Comparison of Soil Test Data, Obtained with Different Probes

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ABSTRACT: The paper presents clay test data with different dilatometers, including Marchetti and Russian-made ones. There are shown deformation isofields, obtained by means of image processing method for flat and round probes in sandy soil. Typical stiff dilatometer test results are shown for lateral stresses versus time. Equations are given for deformation moduli calculation. There are compared soil deformation moduli, obtained by different field and laboratory tests.

I INTRODUCTION

Flat probes are applied to determine soil mechanical parameters in situ. They differ from probes for static tests as to their shape and dimensions. The shape of a flat probe is better than that of CPT for measuring mechanical soil properties. Wedge shape and small width (10-15 cm) with the gauge, mounted on the side rather than under the tip, ensures minimum soil disturbance due to the probe penetration.

Fig. 1 shows two digital shear strains iso-fields, for flat DMTs (left) and for circular dilatometers (right) (Melnikov & Boldyrev, 2014). Evidently, flat probe penetration produces more homogeneous deformations as compared to the circular probe. In both cases maximum shear occurs close to the wedge part of the probes. Such data was earlier obtained by Baligh & Scott (1975). The second feature is the capacity to measure in situ lateral stresses i.e., soil in situ condition.

2 DILATOMETER TYPES

There are several dilatometer types (Fig. 2). In Europe, USA and elsewhere there are applied Marchetti dilatometers. In Russia there are flat probes, developed by V. F. Sidorchuk (1984), by

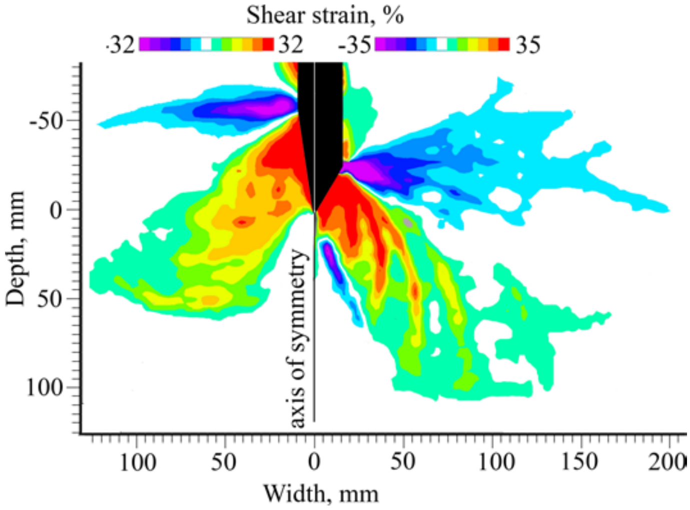

Fig. 1. Sand deformations, caused by the probe movement.

L.S.Lavrov (1990) and by L.S. Amaryan (1980). The first one is called RSD – Russian Stiff Dilatometer, the second one RWD – Russian Wedge Dilatometer, and the third one RBD – Russian Blade Dilatometer.

Marchetti dilatometer is broadly applied worldwide. Its specification is included in several international standards. So far, Marchetti dilatometer is increasingly applied in Russia for geotechnical investigations. There are plans to develop DMT standard regulations for field tests. So far there is GOST 20376 (2012) i.e., the code for tests with a stiff 70 mm dia dilatometer (Amaryan, 1980), however, this dilatometer is not produced on industrial scale so far.

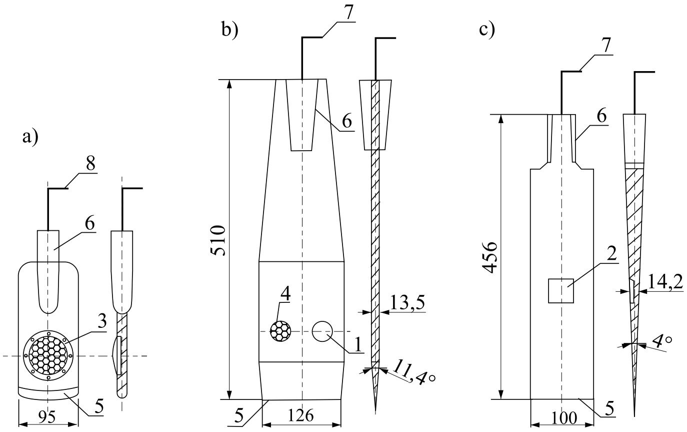

Fig. 2. Flat probe designs:
a – Marchetti dilatometer; b – stiff probe; c – wedge-out dilatometer;
1 – stiff pressure gauge; 2 – flexible pressure gauge; 3 – membrane; 4 – pore pressure gauge; 5 – tip; 6 – tail-expander; 7 – cable; 8 – pneumatic electrical cable

Stiff dilatometer and wedge-out dilatometer differ as to both their dimensions and the gauges for measuring lateral stresses. The first dilatometer is equipped with high-stiffness pressure gauges while in the second one – a flexible membrane with a tensoresistor, glued on it (Lavrov, 1990).

If Marchetti dilatometer and the wedge-out dilatometer could be classified as “flexible” then Sidorchuk dilatometer could be called ”stiff” to emphasize the difference. Marchetti dilatometer is equipped with a thin steel membrane, expanded by the pressure of liquid or air/gas. In the stiff dilatometer the pressure gauge is active thanks to the element, incorporated in the probe side surface. The pressure gauge is dozens times stiffer than soil and, therefore, applicable for coarse-grain soils or clays, having such inclusions. The second feature of the dilatometer is direct measurement of lateral and pore pressure.

Tests with stiff dilatometers are performed, as follows. The dilatometer is sunk into soil to the specified depth, then lateral stresses σ_h^o are immediately measured and then are measured again after relaxation σ_h (Fig. 3). Young modulus is determined from Ter-Martirosyan et al. equation (1984), obtained from elastic solution for a slot opening in space:

$$E_{RSD} = \left(1-\nu^2\right)\sigma_h^o \frac{b}{h} \qquad (1)$$

with σ_h as lateral stress after relaxation; ν as Poisson ratio; h and b as half thickness and half width of the probe respectively.

In wedge-out dilatometer tests the similar relaxation technique is used, however, soil is deformed by specified steps of lateral displacements while the lateral stresses are measured with the help of a pressure gauge. These geometrical dimensions of the wedge-out dilatometer ensure linear deformation of surrounding soil along the most of the active sides surface. The value of Young modulus is determined from modified Schleicher solutions (1926):

$$E_{RWD} = \frac{\pi(1-\nu^2)\omega d q_a}{2S_a \arcsin\frac{d}{b}}, \qquad (2)$$

with ν as Poisson ratio; ω as coefficient, accouning for stiffness and shape of the probe active sides; d as width of the pressure gauge sensitive membrane; q_a as contact pressure from the sensor readings; S_a as soil displacement at the pressure gauge center; b as the probe width.

Marchetti DMT determines two moduli: E_{DMT} dilatometric modulus that relates soil behavior due to the lateral load, determined from solution for elastic half-space (Marchetti, 1980):

$$S = \frac{2D\Delta p}{\pi}\frac{\left(1-\nu^2\right)}{E} \qquad (3)$$

with S as deformation (mm), E as Young modulus, D as diameter of active portion of the loaded element, ν as Poisson ratio, Δp as load, required to initiate deformation S.

By inserting the known parameters of the probe in the above equation (D=60 mm and S=1,1 mm) we obtain:

$$E_{DMT} = 34,7\Delta p\,. \qquad (4)$$

The second oedometer modulus E_{oed} is determined, accounting for the soil type and the loading history:

$$E_{oed} = R_M E_{DMT}\,, \qquad (5)$$

with R_M as coefficient, accounting for soil properties.

3 TEST RESULTS

Tests with dilatometers of different designs were carried out on sites with clay soils down to 10 m depth.

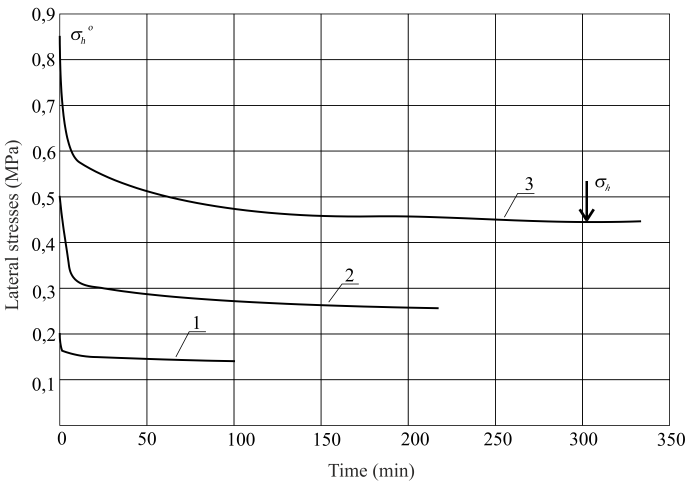

Fig. 3. Lateral stress relaxation versus time:
1 at 1,3 m level; 2 at 3,3 m level; 3 at 7,3 m level.

Fig. 3 shows typical results of lateral stresses versus time ratio measurement in a high-stiffness dilatometer test. The process is slowly dying out and it is hardly possible to observe its completion. For registering lateral stresses stabilization relative relaxation function was applied i.e., ratio of lateral stresses over time interval, divided by instantaneous value of lateral stresses, when the probe *s* rests at a specified depth, %/min:

$$\nu = \frac{\sigma_i - \sigma_{i-1}}{(t_i - t_{i-1}) \cdot \sigma_h^0} 100\,\%, \tag{6}$$

As is evident from Fig. 4, when relative stress relaxation rate parameter achieves 1%/min value then stress relaxation practically stops. It corresponds to about 10 minutes time after dilatometer immersion into clay. The stress variation versus time function can be approximated differently. The best results are obtained by power and logarithmic functions. Fig. 5 demonstrates Beside in-situ tests with dilatometers of different designs there were performed the tests with a screw plate (RST – Russia Screw Test, 600 cm^2), CPT, laboratory oedometer and triaxial tests. The oedometer Young modulus was measured by CPT there was applied the equation, borrowed from EN 1997-2:2007:

$$E_{oed} = \alpha q_c, \tag{7}$$

with q_c as measured tip resistance. The coefficient α value depends on the type of soil, stress history.

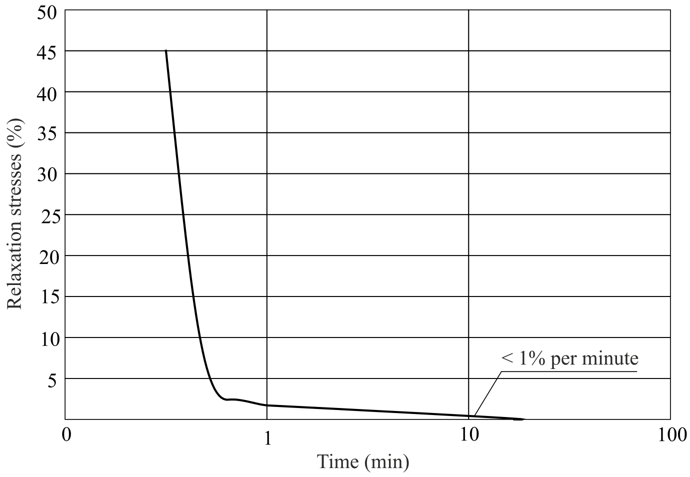

Fig. 4. Lateral stresses relaxation rate.

comparison of Young modules from field tests by dilatometers of different designs.

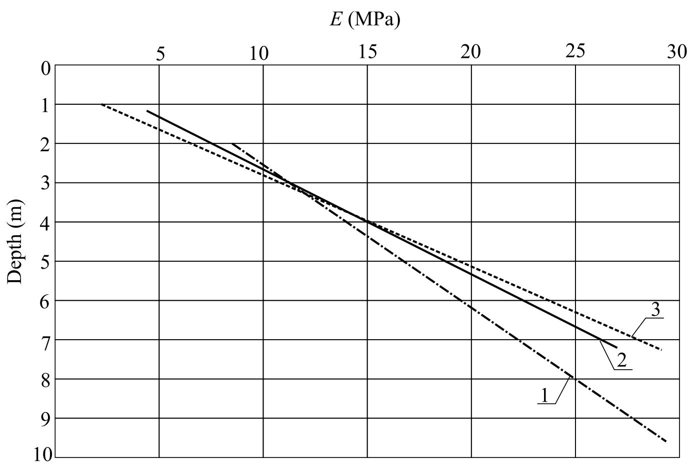

Fig. 5. Young modulus versus depth variation. 1,2,3 are data linear approximation of data, measured with dilatometers RWD, DMT and RSD respectively, R^2 – 0,747; 0,763; 0,697.

The value of Young modulus in screw plate tests is determined with Schleicher equation (Schleicher, 1926; GOST 20276):

$$E_{RST} = \frac{(1-\nu^2)\omega D \Delta p}{\Delta s}, \tag{8}$$

with Poisson ratio ν equal to 0,3 for sands and sand loams, 0.35 for clay loams and 0.42 for clays; dimensionless coefficient ω is equal to 0,8 for circular plate; D as plate diameter; Δp as pressure increment within the linear range of $s=f(p)$ curve; Δs as plate settlement increment, corresponding to Δp.

Fig. 6 shows comparison of the above mentioned test methods.

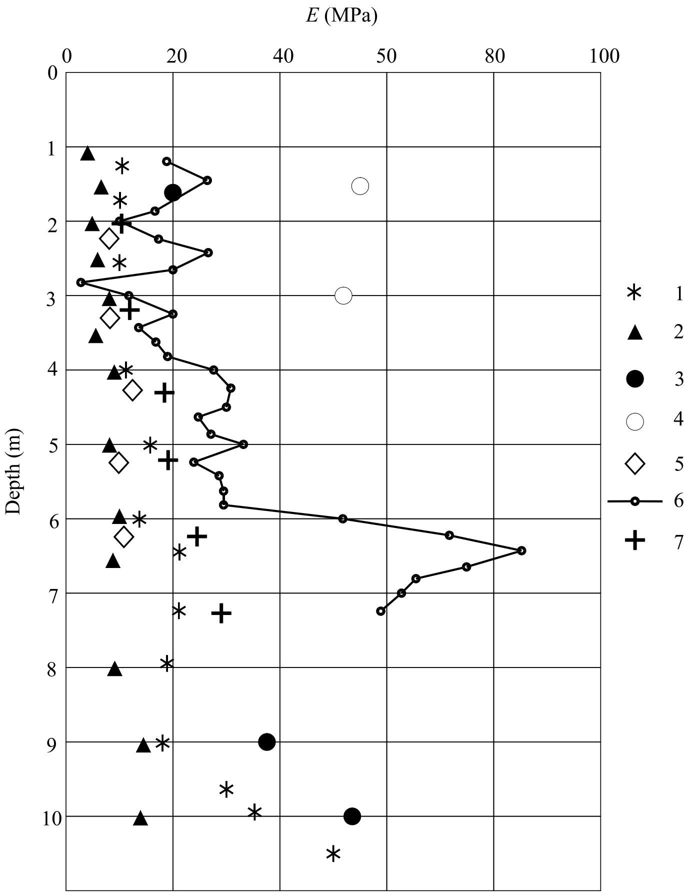

Fig. 6. Modulus of deformation versus depth variation: 1 – CPT (E_{oed}); 2 – oedometer test (E_{oed}); 3 – triaxial test; 4 – RST (E_{RST}); 5 – RSD (E_{RSD}) ; 6 – DMT (E_{DMT}); 7 – RWD (E_{RWD}).

4 CONCLUSIONS

1. The obtained data tightness shows that all the applied dilatometers yield identical statistical data fidelity. The values of dilatometer modules are also close. E.g. the approximate values of the module at 3,3 m depth for all dilatometers are equal to 12,2 MPa.

2. Comparison of soil test data, obtained with flat probes of different configurations, as well as their growing performance (both technical and analytical) demonstrate the advantages of this field tests over other tests. DMTs enable fast and essentially high-accuracy direct measurement of Young modulus and other soil parameters in undisturbed soil anywhere on the site.

3. Marchetti dilatometer differs from its Russian analogues in that it measures Young modulus and other soil parameters. The main advantage of the wedge-out dilatometer and stiff probe enable measurement of lateral stresses in soil as well gravely clays inclusive.

5 REFERENCES

Baligh, M.M. and Scott, R.F. (1975). "Quasi Static Deep Penetration in Clays". *J. Geotech. Eng. Div., m.Soc. Civ. Eng.*,101(11), 1119–1133.

Marchetti, S. (1980). “In situ tests by flat dilatometer.” ASCE JCED *Journal of Geotechnical Engineering Division*, vol. 106:GT3, 299-321.

Melnikov, A.V. and Boldyrev, G.G. (2014). “Experimental study of sand deformations during a CPT.” *The 3rd International Symposium on Cone Penetration Testing*, Vegas, Nevada, May 13-14, 339-345.

Schleicher, F. (1926). “Kreisplatten auf elastischer Unterlage.*”* *Springer-Verlag*, Berlin (in German).

Amaryan, L.S. (1995). “New technical means for geotechnical survey within urban areas.” № 4, 8-12 (in Russian).

GOST 20276. (2012). “Methods of determine strength and deformation parameters.” *State Standard 20276* (in Russian).

Lavrov S.N. (1990). “Experience and perspective of wedge indenters application for field soil investigations.” *Materials XIV conference of young speyotsialist on geology and geophysics of Eastern Siberia*, Ircutsk, 1990 (in Russian).

Ter-Martirosyan, Z.G., Kijtov N.H. and Sidorchuk, V.F. (1984). “Experimental basics for determining soil stress and strain behavior in situ.” *Engineering geology,* №4, 13-25 (in Russian).