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Improvement of settlement calculations of building foundations by increasing the reliability of determining soil compressibility indices

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Ways to improve the methods of calculating the foundations bases' settlements by increasing the reliability of determining the soil compressibility indices are substantiated. The complex approach to refinement of the buildings bases' settlements calculation by the layer summation method is investigated by accounting for the soil deformation modulus variability in the full pressure range perceived by the base at loading; soil strength coefficient β_Z; soil deformation anisotropy by elastic orthotropic model; tendencies to magnitude variation in the soil deformation modulus in depth of the body under the foundations and within the artificial bases built with the soil compaction. There was also proved the possibility of increasing the accuracy of the predicting method for the buildings' foundations base settling using the soil compression index and accounting for the pressure effect on the soil deformation parameters in depth of the compressible strata.

Keywords: settlement, method of layer-by-layer summing up, reliability, soil compression test, soil porosity coefficient, soil deformation modulus, soil compressibility index, anisotropy.

Удосконалення розрахунку осідань основ будівель підвищенням достовірності визначення показників стисливості ґрунту

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Проаналізовано сучасні підходи щодо удосконалення аналітичних методів розрахунку осідань основ будівель і споруд. Встановлено, що більшість з них мають свої певні області раціонального застосування стосовно ґрунтових умов, обладнання з визначення властивостей стисливості ґрунтів, видів і розмірів фундаментів чи штучних основ, задач проектування і не носять комплексного характеру. Обґрунтовано шляхи удосконалення методів розрахунку осідань основ фундаментів підвищенням достовірності визначення показників стисливості ґрунту. Розглянуто комплексний підхід до уточнення розрахунку осідань основ будівель методом пошарового підсумовування шляхом урахування: змінності модуля деформації ґрунту в усьому діапазоні тиску, який сприймає основа при навантаженні; коефіцієнта β_Z за міцністю ґрунту; деформаційної анізотропії ґрунтів за пружною ортотропною моделлю; закономірностей зміни величин модуля деформації ґрунту за глибиною масиву під фундаментами і в межах штучних основ, що зводяться з ущільненням ґрунту. Також доведено можливість підвищення точності методики прогнозування осідання основи фундаментів будівель використанням в ній показника стискання ґрунту й урахуванням впливу тиску на деформаційні параметри ґрунту за глибиною стисливої товщі. Подано приклади застосування аналітичних методик розрахунку осідань основ будівель.

Ключові слова: осідання, метод пошарового підсумовування, достовірність, компресійне випробування ґрунту, коефіцієнт пористості ґрунту, модуль деформації ґрунту, показник стискання ґрунту, анізотропія.

Introduction

Predicting the deformation magnitude of «Soil base – foundation – building (structure)» system is a complex, but at the same time a priority task when designing the foundations of buildings and structures. The reliability and cost-effectiveness depend on the reliability of the deformation calculation. Most of the abnormal deformations of buildings and structures are caused by errors in determining the compressibility parameters of the soil base.

Prof. Dalmatov considered the settlement of each foundation base to be the sum of five components [1]:

1) settlement due to the compaction of the natural structure soils at the increasing stresses from the foundations' weight;

2) settlement associated with decompression of the upper soil strata that lies below the bottom of a foundation ditch, due to the reduction of stresses during excavation;

3) settlement due to the soil squeezing (extrusion) from beneath the foundation caused by the progression of plastic deformations;

4) settlement of the disruption, which progresses due to the soil compressibility increase at its natural structure distortion during execution;

5) settlement caused by changes in the stress state or deformation of the soil base during the building (structure) operation.

In geotechnical practice, usually, only the first two components of deformation are considered. The buildings' foundations settlements are calculated using analytical methods (layer summation method (LSM), etc.) [2, 3] and finite element modeling (FEM) [2]. Particularly, in the LSM, recommended by the building codes for practical calculations, the settlement of the foundations' bases is determined using the calculated scheme of linear-deformed half-space by expression

$$S = \beta \sum_{i=1}^{n} \frac{\sigma_{zp,i} h_i}{E_i}, \tag{1}$$

where $\beta = 0.8$ is the coefficient taking into account the lateral extension of the soil;
$\sigma_{zp,i}$ is the average value of the additional stress in the i^{th} elementary soil layer;
h_i, E_i are respectively, the thickness and deformation modulus of the i^{th} layer of soil;
n is the number of elementary layers within the compressed strata under the foundation footing.

This method, with all its versatility and clarity, is, however, based on a number of assumptions [2 - 5], in particular: the soil is a continuous, isotropic, linearly deformed body; settlement is caused by the vertical stress action only, and other components are not considered; lateral expansion of the soil at the base is impossible; stresses are determined under the center of the foundation footing; when determining stresses, differences in the compressibility of individual layers are neglected [4]; the foundation has no rigidity; deformations are analyzed only within the compressed strata; lateral expansion of the soil is taken into account by the parameter $\beta = 0.8$ regardless of the type and condition of the soil, etc.

Comparisons show that the calculated values of settlements of the foundations of buildings are sometimes up to several times different from the values of stabilized settlements of full-scale objects [6]. The defining characteristics that affect the accuracy of the prediction of the base's settlements are the parameters of compressibility, in particular, the modulus of deformation of each soil layer within the compressed strata [1 - 6].

Review of research sources and publications

Geotechnicians have experimentally and theoretically substantiated a number of original techniques aimed at improving (increasing the reliability) of analytical calculations of the bases' settlements of the building foundations (whereas the LSM is taken as a base) by:

– determination of the soil deformation modulus magnitude and the compressive strata, with regards to the footing area of the large-scale foundations [7];

– introduction of the correction (increasing) coefficient (Agishev, I.A.) m_k to the values of soil deformation modules obtained from compression tests in the pressure interval of $\sigma = 0.1 – 0.2$ MPa (m_k value at liquidity index of $0.5 < I_L < 1$ for sandy loam, sandy clay and clay varies between 2 and 6 based on soil type and its porosity index e) [8]. However, the results of long geodetic surveys of the settlement of buildings and structures on loose [9] and wetted (degraded) soils [10, 11] showed that it is more correct to use the results of compression tests without increasing coefficient m_k;

– considering the variability of the soil deformation modulus over the depth of the compressible strata [12];

– considering the deformation anisotropy of soils (most often according to the ratio of soil deformation modules in the vertical and horizontal directions within the model of elastic orthotropic environment) [13, 14];

– accounting for the structural strength of soils when assigning values of soil compressibility characteristics and compressive strata capacity [15, 16];

– considering the variability of the soil deformation modulus over the full pressure range, which is perceived by the base at loading [17 - 20], ie the deformation modulus is a function of the stresses in the massif and the corresponding changes in the porosity coefficient. The parameters of the soil model can be set by interpreting the logarithmic function of the soil compression test data according to the speed of pressure transfer during the operation of the bases [17 - 19]. The disadvantage of the odometer is the low accuracy of measurements, because the friction forces of the sample behind the walls of the ring reduce by 10 - 50% (depending on humidity, type of soil, conditions of the experiment) the pressure applied to the sample, especially with increasing stresses in the soil.

This leads to a false increase in the actual magnitude of the deformation modulus [21]. Therefore, in order to avoid the high soil friction force behind the walls of the ring, especially at high pressure, and to ensure the sampling of the undisturbed structure, the «Ring for soil testing in one-dimensional deformation» is used [17];

– the use of so-called soil compression index (which reflects the relative change in the porosity coefficient of soil compression and more correctly than the standard parameters of compressibility characterizes the deformation properties of the base at specific stress values) and taking into account the effect of pressure on the deformation parameters of the soil and its porosity variation over the compressed strata depth [22, 23];

– application of probabilistic calculations of bases taking into account the parameters of the heterogeneity of soil massifs. According to this approach to determining the bases' settlement, in particular, it is established that there is a probability of linear and nonlinear stages of the base deformation when the pressure under the foundation footing exceeds the calculated soil resistance under the deterministic approach. This effect is caused by the heterogeneity of the physical and mechanical parameters of natural and compacted soils and the random nature of loads and influences on the foundations [24, 25];

– the use of soil deformation parameters obtained in three-axis compression devices, where it is possible to take into account the effect of changing the modulus of deformation as a function of horizontal stresses, which enables interpreting the obtained parameters with respect to over compacted soils, structural strength of strata and other specific properties of rocks, and accounting for elastic-plastic nature of a soil [26].

Definition of unsolved aspects of the problem

However, it should be noted that the original methods analyzed are fairly correct in themselves, but most of them have their specific areas of rational application for specific soil conditions, laboratory or field equipment to determine the characteristics of soil compression, types, and sizes of foundations or artificial basis, design problems, etc., and, most importantly, they are not complex yet.

Problem statement

Therefore, as the purpose of the work presented the improvement of analytical methods for calculating the settlements of the foundations' bases of buildings and structures was adopted utilizing a comprehensive account of the reliability increasing methods of determining the soil compressibility parameters.

Basic material and results

Consider a comprehensive approach to clarify the calculation of the buildings' foundations settlement by LSM taking into account:

1) the variability of soil deformation modulus in the full pressure range, which perceives the base during loading;

2) coefficient β_Z of soil strength;

3) deformation anisotropy of soils by elastic orthotropic model;

4) regularities of the soil deformation modulus change in depth of the massif under the foundations and within the artificial bases, erected with soil compaction.

Table 1 provides typical examples of determining the compressibility characteristics of clayey soil, depending on the standard degrees of pressure for different densities of loam. For example, according to the data of compression tests according to the standard method of DSTU B B.2.1-4-96 specimens of loess semi-solid loam with a natural humidity of 0.24 and a coefficient of porosity of 0.86 in the range of stresses 0 - 2.7 MPa an increase in the value of the deformation modulus from 3 to 22 MPa was established [17].

Table 1 – Variability of the deformation modulus values in the clay loam test

Place of soil sampling	Porosity coefficient e	Wetness w, %	Soil deformation module E, MPa, in vertical pressure intervals σ, MPa			
			0 - 0.05	0.05 - 0.1	0.1 - 0.2	0.2 - 0.3
in the massif of natural structure	1.45	25	0.765	1.06	1.19	0.53
	1.27	18	1.83	1.35	1.03	0.81
	0.74	20	5.43	4.85	9.52	6.25
	0.67	16	5.95	5.21	10.4	6.40
	0.56	15	5.56	6.49	7.81	13.0
in the ground bed	0.48	16	17.0	10.5	12.2	16.2
	0.46	14	24.1	11.4	14.0	22.8
for in-situ piles in drilled wells	0.60	19	13.2	9.7	12.7	9.80

Considering the variability of the soil deformation module, it is advisable to make the basis of the known relationship between deformations and stresses, which has the best statistics in power form

$$\Delta h = b(\sigma_i / \sigma_0)^a \qquad (2)$$

Concerning tests in expression (2) Δh is the specimen deformation under stress σ_i when conditional stabilization is achieved (this is a strain rate of 6.25 mm/h). Empirical coefficients: a – dimensionless value, which varies within narrow limits (for clay soils of Poltava a = 0.6 – 1.5). The coefficient b has a linear dimension that corresponds to the

Δh value and ranges in a much larger range from a few units to several tens. b value is closely related to the soil porosity coefficient e_0. By expression (2) the equation of the compression curve is corrected

$$e_\sigma = e_0 - \frac{b(\sigma_i / \sigma_0)^2}{h}(1 + e_0) \tag{3}$$

where e_0 and e_σ respectively, the soil porosity coefficients at $\sigma = 0$ and $\sigma = \sigma_i$, and h is the height of the specimen.

At any pressure interval, based on (2) and classical expressions of soil mechanics, the coefficient of compressibility is

$$m_0 = \frac{\left[e_0 - \frac{b(\sigma_{н} / \sigma_0)}{h}(1 + e_0)\right]}{\sigma_{к} - \sigma_{н}} - \frac{\left[e_0 - \frac{b(\sigma_{к} / \sigma_0)}{h}(1 + e_0)\right]}{\sigma_{к} - \sigma_{н}} \tag{4}$$

where σ_H and σ_K are the vertical stresses at the beginning and end of the interval. After simplification we have

$$m_0 = \frac{b(1 + e_0)\left[(\sigma_{к} / \sigma_0)^a - (\sigma_{н} / \sigma_0)^a\right]}{h(\sigma_{к} - \sigma_{н})} \tag{5}$$

The given coefficient of compressibility is equal

$$m_v = \frac{b\left[(\sigma_{к} / \sigma_0)^a - (\sigma_{н} / \sigma_0)^a\right]}{h(\sigma_{к} - \sigma_{н})} \tag{6}$$

Finally, the formula for determining the modulus of deformation looks like

$$E = \frac{\beta_z \cdot h \cdot (\sigma_{к} - \sigma_{н})}{b\left[(\sigma_{к} / \sigma_0)^a - (\sigma_{н} / \sigma_0)^a\right]} \tag{7}$$

where β_Z is the coefficient which takes into account the absence of transverse soil expansion in the compression device (not to be confused with β coefficient in expression (1)) and which is calculated according to DSTU B B.2.1-4-96 depending on the transverse deformation coefficient (Poisson coefficient) ν. In the absence of research data DSTU B B.2.1-4-96 enables adopting ν depending on the type and condition of the soil.

β_Z coefficient depends on indicators of the physical and mechanical properties of the cohesive soil. It can be determined using formula [17]

$$\beta_z = \frac{0.5 \cdot \sigma_1 \cdot (1 - \sin\varphi_{II}) - c_{II} \cdot \cos\varphi_{II}}{\sigma_1 - c_{II} \cdot \cos\varphi_{II}} \tag{8}$$

where σ_1 is vertical stress acting under the foundation footing for conditions b = 0; φ_{II}, c_{II} are internal friction angle and specific adhesion for water-saturated bonded soil.

Then, for the LSM, the base settlement will be

$$S = \beta \cdot \sum_{i=1}^{n} \frac{(\sigma_n + \sigma_k) \cdot 0.5 \cdot h_i}{\beta_z \cdot h \cdot (\sigma_n - \sigma_k)} \cdot b \cdot \left[\sigma_n^a - \sigma_k^a\right] \tag{9}$$

Equation (9) is final and, given expressions (7) and (8), enables us to improve the calculation of the settlements of the foundation's bases of buildings.

Now, using expression (9), having the magnitudes of the additional stresses at the boundary of the elementary layers z, into which the compressible strata H_C is divided, it is sufficient to simply take into account the variability of the modulus of deformation by the nature of the additional pressure plot. Of course, if there are different layers of soil within the compressive thickness, the parameters a and b should be set separately for each layer.

Here is an example of the calculation: for individual foundations of different sizes with a depth of laying $d = 2$ m, under the footing of which the average pressure is $p = 250$ kPa. The base is a clayey loam that has the strength indicators of $\varphi_{II} = 22^\circ$ and $c_{II} = 15$ kPa in the water-saturated state. Table 2 contains the averaging data of six long-term compression tests that were performed until the standard conditional stabilization rate ($v = 6.24 \cdot 10^{-4}$ mm/h) was achieved. Sample height is $h = 35$ mm. The processing of the results by expression (2) gave the following parameters of the compression curve with a high correlation coefficient $r = 0.998$: $b = 5.87$; $a = 1.146$; $\Delta h = 5.87 \cdot \sigma^{1.146}$.

In the pressure intervals from 0.1 to 0.2 MPa and 0.2 to 0.3 MPa with $\beta = 0.5$ compression modulus, respectively: $E = 3.4$ and 3.2 MPa. These values are usually used to calculate the settlement by DBN B.2.1-10-2009. If we consider the subsidence of (9) accounting for the variability of E and β_Z depending on the magnitudes of the additional pressure, then we have the data contained in table 3.

Therefore, such an algorithm for analytical precipitation determination is recommended.

1. Compression testing of clay soil samples with the obligatory fulfillment of deformation stabilization conditions.
2. Approximation of compression results by dependence (2) and determination of parameters a and b.
3. Testing of samples of clay soil for displacement and determination of strength and further critical pressure.
4. Calculation of parameters of lateral extension β_Z and ν.
5. Calculation of additional pressure according to the DBN scheme B.2.1-10-2009.
6. Determination of the values of the modulus of deformation considering the curve of additional pressure within the compressive strata.
7. Settlement calculation based on the variability of lateral expansion parameters and deformation modules. Therefore, in comparison with the traditional method of using the modulus of general deformation, expression (7) together with the refined β_Z coefficient allows increasing the value E. This increase, for water-saturated clayey soil, gives grounds for limiting the use of coefficients m_k, which are taken into account in the transition from the compression module to the stamp. In each case, it is possible to account for specific indicators of the physical and mechanical properties of the soil, rather than constant values, which are assigned only by the plasticity number.

Numerous experimental data [14] of primary (natural) and secondary (induced, i.e., after compaction or consolidation of soil) soil anisotropy substantiate the need to account for this effect to clarify the calculation of sediment bases. Some fairly typical examples of soil deformation anisotropy from the authors' practice are shown in Table 4.

Table 2 – The results of the compression test of clay loam

	Vertical pressure σ, MPa						
	0.00	0.05	0.10	0.15	0.20	0.25	0.30
Deformation Δh, mm	0.00	0.18	0.45	0.67	0.96	1.20	1.40
Porosity index e	0.843	0.833	0.821	0.808	0.794	0.780	0.765

Table 3 – Calculation of settlements of the bases of individual square foundations by (9)

z, m	B	1.5 m			2.1 m			2.7 m			3.3 m		
	σ_{zp}	216.0 kPa			216.0 kPa			216.0 kPa			216.0 kPa		
	σ_1	231.3 kPa			223.8 kPa			216.4 kPa			209.0 kPa		
	β_z	0.803			0.805			0.808			0.811		
		σ^c, kPa	E, MPa	S, cm	σ^c, kPa	E, MPa	S, cm	σ^c, kPa	E, MPa	S, cm	σ^c, kPa	E, MPa	S, cm
0		168	5.43	2.5	187	5.36	2.8	196	5.33	2.9	203	5.23	3.11
1		83.7	6.02	1.11	118	5.58	1.69	147	5.60	2.1	160	5.52	2.32
2		35.3	6.82	0.37	60.3	6.32	0.76	85.2	6.03	0.71	107	5.86	1.46
3		22.2	7.3	0.13	33.9	6.87	0.39	51.5	6.48	0.64	69	6.24	0.88
4		$\sum S = 4.11$ (7.1)*			21.3	8.05	0.12	33.5	6.91	0.39	47	6.60	0.57
5					$\sum S = 5.76$ (10.2)*			25.1	7.10	0.14	33	6.94	0.38
6								$\sum S = 6.88$ (13.1)*			26	7.18	0.14

$\sum S = 8.86$ (15.6)* – in the brackets settling on the recommendations of the DBN B.2.1-10-2009

Table 4 – Soil deformation anisotropy coefficients

Type of soil	Place of sampling	Porosity ratio e	Wetness w, %	The deformation module E_{-}, МПа	Coefficient $n_{E\perp}$
loess loams	natural massif	1.10 1.07 0.87 0.83 – 0.96 0.825	16.5 22.5 27.5 13 – 20 19	1.5 3.7 5.4 2.8 5.6 – 6.0	0.93 0.91 0.87 0.7 – 0.9 0.7 – 0.9
clay loam	bulk foundation * bulk foundation **	1.0 – 1.05 0.8 – 0.86	24 25	1.9 2.8	0.75 0.86
clay loam	ground bed	0.44 – 0.57	14 – 21	13.7 – 18.7	0.62 – 0.89
loess loams	under the foundation footing***	1.04 0.85	22.5 27.5	3.9 6.9	0.92 0.82
clay loam	for in-situ piles in drilled wells	0.60	19	12.7	0.76

* – drop-out time of about 40 years; ** – a break time of more than 10 years;
*** – lifetime of about 100 years at the ratio of the average pressure under the foundation footing to the calculated soil resistance p/R ≈ 100%

The anisotropy coefficients were determined by the formula

$$n_{E\perp} = E_{\perp}/E_{-} \,, \qquad (10)$$

where is E_{-} deformation of the soil in the case of orientation of the rings when selected at an angle $\alpha = 0^{\circ}$ relative to the horizontal plane; $E_{\perp}$ is the same but $\alpha = 90^{\circ}$.

It is proposed to consider the deformation anisotropy of soil soils by determining the additional pressure in formula (1) by the expression

$$\sigma'_{zp,i} = \sigma_{zp,i} / \sqrt{n_{E\perp}} \;. \qquad (11)$$

In this case, for the conditions of calculating the sediment of a separate foundation, discussed above, at $n_{E\perp} = 0.8$ the settling value will increase by about 10%.

The regularities of changing the values of the soil deformation modulus at the depth of the compacted zone, the use of which increases the accuracy of calculating the settlement of the foundations, which are reduced with compaction of its bases, can be rationally obtained within the first stage of modeling using the complex “PRIZ-Pile” [17 – 19].

The following is also another comprehensive approach to improving the settlement calculation of the base of MPP foundations on the N_{pw} soil compression index. This indicator reflects the relative change in the porosity ratio of the sample in compression tests [22]. Soil compressibility depends on its initial porosity and, accordingly, the initial porosity ratio. Therefore, to exclude the effect of the porosity of individual samples on the compressibility characteristic of its size, it is advisable to determine it as the relative decrease in the porosity coefficient when compressing the soil sample by expression

$$N^i_{pw} = (e^i_0 - e^i_p) / e^i_0 = \Delta e^i_p / e^i_0 \qquad (12)$$

where $N_{pw}{}^i$ is the index of compression of the ith sample;

e^i_0, e^i_p are the coefficients of porosity of the ith soil sample, respectively initial and after application of pressure p ;

Δe^i_p is a decrease in the coefficient of porosity of the ith sample after applying pressure p.

N_{pw} parameter is called indicator of soil compression. It is defined as the average of the compression indices of the samples $N_{pw}{}^i$

$$N_{pw} = \sum_{i=1}^{n} \frac{e^i_0 - e^i_p}{e^i_0 \cdot n} = \sum_{i=1}^{n} \frac{\Delta e^i_p}{e^i_o \cdot n} = \sum_{i=1}^{n} \frac{N^i_{pw}}{n} \qquad (13)$$

where N_{pw} is an indicator of soil compaction of certain humidity w from the stress p.

Index of N_{pw} shows that it's determined at specific values of humidity w and the stress p. The compression ratio of the soil reflects the relative decrease in its porosity ratio during compression.

Settlement of the soil layer is expressed by expression

$$e_p = e_o - \Delta h / h (1 + e_o) \qquad (14)$$

where e_0 and e_p are respectively porosity the soil coefficients: initial and under the pressure p.

$$\Delta h/h\ (1 + e_0) = e_0 - e_p \qquad (15)$$

then the settlement Δh of the soil layer h is equal to

$$\Delta h = (e_0 - e_p)/(1 + e_0) \cdot h \qquad (16)$$

From formula (12), the reduction of the porosity coefficient of compression is

$$e_0 - e_p = N_{pw} \cdot e_0 \qquad (17)$$

Substituting (17) into formula (16), we have

$$\Delta h = h\ (N_{pw} \cdot e_0)/(1 + e_0) \qquad (18)$$

Substituting Δh by the thickness of the ith layer of soil S_i of thickness h_i, we obtain

$$S_i = N_{pw}{}^i \cdot h_i \cdot e_0 / (1 + e_0) \qquad (19)$$

From where the sum of the settlements of the individual layers can be described by the following expression

$$S = \sum_{i=1}^n S_i = \beta \sum_{i=1}^n N_{pw}{}^i\, h_i\, (e_0{}^i)/(1 + e_0{}^i) \qquad (20)$$

Where S_i is subsidence of the soil base from loading of the foundation; coefficient $\beta=0.8$; $N_{pw}{}^i$ is the index of compression of the ith layer of soil; h_i is the thickness of the ith layer of soil.

The calculation of (20), expressed in terms of N_{pw} the subsidence of the LSM, takes into account the change in the stress state at the depth of the base from the load and the effect of soil porosity on its compression. The subsidence of the substrate was determined by two deformation parameters (the modulus of deformation and the compression ratio of the soil) obtained in the standard K-1 compression device and the CLES device (compressibility with a lateral extension of the soil) [22].

Comparison of the results of long geodetic surveys of settlements of a field object (section of a six-story building) and calculated by the index of compression of the soil and the modulus of deformation. The site belongs to the Poltava Forest Plateau. Groundwater level - 5 m from the daily surface. The following engineering-geological elements (EGE) are distinguished:

EGE-1 – bulk soil and soil-vegetation layer (1.4 m thick);

EGE-2 – loamy forest, solid, highly porous, subsidence (3.1 m);

EGE-3 – loamy forest, fluid-plastic (5.6 m);

EGE-4 – loam is rigid plastic (4,8 m);

EGE-5 is a loamy forest, microplastic (17 m deep).

Soil physical and mechanical characteristics are given in Table 5.

The average pressure under the sole of the tape foundations on a natural basis was p = 180 kPa at the calculated soil resistance R = 200 kPa. In the process of erection and operation of the building by Professor M.L. Zotsenko organized a geodetic survey of its sediments [19].

The calculations of the bases settlement of the foundations are made by the MPP (fig. 1) through 1) the soil deformation module; 2) the compression ratio of the soil, which is defined in each layer at the appropriate pressure at depth, taking into account the initial coefficient of porosity of this layer (fig. 2). Comparison of the calculated values of settlements of the foundation of the building by two methods with the data of field observations is shown in table 6.

Comparing the results of the calculations by the two methods with the data of the field observations, it was found that the subsidence of the basis determined by the new method is closer to the actual values than to the normative ones. The amount of subsidence of the soil by the soil compression index by 36% exceeds the value calculated by the modulus of deformation. At the same time, the subsidence of the base, determined by the soil compression index, is 13.8% higher than the value obtained from geodetic observations, and the settlement calculated through the deformation module of the soil is 26% less than the observation data.

Table 5 – The value of the physical and mechanical soil properties on the site

Soil characteristics	EGE numbers, value of characteristics				
	1	2	3	4	5
Humidity on the verge of fluidity	-	0,36	0,28	0,36	0,29
Humidity on the verge of plasticity	-	0,21	0,18	0,21	0,19
Number of plasticity	-	0,15	0,10	0,15	0,10
Humidity is natural	0,16	0,20	0,26	0,28	0,25
Fluidity index	-	-0,07	0,80	0,47	0,60
Specific gravity of soil, kN / m^3	15,00	16,60	18,66	18,47	18,79
Specific gravity of dry soil, kN / m^3	-	13,83	14,81	14,43	15,03
Porosity ratio	-	0,92	0,78	0,84	0,76
Soil specific gravity,γ_{II}, kN / m^3	-	16,46	18,52	18,33	18,62
Specific cohesion, c_{II}, kPa	-	11	8	16	9
The angle of internal friction, φ_{II}, deg.	-	25	28	26	28
The deformation module, E, MPa	-	6	8	11	8

Table 6 – The results comparison of the foundations' bases settlements of the house section with the data from field observations calculated by the two methods

№ EGE	Initial coefficient of soil porosity e_0	Soil deformation module *E*, MPa	Base settlement *S*, m, determined through the deformation module *E*	Soil compression ratio index N_{pw}	Base settlement *S*, m, determined through the N_{pw}	Base settlement *S*, m, determined by geodetic observations
2	0,92	6,0	0,088	7,62	0,138	0,119
3	0,78	8,0		6,45		
4	0,84	11,0		5,61		

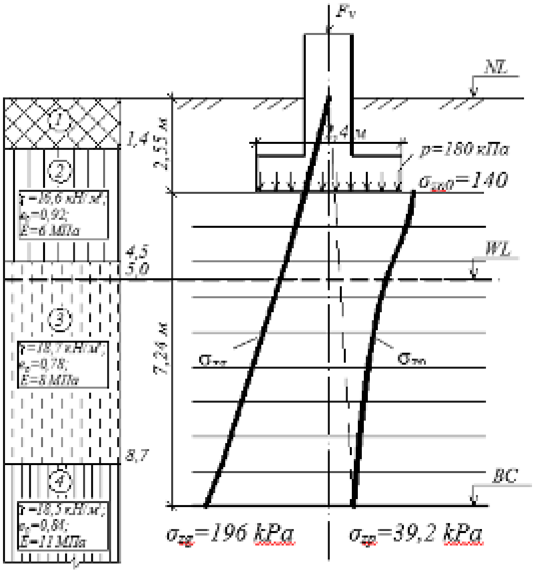

Figure 1 – The scheme to determine the settlement of the foundations' bases by the method of layer summation by the soil deformation modulus

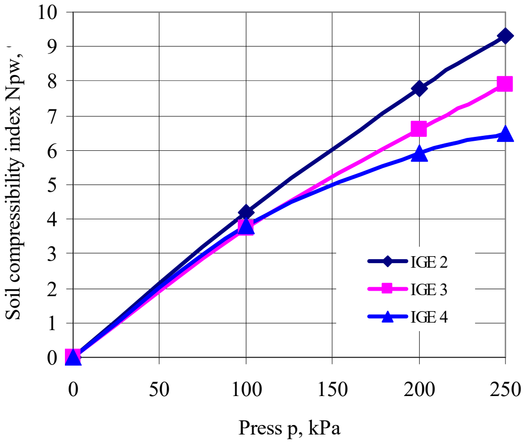

Figure 2 – Determination of soil compression indexes N_{pw} to calculate the base settlement

Conclusion

Thus, it is possible to clarify the calculation of the base settlements by LSM by a complex consideration: variability of the soil deformation module in the full pressure range, which is perceived by the base at loading; soil strength coefficient; deformation anisotropy of soils; regularities of change in the size of the soil deformation modulus in depth of the array under the foundations and within the artificial bases, which are reduced to soil compaction.

The developed compression index reflects the relative change in the porosity coefficient of soil compression, and more correctly than the standard parameters of compressibility characterizes the deformation properties of the substrate at specific stress values, which vary in depth of the compressive strata under the foundation, taking into account the effect of porosity on the compression. The accuracy of the method of determining the settlement of the foundations is enhanced using soil compression index. The settlement of the foundations, determined through this indicator, up to 27% exceeds, calculated through the module of soil deformation.

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