Results of Field Experimental Studies of Artificial Foundation Soils from Composite Soils

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Abstract: The article presents the results of static stamp tests of composite soils of foundations of buildings and structures and an analysis of the change in the modulus of their deformation is performed.

Keywords: composite soil, deformation modulus, foundation, footing, plate load test, settlement, subsidence.

INTRODUCTION

Typically, residential and industrial sites are allocated for construction on sites unsuitable for agricultural cultivation (marshy areas, ravines, etc.). The soils in such sites often have low strength, and foundations are constructed unevenly. In such geological conditions, in addition to pile foundations, which are relatively effective, soil foundations with artificially enhanced properties or improved performance characteristics of the foundation soil may in some cases be more effective. While the performance characteristics of the foundation soil are improved through structural methods, artificial improvements are achieved through compaction or strengthening.

To structurally improve the properties of foundation soils, methods such as the installation of soil cushions, the use of sheet piles, and soil reinforcement are used. Surface compaction, in-depth vibration compaction, compaction with soil piles, compaction with vertical drains under static loads, and compaction by lowering the water level are used to improve the properties of foundation soils. Soil strengthening methods include cementation, revivification, thermal strengthening, bituminization, chemical and electrochemical strengthening.

At the same time, composite soils are widely used in the construction of artificial foundations for buildings and structures, railway and highway foundations, hydraulic structures, and earthen dams. Naturally, in most cases, they are used in their natural composition for these purposes, without paying special attention to the composition of soils in the areas adjacent to construction sites. However, in most cases, compacting the natural soil layer and constructing artificial foundations is ineffective. Furthermore, it goes without saying that composite soils can only be effective if their composition matches the soils of the area adjacent to the construction sites. Therefore, in some cases, constructing artificial foundations using an effective ratio of sandy and clayey soil or a mixture of gravel and clayey soil will result in cheaper design solutions and ensure the structural strength for a relatively long period.

To perform design calculations for foundations and substructures, physical, mechanical, and permeability properties of complex soils are necessary. To address these practical issues, regulatory documents must include standard and calculated values for tabular strength, deformation, and permeability parameters based on the physical properties of complex soils consisting of sand and clay soils, or a mixture of gravel and clay soils.

There are still few scientific works devoted to the study of the properties of soils formed from a mixture of sand and clay particles in their natural state. Among them, the works of V.I.Fedorov [1], A.A.Vasiliev et al. [2], and A.V.Konviz [3] can be noted.

The results of extensive laboratory and construction site experiments conducted under the leadership of V.I. Fyodorov on composite soils, i.e., natural (naturally structured) mixed soils consisting of coarse-grained soil and clayey soils, were subjected to probabilistic and statistical analysis and recommended in the form of practical guidelines for design practice.

MAIN PART

The main of the research on composite soils was to obtain a high-strength, low-deformation, convenient and effective mixed soil solution. To this end, experiments were conducted in laboratory conditions on mixtures of coarse and medium-grained sand with natural loamy soil in various proportions.

Extensive experimental studies were conducted in laboratory conditions for cases where the compositional ratios of composite soils formed from coarse sand and medium-sized sand and loamy soil mixtures were different. According to the results of the experiments, the optimal ratios of the components of composite soils were determined, and the strength, deformation and water permeability indicators were determined depending on their physical parameters. Their results, namely the calculated physical and mechanical parameters, were analyzed using probabilistic-statistical methods and tabulated depending on their physical parameters [4].

For the design of building and structure foundations, soil strength and deformation parameters determined in the field are essential. To determine the deformation modulus of complex soils in the field using static tests conducted in the "Kaynama" mahalla, the foundation of a 52-apartment multi-story residential building under construction near 35 "Buyuk El" Street in the Samarkand District was chosen as the test site. The foundation soil consists of Category I loess loam with high subsidence. A 2.4 x 3.6 m pit was excavated at a depth of 0.75 m below the foundation depth. A 20 sm layer of a mixture of 40% coarse sand and 60% loamy soil (complex soil) with an optimal moisture content of 12-13% was filled into the pit and compacted layer by layer using a vibratory roller. Since the 20 sm thick layer became 15 sm after compaction, the total thickness of the 5 layers was 75 sm.

FIGURE 1. Process of stamping test of composite soils.

The tests were conducted using a dynamometer with a maximum load of 10 tons and a standard round punch with a diameter of 28.2 sm. The loading through the punch was carried out gradually in 14 stages (50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700). The pressure at the first stage was also taken into account, resulting from the weight of the punch and mounting elements. According to STATE STANDART 20276.1-2020, the deflection of the punch from each stage of the load was recorded after the deformation had stabilized conditionally [5, 6]. The pressure transmitted to the punch was controlled using a dynamometer indicator. The deflections were measured using special indicators (Fig. 1).

RESULTS

In the experiments, the relationship between the pressure transmitted to the soil through the stamp and the settlement of the stamp was obtained in the following graphical form (Fig. 2).

Stage 1 (pressure in the range 0–300 kPa) is compacted under the stamp proportionally with aging and springy character. Plastic deformations begin to occur under the edges of the stamp. At stage II (when the pressure exceeds 300 kPa), the zone of plastic deformation begins to spread out from under the stamp in the sides and in the ground, intensive shock deformation develops, compaction begins to occur outside the zone of plastic deformation, the radius of curvature decreases.

First stage (pressure in the range of 0–300 kPa) - compaction is observed under the stamp in proportion to the aging pressure and acquires an elastic character. Plastic deformations begin to appear under the edges of the stamp. In second stage (when the pressure exceeds 300 kPa), the zone of plastic deformations begins to develop from under the stamp to the sides and intensive shear deformations develop in the soil, compaction begins to occur outside the zones of plastic deformation, and the radius of curvature of the graph decreases.

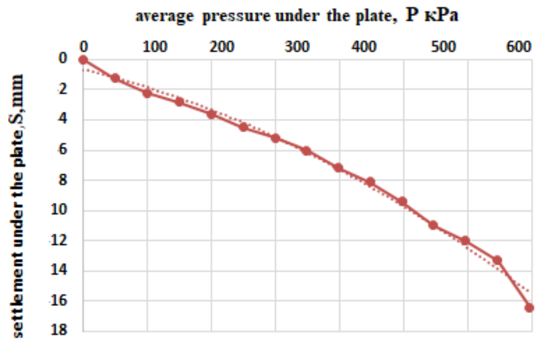

FIGURE 2. Composite soil foundation settlement pressure graph.

Graphical changes are based on the content of the data and conditionally divided into two stages:

In the course of the experiment, in order to determine the reduction of the super-sedimentation properties of the composite soil, the soil was dug from the pit of the experimental site, and soil samples were taken from every 15 cm depth. The ultra-slumpability properties of the obtained soil samples were determined in laboratory conditions by the "double curve" method in a compression device (Fig. 3).

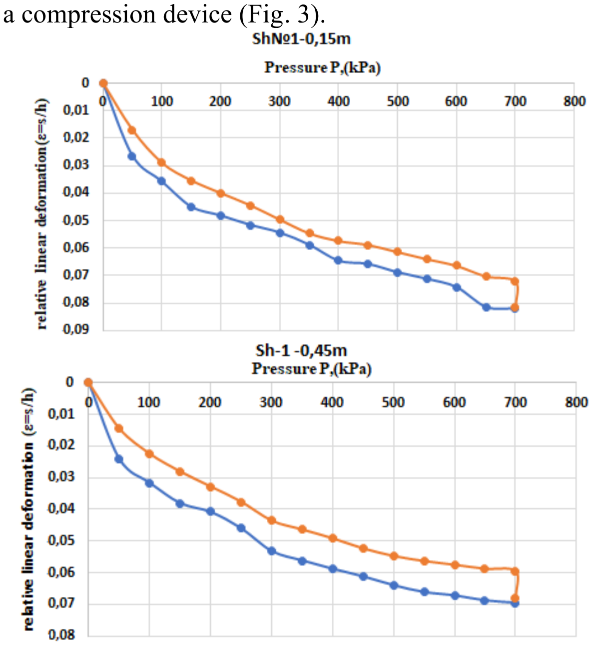

FIGURE 3. Graphs of experiments to determine the super-slumpability of composite soil samples taken from different depths with the help of a compression device.

Here ε_{zi} is the relative deformation of the soil at natural moisture; $\varepsilon_{zi,sat}$ is relative deformation of soil sample in water-saturated condition.

The graph shows that the relative supersedimentation of the composite soil prepared by mixing loess with super-sedimentation sandy soil is ε_{se}<0.01 even in the pressure range of 0÷700 kPa. Thus, during the compaction of the composite soil, the supersedimentation of the loamy soil in its composition disappears. The small difference between the relative deformation of the water-saturated composite soils in the graphs and the relative deformation of the composite soils at natural humidity is explained by the relative decrease in the strength of the interparticle bonding of the loamy soil in the composite soil under the influence of humidity and the compact arrangement of sand particles.

The relationship between settlement and the pressure transmitted to the foundation is widely discussed in scientific literature, for example, according to the F. Schleicher method recommended in STATE STANDART 20276.1-2020 [7, 8], this relationship is determined as follows:

$$E = (1-\mu^2)K_1 \cdot D\frac{\Delta p}{\Delta S} \quad (1)$$

where: μ is Poisson's ratio;

K_1 is the accepted coefficient for a round rigid stamp is 0.79;

D is round stamp diameter;

Δp is overpressure, determined by the ratio of the load on the stamp to the surface area, kPa:

ΔS is stamp increments, sm;

The expression for calculating the depression of a single round stamp is generally known to have the following form

$$S = \frac{\pi}{4} \cdot \frac{p \cdot D \cdot (1-\mu^2)}{E} \quad (2)$$

where p is the ratio of the load transmitted through the stamp to the surface, its average pressure;

μ is Poisson's ratio;

The relationship (2) means that the static test results of the single stamp can be used to determine the parameters of the soil at the stage of linear deformation of the base soil. For example, to determine the deformation modulus by expression (2), it is enough to solve it with respect to E. In this case

$$E = \frac{\pi}{4} \cdot \frac{p \cdot D \cdot (1-\mu^2)}{S} \quad (3)$$

Expression (3) is based on considering the foundation soil as an elastic medium, that is, it emphasizes that the relationship between the pressure transmitted to the soil and the soil deformation should be linear. This means that the pressure transmitted to the soil should not exceed the initial limit pressure.

In order to compare the data obtained from the stamp tests, the deformation moduli obtained as a result of the experiment were determined using expressions (1) and (3), and their values are given in Table 1. According to this table, the decrease in the deformation modulus of the soil as the pressure increases can be explained by the fact that the pressure acting on the soil exceeds the initial limiting pressure and approaches the upper limiting pressure.

Using Table 1, comparison graphs of the deformation moduli determined by punch testing and calculation are given in Fig. 4 and Fig. 5.

TABLE 1. Table of calculated values of deformation modulus based on experimentally determined settlement of composite soils

Stamp diameter D, sm	Load, N kg	Pressure under the stamp p, kPa	Stamping, $\boldsymbol{S}$, sm	According to $E = (1-\mu^2)K_1 \cdot D\frac{\Delta p}{\Delta S}$ the value of the deformation modulus, MPa	According to $E = \frac{\pi}{4} \cdot \frac{p \cdot D \cdot (1-\mu^2)}{S}$ the value of the deformation modulus, MPa
28,3	0,00	0,00	0,000	0,00	0,00
	3,14	49,95	0,125	35,4	34,1
	6,28	99,89	0,221	35,35	33,87
	9,42	149,84	0,284	34,79	31,2
	12,56	199,78	0,363	32,37	29,3
	15,7	249,73	0,450	29,41	26,5
	18,84	299,67	0,520	28,35	25,11
	21,98	349,06	0,600	26,5	23,54
	25,12	398,29	0,72	24,6	21,4
	28,26	447,37	0,810	22,4	18,99
	31,4	497,08	0,940	20,49	17,1
	34,54	546,79	1,1	17,98	15,6
	37,68	596,50	1,20	16,6	13,4
	40,82	646,20	1,330	15,47	12,1
	43,96	695,91	1,64	11,52	10,1

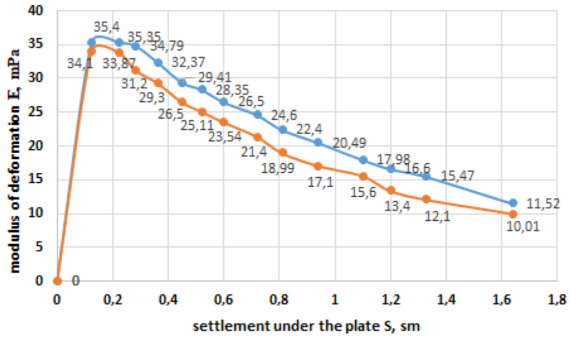

FIGURE 4. Graph of the dependence of the deformation modulus E on the settlement S: 1-(1) according to expression; 2-(3) according to expression.

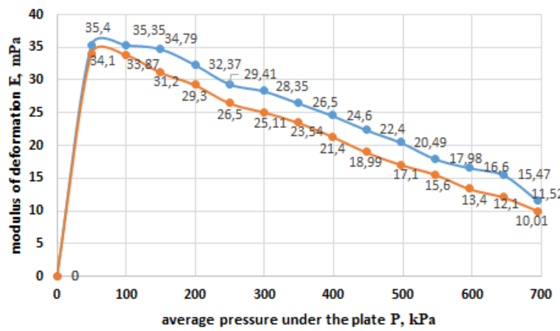

FIGURE 5. The graph of the dependence of the modulus of deformation E on the average pressure R: According to expression 1-(1); 2- According to expression (3).

Figure 5 shows that during the initial stage of loading, during the adaptation of the stamp to the soil, the deformation modulus - E increases sharply and, after reaching a maximum value, gradually decreases according to a law close to a straight line. The conducted experiments and the analysis of their results revealed that the values of the deformation moduli calculated using two different methods, namely the methods of F. Schleicher and N. A. Tsytovich, had significant differences.

In order to design the main foundations, in particular, using the calculation scheme of a linearly deformable half-space, the deformation modulus determined by the stamp is used in the calculation of the settlement. The values of the compressive deformation modulus and the results of the stamp tests can be reduced to a calculated value using the transition coefficient. For this, the following expression is used:

$$E_{pl} = m_k E_{oed} \tag{4}$$

where, $m_k = E_{pl} / E_{oed}$ the experimentally determined transfer coefficient;

E_{pl} is the deformation modulus determined by the stamp experiment;

E_{oed} is the deformation modulus determined by compression, usually determined in the pressure range of 0.1 - 0.3 MPa.

The results of field conditions and laboratory experiments were compared and expressed in (4), and the results are presented in Table 2.

TABLE 2. Table of the results of the calculation of the general deformation modulus

Soil type	Modulus of deformation, MPa		The coefficient is perecho m_k
	Based on field conditions (stamp), E_{pl}	Based on compression (odometer), E_{oed}	
Composite soil (40% coarse sand and 60% soil)	34,79	31,4	1,1
	29,41	35,2	0,835
	26,5	38,7	0,685
	24,6	42,3	0,581
	22,4	48,7	0,459
	20,49	51,4	0,398

Based on the experimental data and their comparative analysis with the solutions of the theory of linearly deformable media, the following main conclusions can be drawn:

CONCLUSION

1) It was confirmed that the graphs of the dependence of the settlement of the stamps on the applied load can be divided into 2 zones, namely in the compaction phase - the connection is linear, in which the deformation is damping, and the second - the sliding phase, in which the connection is curvilinear;

2) It was found that it is impossible to obtain the same values of deformation indicators using different, that is, laboratory and field testing methods;

3) Since it is laborious and expensive to determine the physical and mechanical parameters of the soil through experiments conducted in field conditions, it is sufficient to conduct them in laboratory conditions and, based on comparison, determine their calculated values based on the introduction of the coefficient of transfer mk.

4) According to the results of laboratory tests, the values of the compressive deformation modulus were found to be 1.1–1.5 times higher than the deformation moduli determined in field conditions by loading the soil mass with large round stamps.

5) Analysis of the experimental results made it possible to determine the calculated values of the deformation modulus. At the same time, to ensure the reliability of the foundations of buildings and structures, it is necessary to use the minimum calculated values of the deformation modulus.

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