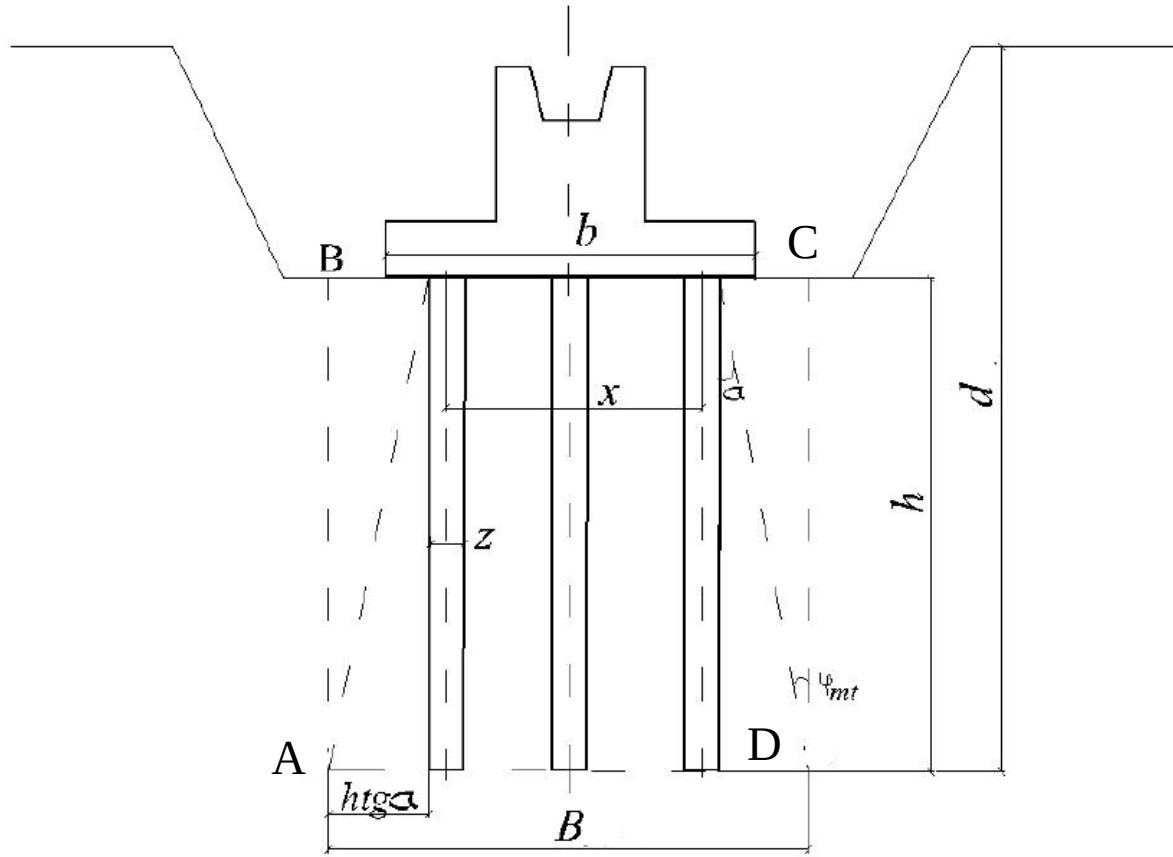


CALCULATION OF PILE FOUNDATIONS BY THE SECOND GROUP OF LIMIT STATES BY DEFORMATIONS



This calculation is performed as for a *conditional foundation* on a natural basis.

1. We determine the contours of the conditional foundation (Fig.1). The limits of the conditional foundation are as follows:

- from below - bounded by the AD plane;
- on the sides - limited by vertical planes AB and CD, distant from the outer faces of the outermost rows of vertical piles at a distance of $htg\alpha$, but not more than $2d$ in cases where dusty clayey soils with a liquidity index $I_L > 0.6$ lie under the lower ends of the piles;
- from above - limited by the planning surface of the BC.

1. Determine the average value of the angle of internal friction of soils cut through by piles:

$$\varphi_{II,mt} = \frac{\sum_{i=1}^n \varphi_{II,i} \cdot h_i}{\sum h_i}$$

where h_i is the thickness of the i-th layer in contact with the lateral surface of the pile.

2. Determine the average value of the angle of internal soil friction, degrees:

$$\alpha = \frac{\varphi_{II,mt}}{4}$$

3. We determine the width of the conditional foundation:

$$B_{cf} = x + z + 2 \cdot h \cdot \operatorname{tg} \alpha$$

where x is the distance between the outermost piles, m;

z – pile width, m.

4. Determine the length of the conditional foundation:

$$L_{cf} = y + z + 2 \cdot h \cdot \operatorname{tg} \alpha$$

where y is the distance between the outermost piles, m.

5. We determine the normative weight of the piles:

$$G_p^n = n(L_p \cdot G_{p,1} + G_t)$$

where n is the number of piles;

L_p – pile length;

$G_{p,1}$ – weight of 1 m pile, kN;

G_t – weight of the pile tip, kN.

6. We determine the normative weight of the soil in the amount of ABCD, kN

$$G_{s.cf}^n = B_{cf} \cdot L_{cf} \cdot \sum \gamma_i \cdot h_i$$

7. We determine the average pressure under the sole of the conditional foundation, kPa:

$$P'' = \frac{N^n + G_{pc}^n \cdot 1.1 + G_p^n + G_g^n}{B_{cf} \cdot L_{cf}}$$

where N^n is the normative vertical load on the pile, kN;

G_{pc}^n – normative weight of the pile cap, kN;

G_p^n – normative weight of piles, kN;

G_g^n – normative weight of soil in the amount of ABCD, kN.

Table 1– Coefficients of working conditions γ_{c2} , γ_{c2}

soils	Coefficient γ_{c1}	Coefficient for structures with a rigid structural scheme when the ratio of the length of the structure or its section to the height L/H is equal to	
		4 and more	1,5 and less
Large-clastic with sandy aggregate and sand, except small and dusty	1,4	1,2	1,4
The sands are fine	1,3	1,1	1,3
Dusty sands:			
- low moisture and wet,	1,25	1,0	1,2
- saturated with water	1,1	1,0	1,2
Clay, as well as large-fragmented with clay aggregate with a Liquidity index of the soil or aggregate $I_L \leq 0,25$	1,25	1,0	1,1
The same with $0,25 < I_L \leq 0,5$	1,2	1,0	1,1
The same with $I_L > 0,5$	1,0	1,0	1,0

Notes:

1 Buildings with a rigid structural scheme include buildings whose structures are specially adapted to absorb forces from deformation of the foundations, including due to the measures specified in Appendix K [1].

2 For buildings with a flexible structural scheme, the value of the coefficient γ_{c2} is assumed to be equal to one.

3 At intermediate L/H values, the γ_{c2} coefficient is determined by interpolation.

4 For loose sands γ_{c1} and γ_{c2} taken equal to 1.

Table 2 - Coefficients M_γ , M_q , M_c

Angle of internal friction , deg. φ_{II}	Coefficients			Angle of internal friction φ_{II} , deg.	Coefficients		
	M_γ	M_q	M_c		M_γ	M_q	M_c
0	0	1,00	3,14	23	0,69	3,65	6,24
1	0,01	1,06	3,23	24	0,72	3,87	6,45
2	0,03	1,12	3,32	25	0,78	4,11	6,67
3	0,04	1,18	3,41	26	0,84	4,37	6,90
4	0,06	1,25	3,51	27	0,91	4,64	7,14
5	0,08	1,32	3,61	28	0,98	4,93	7,40
6	0,10	1,39	3,71	29	1,06	5,25	7,67
7	0,12	1,47	3,82	30	1,15	5,59	7,95
8	0,14	1,55	3,93	31	1,24	5,95	8,24
9	0,16	1,64	4,05	32	1,34	6,34	8,55
10	0,18	1,73	4,17	33	1,44	6,76	8,88
11	0,21	1,83	4,29	34	1,55	7,22	9,22
12	0,23	1,94	4,42	35	1,68	7,71	9,58
13	0,26	2,05	4,55	36	1,81	8,24	9,97
14	0,29	2,17	4,69	37	1,95	8,81	10,37
15	0,32	2,30	4,84	38	2,11	9,44	10,80
16	0,36	2,43	4,99	39	2,28	10,11	11,25
17	0,39	2,57	5,15	40	2,46	10,85	11,73
18	0,43	2,73	5,31	41	2,66	11,64	12,24
19	0,47	2,89	5,48	42	2,88	12,51	12,79
20	0,51	3,06	5,66	43	3,12	13,46	13,37
21	0,56	3,24	5,84	44	3,38	14,50	13,98
22	0,61	3,44	6,04	45	3,66	15,64	14,64

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

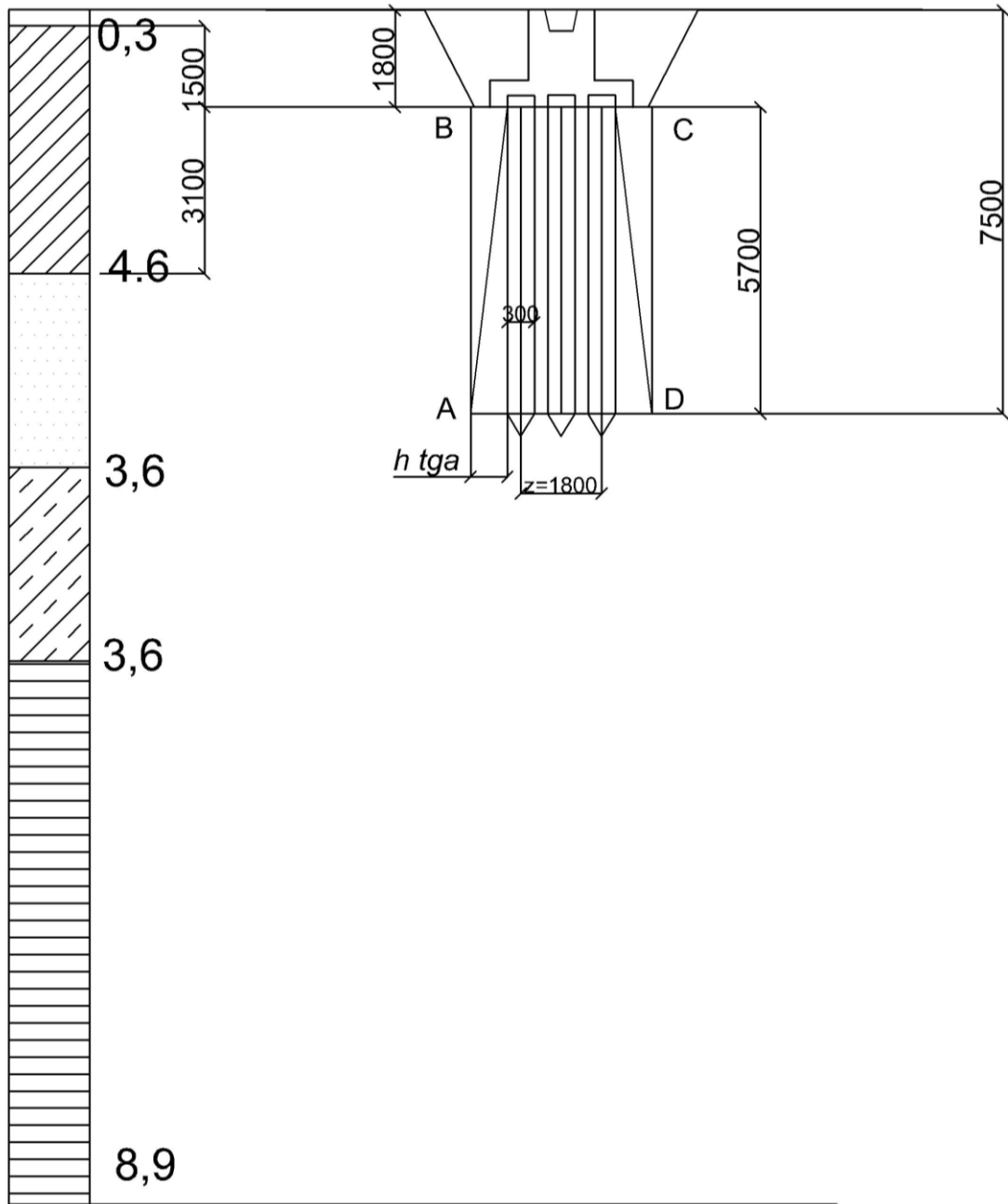
Name	Legend	Units of measurement	Layer number				
			1	2	3	4	5
Density	ρ_{II}	t/m ³	1,39	1,72	2,01	1,98	2,06
Solid Particle density	ρ_s	t/m ³		2,73	2,68	2,69	2,70
Water content	W			0,15	0,24	0,26	0,22
Liquid limit	W _L			0,35		0,28	0,40
Plastic limit	W _p			0,19		0,22	0,20
Angle of internal friction	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



1. Determine the average value of the angle of internal friction of soils cut through by piles:

$$\varphi_{II,mt} = \frac{\sum_{i=1}^n \varphi_{II,i} \cdot h_i}{\sum h_i} = \frac{21 \cdot 3,1 + 33 \cdot 2,6}{3,1 + 2,6} = 26,5^\circ$$

where h_i is the thickness of the i-th layer in contact with the lateral surface of the pile.

2. Determine the average value of the angle of internal soil friction, degrees:

$$\alpha = \frac{\varphi_{II,mt}}{4} = \frac{26,5}{4} = 6,6^\circ$$

3. We determine the width of the conditional foundation:

$$B_{y\phi} = y + z + 2 \cdot h \cdot \operatorname{tg} \alpha = 1,8 + 0,3 + 2 \cdot 5,7 \cdot \operatorname{tg} 6,6 = 3,4 \text{ m}$$

where x is the distance between the outermost piles, m;

z – pile width, m.

4. Determine the length of the conditional foundation:

$$L_{y\phi} = x + z + 2 \cdot h \cdot \operatorname{tg} \alpha = 2,7 + 0,3 + 2 \cdot 5,7 \cdot \operatorname{tg} 6,6 = 4,3 \text{ m}$$

where x is the distance between the outermost piles, m.

5. We determine the normative weight of the piles:

$$n=10 \text{ -- where } n \text{ is the number of piles; } G_p^n = n(L_{II} \cdot G_{II,1} + G_B) = 10(6 \cdot 22 + 0,5) = 1325 \text{ kH}$$

L_{II} – pile length, m

$G_{II,1} = 22 \text{ kH}$ – weight of 1 m pile, kN,

$G_B = 0,5 \text{ kH}$ – weight of the pile tip, kN

Standard weight of the pile cap

$$G_{pc}^n = 2,6 \cdot 3,5 \cdot 0,5 \cdot 25 = 113,75 \text{ kN}$$

We determine the normative weight of the soil in the amount of ABCD, kN

$$G_g^n = B_{cf} \cdot L_{cf} \cdot \sum \gamma_i \cdot h_i = 3,4 \cdot 3,4 (17,2 \cdot 3,1 + 20,1 \cdot 2,6) = 1543,6 \text{ kN}$$

The average pressure under the sole of the conditional foundation

$$P'' = \frac{N^n + G_{pc}^n \cdot 1,1 + G_p^n + G_g^n}{B_{cf} \cdot L_{cf}} = \frac{2520 + 113,75 \cdot 1,1 + 1325 + 1543,6}{3,4 \cdot 4,3} = 377,1 \text{ kPa}$$

We determine the average pressure under the sole of the conditional foundation, kPa:

$$R = \frac{\gamma_{c1} \cdot \gamma_{c2}}{k} \cdot (M_\gamma \cdot B_{y\phi} \cdot \gamma_{II} + M_q \cdot d_{y\phi} \cdot \gamma'_{II} + M_c \cdot c_{II})$$

$$\gamma_{c2} = k = k_z = 1 \quad d_b = 0 \quad \gamma_{c1} = 1,4 \quad c = 1 \text{ кПа}$$

$$\text{If } \varphi_2 = 33 \quad M_\gamma = 1,44 \quad M_q = 6,76 \quad M_c = 8,88$$

$$\gamma = \frac{20,1 \cdot 1 + 19,8 \cdot 3,6}{4,6} = 19,9 \text{ kN/m}^3 \quad \gamma' = \frac{13,9 \cdot 0,3 + 17,2 \cdot 4,6 + 20,1 \cdot 2,6}{7,5} = 18,07 \text{ kN/m}^3$$

$$R = \frac{1,4 \cdot 1}{1} [1,44 \cdot 3,4 \cdot 19,9 + 6,76 \cdot 7,5 \cdot 18,07 + 8,88 \cdot 1] = 1431,4 \text{ kPa}$$

$$377,1 \text{ kPa} < 1431,4 \text{ kPa}$$