existence of hard highly plastic silty clay layer (CH) in the top 4.0m. This is followed by alternative layers of very dense clayey sands (SC) and hard low plastic silty clay (CL) extended down to the bottom of the boreholes at about 20.0m depth. The soils encountered in the present site are relatively dry, no groundwater or surface water was observed during the boreholes drilling process.

Extensive laboratory testing program was conducted for the soil samples to evaluate the physical and mechanical properties of the encountered soils. The tests included classification tests, shear strength tests and volume change tests. The tests procedures followed based on those recommended in the British Standard BS 1377 (1990).

Based on the results of the Atterberg limits and particle size distribution the soils of the site were classified according to the USCS as presented in Table 1 below:

Table 1. Soil classification

Depth Range (m)	Atterberg Limits LL %	PI %	% Passing Sieve # 200	Soil Classification According to USCS
0 - 4	55 to 68	29 to 42	54 to 88	CH
5 – 11	29 to 45	11 to 29	28 to 49	SC
12 - 20	27 to 41	10 to 22	50 to 68	CL

2.2 Preseeuremeter Test (PMT)

The results of Menard pressuremeter are normally presented in graphical form of pressure (*p*) versus total cavity volume change (*V*). The pressuremeter modulus (E_p) was calculated using the theory of expansion of an infinitely thick cylinder (ASTM D 4719, 2000) as follows:

$$E_p = 2(1+\mu).v_{m.}(\Delta p/\Delta v) \quad (1)$$

Where

E_p = Pressuremeter Modulus (Elastic Modulus).
μ = Poisson's ratio
v_m = The average volume of the probe over the considered stress range
$\Delta p/\Delta v$ = Slope of the linear portion of the stress versus probe volume curve

Then the shear modulus (G) can be obtained by (Mair & Wood 1987):

$$G = E/2(1+\mu) \quad (2)$$

The results of tests carried out in two different boreholes at several depths with regular intervals are shown in Figure 2 below:

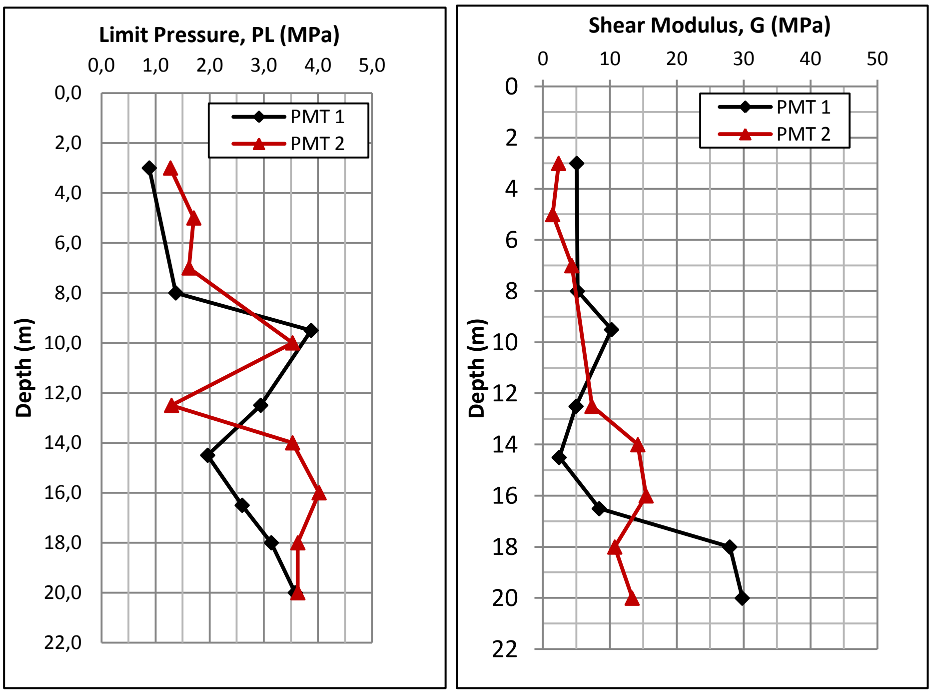

Figure 2: Pressuremeter test results

2.3 Up-hole Seismic Test

In up-hole seismic test a spread of 24 geophones was used in each hole. The geophone horizontal interval is 5.0m along a line was laid down approximately trending north-south while the borehole is laid midway between geophones 12 and 13 (Telford et al. 1976). Shooting was started from below by firing the capsules one for each depth interval and the arrival times at the 24 geophones were recorded by Terraloc Mk 6 V 2.22 (ABEM) 24 - channel seismograph. The shear modulus (G) and Poisson's ratio (μ) estimated from the two up-hole seismic shootings are presented in Figure 3 below:

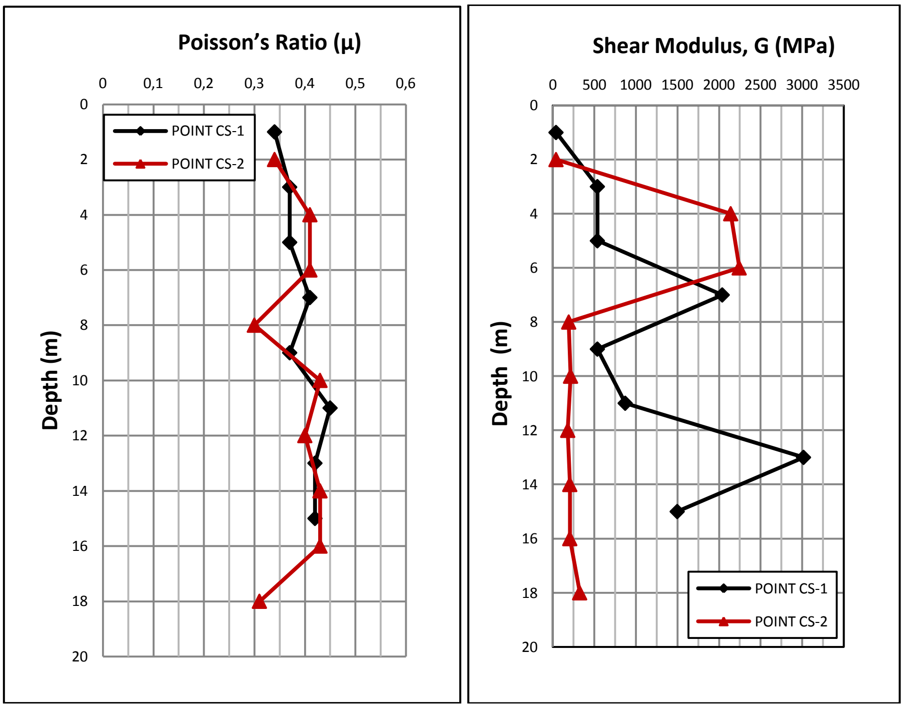

Figure 3. Up-hole Seismic Shootings Results

2.4 Plate Load Test (PLT)

Six standard plate load tests were performed in the site at a depth of 2.5m to 3.0m below the ground level. The soil during the test was loaded to the maximum test load in twelve stages. A steel plate of 600mm width was used for conducting the test and loaded to a maximum load of 800 kPa. The values of elastic modulus (E) were calculated from the test results using the following equation (Rao 2000):

$$E = \frac{(1-\mu^2).B_p.I_w}{\Delta\rho/\Delta q_p} \qquad (3)$$

Where

E	=	elastic modulus
μ	=	Poisson's ratio
$\Delta\rho/\Delta q_p$	=	slope of settlement versus plate pressure
B_p	=	width of plate
I_w	=	influence factor, (π/4)

The results of the tests and calculated values of elastic moduli and shear moduli are presented in Table 2 below:

Table 2. Plate Load Test Results

Nest No.	Max. Settlement, mm	Elastic Modulus, E MPa	Shear Modulus, G MPa
PLT - 1	6.38	44.90	16.88
PLT - 2	4.87	80.41	30.23
PLT - 3	5.54	81.42	30.61
PLT - 4	16.24	55.93	20.03
PLT - 5	3.66	115.78	43.53
PLT - 6	4.31	50.39	18.94

3 ANALYSIS OF THE RESULTS

A comparison of shear modulus values obtained from pressuremeter test results with shear modulus values determined by seismic tests and plate loading tests is shown in Figure 4. Values of shear modulus are plotted against depth for each test type.

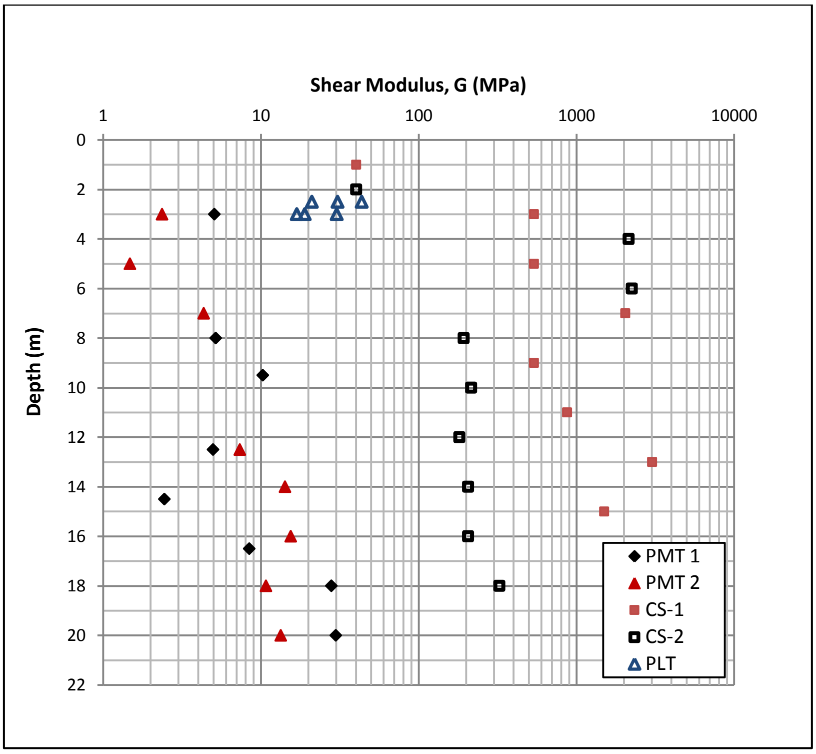

Figure 4. Comparison of shear modulus determined by various methods

The strain level in pressuremeter test - both initial loading PMT and unload-reload PMT - is higher than seismic test, so the shear modulus from PMT could be expected to be lower than from seismic test. Also the level of strain in plate load test is higher than in seismic test, therefore the shear modulus from seismic test is higher than that from plate load test. The range of strain which is typically used in initial loading pressuremeter testing and plate loading test is about 10^{-2} to 10^{-3}, while the seismic tests usually subjected the soil to very small strain amplitude in the range of about 10^{-5} to 10^{-6}. Penetration tests such as standard penetration test (SPT) and cone penetration test (CPT) are conducted in the highest strain level ranges between 1.0 and 10. Figure 5 shows the relationship between the shear strain amplitude and shear modulus for different types of field tests (Sabatini et al. 2002).

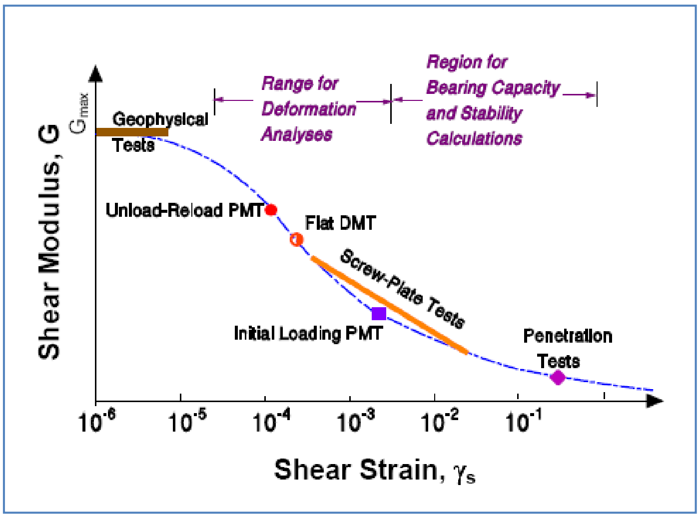

Figure 5. Variation of shear modulus with strain level (Sabatini et al. 2002)

The small-strain shear modulus - from geophysical tests - should be reduced for use in foundation deformation calculations since strains associated with foundation loadings are greater than those corresponding to the small-strain tests. The equivalent elastic modulus (E_s) can be calculated from the initial modulus (E_o') which is given by small-strain tests as:

$$E_s = (E/E_0)\, E_0' \qquad (4)$$

The initial modulus (E_o') is reduced to a value consistent with an appropriate working stress level for the desired factor of safety (FOS) for the structure. This reduction factor (E/E_o) is also known as the modulus degradation value (Sabatini et al. 2002).
A graphical procedure can be used to reduce the small-strain stiffness (E_o') to those at working stress levels. The stress ratio (q/q_{ult}) at the desired working stress (q) is required. The factor of safety (FOS) for the structure is defined as the stress ration q/q_{ult} = 1/FOS. Figure 6 illustrates the suggested trends for modulus of degradation for intact clays and uncemented sands based on a curve fitting parameter (g) value of 0.3 for hyperbolic relationship (Burns & Mayne 1996).

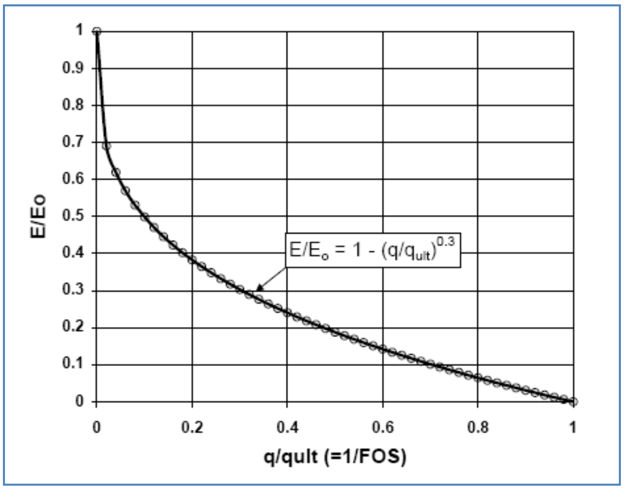

Figure 6. Modulus of degradation based on g = 0.3 (Burns & Mayne 1996)

The shear modulus (G) corresponding to the equivalent elastic modulus (E_s) can then be estimated using equation (2) above.

4 CONCULSIONS

The in-situ tests are quite suitable for the characterization of clay plain and weak rocks in central and southern Sudan which is covered by partially saturated highly plastic hard clays in the top layers and weak sedimentary rocks in the bottom layers. At the site situated in the central clay plain the shear modulus values obtained from pre-bored Menard pressuremeter have been compared with those given by plate load tests and seismic tests. The comparison showed that the stiffness - shear modulus - of soil measured by seismic tests is almost ten times higher than the stiffness given by initial loading pressuremeter tests and plate load tests for the same soil. This variation in soil stiffness is due to the different levels of strains at which the different tests were performed. The tests conducted at high levels of strain showed low values of stiffness, while tests carried out at low level of strain indicated high values of stiffness. The high values of shear modulus - given by seismic tests - should be reduced for use in foundation design calculation. A reduction factor - modulus degradation ratio - estimated based on the factor of safety of the structure. This can be used to reduce the high values of stiffness to the values at actual working stress level.

Seismic testing can be carried out faster and less costly compared to the other in-situ tests. Therefore, further studies in the area of modulus of degradation will be useful in geotechnical characterization for foundation design. For future studies it is recommended to carry out more tests in this type of soil to confirm findings in this investigation. Unload-reload pressuremeter should be carried out to compare the results with initial loading results. The Menard pressuremeter has been used extensively for foundation design in some parts of the world e.g. France. These methods and procedures should be looked into locally in Sudan, where stiff soils and weak rocks are encountered.

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