Estimate of allowance in the standard documents according to the calculation of foundation settlement

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Abstract -According to development of the main standards in construction *TKP 45-5.01-67-2007 (02250)* and *SP 22.13330.2011*, the rules containing recommended or permitted instructions are not mandatory and intended for application on a voluntary basis.To calculate the foundation settlement, in the standard *TKP 45-5.01-67-2007 (02250)* "Slab foundations" the rules of designing used. This document has two methods for calculating the settlement - the method of the limit depth assumption and the linearly deformable layer method (*LDS*). In these methods, there are many rules that are not mandatory for use. The article analyses these assumptions and their effect on the results of calculations.

Key words: foundation, settlement, TKP 45-5.01-67-2007 (02250), SP 22.13330.2011, the linearly deformable layer method (LDS), void ratio.

The method of the limit depth assumption

Limit depth assumption is the rule for the boundary of the compressible thickness H_c ($\sigma_{zp} = 0.5\ \sigma_{zg}$ instead of $\sigma_{zp} = 0.2\ \sigma_{zg}$) and to take into account the stresses from the excavation. In this method, the lateral expansion coefficient β = 0.8 is used and the settlement calculated by assumptions of the settlement in (n) layers from i = 1 to i = n by the formula:

$$S = \beta \sum (\sigma_{zp,i} - \sigma_{zy,i})\, h_i / E_i + \beta \sum \sigma_{zy,I}\, h_i \ /\ E_{o,i} \qquad (1)$$

The deformations divided into elastic deformations with a module E_0 (from the stresses from the excavation $\sigma_{zp,\ i}$) and plastic with a module E (from stresses x exceeding those formed from the excavation). The ratio of the deformation moduli E_0 and E denoted as heterogeneity coefficient $\lambda = E_o / E$.

The method of a linearly deformable layer

In the *LDS* method as a factor which provides limits at the stress zone, and this factor is the thickness of the layer *H*.

The settlement calculated from the formulas of the theory of elasticity, but they calculate the total pressure under foundation σ_{zg}, instead of the additional pressure to the natural pressure p. The stress along the depth σ_{zp} determined to take into account all the components of the stress tensor without coefficient β.

The *LDS* method could be called as a method of multilayered integration of settlements.

Determination of compressibility characteristics

The characteristics of soils compressibility determined by plate load test, pressuremeters, compression or triaxial soil tests.

It is obvious the variety of strain modulus *E* obtained by the plate load test and the deformation modulus obtained by the compression test E_k. In *SP 22* the coefficients $m_k = E / E_k$ (table 1) are given, although it has been considered the standard module E, which obtained by a plate load test with an area of 5000 cm^2.

Table 1 – Values of $m_k = E/E_k$

Soil type	Voids ratio e					
	0.45-0.55	0.65	0.75	0.85	0.95	1.05-1.5
Silt	4	3.5	3	2	-	-
Silty clay	5	4.5	4	3	2.5	2
clay	-	6	6	5.5	5	4.5

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In SP 22 there are no instructions for determining of the coefficient of diversity. It is assumed that it is determined from the ratio of the slope angles of the straight line and expansion lines of the consolidation test.

In table 63 "Manuals for the design of the foundations of buildings and structures (*SNIP 2.02.01-83*)" the reference values λ are given - from 1.5 to 4 (Table 2.).

Assumptions:

SP 22 contains rules that can be applied by willingness of the researchers:

1. Taking into account of the influence of the excavation that it is allowed to take into account at a depth $d \geq 5$ m, and at $d < 5$ m the second term of formula (1) cannot be taken into account.
2. the coefficient of different modularity allows that it is taken to $\lambda = 5$;
3. the impact of the pit dimensions, the dimensions of the excavation are not indicated, except for the note "... in the calculation of σ_{zy}, the dimensions are used in the pit plan, not the foundation";
4. the *LDS* calculation is allowed for preliminary calculations of foundations for $b \geq 10$ m, $d \leq 5$ m, p = 150-500 kPa and $E \geq 10$ MPa);
5. Also there is no complete explanation of how to take the initial (settlement) contact pressure along the base of the foundation *p*. From *SP 22* it is not completely clear whether the definition from paragraph 5.5.62 of *SP 22* is the same. "Vertical stresses from external load $\sigma_{zp} = \sigma_z - \sigma_{zu}$ (σ_{zu} - stresses after excavation) depend on the size, shape and depth of foundation, soil on its sole and the properties of the foundation soils ... " must be used the formula for determining the settlement pressure $\sigma_{zp,\,0} = p - \sigma_{zg,\,0}$ or the formula $\sigma_{zp,\,0} = p$.

Table 2 – The ratio of modules E_e и E

Soils type	Liquidity index I_L	Values of $\lambda = E_e / E$ at e			
		$e \leq 0.5$	$0.5 \leq e \leq 0.8$	$0.8 \leq e \leq 1.1$	$e \geq 0.5$
Silt	$0 \leq I_L \leq 1$	1.5	2	2.5	3
Silty clay	$I_L \leq 0.25$	1.5	2	2.5	3
	$0.25 \leq I_L \leq 0.75$	1.5	2	2.5	3
	$0.75 \leq I_L \leq 1$	2	2.5	3	3.5
Clay	$I_L \leq 0.25$	2	2.5	2.5	3
	$0.25 \leq I_L \leq 0.75$	2	2.5	3	3.5
	$0.75 \leq I_L \leq 1$	2.5	3	3.5	4

Results Of Calculations

Calculations of the settlement of the foundations were made by the methods of *PS* and *LDS* for square and strip foundations with the size of sides from 1 to 20 m, with taking into account the above assumptions.

The results of calculating the square foundations are shown in Table 3 and in Figure 1.

When performing the calculations, the following conditions were met:

The pit depth is d = 2 m, d = 5 m;

Pressure on the base of foundation p = 300 kPa;

Specific gravity of the soil $\gamma = 18$ kN / m^3;

The deformation modulus E = 10 MPa,

Coefficient $\beta = 0.8$;

The condition on the boundary is H_c ($\sigma_{zp} = 0.5\,\sigma_{zg}$ and $\sigma_{zp} = 0.2\,\sigma_{zg}$).

The coefficients of heterogeneity $\lambda = 2$ and $\lambda = 5$;

Soil – silty clay;

The center of the excavation and foundation are the same;

The size of excavation for earthworks is 0.6 m more than the distance from the edge of the excavation to the face of the foundation;

To assess the effect of factors on the settlements of a square foundation, calculations are made for SP 22 at full pressure p without taking into account the assumptions and are highlighted in gray in lines 4 of Table 3 and in red in Figure 1.

For comparison, in lines 1-3 of Table 3, make calculations for *SNiP 2.02.01-83* and *TKP 45-5.01-67-2007 (02250)* are also shown for the additional pressure $\sigma_{zp,0} = p - \sigma_{zg,0}$ (in the examples $\sigma_{zp,0} = 264$ kPa for the depth d = 2 m and $\sigma_{zp,0} = 210$ kPa for a depth of d = 5 m).

In all the examples, the influence of the condition on the boundary H_c-$\sigma_{zp} = 0.5\,\sigma_{zg}$ and $\sigma_{zp} = 0.2\,\sigma_{zg}$ is estimated.

The results of calculations of the excavation effect are shown in lines 5 and 6 of Table 3 for $\lambda = 2$ and $\lambda = 5$. The results of *LDS* calculations are shown in lines 7 and 8.

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The degree of influence of various factors on the settlements of a square foundation is shown in columns "S%" in Table 3 for each base calculation result of depth d and width b, in which the result of calculating each base variant is taken as 100%.

Table 3 – The influence of factors on the settlement of a square foundation

Depth of excavation d = 2 m										
Size of foundation b, m >	1.0		3.0		5.0		10.0		20.0	
Calculation results >	S cm	S %	S cm	S %	S cm	S %	S Cm	S %	S cm	S %
1 –TKP 45-5.01-67 (or SNiP 2.02.01-83), p = 264 кПа, $\sigma_{zp} = 0.2\ \sigma_{zg}$	2.0	91	5.8	97	9.4	98	17.7	97	32.0	95
2 – Also, $\sigma_{zp} = 0.5\ \sigma_{zg}$	1.9	86	5.3	88	8.5	89	16.0	88	26.3	70
3 – SP 22, p = 300 кПа, $\sigma_{zp} = 0.2\ \sigma_{zg}$	2.3	105	6.6	110	10.7	111	20.1	110	38.6	115
4 – SP 22, p = 300 кПа, $\sigma_{zp} = 0.5\ \sigma_{zg}$	2.2	100	6.0	100	9.6	100	18.2	100	33.6	100
5 – Also, taking into account the excavation, λ = 2	1.9	86	5.5	92	8.9	93	17.0	93	31.5	94
6 – Also, λ = 5	1.7	77	5.2	87	8.5	89	16.2	89	30.2	90
7 – SNiP 2.02.01-83*, LDS, p = 336 кПа	-	-	-	-	-	-	14.0	77	17.1	51
8 – SP 22, the LDS method, p = 300 кПа	-	-	-	-	-	-	12.5	69	15.3	46
Depth of excavation d = 5 m										
Size of foundation b, m >	1.0		3.0		5.0		10.0		20.0	
Calculation results >	S cm	S %	S cm	S %	S cm	S %	S Cm	S %	S cm	S %
1 –TKP 45-5.01-67 (or SNiP 2.02.01-83), p = 264 кПа, $\sigma_{zp} = 0.2\ \sigma_{zg}$	1.5	75	4.4	76	7.0	77	13.5	80	23.5	79
2 – Also, $\sigma_{zp} = 0.5\ \sigma_{zg}$	1.4	70	3.8	66	5.9	65	11.7	70	20.9	70
3 – SP 22, p = 300 кПа, $\sigma_{zp} = 0.2\ \sigma_{zg}$	2.2	110	6.0	103	9.6	105	18.2	108	33.6	113
4 – SP 22, p = 300 кПа, $\sigma_{zp} = 0.5\ \sigma_{zg}$	2.0	100	5.8	100	9.1	100	16.8	100	29.8	100
5 – Also, taking into account the excavation, λ = 2	1.3	65	4.9	84	7.4	81	14.0	83	25.1	84
6 – Also, λ = 5	1.0	50	3.9	67	6.4	70	12.3	73	22.2	74
7 – SNiP 2.02.01-83*, LDS, p = 336 кПа	-	-	-	-	-	-	16.7	99	19.8	66
8 – SP 22, the LDS method, p = 300 кПа	-	-	-	-	-	-	12.8	76	15.2	51

Analysis the Results of Calculation

At the time of estimating the results of calculations, the requirements of *GOST 20522* standard were taken into account. For these requirements, the allowable coefficient of variation for the strain modulus V ≤ 030, and the average accuracy index $\rho_{\alpha = 0.85} = 0.1 – 0.15$.

Thus, an error of 10-15% can be a criterion for assessing the appropriateness of taking into account the influence of a factor on the foundation settlement under the deformation module E = 10 MPa and the assumed contact pressure of foundation p = 300 kPa.

1. Influence of the condition on the boundary of H_c and the settlement pressure $\sigma_{zp,\,0} = p$.

The condition on the boundary of H_c, $\sigma_{zp} = 0.5\ \sigma_{zg}$ instead of $\sigma_{zp} = 0.2\ \sigma_{zg}$ leads to a decrease in the settlement from 5-10 to 13-15%. This is shown in lines 1-2 and 3-4 of Table 3.

The increased settlement pressure ($\sigma_{zp,0} = p$ against $\sigma_{zp,0} = p - \sigma_{zg,0}$) leads to a proportional increase in the settlement - from 15 to 20%. This is shown in rows 1-4 of Table 3.

Conclusion:

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the two discussed factors (conditions on the boundary of H_c and settlement pressure $\sigma_{zp,0} = \rho$) affect the settlement in approximately equal proportions, but in different directions.

2. Effect of the excavation and the coefficient of heterogeneity.

At depth d = 2 m, the influence of the excavation: for λ = 2, the effect is 5-15%, for λ = 5 the effect is 10-23%;

At a depth of d = 5 m, the influence of the excavation is: for λ = 2, the influence is 15-35%, for λ = 5 the effect is 25-50%.

Conclusion:

Comparison of rows 4 and 5 of Table 3 showed that the influence of the excavation with minimum dimensions should be considered significant:

- at d = 2 m and λ = 5 for foundations with width b < 3 m;
- at d = 5 m and λ ≥ 2 for foundations with width b ≥ 1 m.

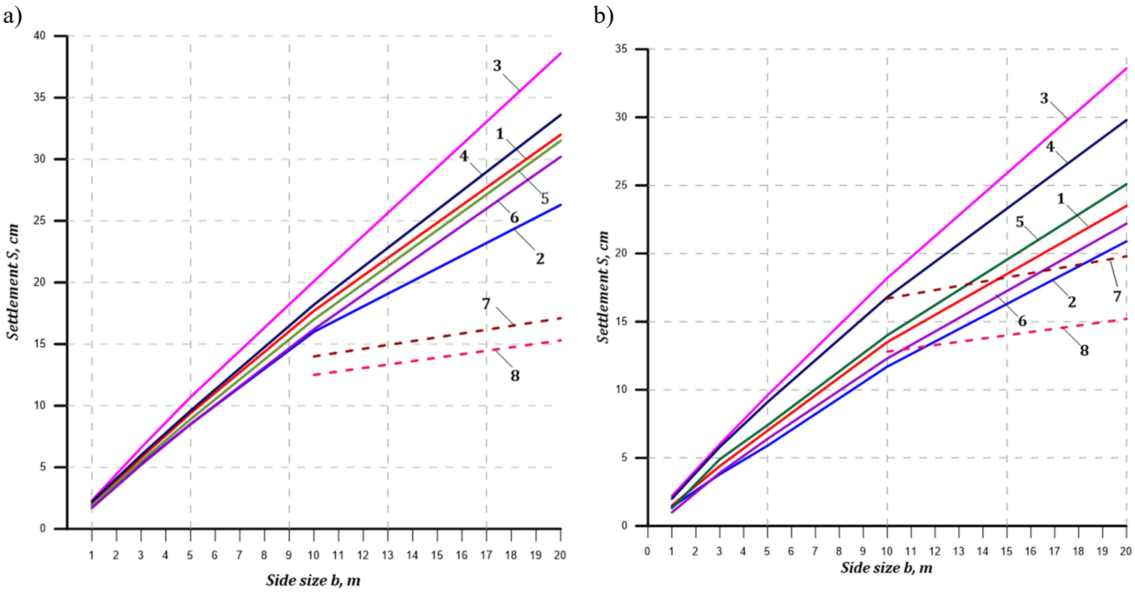

Fig.1 Influence of methods for calculating the settlement of a square foundation at the depth of d = 2 m (a); b = 5 m (b); Line numbers 1-8 are shown in Table 3.

3. Influence of the pit size.

If increase the size of the pit on both sides of the excavation for two cells in table 3, which are highlighted in gray ("d = 2 m; b = 5 m" and "d = 5 m; b = 3 m"), for example, at b_k = 2 m, the settlement of the excavation will decrease:

for the cell with "d = 2 m; b = 5 m "- by 7%, with S = 8.5 to 7.9 cm;

for the cell with "d = 5 m; b = 3 m "- by 33%, with S = 3.9 to 2.6 cm.

The size of the excavation, in which the settlement of the foundation becomes zero:

for the cell "d = 2 m; b = 5 m "- with b_k = 50 m;

for the cell "d = 5 m; b = 3 m " with b_k = 12 m.

If the size of the excavation continues to increase, it is possible to obtain negative values of the foundation settlement.

Conclusion:

The impact of an excavation with large size on the foundation's settlements is very important, especially for foundations with no very large dimensions.

4. Influence of the position of the calculated point.

Table 4 shows the results of calculations for two positions of the calculated points:

"Center" - in the center of the foundation and "(center+edge)/2" – at the half of the distance between the center and the edge. Vertical stresses σ_z are calculated by the method of uniformly loaded rectangular area.

On the basis of the analysis, it is obvious that the settlement at the point "(center + angle)/ 2" decreases with the size of the square: at d = 2 m - up to 57%, and at d = 5 m - up to 68%. The influence of the calculated point H_c is up to 47%.

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The effect of the position of the calculated point's settlement of the foundation is significant.

Table 4 – The influence of the position of the calculated point

Square foundation, d = 2m, $\sigma_{zp} = 0.5\ \sigma_{zg}$								
Point position	b = 1 m		b = 3 m		b = 5 m		b = 10 m	
	S, cm	H_c, m	S, cm	H_c, m	S, cm	H_c, m	S, cm	H_c, m
Centre	2.2	2.1	6.0	4.5	9.6	6.5	18	11
(centre+ edge)/2	0.95	1.2	2.6	2.4	4.4	5.0	7.9	6.0
ΔS и ΔH_c, %	57	43	56	46	54	23	56	45
Square foundation, d = 5m, $\sigma_{zp} = 0,5\ \sigma_{zg}$								
Centre	2.0	1.5	5.8	3.9	9.1	5.5	17	9.0
(centre+ edge)/2	0.87	0.8	2.5	2.1	3.9	3.0	7.2	5.0
ΔS и ΔH_c, %	65	47	57	46	68	45	58	44

5. Calculations by the *LDS* method.

The results of the calculation using the *LDS* method are shown in the rows and curves 7 and 8 in table 3 and in figure 1. The interval of the basement size b was from 10 to 20 m. The results showed that with the increase in the side of the square, the settlement of the foundation grow less intensively, than in any of the variants of the PS method.

In addition, the following distinctions were made:

1) Differences in the results of calculations using *LDS* and *PS* methods:

- at d = 2 m, the difference between curves 4 and 7 in figure 1 reaches 23-50%;
- at d = 5 m and b = 10 m, the difference decreases to approximately 0, but at b = 20 m, the difference between curves 4 and 7 reaches 50%;

2) In the calculations for *SNiP 2.02.01-83* and *TKP 45-5.01-67*, the *LDS* method (taking into account the total stresses $p = \sigma_{zp,0} + \sigma_{zg,0}$) leads to an increase in the depth of the foundation. The obtained results do not correspond to calculations based on the PS method and general rules on the influence of ground weight on the results of calculations.

Conclusion:

Calculations showed that the results obtained by the *LDS* method and the results obtained by the *PS* method have a great difference. Thus, it is reasonable to exclude the *LDS* method from *SP 22* standard or change its coefficients so that the results of calculations are consistent with the *PS* method, the general rules of influence of the size, depth of foundation and other factors.

Conclusions

The performed analysis shows that many of the rules from *SP 22* should be supplemented with the following results:

1) the second part of formula (1) or the second term of formula (1) should be taken into account:
- for foundations with width size b < 3 m at depth d ≥ 3 m and coefficient λ = 5;
- for foundations with width size b ≥ 1 m at depth d = 5 m and coefficient λ ≥ 2.

2) the dimensions of the excavation and the place of the foundation in it must be determined exactly;

3) the rules of the calculated point need to be supplemented with tables with coefficients α at this point;

4) the *LDS* method needs to be supplemented or changed.

It should be noted that the finding results can also change under the following conditions:
- at the modifying of the module *E*, but with preserving the proportions indicated in table 3;
- at the changing of the pressure *p*, their correction can be made by changing the boundary of the compressibility thickness H_c.

References

[1] TKP 45-5.01-67-2007 (02250) Slab foundations, rules of designing; Ministry of Architecture and Construction of the Republic of Belarus, 2008.

[2] SNiP 10-01-2003, system of standard documents in construction basic principles; State Committee of the Russian Federation for Construction and Housing and Communal Services (State Building of Russia).

[3] SP 22.13330.2011, Soil bases of buildings and structures; Ministry of Regional Development of the Russian Federation (2011).

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