

CALCULATION OF SETTLEMENT BY THE METHOD OF LAYER SUMMATION

The layer-by-layer summation method is based on the following assumptions:

the soil is a solid, isotropic, linearly deformable body;

settlement is caused only by the effect of vertical stress σ_z , other stress components are not taken into account;

lateral expansion of the soil at the base is impossible;

the stress σ_z is determined under the center of the foundation sole;

when determining the stress σ_z , the difference in compression of individual soil layers is neglected;

foundations do not have rigidity;

deformations are considered only within the compressible layer, H_c ;

the lateral expansion of the soil is taken into account by the coefficient β , which is equal to 0.8 regardless of the type of soil.

Due to the complexity of determining the law of stress reduction with depth, the soil stratum is divided into a number of layers, within which the pressure can be considered constant without a large error. Then the total settlement can be determined using the expression for the elementary layer, summing up the settlement of individual layers within the compressible stratum.

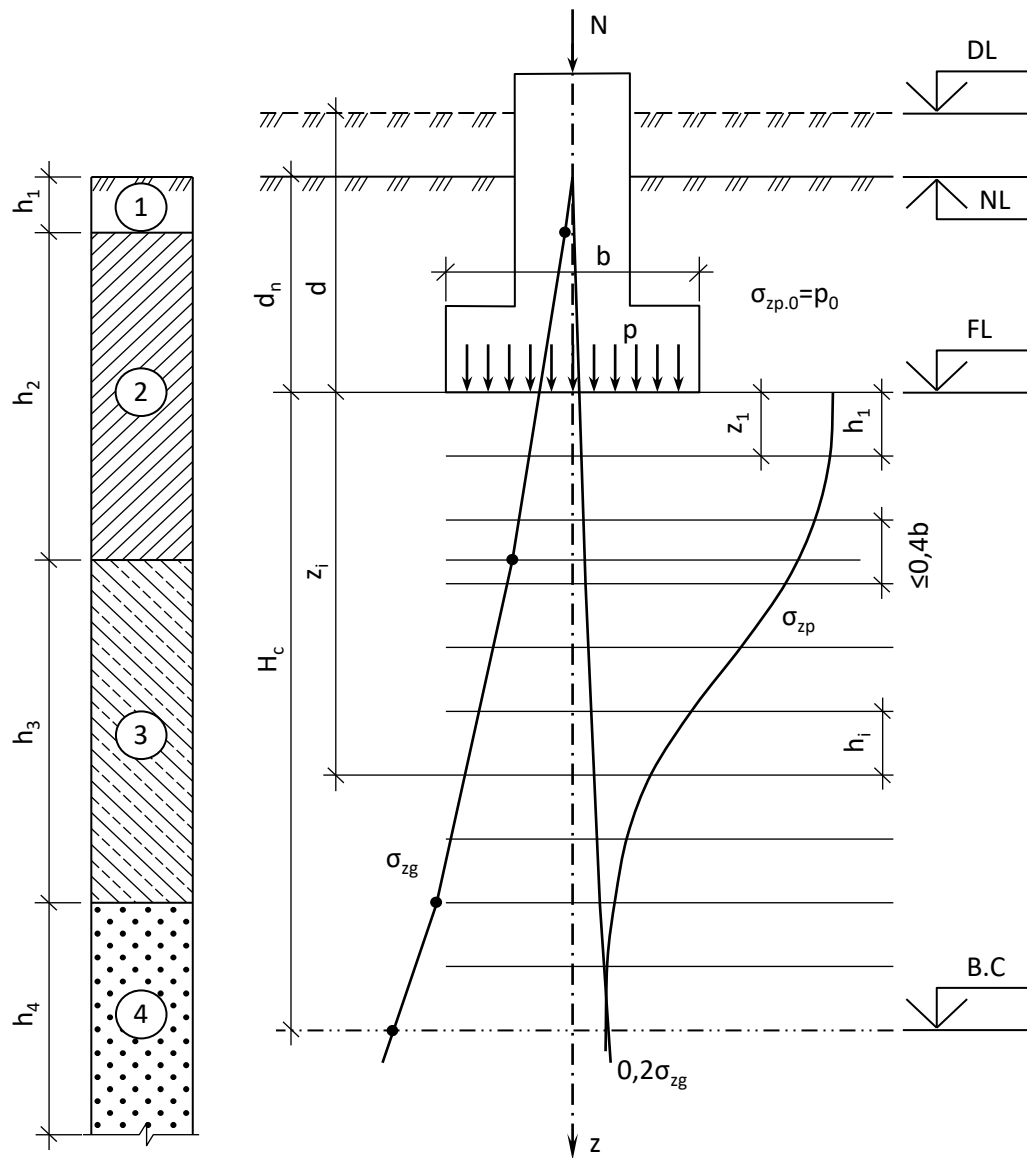


Fig. 2 Scheme for the determination of settlement by the method of layer-by-layer summation

Conventional designations are as follows:
DL – planning mark;
NL – mark of the surface of the natural relief;
FL – foundation sole mark;
B.C. - the lower limit of the compressible thickness;
 d and d_n - the depth of laying the foundation sole from the level of the natural relief and the planning level;
 p – average pressure under the sole of the foundation;
 N is the net effect of external vertical forces on the edge of the foundation.

The calculation is performed in the following order:

1. The contour of the foundation is applied to the geological section.
2. Plot the stress σ_{zg} from the self-weight of the soil.
3. Determine the pressure p acting on the sole of the foundation
4. The layer below the base of the foundation is divided into elementary layers with a thickness of $h=0.4b$ (to facilitate interpolation). Within each type of soil, a whole number of elementary layers must be allocated, so the last elementary layer can be less than $0.4b$.

5. Determine the stress damping coefficients along the depth $\alpha = f\left(\frac{2z}{b}, \frac{\ell}{b}\right)$

depending on the depth z and the ratio ℓ/b , where ℓ is the longer side of the foundation.

6. Build a plot of additional vertical stresses $\sigma_{zp} = \alpha \cdot p$

7. The lower limit of the compressible layer of the base is taken at the depth $z = H_c$, where the condition $\sigma_{zp} = k\sigma_{zg}$ is fulfilled, where $k = 0.2$,

$$\sigma_{zg} = \sum_{i=1}^n \gamma_i \cdot h_i$$

8. We build a graph of vertical stresses from the self-weight of the soil removed in the pit to the level of the foundation sole, at a depth of z :

$$\sigma_{z\gamma} = \alpha_k \cdot \sigma'_{zg,0}$$

$\sigma'_{zg,0}$ is the vertical stress from the self-weight of the soil removed from the pit at the level of the base of the foundation and is equal to

$$\sigma'_{zg,0} = \gamma_{rp} \cdot d_n$$

9. We define the total settlement as the sum of the settlements of individual elementary layers according to the formula, m :

$$s = \beta \sum_{i=1}^n \frac{(\sigma_{zp,i} - \sigma_{z\gamma,i}) \cdot h_i}{E_i} + \beta \sum_{i=1}^n \frac{\sigma_{z\gamma,i} \cdot h_i}{E_{e,i}}$$

where β is a dimensionless coefficient equal to 0.8;

E_i – deformation modulus of the i -th soil layer along the branch of primary loading, kPa;

$E_{e,i}$ is the modulus of deformation of the i -th soil layer along the branch of secondary loading (modulus of elasticity), in the absence of data, it is possible to take $E_{e,i} = 5E_i$, kPa

When calculating the settlement of foundations erected in pits with a depth of less than 5 m, the second appendix in the settlement formula is not taken into account

Table - Coefficient α

ζ	Coefficient α for foundations							
	round	rectangular with the ratio of sides $\eta = l/b$,						strip ($\eta \geq 10$)
		1,0	1,4	1,8	2,4	3,2	5	
0	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
0,4	0,949	0,960	0,972	0,975	0,976	0,977	0,977	0,977
0,8	0,756	0,800	0,848	0,866	0,876	0,879	0,881	0,881
1,2	0,547	0,606	0,682	0,717	0,739	0,749	0,754	0,755
1,6	0,390	0,449	0,532	0,578	0,612	0,629	0,639	0,642
2,0	0,285	0,336	0,414	0,463	0,505	0,530	0,545	0,550
2,4	0,214	0,257	0,325	0,374	0,419	0,449	0,470	0,477
2,8	0,165	0,201	0,260	0,304	0,349	0,383	0,410	0,420
3,2	0,130	0,160	0,210	0,251	0,294	0,329	0,360	0,374
3,6	0,106	0,131	0,173	0,209	0,250	0,285	0,319	0,337
4,0	0,087	0,108	0,145	0,176	0,214	0,248	0,285	0,306
4,4	0,073	0,091	0,123	0,150	0,185	0,218	0,255	0,280
4,8	0,062	0,077	0,105	0,130	0,161	0,192	0,230	0,258
5,2	0,053	0,067	0,091	0,113	0,141	0,170	0,208	0,239
5,6	0,046	0,058	0,079	0,099	0,124	0,152	0,189	0,223
6,0	0,040	0,051	0,070	0,087	0,110	0,136	0,173	0,208
6,4	0,036	0,045	0,062	0,077	0,099	0,122	0,158	0,196
6,8	0,031	0,040	0,055	0,064	0,088	0,110	0,145	0,185
7,2	0,028	0,036	0,049	0,062	0,080	0,100	0,133	0,175
7,6	0,024	0,032	0,044	0,056	0,072	0,091	0,123	0,166
8,0	0,022	0,029	0,040	0,051	0,066	0,084	0,113	0,158
8,4	0,021	0,026	0,037	0,046	0,060	0,077	0,105	0,150
8,8	0,019	0,024	0,033	0,042	0,055	0,071	0,098	0,143
9,2	0,017	0,022	0,031	0,039	0,051	0,065	0,091	0,137
9,6	0,016	0,020	0,028	0,036	0,047	0,060	0,085	0,132
10,0	0,015	0,019	0,026	0,033	0,043	0,056	0,079	0,126
10,4	0,014	0,017	0,024	0,031	0,040	0,052	0,074	0,122
10,8	0,013	0,016	0,022	0,029	0,037	0,049	0,069	0,117
11,2	0,012	0,015	0,021	0,027	0,035	0,045	0,065	0,113
11,6	0,011	0,014	0,020	0,025	0,033	0,042	0,061	0,109
12,0	0,010	0,013	0,018	0,023	0,031	0,040	0,058	0,106

Example

Geological structure and hydrogeological conditions of the construction site

№ layer	Soil	Well number and the depth of the sole of each soil layer from the surface of the earth, m				
		1	2	3	4	5
1.	plant layer	0,3	0,3	0,3	0,3	
2.	Subsidence soil	4,8	4,6	4,9	4,8	
3.	Sand medium-sized	3,4	3,6	3,5	3,3	
4.	sandy loam	3,5	3,6	3,7	3,6	
5.	Clay gray	8,7	8,9	8,8	8,7	
	The depth of underground water	8,2	8,0	8,3	8,1	
	Well mark, m					

Variant	Cross section of the column , mm	Combination			
		I		II	
		N,MN	M, MNm	N,MN	M,MNm
	600x400	2,1	0,26	1,2	0,41

Characteristics of soil properties

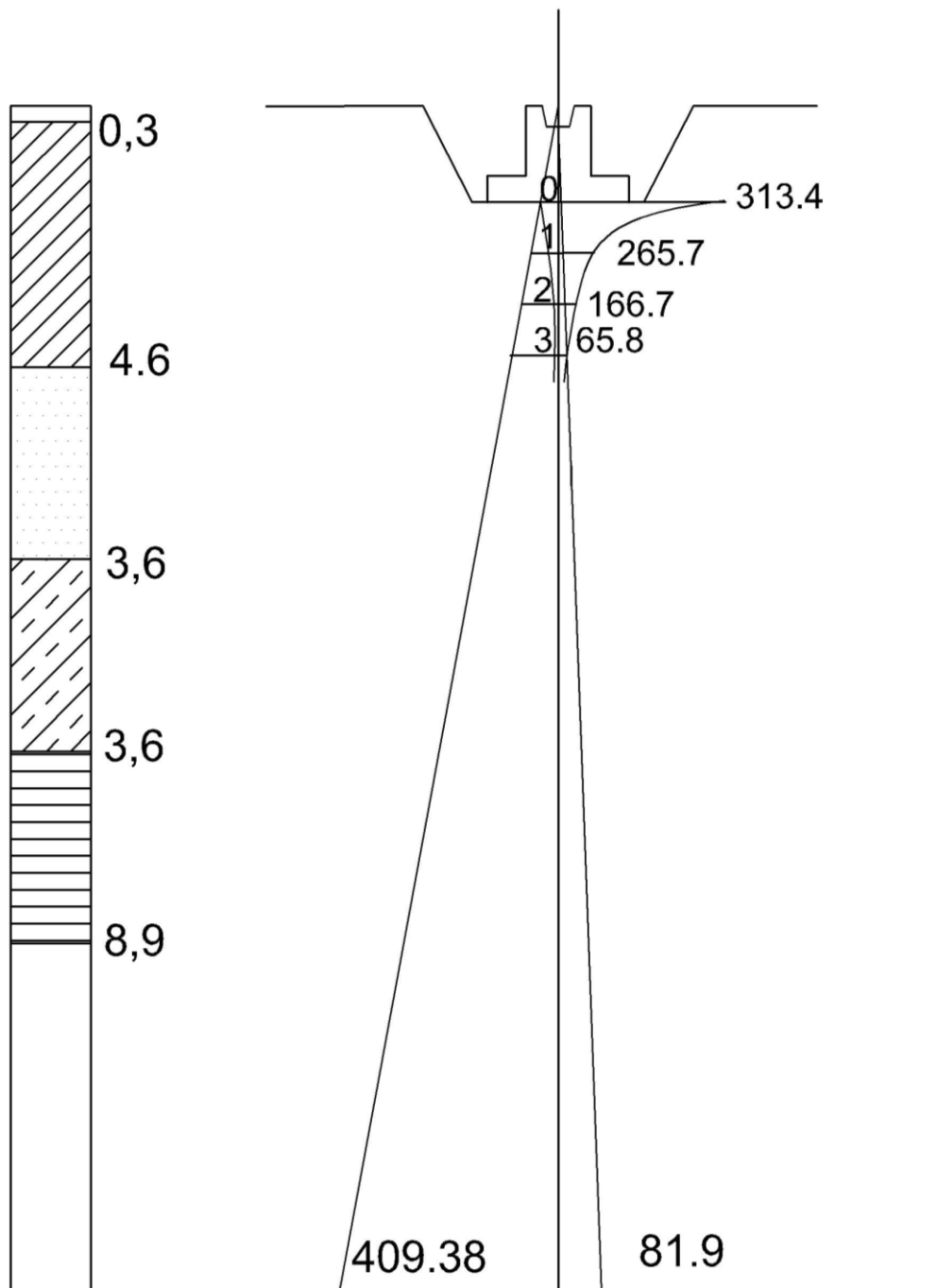
Name	Legend	Units of measurement	Layer number				
			1	2	3	4	5
Density	ρ_{II}	t/m ³	1,39	1,72	2,01	1,98	2,06
Solid Particle density	ρ_s	t/m ³		2,73	2,68	2,69	2,70
Water content	W			0,15	0,24	0,26	0,22
Liquid limit	W _L			0,35		0,28	0,40
Plastic limit	W _p			0,19		0,22	0,20
Angle of internal friction	φ_{II}	degree		21	33	20	15
Specific cohesion	C _{II}	kPa		25	1	12	80
Modulus of Deformation	E	MPa		20	30	15	50
Relative subsidence under pressure p, MПа	ϵ_{SL}	p=0,1		0,04			
		p=0,2		0,073			
		p=0,3		0,082			
Angle of internal friction water-saturated soil	$\varphi_{II,sat}$	degree		19			
Specific cohesion water-saturated soil	C _{II,sat}	kPa		5			
Modulus of Deformation water-saturated soil	E _{sat}	MPa		6			

Soil classification indicators

№ Layer	e	S_r	I_p	I_l	Soil properties
1					plant layer
2	0.825		0.16	-1.25	Subsidence soil loam solid
3	0.653	0.389			Sand medium-sized low moisture Medium density
4			0.06	0.667	sandy loam nplastic
5			0.2	0.1	Clay semi-solid

$$\rho_{sat} = \frac{\rho}{1+W} \cdot \left(1 + \frac{S_{r,sat} \cdot e \cdot \rho_w}{\rho_s} \right) = \frac{1,72}{1+0,15} \left(1 + \frac{0,9 \cdot 0,825 \cdot 1}{2,73} \right) = 1,93 \text{ t/m}^3$$

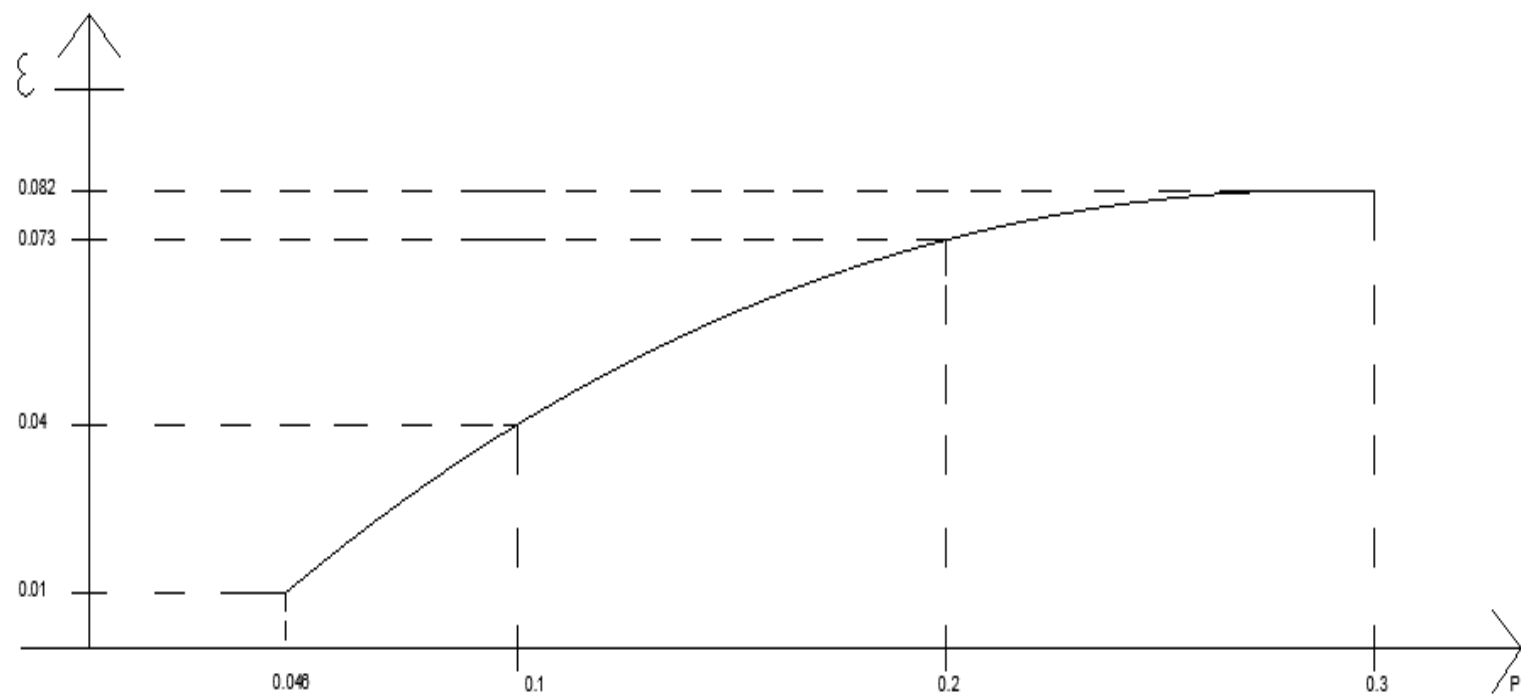
Psl=46 kPa



$$b=2,4 \text{ m}, l=3,4 \text{ m}, d=1,8 \text{ m}$$

$$\rho_{sat} = \frac{\rho}{1+W} \cdot \left(1 + \frac{S_{r,sat} \cdot e \cdot \rho_w}{\rho_s} \right) = 1.93 \text{ t/m}^3$$

$$P_{cp} = \frac{2100}{2.4 \cdot 3.4} + 20 \cdot 1.8 + 20 = 313.4 \text{ kPa} < 330.4 \text{ kPa}$$



$P_{sl}=0.046 \text{ MPa}=46 \text{ kPa}$

2. Determine the stress from the soil's own weight

$$\sigma_{zg,1} = \gamma_1 \cdot h_1 = 1.39 \cdot 10 \cdot 0.3 = 4 \text{ kN/m}^2$$

$$\sigma_{zg,2} = \gamma_1 \cdot h_1 + \gamma_2 \cdot h_2 = 0.4 + 1.72 \cdot 10 \cdot 4.6 = 83.12 \text{ kN/m}^2$$

$$\sigma_{zg,3} = \sigma_{zg,2} + \gamma_3 \cdot h_3 = 83.12 + 2.01 \cdot 10 \cdot 3.6 = 155.48 \text{ kN/m}^2$$

$$\sigma_{zg,4} = \sigma_{zg,3} + \gamma_4 \cdot h_4 = 155.48 + 1.96 \cdot 10 \cdot 3.6 = 226.04 \text{ kN/m}^2$$

$$\sigma_{zg,5} = \sigma_{zg,4} + \gamma_5 \cdot h_5 = 226.04 + 2.06 \cdot 10 \cdot 8.9 = 409.38 \text{ kN/m}^2$$

We determine the stress from the soil's own weight at the level of the foundation sole

$$\sigma_{zg,0} = \sigma_{zg,1} + \gamma_2 \cdot h_d = 4 + 1.72 \cdot 10 \cdot 1.5 = 29.8 \text{ kN/m}^2$$

3. The soil layer under the foundation is divided into elementary layers with a thickness of h , but no more than 1 m:

$$h \leq 0.4b$$

$$h = 0.4 \cdot 2.4 = 0.96 \text{ m}$$

Table - Settlement calculation

№ layer	№	soil	h, m	z, m	$\zeta = \frac{2 \cdot z}{b}$	α	кПа $\sigma_{zp} = \alpha \cdot p$	$\sigma_{zp, cp}$	$\zeta_k = \frac{2 \cdot z}{B_k}$	α_k	кПа $\sigma_{z\gamma} = \alpha_k \cdot \sigma'_{zg, 0}$	$\sigma_{z\gamma, cp}$	E _i , кПа	$0,8 \cdot \frac{(\sigma_{zp, i, cp} - \sigma_{z\gamma, i}) \cdot h_i}{E_i}$	S _i , M
	0		0	0	0	1	313,4		0	1	29,8				
	1		0,96	0,96	0,8	0,848	265,76	289,58	0,564	0,848	25,27	27,54	20000	0,01006	
	2		0,96	1,92	1,6	0,532	166,73	216,25	1,129	0,532	15,85	20,56	20000	0,00751	
	3		0,96	2,88	2,4	0,325	101,86	134,29	1,6941	0,325	9,69	12,77	20000	0,00467	
	4		0,96	3,84	3,2	0,21	65,81	83,83	2,258	0,21	6,26	7,97	20000	0,00291	

$S=2,84 \text{ cm} < 10 \text{ cm}$