Testing of the Soil Deformation Properties In-situ by Flat Wedge Dilatometer

Leonid V. Nuzhdin
Novosibirsk State Univ. of Architecture and Civil Engineering, Novosibirsk, Russia. nuzhdin_ML@mail.ru
Sergey Lavrov
Company "Novosibirsk Engineering Center", Novosibirsk, Russia. lavrovsn@list.ru
Matvey Nuzhdin
SPEC Company "O&F", Novosibirsk, Russia. 89139059520@mail.ru

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ABSTRACT: The testing of the mechanical characteristics of soil properties in field conditions are most authentic, because of the absence of distortions which are connected with selection of samples and their transportation. It is offered to use a wedge dilatometer for definition of the module of deformation and elastic module (module of dynamic deformation) soils in field conditions. The device realizes in practice method of controllable moving, which is an untraditional approach to a problem of the investigation of deformation of soil properties. The loading of a soil by given moving is carried out with the help of relaxation type devices. The kinematic scheme of such devices in general is simpler than the loading of sample in traditional way (pressure growing by steps). The realization of relaxation method in field conditions the result in a very simple design of a loading appliance (sensor which body while pressing in a ground and receiving definite movings, serves simultaneously registrar of the pressure that arises in ground). The construction of static and dynamic wedge dilatometer, method of testing and experience it's successfully used in practice is presented.

1 INTRODUCTION

The process of deformation of soils as a complex multiphase polydisperse medium depends on a number of external and internal factors. Perhaps, this is why reliable definition of soils deformation properties is an urgent topical problem for geotechnique.

In difficult situations analysis of volume deformations and shear deformations of soil medium in the buildings foundation requires to use modules of volume deformation and soils shear. Elasticity module (module of dynamic deformation) of soils is used to forecast the parameters of dynamic behavior of the foundations. However, for the most part in order to estimate soil deformability and to design foundations we need to define the module of deformation (general deformation) for the soil characterizing its total (elastic and residual) deformations. Such deformation characteristic usually assumes linear dependence between strains and deformations.

Excessive sensitivity of disperse (clay and sandy) soils to influences inevitably occurring during sampling, samples transportation and preparation for laboratory tests, sets high standards to preserve natural structure of the soils. In addition to purely mechanical damage sample extraction from a well or a pit-hole is accompanied by strain reduction in the soil skeleton and by pore water pressures decrease to zero level. This is why there are errors, sometimes rather significant, in all laboratory tests of soils trying to determine their deformation modules. The greatest problem is to evaluate deformation properties of weak water-bearing and loose soils, which are very difficult (and sometimes impossible) to sample drilling a well or digging a pit-hole. This is why it is preferable to use field research methods to obtain reliable results trying to define soils deformation modules.

This also refers to dislocated and all altered soils which may have rather high deformation parameters, but which are often deemed to be of little use due to considerable irregularity of their properties in the bedding area, which cannot be predicted in usual geological engineering surveys.

2 CONTROLLABLE STRAIN METHOD (MCS)

It should be noted, that in order to determine deformation modules for soils, just as for other materials, it is necessary to use external influence to bring the analyzed massif to its stress and strain state different from its initial one, and then to calculate the required parameter using analytical solution for the particular area. It is possible to apply incrementally-increasing loads to the analyzed soil measuring its second parameter – deformation (displacement), as a consequence of the applied power load. This method can be defined as a controllable strain method (MCS).

On the other hand it is possible to deform the soil massif using by set displacements, registering in the process the second parameter – tension, as a consequence of deformation influence. Theoretically both schemes of exerting influence on soil described above are absolutely equivalent, since most physical models establish one-to-one correspondence between pressure and deformations. In practice the method of controllable moving (MCM), when the soil is loaded and deformed by pre-set increasing displacements, and tensions arising in the soil are monitored as researcher-independent values, allows to use simpler test patterns and to reduce time required to carry out such tests.

MCM is based on the principle of strain relaxation in time down to a relatively stabilized value. Its application is a promising area for researchers developing devices and methods to define deformation modules of disperse soils both in field and laboratory conditions (Lavrov et al. 2003, 2004, Nuzhdin & Lavrov 2012).

3 FLAT WEDGED DILATOMETER

Use of relaxation method in field conditions brings about a very simple design of the load-applying device in the form of indenter forced into the ground, and the housing of the indenter feeling specific displacement allows at the same time to register tensions arising in the ground. General view of the installation to study soil base with the help of wedge dilatometer is shown in the figure 1. Initially the West-Siberian trust of geoengineering researches ZapSibTISIZ («Stroyizyskaniya Geoengineering» Inc.) with the assistance of Novosibirsk State University of Architecture and Civil Engineering (Sibstrin) has proposed and developed a dilatometer with wedged indenter, designed to define the module of general deformations for disperse soils.

Design engineering of a wedged dilatometer required a complex of special research in order to evaluate the influence of various design features of the indenter and the influence of the technique of soils tests performance on the quality of the resulting information.

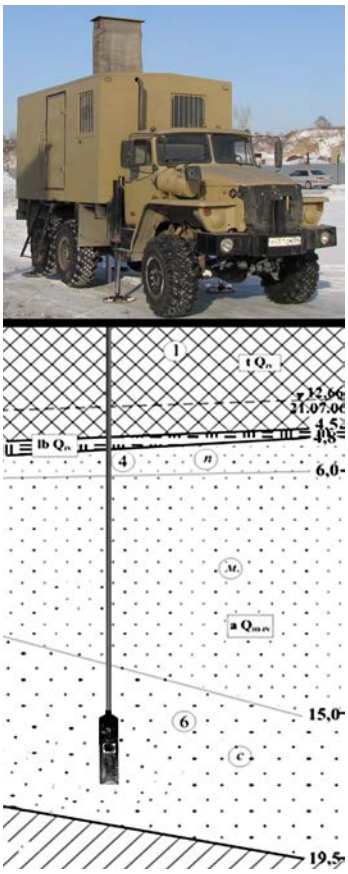

Fig. 1. General view of field installation to test soils deformation properties using a flat wedged dilatometer, consisting of motor vehicle with static probing device, probing rods column and V-shaped indenter.

With the help of numerical analysis using the finite elements method (FEM) we evaluated changes in the deflected mode of the soil medium when it is penetrated by a V-shaped indenter. Later the process of fluctuations of an indenter immersed into the soil and peculiarities of dynamic strain development in the soil were digitally modeled (Nuzhdin et al. 2007, Nuzhdin 2009, 2010a). Soil was regarded as an elastic (linearly-deformed) and elastic-plastic medium. Existence and arrangement of the soil elastic behavior area, the sequence of development and the size of limit soil stress state around the indenter were also studied.

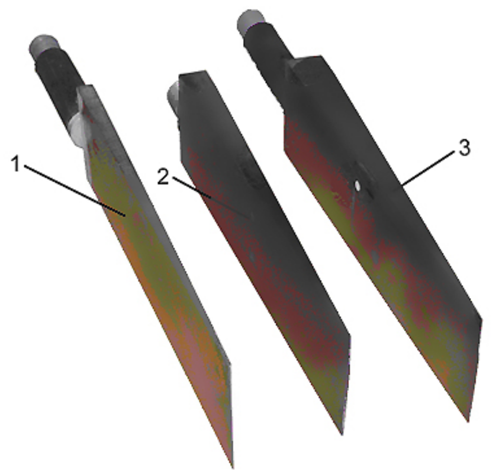

Fig. 2. Experimental V-shaped indenters with different working edge opening angles: 1 – α=2° (±1°), 2 – α=4º (±2°), 3 – α=6º (±3°).

Experimental research included checkup of the results of the obtained numerical solutions, development of certain design parameters for the working tip (see fig. 2, 3) and testing procedures. Research was conducted in field conditions on pilot testing sites and independent job sites, where geological engineering survey was carried out.

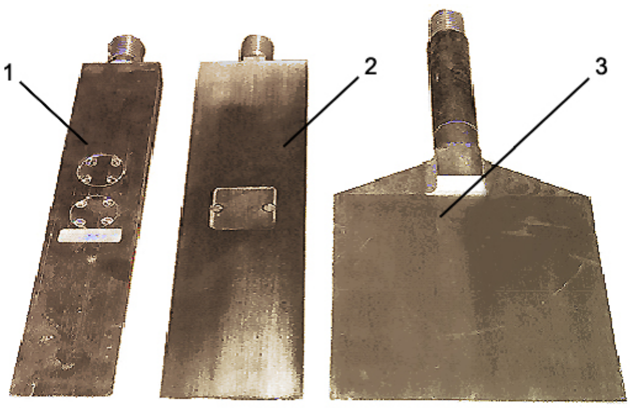

Fig. 3. Experimental V-shaped indenters with the different working edges dimensions: 1 – 70×400 mm, 2 – 100×400 mm, 3 – 200×200 mm.

3.1 *WD-100 dilatometer*

Our research has confirmed that a well-chosen ratio of the wedge geometrical dimensions allows to achieve almost linear deformation of the surrounding soil along the whole height of our V-shaped indenter and to reduce development of limit stress areas to a minimum. In this case strains measured by pressure gauges can be fairly precisely interpreted for immediate determination of the soils deformation modules. A WD-100 dilatometer, shown in figure 4, fully meets these requirements to obtain the general deformation module. It is recommended for wide application in standard surveying (Lavrov et al. 2001, 2002).

Absence of moving parts and the resulting simple design of a V-shaped indenter ensure high operational reliability of the dilatometer in various soil conditions and its large-scale implementation. The whole technological soil test cycle with a dilatometer involves one standard static probing installation, without drilling machines.

Fig. 4. Wedged dilatometer WD-100, consisting of V-shaped indenter (400 mm high, 100 mm wide, reaming edge expansion angle 4º), electric cable and digital recorder CTI-1.

In the course of indenter immersion digital display of the data-acquisition equipment immediately shows the value of soil deformation module which allows to receive continuous in depth information on the module value for the examined soil thickness (see fig. 5).

Dilatometer allows to determine the soils deformation module both during its continuous immersion into the soil being studied, and in the discrete mode when the dilatometer stops at pre-set depths. When soils are tested in continuous immersion mode the speed of speed of dilatometer indentation into the soil must be invariable at the level of 0.3-0.4 meters per minute.

In the course of continuous immersion it is recommended to monitor the current unstabilized values of the soils deformation module on the interval basis (every 0.2 m).

In order to reduce the unstabilized values of the deformation module to the stabilized ones it is recommended to carry out stabilized experiments periodically with the interval of 1 or 2 meters, having completely stopped the dilatometer. Such experiments are carried out according to the discrete tests procedure, monitoring stabilization of the soil deformation module values at fixed intervals.

Stabilized values of the soils deformation module is calculated with the help of mathematical extrapolation of the damping function using the obtained experimental values. Then relaxation factors are determined.

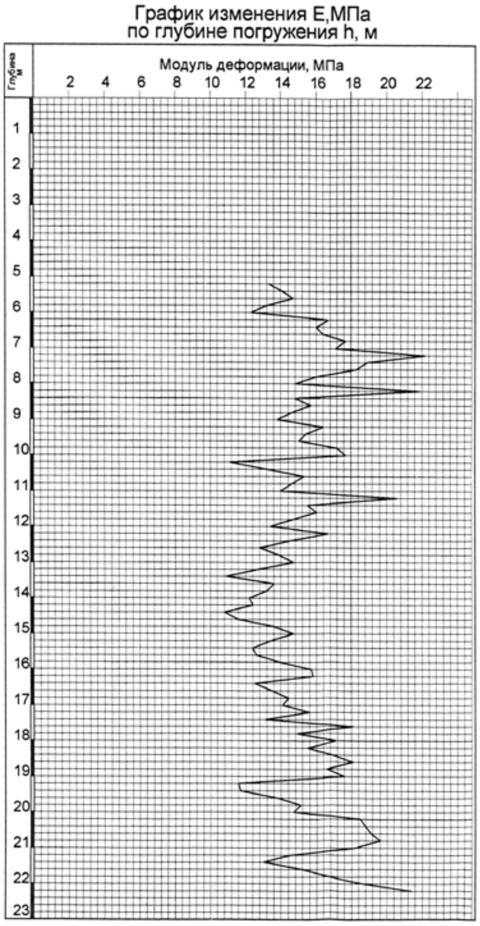

Fig. 5. Example of the deformation module curve according to the depth of geologic cross-section obtained as a result of soils field tests with the help of a wedged dilatometer.

3.2 *Dynamic wedged dilatometer*

Stability of registered parameters in evaluation of soils deformation properties, reliability and accuracy of determined general deformation module reaffirm exceptional convenience of such technical solution. This is why it was decided to update the design of wedge relaxing dilatometer WD-100 to make it possible to determine the module of dynamic deformations (soil elasticity module) and to replace data-acquisition equipment with a laptop and to develop a respective tests procedure (Nuzhdin et al. 2004, 2005). This work is carried out in research Laboratory of bases and foundations dynamics of Novosibirsk State University of Architecture and Civil Engineering (Sibstrin) with the assistance of SPEC Company “O&F”.

Schematic diagram of a dynamic wedged indenter is shown in the figure 6. In order to determine the soil elasticity module in addition to strain-measuring dynamometer measuring horizontal (normal) soil pressure on the diaphragm, a vibration detector is installed in the indenter housing, registering amplitudes of vertical vibration of the indenter. The problem of linear deformation of the analyzed soil is solved with the help of a V-shaped indenter with overall width b=100мм, height h=400 mm and reaming edge expansion angle $\alpha = 4^o$. Values of b and h may be changed, if their correlation is preserved, provided that $0.5 \geq \xi = b/h \geq 0.2$.

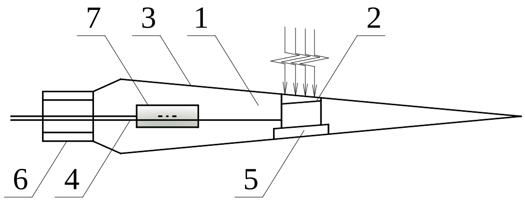

Fig.6 Working tip of a V-shaped indenter: 1 - housing, 2 – strain-gage diaphragm-type dynamometer, 3 – working edges of dilatometer, 4 - cable, 5 - cover of the dynamometer working chamber, 6 - threaded connection with the rods of static probing device, 7 – vertical displacement vibration detector.

Numerical and experimental research established that if the gauge measuring soil tension is placed at the center of the reaming edge of the V-shaped indenter, it allows to eliminate the influence of errors caused by marginal irregularity of saddle-like contact tensions distribution diagrams. If the gauge is installed in the middle part of the reaming edge, it registers most representative data close to the average value of contact tensions arising on reaming edges of the wedge. We have established practically acceptable independence between measured tensions and rigidity of the pressure gauge diaphragm, cutting edge thickness of the indenter, changes of its immersion speed and vibrations frequency. They are set depending on the strength of the analyzed soils and technological features of the pilot plant.

Soils exploration includes smooth immersion of the modernized indenter into the analyzed soil with the help of pressing device of the static probing installation; soil deformation along the immersion axis according to pre-set values; measurement of normal contact soil pressures of the indenter, recalculated into values of the full deformation module; connection of directed action vibrator to the probing rods column and initiation of vertical indenter fluctuations with amplitudes smaller than the amount of plastic deformations of the soil; monitoring of dynamic soil contact pressures on the indenter and amplitudes of its vibration displacements; determination of soils elasticity modules on their basis.

Parameters of relative stabilization of the deformation module in soils analysis with the help of dilatometer are subject to the following condition: their change should not be greater than 0.1 MPa in 2 minutes. Successful dynamic soil tests require that tip vibration amplitudes should not to exceed the soil elastic deformation value. Relaxation of soil pressures occurring during tip immersion requires pre-set «rest» time for the dilatometer, depending on the type of the soil – about 15 minutes. In order to increase investigation accuracy the module of soil elasticity may be defined taking into account possible change of normal pressure values and elastic deformations during vibrations.

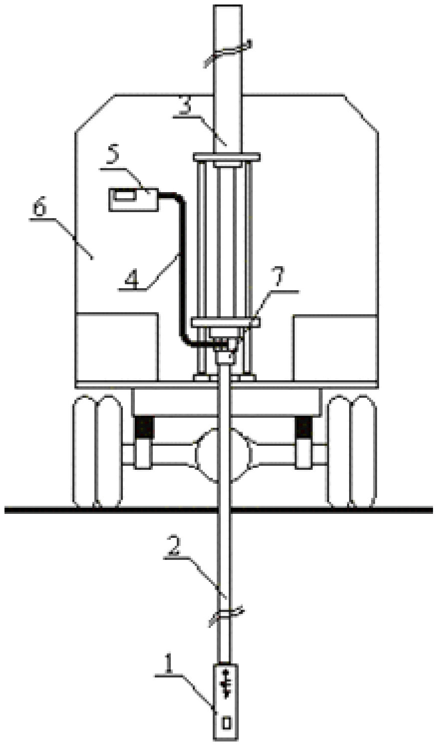

Fig. 7. Field installation to test soils deformation properties using a dynamic wedge dilatometer: 1 – V-shaped indentor, 2 - rods, 3 – hydrocylinder of the static probing device, 4 - connecting cable, 5 – data-acquisition equipment, 6 – motor vehicle with static probing device, 7 – directed action vibrator.

Calculation of the soils deformation module from test results using WD-100 dilatometer is carried out by the established designed dependence based on the modified Schleicher equation. Determination of the soil elasticity module with the help of dynamic dilatometer comes to plotting and analysis of the curves of dynamic contact pressures of the soil and indenter displacement during fluctuations (fig. 8).

In order to facilitate processing of the data, obtained in soils analysis with a wedged dilatometer, we have developed a special service software "DWDresearch", which is used to calculate of the deformation module of according to the log of soils tests with the help of WD-100 dilatometer, to process computer database, to prepare reports and to print lithological columns, to calculate average values of the deformation modules and elasticity of each layer and to draw a graph of the modules change with depth. The software allows to process and store data for different tests points, to group them by certain geological engineering elements or by research objects.

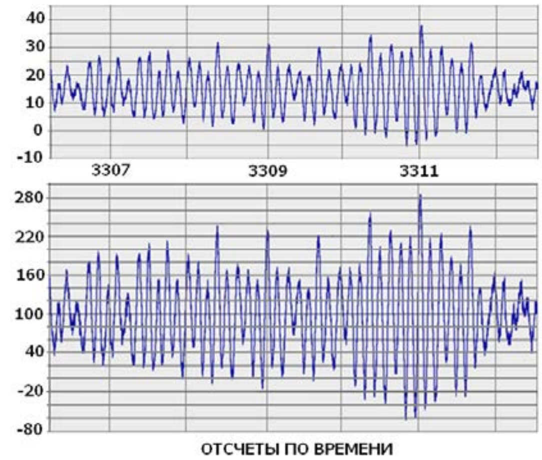

Fig. 8. Example of the obtained information used for evaluation of dynamic deformation properties (soil elasticity module): graphs of dynamic contact pressure variation and elastic deformation amplitudes variation with time.

We carried out joint analysis of the results of dispersive soils, included weak, non-cohesive, dislocated and any altered soils, compressibility using a wedge dilatometer and standard field methods (blade-type pressure meters and punches) to determine soils deformation module (Nuzhdin & Nuzhdin 2010). Results obtained with the help of dilatometer have correlation coefficient 0.95 – 0.96 (Lavrov & Nuzhdin 2011). It allows us to recommend relaxation with wedged dilatometer for wide practical application (Nuzhdin 2010b, Nuzhdin & Nuzhdin 2011).

4 CONCLUSIONS

We are continuing our complex experimental research to fine-tune the procedure of field test works to determine soil elasticity module during soil survey.

Operation experience of wedge dilatometers in various regions in Russia and some CIS countries have already confirmed high serviceability and reliability of dilatometers in various soil and environmental conditions. One powered static probing installation equipped with one wedge dilatometer allows to obtain up to 3 thousand values of soil deformation modules per month.

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