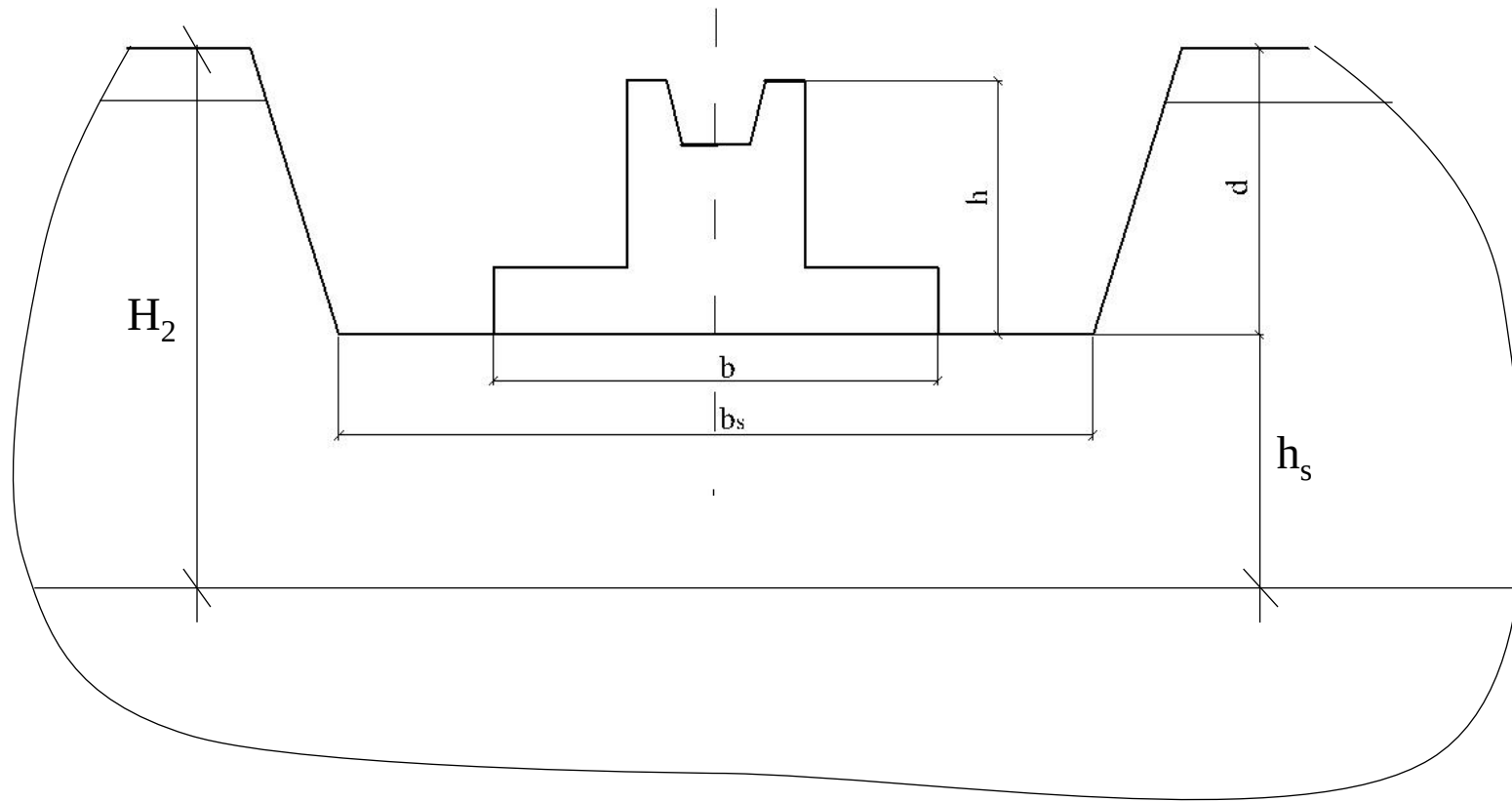


The foundation is on pre-compacted soil



Elimination of subsidence properties of soils can be achieved by compacting them with heavy rammers.

The design of a foundation compacted by a heavy rammer includes the following stages:

We specify the density of dry soil after tamping and the depth of laying the foundation:

$$\rho_{d.s.} = 1,65 \text{ T/M}^3, \quad d = 1,8 \text{ m.}$$

We determine the lowering of the tamped surface, then the thickness of the compacted layer and the depth of excavation of the pit, after that - the diameter of the rammer and its weight.

Lowering of the tamped surface, m

$$\Delta h = 1,2 \cdot (H_2 - d) \cdot \left(1 - \frac{\rho_d}{\rho_{d.s.}}\right) \qquad \rho_d = \frac{\rho}{(1 + w)}$$

The thickness of the compacted layer, m $h_s = H_2 - d + \Delta h$

Depth of pit excavation, m $h_k = d - \Delta h$.

Rammer diameter, m $d_s = h_s / k$

where for sandy loams and loams $k = 1,8$, for clays $k = 1,5$

Rammer weight, t $Q = 1,5 \cdot d_s^2 \cdot \frac{\pi}{4}$

Optimum moisture during tamping $w_0 = w_p - (0,01 \div 0,03)$

The height of the rammer $H = 8 - 10 \text{ m}$, the number of blows per track 10-12 times.

Characteristics of loess loams after tamping:

$$\rho_{t.s.} = \rho_{d.s.} (1 + w_0) \qquad e_{t.s.} = \frac{\rho_s (1 + w_0)}{\rho_{t.s.}} \qquad S_{r.t.} = \frac{\rho_s \cdot w_0}{e_{t.s.} \cdot \rho_w}$$

Design of the foundation on a compacted basis.

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

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

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

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

If $d \geq 2 \text{ M}$: $k_1=0.05$, $k_2=0.2$ – for loam and sandy loam, $k_2=0.2$ – for clays

$$R = R_0 \cdot [1 + k_1(b - 1)] + k_2 \cdot \gamma_{II}(d - 2)$$

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 marginal stresses.

We determine the dimensions of the pit, m:

$$b_s = b + 0,5(b - d_s)$$

$$l_s = l + 0,5(l - d_s)$$

The required amount of water for moistening, m^3 :

$$Q_w = \rho_{d,s} (w_0 - w) \cdot b_s \cdot l_s \cdot \frac{h_s}{\rho_w}$$

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. We specify the density of the dry soil after tamping and the depth of laying the foundation: $\rho_{d.s.} = 1.65 \text{ t/m}^3$, $d = 1.8 \text{ m}$.
2. We determine the lowering of the rammed surface, then the thickness of the compacted layer and the digging depth of the pit, after that - the diameter of the tamping and its weight.

Reduction of the tamped surface:

$$\Delta h = 1,2(H_2 - d) \left(1 - \frac{\rho_d}{\rho_{d.s.}} \right)$$

$$\rho_d = \frac{\rho}{(1+W)} = \frac{1,72}{(1+0,15)} = 1,496 \text{ T/M}^3.$$

$$\Delta h = 1,2(0,3 + 4,6 - 1,8) \left(1 - \frac{1,496}{1,65} \right) = 0,35 \text{ m}$$

The thickness of the compacted layer

$$\mathbf{h_s} = \mathbf{H_2} - \mathbf{d} + \mathbf{\Delta h} = 0,3 + 4,6 - 1,8 + 0,35 = 3,45 \text{ m}$$

Pit digging depth:

$$\mathbf{h_k} = \mathbf{d} - \mathbf{\Delta h} = 1,8 - 0,35 = 1,45 \text{ m}$$

Diameter of rammer $d_s = h_s / k$, sandy loams and loams $k = 1,8$, for clays $k = 1,5$.

Diameter of rammer $d_s = 3,45/1,8 = 1,92$ м.

We accept a rammer $d_s = 2$ м

$$\text{Rammer weight} \quad 1,5 d_s^2 \frac{\pi}{4} = 1,5 \cdot 2^2 \frac{\pi}{4} = 4,71 \text{ т}$$

Optimum moisture during tamping $W_0 = W_p - 0,02 = 0,19 - 0,02 = 0,17$.

The height of tamping reset $H = 8 - 10$ м, the number of blows on one track 10-12 times.

Characteristics of loess loam after tamping

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

$$e_{t.s.} = \frac{\rho_s(1 + W_0)}{\rho_{t.s.}} - 1 = \frac{2,73(1 + 0,17)}{1,93} - 1 = 0,655;$$

$$S_{r.t.} = \frac{\rho_s W_0}{e_{t.s.} \rho_w} = \frac{2,73 \cdot 0,17}{0,655 \cdot 1} = 0,71$$

Design of the foundation on a compacted basis

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 $\varphi_{t.s.}$ и $c_{t.s.}$ for compacted soil have not yet been determined, then R is determined according to building regulations
If $d \leq 2 \text{ м}$: $k_1 = 0.05$

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

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

The difference between b_0 и b_1 , less 10%, accept:

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

8. We perform checks of 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. $N=2100 \text{ kN}$ $M=260\text{kNm}$

$$P_{\max} = \frac{2100}{2.6 \cdot 3.6} + 20 \cdot 1.8 + 20 + \frac{260}{5,616} = 326,7 \text{ kPa} < 338,6 \text{ kPa}$$

$$P_{\min} = \frac{2100}{2.6 \cdot 3.6} + 20 \cdot 1.8 + 20 - \frac{260}{5,616} = 234 \text{ kPa} > 0 \text{ kPa}$$

$$P_{mid} = \frac{2100}{2.6 \cdot 3.6} + 20 \cdot 1.8 + 20 = 280,3 \text{ kPa} < 282,15 \text{ kPa}$$

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

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

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

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

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

Pit size:

$$b_s = b + 0.5(b - d_s) = 2,6 + 0,5(2,6 - 2) = 2,9 \text{ m}$$

$$l_s = l + 0.5(l - d_s) = 3,6 + 0,5(3,6 - 2) = 4,4 \text{ m}$$

Amount of water to permit :

$$Q_w = \rho_{d.s.} (w_0 - w) \cdot b_s \cdot l_s \cdot \frac{h_s}{\rho_w} = 1,65(0,17 - 0,15) 2,9 \cdot 4,4 \cdot \frac{3,45}{1} = 1,45 \text{ t}$$

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.				