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Comparative analysis of the method of calculating the settlements of the foundations according to the field soils tests by a wedging dilatometer with the results of monitoring the precipitation of the foundations of real buildings

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ABSTRACT

The article presents a method for determining the deformations of the soil basement based field soils tests by 100-WD relaxation method. This method allows to increase the accuracy of the calculation of settlements foundations primarily by advancing the reliability of determining the deformation characteristics of soils in the field. The conclusion is made about the possibility and feasibility of using the proposed approach to improve the accuracy of predicting the settlements of structures. A comparative assessment of the results of the calculation of the deformations of the soil basements with observations of precipitation of the foundations of real buildings is performed.

Keywords: soils, settlements, foundations, deformations of soils basement, 100-WD, relaxation method

1 INTRODUCTION

It is known the field research methods allows to obtain the most reliable information about the deformation properties of soil basements. In this case, soil tests take place under conditions of their natural occurrence and with minimal disturbance of the natural state. Relaxation method of evaluation of soil deformation properties is one of the well-proven techniques.

Fig.1. Wedge dilatometer WD-100:
1 – V-shaped indentor;
2 – electric cable; 3 – digital recorder

It is based on the method of stress relaxation (or the method of controlled movements), when the active parameter is deformation of soil, and the passive one is occurring stresses which are time relaxed till conditionally stabilized value. In the field, this method is implemented by the wedging dilatometer, the device to determine the deformation modulus of grained soils. General view of the device is presented in Fig.1.

2 SOIL TESTS BY MEANS OF WEDGING DILATOMETER

2.1 Construction of dilatometer WD-100

A wedge-shaped indenter is used to create controlled displacements (distortions). Power unit squeezes the sensing tip into the soil mass at a constant speed and without prior drilling. While dipping, the reaming edges of the wedge deform soils smoothly to the set value, mainly horizontally. Contact pressures arising on the reaming edge are transmitted to unilaterally located strain-gauge dynamometer, which converts them into the values of soil deformation modulus. With the help of the recording equipment these values are registered at a dipping interval of 20 cm. The recorder and strain-gauge dynamometer are linked by the connecting cable.

CPT equipment or specially equipped rigs, providing static penetration of the indenter, are used for testing soils with dilatometer WD-100. In case of filled or frozen soil at the top of the tested soil layer, a special tip (splitter) can be used for forcing through all the frozen soil body. Depth of investigation of the ground layer using dilatometer WD-100 is regulated by the capacity of the power unit of the CPT equipment, the current value of the soil deformation modulus, as well as the cable length.

Due to its simple design and absence of moving parts, wedging dilatometer is of high operational reliability and practically feasible. Its noticeable advantage comparing with the other methods is significantly shorter time of the test and the possibility to get practically continuous value field of soil deformation modulus. The device is fairly widespread in Russia and abroad. It is produced in small batches. To date, more than 70% of the engineering-geological surveys in Novosibirsk region are carried out with the use of this equipment.

2.2 Processing of results of definition of the soil deformation modulus

Design values of the soil deformation modulus are determined based on the statistical processing of particular values of test results for each of the selected engineering-geologic elements. This takes into account the variability of the values and the number of definitions for a given confidence probability. There should be at least six particular definitions for a selected engineering-geologic element (when determining the deformation modulus by the stamp test results, three test results may be enough, or sometimes even two in case of good agreement between the results).

It should be noted that soils presented by frequently alternating thin layers or pockets of various materials, as well as soils containing individual thin layers of other soil type, can be taken as a single engineering-geologic element. In these cases, the averaged design value of the soil deformation modulus of the selected engineering-geologic element may be rather different from the actual characteristics of the soils which compose the element.

3 CALCULATION OF THE SETTLEMENTS OF FOUNDATIONS USING RESULTS OF THE DETERMINATION OF THE DEFORMATION MODULUS OF SOIL BY DILATOMETER

3.1 Proposed calculation method based on field tests by WD-100

Standard calculations of foundation basement deformations at average pressure under the foundation base p, not exceeding calculated soil resistance R, are made with the help of calculation model in the form of linearly deformed half-space with conditional restriction of the depth of compressed soil thickness H_c. The lower border of the compressed soil thickness is assigned on the basis of certain ratio between average values of vertical pressures under external load σ_{zp} under the center of foundation base and own weight of the soil σ_{zg}. In Russia according to Regulations "SP 22.13330.2016. Soil basements of buildings and structures" depth z is taken as the border of compressed thickness H_c, if it meets the equality condition $\sigma_{zp} = 0{,}5\sigma_{zg}$, or for weak soils (with $E \leq 7$ MPa) $\sigma_{zp} = 0.2\sigma_{zg}$. Depth of the compressed thickness in calculation of settlement for different points of slab foundation is accepted as constant for the whole slab.

Foundation basement settlement S with the help of a calculation model in the form of linearly deformed half-space is determined using a method of level-by-level summation. Thickness of calculated soil layers for definition of the border of compressed thickness and calculation of foundation basement settlement can be assigned arbitrarily, but no more than 40% of the width of the foundation base concerned (0.4b).

Calculation of foundation settlements using the results of field tests of soils by wedge dilatometer is proposed to be carried out in full compliance with current regulatory documentation – SP 22.13330.2016. Characteristic feature of such calculation is splitting of the soil massif into layers corresponding to intervals of definition of the soil deformation module by a wedge dilatometer, i.e. in case of usual survey – layers 0.2 m thick, provided that in each calculated soil layer we take into account its particular value of the deformation module E_{WD}.

For slab foundations in the presence of respective results of deformation module definition, it is expedient to make settlement calculation both for the central point and for corner (or intermediate) points of the slab. In this case, together with obtained absolute values of maximum or average slab settlement we get an opportunity to forecast and estimate possible non-uniformity of settlement caused by existing heterogeneity of the soil base.

3.2 Examples of calculating foundation settlements of residential buildings in Novosibirsk

This approach to the settlements calculation was used in the design of the foundations in the set of construction projects in Novosibirsk in different soil conditions. In particular, sites with homogeneous and heterogeneous bases composed with both soft and relatively low-compressible soils were considered. Comparative calculations by SP 22.13330.2016 using different thicknesses of design layers and soil deformation modules taken by the results of dilatometric studies and after their statistical processing within the engineering-geologic elements, were carried out for foundation slabs with bed width up to 30.0 m.

It should also be noted that at several construction sites, in the course of further soil investigation with dilatometer, following the standard engineering-geological surveys (which included laboratory tests of soil samples and cone penetration tests), splitting of the soil mass into engineering-geologic elements was changed with introduction of additional soil layers only differing by their deformation properties.

In the original report a single soil layer – a solid silt sandy loam with deformation modulus E = 14.3 MPa – was picked in the active zone of foundation bed. After further studies of soils consisting of 10 points of dilatometric tests, geologists came to picking two engineering-geologic elements only differing in deformation modulus, with E_1 = 11.5 MPa and E_2 = 28.0 MPa.

On this construction site on Vybornaya Street, a foundation of a 28-storey residential building in the form of a slab close to a square planform, with side b = 30.00 m, was designed. Total load on the base was N = 339,978 kN, which corresponded to the mean pressure under the slab p = 380 kPa. Vertical loads on the slab were almost completely aligned, and there were no torque loads.

Table 1. Desing settlements of foundation slab A=30.0×30.0 m in Vybornaya Street

Thickness of design layers, h_i	Settlements, S(mm) with change of pressure under the foundation			
	25%	50%	75%	100%
by the data of standard geological engineering surveys				
0.2 m (E_{calc}^{stand})	2.52	44.91	105.74	175.56
0.1b≤3 m (E_{calc}^{stand})	5.30	50.46	114.06	186.65
0.2b≤6 m (E_{calc}^{stand})	8.27	56.40	122.97	198.54
0.3b≤9 m (E_{calc}^{stand})	-	63.66	125.98	208.22
0.4b≤12 m (E_{calc}^{stand})	-	-	138.48	219.64
after additional studies with wedging dilatometer				
0.2 m (E_{calc}^{dil})	2.71	37.13	80.96	129.39
0.1b≤3 m (E_{calc}^{dil})	6.16	43.99	91.25	143.10
0.2b≤6 m (E_{calc}^{dil})	8.99	49.63	99.66	154.33
0.3b≤9 m (E_{calc}^{dil})	-	49.55	99.47	154.10
0.4b≤12 m (E_{calc}^{dil})	-	-	99.19	153.60
0.2 m (E_{WD}^{dil})	2.30	34.79	75.63	122.50

Settlement of foundation beds at this site was calculated through direct determination of the values of dilatometric deformation modulus of soil with thickness of design layers h_i = 0.2 m and averaged design deformation modules constant for each engineering-geologic element, with thickness h_i = 0.2 m, 0.1b, 0.2b, 0.3b and 0.4b of the bed width of the designed foundations. A similar calculation was performed for the same design layers by the standard survey data with (with only one selected engineering-geologic element in the bedding). Results of settlements for the foundation slab, with loads changing from 25% to 100%, are presented in Table 1.

Analysis of the data suggests that consideration of the actual distribution of soil deformation properties influences rather significantly on the results of the calculations (6 ... 26% at full design load – up to 18 ... 291% at the initial stage of the foundation loading). And given the specification of engineering-geological section and soil deformation modulus of dilatometer studies – from 43 … 79% to 10 ... 260%, respectively.

3 COMPARISON OF THE RESULTS OF CALCULATION OF DEFORMATIONS WITH REAL SETTLEMENTS OF BUILDINGS

3.1 Monitoring results of deformation of soil basements

The above examples of design solutions for the foundation of residential buildings is currently fully implemented in kind. Field observations were made of the precipitation of foundations in various soil basements along with numerical experiments, which testify to a fairly good convergence of the obtained calculated results with real deformations of the soil basements.

Fig.2. Residential building in Vybornaya Streetunder construction and after construction

The production and technical department of the PTK-30 group of companies carried out by geodetic observation of the precipitation of the foundations of all buildings at the construction stage and the first period of operation. On the basis of field observations of real settlements of residential buildings, a comparative analysis was conducted of the results of calculating the deformations of the soil basements of the foundations using the SP method and the proposed improved method using dilatometric data. The results are given in Table 2.

It should be noted that when analyzing the actual deformations of the soil basement at the stage of construction (0.25 ... 0.75% of the total design load), it is almost impossible to reliably estimate the actual draft of the foundation and its corresponding load. This is due to a sufficient number of errors and nuances which must be taken into account.

Table 2. Comparison of the calculated values of deformations with the actual settlements for the house on the Vybornaya street

Load	Settlements (proportion)		
	Advanced calculation method using dilatometric datas	Normative calculation method	Real deformations
25%	1.09	2.10	1.00
50%	1.10	2.12	1.00
75%	1.54	2.83	1.00
100%	1.60	2.87	1.00

From Table 2 it can be seen that the values of the calculated settlements according to the SP method exceed the real values of deformations of the soil basement by 187% at full load. While the improved method using direct dilatometric data of the deformation modulus makes it possible to obtain more close to real values of the settlement on 60 %. It may lead to a decrease in the base plate sole and a more cost-effective design solution. The calculated values of settlements according to the proposed method exceed the actual values by 9 ... 54%; when using the SP method these values increase to 110 ... 183% at the stage of erection of building.

3.2 Findings about comparison results

Comparative analysis data suggest an expected trend in the refinement of the calculated settlements by an improved method relative to the SP method with a fairly regular construction of the building. This pattern is most pronounced with homogeneous soil basements, respecting the construction deadlines and the zero cycle technology.

It is important to bear in mind many affected factors on the results of the actual values of the deformation of the soil basements, such as non-compliance with the zero-cycle work technology, soaking of the foundation pit, construction time, etc. They can lead to an increase in settlements of foundations.

3 CONCLUSION

Research records show accurate forecasting of the foundation soil deformation and settlements of building foundations can be improved through better accuracy of experimental investigations of soils and improvement of theoretical model of beds, and through rational approach in selection of the design scheme, and analysis of the pattern of defining the soil deformation characteristics. The above-described integrated approach is especially appropriate in the experimental determination and application in calculations of soil deformation modules with wedging dilatometer.

In field soil tests using a dilatometer allowing us to obtain reliable values of the soils deformation module almost continuously for the whole depth of the compressed massif, direct use of those values can significantly affect accuracy of calculation. Besides, statistical processing of the results of deformation module definition after selection of engineering-geological elements and subsequent use of generalized values averaged by soil type in some cases does not allow reliable estimation of the deformation process at all. For example, it is true for non-uniform soils with small interlayers with deformation properties differing from the main massif. Scatter in forecasted values of deformations depends on the character of distribution of the existing strains, degree of non-uniformity of the soils deformation properties and peculiarities of soils position.

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