UDC 624.131+624.15

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COMPARATIVE ANALYSIS OF DESIGN SETTLEMENT FOUNDATIONS METHODS ACCORDING TO DATA OF CONE PENETRATION TEST ON NATIONAL AND EUROPEAN STANDARDS

It is given a comparative analysis of the methods of computation of foundations settlement according to Cone Penetration Test with the current normative documents of the Republic of Belarus and the Eurocode 7 «Geotechnical design» (part 1, 2). Three methods of computation of foundation settlement for the sediment limit state SLS are considered in accordance to European standards and two methods of computation of foundation settlement are considered in accordance to National standards. The similarities and the differences in construction of the conditional pile foundation are identified according to National and European standards. The similarities and the differences in the methods of foundation settlement computation in accordance to European and National standards are revealed and summarized. The difference of the calculated values of foundation settlement is defined in percentage.

***Keywords:** Cone Penetration Test, foundation settlement, elastic modulus, deformation modulus, equivalent raft foundation, nominal foundation.*

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ МЕТОДОВ РАСЧЕТА ОСАДКИ ФУНДАМЕНТА ПО ДАННЫМ СТАТИЧЕСКОГО ЗОНДИРОВАНИЯ ПО НАЦИОНАЛЬНЫМ И ЕВРОПЕЙСКИМ НОРМАМ

Приведен сравнительный анализ методов расчета осадки фундаментов по данным статического зондирования согласно действующим нормативным документам Республики Беларусь и EUROCODE 7 «Geotechnical design» (part 1, 2). Рассмотрены согласно европейским нормам три метода расчета осадок фундамента для предельного состояния SLS и два метода расчета осадок по национальным нормам. Определены сходства и различия в построении условного свайного фундамента по национальным и европейским нормам. Выявлены и обобщены сходства и различия методов расчета осадок фундамента по европейским и национальным нормам. Определена разница полученных расчетных значений осадок фундамента в процентом отношении.

***Ключевые слова:** статическое зондирование, осадка фундамента, модуль упругости, модуль деформации, эквивалентный плитный фундамент, условный фундамент.*

Introduction. Currently in the Republic of Belarus it is a process of mass introduction of European materials, technologies and equipment. It became necessary to deal with the process of harmonization of National regulatory documents with Eurocodes in order to be able to enjoy these achievements. From July 1st, 2015 the EU design standards (Technical Code of Practice EN) became mandatory when design of all building structures, including bases and foundations.

The comparative analysis of the methods of foundations computation settlement according to European standards and standards of the Republic of Belarus will have undoubted interest for the experts in the field of geotechnical engineering.

Eurocode 7 [4, 5] consists of two parts that cover specific technical aspects. National Annexes to Eurocodes stipulate additional requirements to particular parameters of construction that can be higher but not lower than European requirements. Every country determines such requirements independently and until now there is no developed unified approach in geotechnical engineering.

National regulatory documents [1 – 3] as well as Eurocode 7 [4, 5] prescribe design of various objects according to two groups of limit states (according to Ultimate limit state design and Serviceability limit state design) and they have the uniform terminology and designations, so in general there are no key distinctions between Nation standards of the Republic of Belarus and European tendencies.

To evaluate the limit states of the second group in [1, 2, 3] it is clearly indicated what kind of calculations should be done:

– by deformation of the base buildings due to the external loads and the own weight of soil;
– by training and crack opening in the construction of foundations.

The fields of application of the methods of computation of foundations settlement are clearly stipulated in [1, 3], as well as the calculation formulas are adjusted, the rules on definition of deformation modulus are introduced. These methods combine the techniques of evaluation of joint work of base and superficial structure, where the rigidity of upper foundation structures is taken into account approximately by means of the correction coefficients that depend on type of a structure according to the rigidity. Such methods are developed in standards concerning the design of bases and structures and they are the most frequently used in practice because of their simplicity. The methods of design settlement, given in [1, 3] are the following: the method of layer by layer summing up, the method of equivalent layer, the method of linearly deformable layer of the finite thickness.

And in [4, 5] it is said about the design criterions you should follow when the computations and the mandatory procedure of verification using the partial factors is established as well. The value partial factors are advisory in nature; they can be modified in National Annex. The measures for prevention of the beginning of the limit state, as it is stated in [4], are largely focused on consideration of stabilized and instabilized states. There are two key conditions in [4] that should be studied: the ultimate limit state (ULS) at failure and the serviceability limit state (SLS) when operating loading where the deformation must not exceed the maximum permissible. Even National Annexes to determine ULS strongly differ for these simple cases in spite of the fact they are based on similar principles of destruction, as well as the computations based on these principles also differ. When checking the soil base according to the serviceability limit state the partial factors are set equal to 1.

In Eurocode 7 [4, 5] there is no unified approach to determine the foundation settlement. General requirements and recommendations to determine the limit states and the limit values of displacement foundation are presented. Annex F describes the simple analytical computational methods of settlement [4]. There are four methods of settlement computation in Eurocode part 2 [5] (although they are not presented in Eurocode 7 part 1 [4]), based on the results of field test using the semi-empirical computation models

(Annexes B2, C2 and D4 [5]). Use of this particular method is usually stipulated in National Annex to Eurocode.

When calculation of the settlement pile groups both in European and National standards they use the principle of linear deformation. The foundation calculation using the piles built-in ground coat and its bases according to the deformations should be performed, as a rule, in terms of the nominal raft foundation in compliance with the requirements [1, 2, 3]. The definition of the limits of nominal foundation is performed in [2] and it is well-known to national geotechnical engineers. In accordance with [4,12] the basic methods of calculation of the pile foundations are based on assumption that the group of piles behaves as a fundamental unit with a certain degree of flexibility that depends on the rigidity of pile cap's connection to piles. Taking into consideration this fact it is possible to use the well-known principles of soil engineering to determine the bearing resistance and the settlement of piled foundation. In the present case the equivalent foundation slab is used. The piles arrangement in pile cap is almost identical according to European and National standards. The distance between the centers of driven pile shouldn't be less than three diameters of pile.

Analysis of recent achievements and publications. The examples of calculation of settlement of shallow foundation are given in lectures [6, 7 ,8]. The example of computation of settlement of shallow foundation taking into account the soil consolidation on multiarrayed base is given in study [10]. The example of calculation of settlement of pile foundation is presented in study [13]. The authors [9, 11] explain and comment the articles of Eurocode 7 that contain new approaches to designing; they give the examples of computation of settlement foundations according to European standards. The author [12] gives the examples of calculation of foundation settlement according to data of Cone Penetration Test.

Accentuation of precedently unsolved aspects of general problem. Despite the increased interest of well-known scientists to chosen range of problems, the "harmonization" of foundation settlement design according to data of Cone Penetration Test following National and European standards does not lose relevance. These issues stay unsolved in full and this requires their further development and elaboration.

National standards of the Republic of Belarus and Eurocode 7 have a number of similar provisions concerning the limit state design. However, the designing results are different. In our opinion the direct use of European standards without taking into account national peculiarities of design and foundation computation in the Republic of Belarus is impossible.

Purpose of study – comparison of the results of foundation settlement calculation according to data of Cone Penetration Test following National and European standards of designing.

Main part. There are more than 20 methods of foundation settlement calculation. As the limit calculation value for effect (settlement) – S_d in European standards [4,5] they accept the sum of three constituents of settlement:

$S_d = S_e + S_c + S_s$.

where S_e –is the immediate settlement, that appears immediately after construction.

In European geotechnical engineers' opinion the monetary settlement S_e is dominant for gravel and medium sand. There are several methods of specification and definition of such settlement:

– solving problems of the theory of elasticity (Annex F [4]),
– formula of Janbu et al (1956) with amendments of Christian and Carrier (1978) [13] – is used to determine settlement when undrained condition,
– Schmertmann's method – is used when calculation of settlement in sand (Annex D.3 [5]) or Schmertmann's formula [12, c. 68]).

– S_c – is the settlement caused by consolidation that is dominant for clay soil.

The consolidation settlement S_c is usually calculated using precondition of dimensional compression. It is admissible to determine the deformation parameter of ground coat according to the empirical dependences of Terzaghi's one dimensional consolidation theory [9 – 12], taking into account the average degree of consolidation U_m the corresponding time factor T_v.

– S_s – is the settlement caused by creep (secondary settlement), that is dominant for ground coat with significant rheological properties.

Secondary settlement continues for a long time.

Stage 1. Design settlement shallow foundation.

Let's consider the simplest case of mutual interaction of shallow foundation with one layer supporting ground. We'll restrict ourselves by problem of determining ultimate stabilized settlement foundation due to the load action that is transmitted to ground coat through the bottom of foundation.

To calculate foundation settlement the results of Cone Penetration Test on the territory of Vitebsk region of the Republic of Belarus were taken into consideration.

Ground coat – is medium sand, with medium strength. The design value of ground coat specifications:

q_s = 6,53 MPa, E = 26,85 MPa, γ_{II} = 18,8 kN/m^3, c_{II} = 0,001 MPa, φ_{II} = 35,5^o .

Shallow foundation, foundation depth is of 1,5 m, correlation of length and width of foundation is equal to 1.

Vertical load on foundation N = 1500kN (set conditionally).

1.1. Calculation of shallow foundations settlement according to National standards of the Republic of Belarus.

The final foundation settlement S_c with the use of design scheme in terms of linearly-deformable halfspace with conditional constraint of compressible thickness layer is determined by the method of layer by layer summing up using the following equation:

$$S = \beta \cdot \sum_{i=1}^{n} \frac{\sigma_{zp,i} \cdot h_i}{E_i}, \qquad (1)$$

where β – is the dimensionless coefficient, equal to 0,8;

$\sigma_{zp,i}$ – is the average value of vertical stress beneath load in i^{-th} elementary layer of soil equal to semi-sum of subjecting to stress on upper and lower limits of i-th elementary layer, kPa;

h_i and E_i – are consequently depth and deformation modulus of i-th elementary layer of ground coat. The depth of h_i layer should not exceed 0,4 of foundation width;

n – is a number of layers into which compressible soil column is divided.

The computation is performed for the varying bottom width of a foundation. The calculation results are recorded in Table 1.

Table 1 – Calculation results of foundation settlement according to formula (1)

Dimensions of foundation base	1×1	2×2	3×3	4×4
Value of settlement according to method of layer by layer summing up, m	0,045	0,019	0,01	0,006

The final settlement impaction (maximal ultimate value – for slender foundations and average – for rigid foundations) using the equivalent layer method is determined with the use of the theory of filtration consolidation assuming that base of foundation is a linearly-deformable body, according to the formula:

$$S = h_э \cdot m_v \cdot p_0, \tag{2}$$

where m_V – is the coefficient of volume change of ground coat of homogeneous foundation,

p_0 – is the additional pressure at the level of foundation base, MPa;

$h_э$ – is the power of equivalent layer, m, is determined using the formula:

$$h_э = A_\omega \cdot b, \tag{3}$$

where A_ω – is the coefficient of equivalent layer taken according to the type of ground coat and form of foundation base, (Table 5.14 [3]);

b – is a bottom width (diameter) of a foundation, m.

In the study we find out the coefficient of volume change of ground coat of homogeneous foundation using the following formula:

$$m_v = \frac{\beta}{E}, \tag{4}$$

where E – is the total soil deformation modulus,

$$\beta = \frac{1-2\nu^2}{1-\nu}, \tag{5}$$

ν – is the coefficient of lateral dilatation of ground coat accepted according to Table 5.14 [3].

We make the computation for various bottom widths of a foundation. The calculation results are recorded in Table 2.

Table 2 – Calculation results of foundation settlement according to formula (2)

Dimensions of foundation base	1×1	2×2	3×3	4×4
Value of settlement according to method of equivalent layer, m	0,063	0,029	0,018	0,011

1.2. Calculation of shallow foundations settlement according to European standards.

As it was stated above, the foundation settlements according to European standards can be determined using the different formulas. In this case the characteristics of ground coat are obtained with the help of Cone Penetration Test and it is said in [5] that «it should be used the semiempirical methods of computation as well as the mathematical method of design».

If the adapted method of recoverability specification (with account of necessary improvements) is used for the computation of shallow foundation settlements according to the results of Cone Penetration Test, then by the load resistance it is possible to determine the drained (long-term) Young's of elasticity E_m (Annex F [4]). There is some uncertainty when determination of value of E_m according to data of Cone Penetration Test. Eurocode 7 Annex D [5] offers to determine with the help of two methods: using tabular data and using the coefficient $\alpha = 2 \ldots 4$ [12].

For the computation we use the calculation formula of elastic settlement Annex F [4].

$$S = \frac{P \cdot b \cdot f}{E_m}, \tag{6}$$

where P – is the bearing pressure (linearly distributed) on the base of the foundation;

E_m – is the design value of the modulus of elasticity;

b – is the foundation's width;

f – is a settlement coefficient:

$$f = (1 - \nu^2) \cdot I \, , \tag{7}$$

where ν – is the Poisson's ratio for sands;

I = 1,12 (ratio of length and foundation width equal to 1 and determination of extreme draft under the center of the foundation).

$E_{m1} = \alpha q_c = 4 \times 6{,}53$ MPa = 26,12 MPa.

Young's modulus when Cone Penetration Test can be also determined using the formula [12, c. 70]:

$$E_{m2} = \alpha_E \cdot (q_t - \sigma_{v0}), \tag{8}$$

$$\alpha_E = 0.015 \cdot [10 \cdot (0.55 \cdot I_c + 1.68)] \tag{9}$$

where I_c – is a coefficient acceptable according to the Table in [12, p. 27],

$q_t = q_c$ for sands,

σ_{v0} – is a total vertical pressure at the considered depth.

E_{m1} = 16,56 MPa.

As it was already mentioned above, the settlement calculated by the formula (6), is dominant for river and medium gravels. Therefore, in this case we can write the following $S_d = S_e$.

We make the computation for various bottom widths of a foundation. The calculation results are recorded in Table 3.

Table 3 – Calculation results of foundation settlement according to formula (6)

Dimensions of foundation base	1×1	2×2	3×3	4×4
Value according to adjusted elasticity method, m with E_{m1}	0,059	0,028	0,017	0,010
Value of settlement according to adjusted elasticity method, m with E_{m2} of equivalent layer , m	0,093	0,044	0,026	0,017

The second method of determination of foundation settlement according to data of Cone Penetration Test is the calculation using the Schmertmann's method [5, 12]. Foundation settlement s due to load q is determined using the following formula:

$$s = C_1 \cdot C_2 \cdot (q - \sigma'_{v0}) \cdot \int_0^{z1} \frac{I_z}{C_3 \cdot E'} dz \, , \tag{10}$$

where $C_1 = 1 - 0{,}5 \cdot [\sigma'_{v0} / (q - \sigma'_{v0})]$,

$C_2 = 1.2 + 0.2 \lg t$,

C_3 – is the correction for shape of footing (for square footings C_3 =1,25),

σ'_{v0} – is a primary effective vertical stress at the level of the footing,

t – is the time, year,

I_z – is an influencing factor of subjecting to stress,

E' – is Young's of elasticity, in this case $E' = 2{,}5\, q_c$.

The calculation of settlement using the formula (10) we will mention as an instance for the foundation with dimension 1×1 m when the ground conditions mentioned above.

We will replace the sample profile of Cone Penetration Test by the diagram (Figure 1), where the vertical lines combine the areas having the average CPT resistance for a sublayer q_c.

$$\Delta q = q - \sigma'_{v0} = \frac{1500}{1\times1} - 18{,}8\times1{,}5 = 1471{,}8 \text{ kPa},$$

$$\sigma'_{vp} = 18{,}8\times1{,}5 + 18{,}5\frac{1}{2} = 37{,}6 \text{ kPa},$$

$$I_z = 0{,}5 + 0{,}1\sqrt{\frac{\Delta q}{\sigma'_{vp}}} = 0{,}5 + 0{,}1\sqrt{\frac{1474{,}8}{37{,}6}} = 1{,}13 .$$

Knowing the value I_z we construct a graph of distribution of the impact factor of vertical intensity for square foundation having the following dimension 1×1 m (Figure 1).

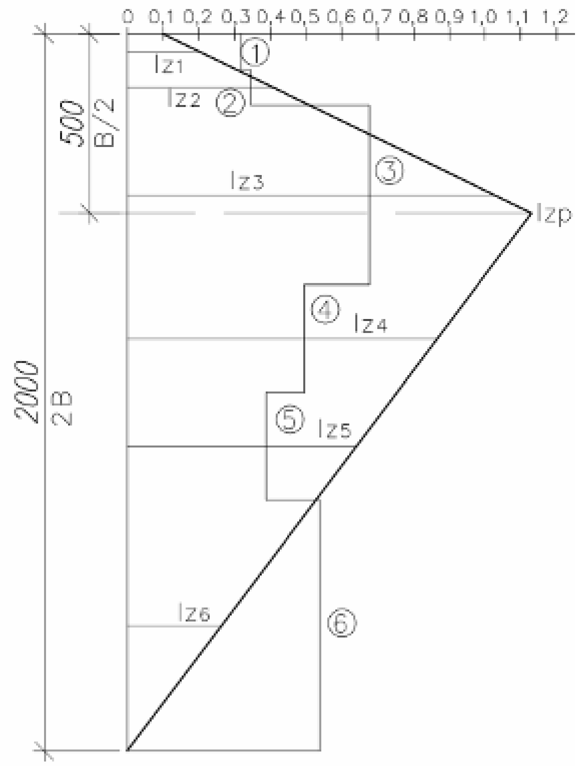

Figure 1 – Graph to determine impact factor of subjecting to stress

The calculated data are summarized in Table 4.

Table 4 – Calculated data to determine settlement using the Schmertmann's method

Number of layer	Resistance for sublayer q_c, MPa	Impact factor I_{zi}	Young's of elasticity in i-th layere E', MPa	Layer thickness, m
1	3,17	0,2	7,9	0,1
2	3,45	0,41	8,62	0,1
3	6,77	1,03	16,9	0,5
4	4,95	0,87	12,37	0,3
5	3,87	0,64	9,67	0,3
6	5,39	0,26	13,47	0,7

where $C_1 = 1 - 0{,}5 \cdot [28{,}2/1471{,}8] = 0{,}99$, $C_2 = 1$ for the end of construction.

$$s_1 = 0{,}99 \cdot 1 \cdot 1471{,}8 \cdot \frac{0{,}0852}{1{,}25} = 0{,}099 \text{ m.}$$

The further computations are made for various bottom widths of a foundation. The calculated data are summarized in Table 5.

Table 5 – Calculation results of foundation settlement according to formula (10)

Dimensions of foundation base	1×1	2×2	3×3	4×4
Value of settlement according to the Schmertmann's method, m	0,099	0,033	0,016	0,007

Stage 2. Settlement computation of piled foundations.

The piled foundation composed of 4 displacement piles C8-40. The pile's interfacing with the foundation piling is non-yielding. The depth of pile setting in the foundation piling is of 0,5 m. The laying depth of the foundation piling is of 1,5 m.

The vertical load on the piled foundation N = 3000 kN (given conditionally).

For this calculation we assume that the settlement is homogeneous. The computation is carried out on the assumption of that there is only one soil layer in the subfoundation - medium coarse sand, with average strength.

2.1. Settlement computation of piled foundation according to National standards.

The foundation computation of the piles built-in ground coat and its primary structure according to the deformations should be performed, as a rule, in terms of the conventional foundation slab according to the requirements [3]. The determination of limits of the conventional foundation is given in [2] and it is well-known to national geotechnical engineers.

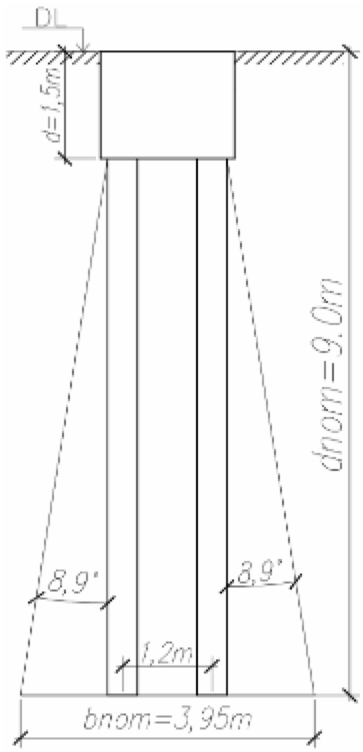

Figure 2 – Graphical conduit of conventional foundation according to National standards

We will determine the settlement of the conventional foundation using the formulas (1 – 2), mentioned above. The calculation results are recorded in Table 6.

Table 6 – Calculation results of settlement of conventional foundation

Method of computation of settlement according to National standards	Value of settlement, m
Method of layer by layer summing up	0,021
Method of equivalent layer	0,037

2.2. Settlement computation of piled foundation according to European standards.

There is practically no information concerning the determination of settlement of the piled foundations in Eurocode 7 [4, 5].

The first step in the settlement analysis is to determine the vertical stress distribution below the base of the equivalent raft or block foundation, built under the principle 1:4 (Figure 3), while using the graph [13, p 254]. An approximate method that is often used in the calculations lies in the supposition that the effective level of transmission is at the depth of 2 D/3 below the top of the pile. European geotechnical engineers consider the application of the method of equivalent foundation slab to calculate the settlement of the piled foundation sufficiently reliable. This method is widely used to determine the preliminary settlements or to check the settlements obtained by computer calculation. When checking the limit state of SLS piles group [4] it is recommended to use the partial coefficient 1,0 for actions and properties of the ground coats unless otherwise specified.

The second step is to determine the limit of the compressible thickness where the vertical stress resulting from the net pressure at the foundation level amounts only to 20% of the initial intergranular stress caused by the weight of the ground coat.

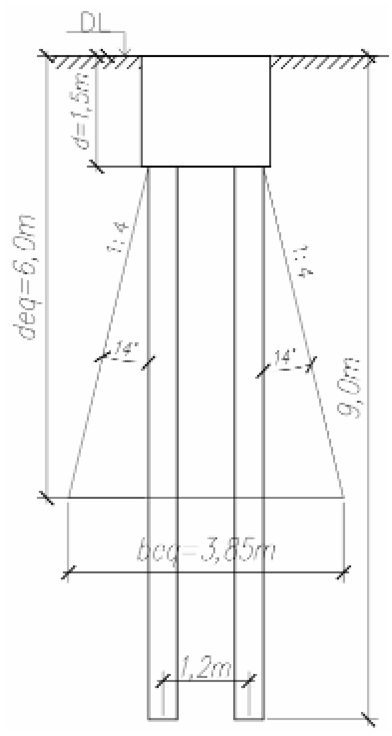

Figure 3 – Graphical construction of equivalent raft foundation according to European standards

The third step is to calculate the settlement of the foundation. As it is shown in Annex F [4], it is possible to perform the settlement computation using the «stress-strain method». The second method of the settlement calculation is the adjusted elasticity method. The graphical representation of this method that is adapted to the equivalent conditional foundation is shown in Figure 4.

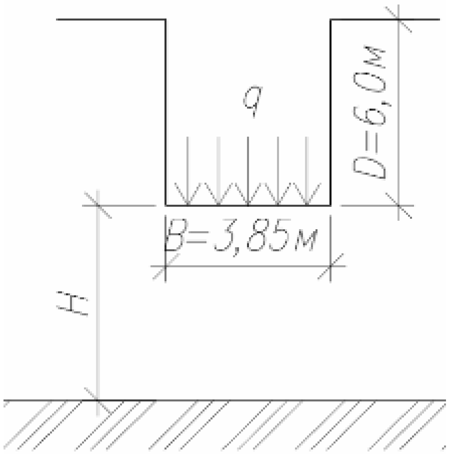

Figure 4 – Equivalent foundation slab for settlement computation

The average settlement of the piled foundation can be determined using the following formula:

$$s_e = \frac{\mu_1 \cdot \mu_2 \cdot q_n \cdot B}{E_u}, \qquad (11)$$

where μ_1, μ_2 – are the influence factors, that are determined using the graphs of Christian and Carrier. These coefficients can be determined by the graphs [13, p 260].

The coefficient μ_0 depends on the ratio $D / B = 6 / 3.85 = 1.56$, correspondingly $\mu_0 = 0.91$.

The coefficient μ_1 depends on the ratio $H / B = 6 / 3.85 = 1.56$, $L / B = 3.85 / 3.85 = 1.0$, correspondingly $\mu_1 = 0.55$.

q_n – is the pressure at the level of foot portion of the equivalent foundation slab.

B – is the width of bottom of the equivalent foundation slab (Figure 3).

E_u – is the elastic modulus.

In this study the soil characteristics were obtained with the help of Cone Penetration Test. We will take the Young's modulus from the section 1.2 of the study. E_{m1}=26,12MPa, E_{m2}=16,56MPa.

The formula (11) is designed to calculate the average settlement of slender piled foundations that's why for the use of the non-yielding pile foundations when the computation the correcting coefficient 0,8 is introduced.

The average settlement of the piled foundation is equal to:

when E_{m1} $s_e = 0{,}8 \cdot \frac{0{,}91 \cdot 0{,}55 \cdot 202{,}43 \cdot 3{,}85}{26120} = 0{,}012\text{м}$

when E_{m2} $s_e = 0{,}8 \frac{0{,}91 \cdot 0{,}55 \cdot 202{,}43 \cdot 3{,}85}{16560} = 0{,}019\text{м}$

The results of the executed researches.

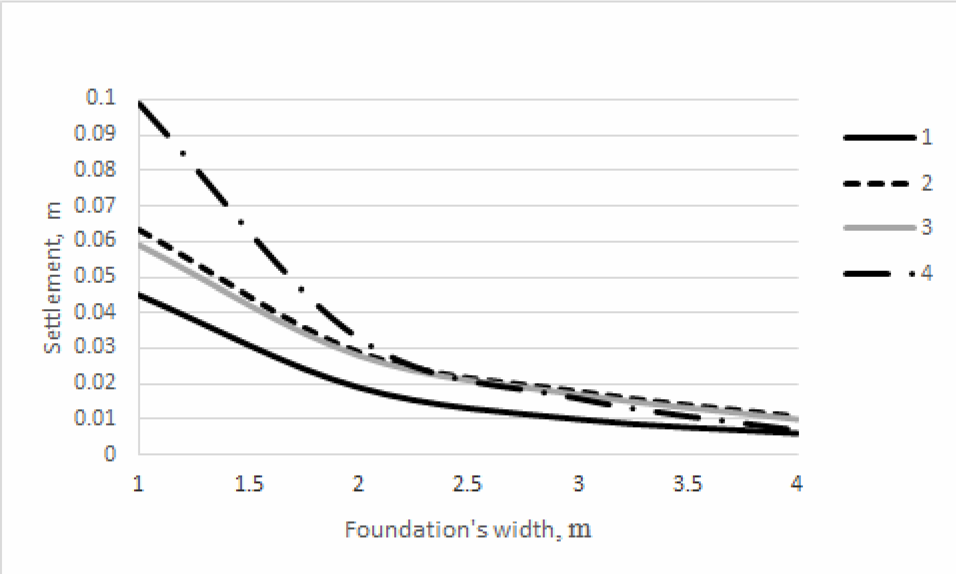

Figure 5 – Graph of settlements of shallow foundation subfoundation.
1 – method of layer by layer summing up,
2 – method of equivalent layer,
3 – adjusted method of elasticity Annex F [4] (when E = 26,12 MPa),
4 – Schmertmann's method.

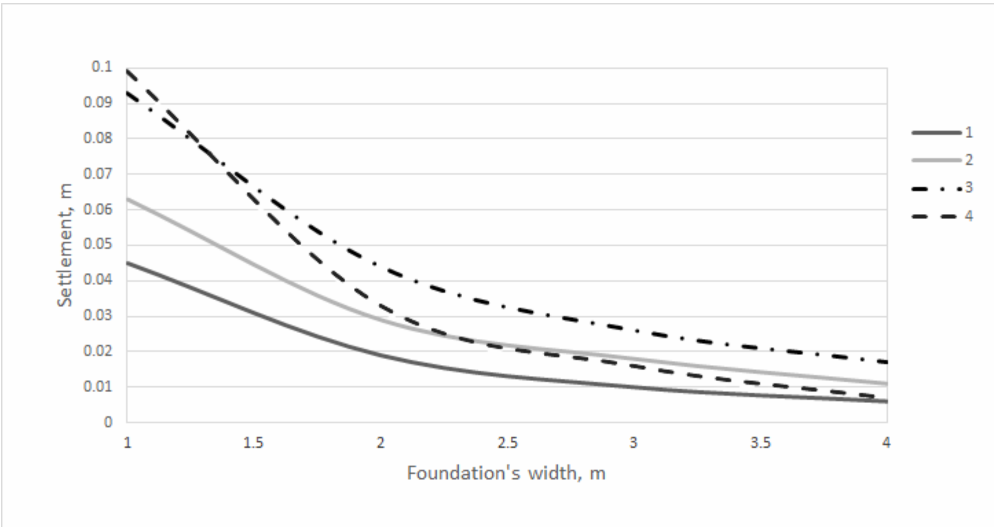

Figure 6 – Graph of settlements of shallow foundation subfoundation
1 – method of layer by layer summing up ,
2 – method of equivalent layer,
3 – adjusted method of elasticity Annex F [4] (when E = 16,56 MPa),
4 – Schmertmann's method.

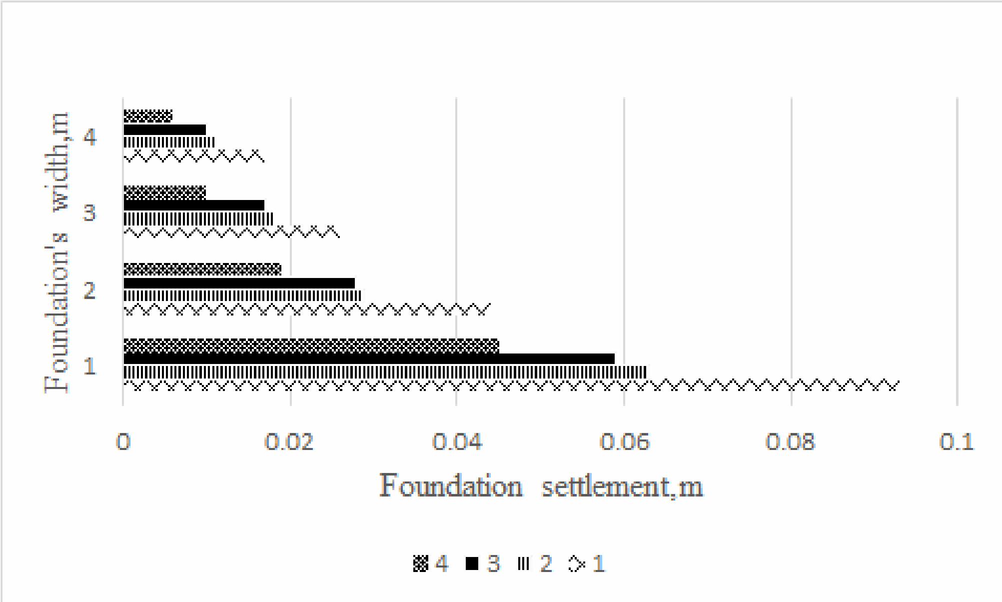

Figure 7 – Quantitative ratio of values of slabby subsurface foundation settlements
1 – adjusted method of elasticity Annex F [4] (when E=16,56MPa),
2 – method of equivalent layer,
3 – adjusted method of elasticity Annex F [4] (when E=26,12MPa),
4 – method of layer by layer summing up.

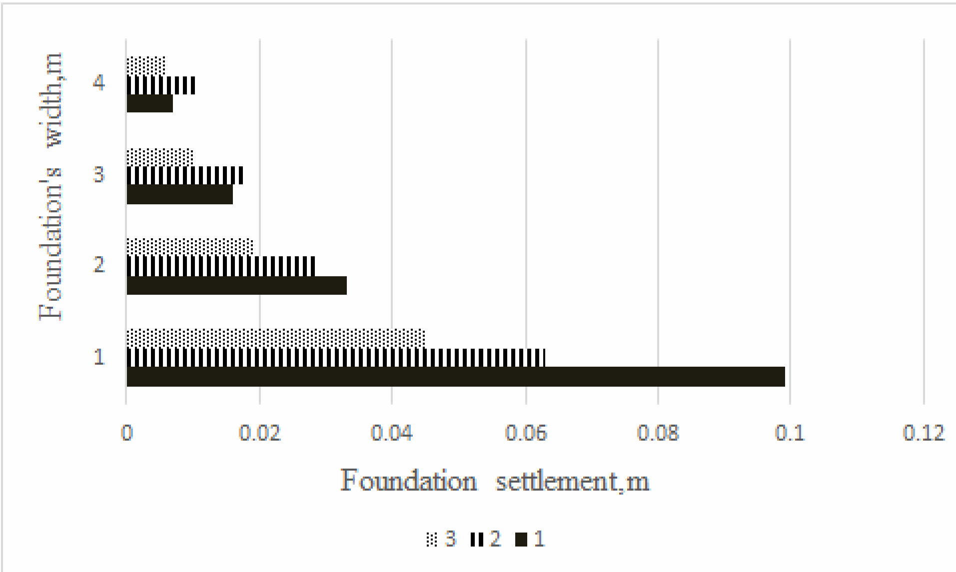

Figure 8 – Quantitative ratio of values of slabby subsurface foundation settlements:
1 – Schmertmann's method, 2 – method of equivalent layer,
3 – method of layer by layer summing up

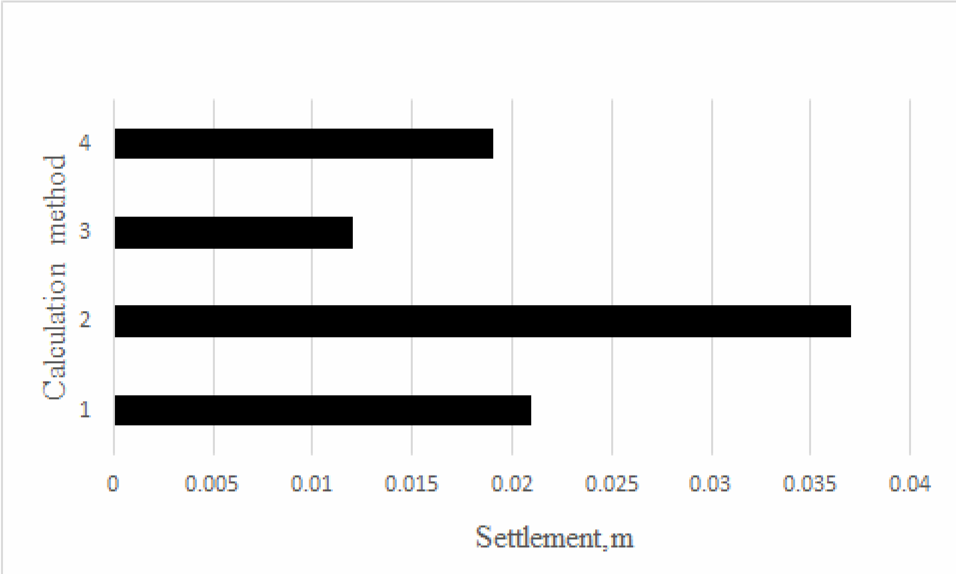

Figure 9 – Quantitative ratio of values of piled foundation settlements:
1 – method of layer by layer summing up,
2 – method of equivalent layer,
3 – adjusted method of elasticity Formula 11 (when E = 26,12 MPa),
4 – adjusted method of elasticity Formula 11 (when E = 16,56 MPa).

Conclusions:

1. The computation of the settlement of shallow foundations in sandy ground according to European standards as well as according to National standards is based on the same principles of the stress distribution in soil body. If there is the value of loads that correspond to impaction phase, so the values of the settlement using the method of equivalent layer, the Schmertmann's method and the adjusted method of elasticity (when E = 26.12 MPa) Annex F [4] are practically the same.

2. The difference between the settlement values obtained by the computation using the method of layer by layer summing up and the settlement values obtained with the use of the Schmertmann's method and the adjusted method of elasticity (when E=16,56 MPa) Annex F [4] amounts to 35-40%. This difference is due to the various approaches to the definition of E (modulus of deformation).

3. The length and the width of the conditional foundation according to National standards depend on type of the ground coat (drained angle of internal friction), situated along the length of the pile. According to European standards the inclination of profile planes to determine the equivalent foundation slab is always the same and it is equal to 1:4 (14^0). However, the dimensions of the conditional foundation base are obtained practically the same, due to the difference in determining the depth of the conditional foundation.

4. The value of settlement of the piled foundation in sandy ground when computation by the method based on the solutions of the theory of elasticity with the use of the coefficients that are determined by the graphs of Christian, J.T. and Carrier, W.D. Formula (11) when E=26,12 MPa is 42% less than the value of settlement with the use of the method of layer by layer summing up and almost 2 times less than the value of settlement with the use of the method of equivalent layer. The value of settlement of the piled foundation under the formula (11) when E=16,56 MPa is 10% less than the value of settlement under the method of layer by layer summing up and 49% less than the value of settlement under the method of equivalent layer.

5. The maximum limiting draft of settlement of house footings and buildings according to Eurocode 7 is accepted at the rate of 5,0 cm. Some well-known European geotechnical engineers [6, 11] suppose that the maximum limiting draft of settlement of foundations of framed buildings and buildings is at the rate of 7,5 cm (sand) and 13,5 cm (clay). According to National standards the maximum limiting draft of settlement of foundations of framed buildings and buildings is at the rate of 8 cm (for reinforced concrete structural framing) and 12 cm (for steel framework) and it does not depend on type of the ground coat under the foundation base.

6. The values of the Young's modulus when the computation according to European standards were determined either with the use of tables or with a help of the coefficient of correlation that don't take into account the ground conditions of the Republic of Belarus. It makes sense to develop the regional correlation dependences to determine the Young's modulus taking into consideration the soil resistivity under the penetrometer cone. Probably, then there will be no such divergence of the values of settlement according to National and European standards.

References

1. *Bases and foundations of buildings and structures. Basic provisions. Building regulations of designing: Technical Code of Practice 45-5.01-254-2012 (02250). – [Introduced on 01.07.2012]. – Minsk: Ministry of Architecture and Construction of the Republic of Belarus, 2012. – 102 p.*
2. *Bases and foundations of buildings and structures. Displacement piles. Design rules and devices: Technical Code of Practice 45-5.01-256-2012 (02250). – [Introduced on 01.07.2012]. – Minsk: Ministry of Architecture and Construction of the Republic of Belarus, 2013. – 137 p.*
3. *Foundation slabs. Design rules: Technical Code of Practice 45-5.01-67-2007 (02250). – [Introduced 02.04.2007]. – Minsk: Ministry of Architecture and Construction of the Republic of Belarus, 2008. – 137 p.*
4. *Eurocode 7. Geotechnical designing. Part 1. Common rules: Technical Code of Practice EN 1997-1-2009 (02250). – [Introduced on 10.12.2009]. – Minsk: Ministry of Architecture and Construction of the Republic of Belarus, 2010. – 121 p.*
5. *Eurocode 7. Geotechnical designing. Part 2. Soil investigation and testing: Technical Code of Practice EN 1997-2-2009 (02250). – [Introduced on 10.12.2009]. – Minsk: Ministry of Architecture and Construction of the Republic of Belarus, 2010. – 153 p.*
6. *Scarpelli G. Shallow foundations – design of spread foundations. Geotechnical Design with worked examples / G. Scarpelli – Dublin, 13-14 June, 2013. – 36 p.*
7. *Frank R. Geotechnical aspects of building design (EN 1997) / R. Frank – Brussels, 20-21 October,2011 – 55p.*
8. *Orr Trevor L.L. Eurocode 7. Workshop / Trevor L.L.Orr Brussels, 18-20 February, 2008 – 26 p.*
9. *Guidelines for designers to Eurocode 7. Geotechnical designing / R.Franck, K. Bauduin, R. Driscoll and others; under the scientific. ed. of A.Z. Ter-Martinosyan. – Moscow: MSCEU, 2013. – 360 p.*
10. *Eurocode 7: Geotechnical Design. Worked examples. Support to the implementation, harmonization and further development of the Eurocodes / Andrew J. Bond, Bernd Schuppener, Giuseppe Scarpelli, Trevor L.L. Orr, – Dublin, 13-14 June, 2013.-172p.*
11. *Bond A. Decoding Eurocode 7 / A. Bond, A. Harris, – London and New York. Taylor&Francis Group, 2008 – 621 p.*
12. *Robertson P. K. Guide to Cone Penetration Testing for Geotechnical Engineering. 6th Edition / P. K. Robertson. K.L. Cabal, – California. Gregg Drilling & Testing, Inc, 2015 – 143 p.*
13. *Tomlinson M. Pile Design and Construction Practice. Sixth Edition / M. Tomlinson, J. Woodward. – Boca Raton. CRC Press, 2015. – 598 p.*

Received 30.11.2016