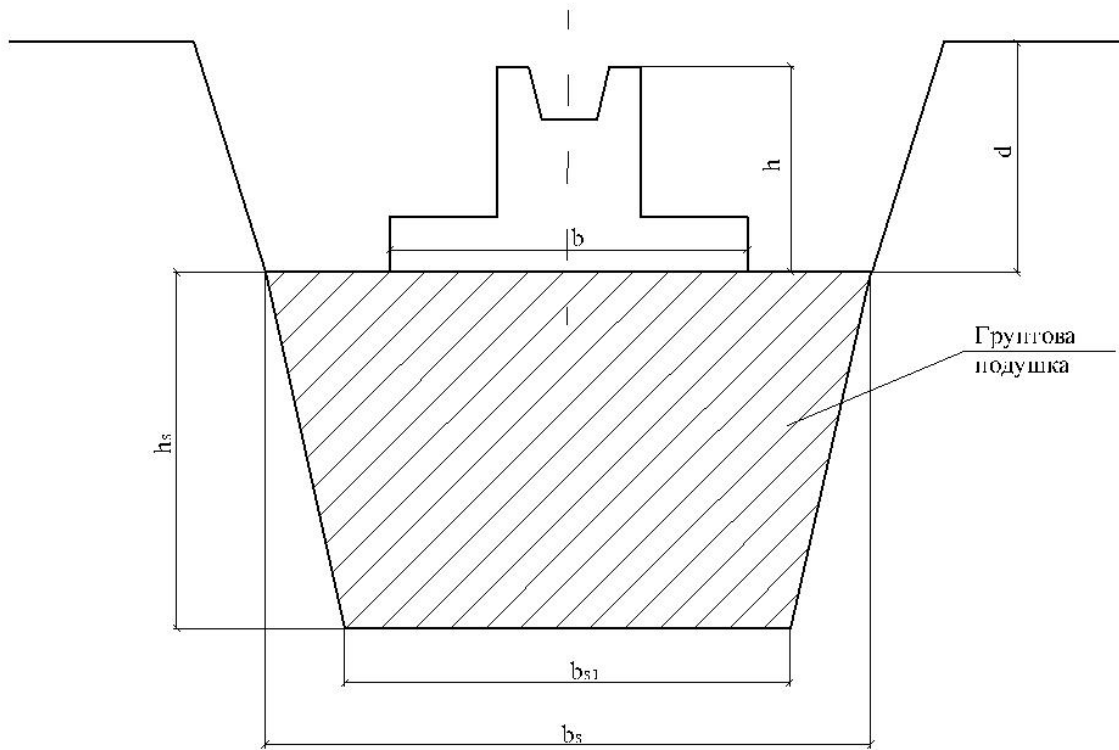


Foundation on a soil cushion



The moisture content of the soil of the cushion should be optimal w_0 during compaction $w_0 = w_p$ during rolling, the moisture content of the replacement soil can be any.

The density of the dry soil of the cushion should be $\rho_{d.s.} \geq 1,6 \text{ T/M}^3$ in liquidation of subsidence and $\rho_{d.s.} \geq 1,7 \text{ T/M}^3$ in case of creating a waterproof screen after compaction.

The soil cushion replaces the subsidence soil completely (cutting through) or only in the upper part (hanging). In the latter, the general deformation of the base, settlement and subsidence must be within permissible limits.

Soil cushions are made with a thickness of 1.5-5 m, sometimes 10-12 m and, as a rule, from local clay soil. In subsiding soils, cushions are poured in layers 0.1 - 0.35 m thick when compacted with rollers, when compacted with heavy rammers, the layers can be thicker.

Design of the foundation on the soil cushion

We find the width of the sole of the foundation by the formula at $\rho_{d.s.} = 1,65 \text{ т/м}^3$ and R_0 for compacted subsidence soil

$$b = \sqrt{\frac{N \cdot 1000}{\eta \cdot (R - \gamma_{mt} \cdot d - q)}}$$

Since $\varphi_{t.s.}$ и $c_{t.s.}$ for compacted soil have not yet been determined, then R is determined according to the formula.

$$\text{If } d \leq 2M \quad R_1 = 0.25 \cdot R_0 \cdot (d + 2) \cdot [1 + k_1(b - 1)]$$

We clarify b_1 и R_2

The difference between b_2 and b_1 , R_2 and R_1 is less than 10%, we accept b_2 and l_2 .

We perform a check of the ultimate stresses.

The thickness of the cutting cushion is taken, m:

$$h_s = H_{sl} - d$$

Dimensions of the lower part of the soil cushion, m:

$$b_s = b(1 + 2k_h)$$

$$l_s = l + 2bk_h.$$

$k_h = 0,3$ at $p = 150 - 200 \text{ kPa}$, $k_h = 0,35$ at $p = 250 - 300 \text{ kPa}$, $k_h = 0,4$ at $p = 350 - 400 \text{ kPa}$.

In addition, the dimensions of the soil cushion should be larger than the foundation dimensions by at least 0.4 m at the bottom and 0.6 m at the top

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

Psl=46 kPa

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

$$\rho_{t.s.} = \rho_{d.s.}(1 + W_0) = 1,65(1 + 0,17) = 1,93 \text{ t/m}^3.$$

Design of the foundation on the soil cushion

When designing a soil cushion, the following are first set : $\rho_{d.s.} = 1.65 \text{ t/m}^3$

According to the tables of norms at $\rho_{d.s.} = 1,65 \text{ t/m}^3$, $R_0 = 275 \text{ kPa}$.

$$b_0 = \sqrt{\frac{2100}{1,4 (275 - 20 \times 1.8 - 20)}} = 2,6 \text{ m}$$

Since $\varphi_{t.s.}$ i $c_{t.s.}$ for compacted soil have not yet been determined, then R is determined according to the formula.

$$\text{If } d \leq 2M \quad R_1 = 0.25 \cdot R_0 \cdot (d + 2) \cdot [1 + k_1(b - 1)]$$

$$\mathbf{R_1 = 0.25 \cdot R_0 \cdot (d + 2) \cdot [1 + k_1(b - 1)] = 0,25 \cdot 275(1,8 + 2)[1 + 0,05 \cdot (2,6 - 1)] = 282,15 \text{ kPa}}$$

$$b_1 = \sqrt{\frac{2100}{1,4 (282,15 - 20 \times 1.8 - 20)}} = 2,58 \text{ m}$$

The difference between b_2 and b_1 , R_2 and R_1 is less than 10%, we accept b_2 and l_2 .

$$b = 2,6 \text{ m}, R = 282,15 \text{ kPa}, l = 1,4b = 3,6 \text{ m}, 1,2R = 338,6 \text{ kPa}.$$

8. We perform checks of the ultimate stresses, kPa:

$$P_{\max} = \frac{N}{b \cdot l} + \gamma_{mf} \cdot d + q + \frac{M}{W} \leq 1.2R$$

$$P_{\min} = \frac{N}{b \cdot l} + \gamma_{mf} \cdot d + q - \frac{M}{W} > 0$$

$$P_{cp} = \frac{N}{b \cdot l} + \gamma_{mf} \cdot d + q \leq R$$

$$W = \frac{b \cdot l^2}{6} = \frac{2,6 \cdot 3,6^2}{6} = 5,616 \text{ m}^3$$

1. $N=2100 \text{ kN}$ $M=260 \text{ kNm}$

$$P_{\max} = \frac{2100}{2,6 \cdot 3,3} + 20 \cdot 1,8 + 20 + \frac{260}{5,616} = 326,7 \text{ kPa} < 338,6 \text{ kPa}$$

$$P_{\min} = \frac{2100}{2,6 \cdot 3,6} + 20 \cdot 1,8 + 20 - \frac{260}{5,616} = 234 \text{ kPa} > 0 \text{ kPa}$$

$$P_{cp} = \frac{2100}{2,6 \cdot 3,6} + 20 \cdot 1,8 + 20 = 280,3 \text{ kPa} < 282,15 \text{ kPa}$$

1. $N=1200 \text{ kN}$ $M=410 \text{ kNm}$

$$P_{max} = \frac{1200}{2.6 \cdot 3.6} + 20 \cdot 1.8 + 20 + \frac{410}{5.616} = 257,2 \text{ kPa} < 338,6 \text{ kPa}$$

$$P_{min} = \frac{1200}{2.6 \cdot 3.6} + 20 \cdot 1.8 + 20 - \frac{410}{5.616} = 111,2 \text{ kPa} > 0 \text{ kPa}$$

$$P_{cp} = \frac{1200}{2.6 \cdot 3.6} + 20 \cdot 1.8 + 20 = 184,2 \text{ kPa} < 282,15 \text{ kPa}$$

We finally accept $b = 2,6 \text{ m}$, $l = 3,6 \text{ m}$.

The thickness of the cutting cushion is taken:

$$h_s = 0.3 + 4.6 - 1.8 = 3.1 \text{ m}$$

The dimensions of the lower part of the cushion are accepted:

$$b_s = b(1 + 2k_h) = 2,6(1 + 2 \cdot 0,35) = 4,4 \text{ m}$$

$$l_s = l + 2 \cdot b \cdot k_h = 3,6 + 2 \cdot 2,6 \cdot 0,35 = 5,4 \text{ m}$$

$k_h = 0,3$ at $p = 150 - 200 \text{ kPa}$, $k_h = 0,35$ at $p = 250 - 300 \text{ kPa}$, $k_h = 0,4$ at $p = 350 - 400 \text{ kPa}$.

In addition, the dimensions of the soil cushion should be larger than the foundation dimensions by at least 0.4 m at the bottom and 0.6 m at the top

Next, the admissibility of the pressure transferred by the cushion to the underlying soil is checked. For this we find:

$$A_z = \frac{N + G_f}{\sigma_{zp}}$$

$$G_f = b \cdot l \cdot (\gamma_{mf} \cdot d + q)$$

σ_{zp} – additional stress at depth from the load on the foundation.

$$\sigma_{zp} = \alpha \cdot P$$

$$G_f = 2,6 \cdot 3,6(20 \cdot 1,8 + 20) = 524.16 \text{ (kN)}.$$

$$p = \frac{N}{b \cdot l} + \gamma_{fm} \cdot d + q = \frac{2100}{2.6 \cdot 3.6} + 20 \cdot 1.8 + 20 = 280,3 \text{ kPa}$$

$$z = h_s = 3,1 \text{ m} \quad \xi = \frac{2 \cdot 3,1}{2,6} = 2,4 \quad \alpha = 0,325$$

$$\sigma_{zp} = 0,325 \cdot 280,3 = 91,1 \text{ (kPa)}.$$

$$A_z = \frac{2100 + 524.16}{91,1} = 28,8 \text{ m}^2$$

Next we find :

$$a = (l - b) / 2 = (3.6 - 2.6) / 2 = 0,5 \text{ m}.$$

$$b_z = \sqrt{A_z + a^2} - a = \sqrt{28,8 + 0,5^2} - 0,5 = 4,9 \text{ m}$$

We calculate R_z for the underlying soil cushion

$$R_z = \frac{\gamma_{cl} \cdot \gamma_{cr}}{k} \cdot (M_\gamma \cdot k_z \cdot b_z \cdot \gamma_{II} + M_q \cdot (d + h_s) \cdot \gamma'_{II} + M_c \cdot c)$$

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

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

$$\gamma = 20,1 \text{ kN/m}^3$$

$$\gamma' = 19,3 \text{ kN/m}^3.$$

$$R_z = \frac{1,4 \cdot 1}{1} (1,44 \cdot 1 \cdot 4,9 \cdot 20,1 + 6,76(1,8 + 3,1) \cdot 19,3 + 8,88 \cdot 1) = 1106 \text{ kPa}$$

We check the condition $\sigma_{zp} + \sigma_{zg} < R_z$

σ_{zg} - stress from the own weight of the soil of the cushion at depth $z = h_s$

$$\sigma_{zg} = \gamma_1 \cdot h_1 + \gamma_{t.s.} \cdot h_2 = 4,17 + 1,93 \cdot 10 \cdot 4,6 = 92,95 \text{ kN/m}^2$$

$$91,1 + 92,95 = 184,05 \text{ kN/m}^2 < 976,2 \text{ kN/m}^2$$

Finally accepts $b = 2,6 \text{ m}$ and $l = 3,6 \text{ m}$

Table 1 – Calculated resistances R_0 of subsiding soils

Sjils	R_0 , kPa (kg/cm ²), soils			
	natural composition with density in the dry state p_d , τ/M^3		compacted with density in the dry state p_d , τ/M^3	
	1,35	1,55	1,60	1,70
Sandy loams	$\frac{300(3)}{150(1,5)}$	$\frac{350(3,5)}{180(1,8)}$	200(2)	250(2,5)
Loams	$\frac{350(3,5)}{180(1,8)}$	$\frac{400(4)}{200(2)}$	250(2,5)	300(3)
Note: the numerator shows the values of R_0, which refer to non-soaked loamy soils with a degree of moisture $S_r \leq 0.5$; in the denominator - R_0 values, which refer to the same soils with $S_r \geq 0.8$, as well as to soaked silty soils.				

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

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