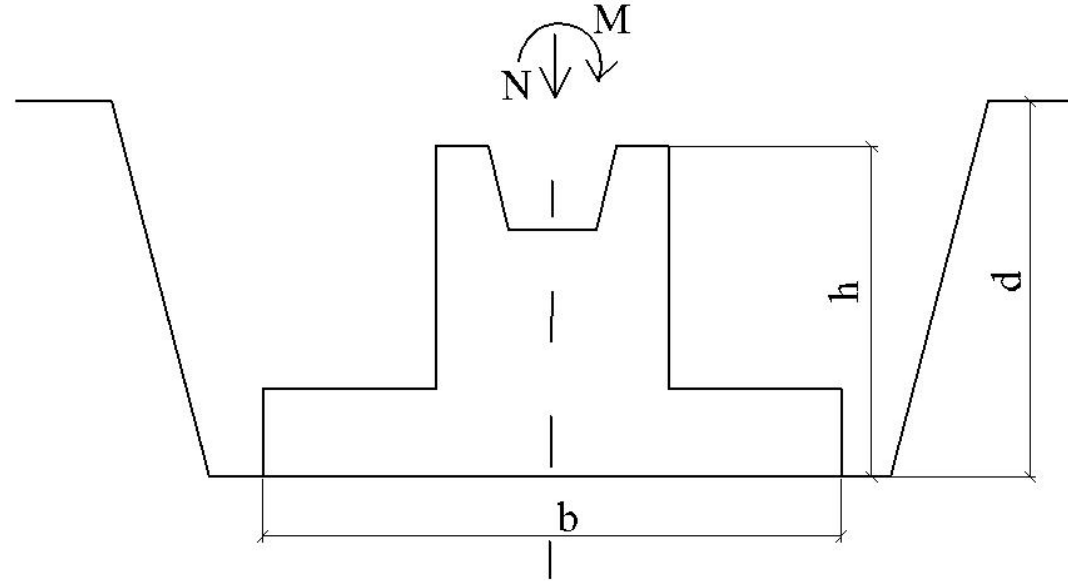


## FOUNDATION ON WATER-SATURATED SUBSIDING SOIL



Elimination of the subsidence properties of soils can be achieved by soaking them. To completely eliminate subsidence during pre-soaking, the soil is also subjected to dynamic effects (hydroblasts, directional vibration, etc.).

Calculation characteristics required for the determination of  $b$  and  $R - N, \eta, \gamma_{fm}, d, q, \gamma_{cr}, k, k_z, \gamma_i, d, d_b$  the same as in the previous calculations.

Others take into account the change in soil properties during water saturation.  $R_{o,sat}$  determined according to the table B. 3;

$$c = c_{sat} \quad \gamma = \gamma_{sat} = 10 \cdot \rho_{sat}$$

## Determining the dimensions of the foundation sole

We design a rigid reinforced concrete foundation.

We will accept the approximate ratio of the dimensions of the sole of the foundation  $\eta = \frac{l}{b} = 1,4$

then the width of the foundation sole, m:

$$b = \sqrt{\frac{N \cdot 1000}{\eta \cdot (R - \gamma_{mt} \cdot d - q)}} \quad (1)$$

$$l = 1,4b$$

where N is the load, MH (we take the larger value from the two combinations),

$\gamma_{mt}$  – the average weight of the foundation and the soil on its edges is assumed to be 20 kN/m<sup>3</sup>,

d - depth of laying, m;

b and l are the width and length of the foundation sole;

q is the load on the floor, for the wake 20 kN/m<sup>2</sup>.

R – estimated soil resistance at the depth of laying d, kPa.

## Calculation algorithm

1. Determine R0 according to the table. 1
2. Find b0 according to formula (1) taking into account R0
3. Determine R1 by the formula:

$$R_{\text{sat}} = \frac{\gamma_{c1} \cdot \gamma_{c2}}{k} \cdot [M_{\gamma} \cdot k_z \cdot b \cdot \gamma_{II} + M_q \cdot d_1 \cdot \gamma'_{II} + (M_q - 1) \cdot d_b \cdot \gamma'_{II} + M_c \cdot c_{\text{sat}}]$$

where  $\gamma_{c1}$   $\gamma_{c2}$  – coefficients of working conditions, which take into account the type and condition of the base soil and the stiffness of the structural scheme of the structure

k - is a coefficient that takes into account the degree of reliability of determining the characteristics of the base soil;

k=1, if the soil strength characteristics ( $\phi_{II}$  and c) are determined experimentally; k=1.1, if the characteristics of soil strength ( $\phi_{II}$  and c) are taken according to DBN

**k=1,1**

$k_z$  – a coefficient that takes into account the features of the joint operation of a wide foundation with the base;

If  $b < 10$  m **kz=1**; if  $b > 10$  m  $kz = z_0/b + 0,2$  ( $z_0 = 0,8$ );

$M_{\gamma}$ ,  $M_q$  и  $M_c$  - coefficients that depend on the angle of internal friction  $\phi_{\text{sat}}$  of the soil and the shape of the foundation in plan;

$c = c_{\text{sat}}$  specific cohesion of the bearing soil layer.

$\gamma_{II}$   $\gamma'_{II}$  - average values of specific unit weight of soils above and below the base of the foundation  $\gamma = \gamma_{\text{sat}} = 10 \cdot \rho_{\text{sat}}$

$d_b$  – basement depth – the distance from the planning level to the basement floor

(for buildings with a basement width  $B \leq 20$  m and a depth of more than 2 m,  $d_b = 2$  is accepted, for a basement width  $B > 20$  m,  $d_b = 0$  is accepted).

$$\gamma' = \frac{\sum \gamma_i h_i}{\sum h_i}$$

$$\gamma'_{II} = 10 \cdot \frac{\rho_1 \cdot h_1 + \rho_2 (d - h_1)}{d}$$

4. We specify the value of b1 at R1

5. We find b2 at R2

6. The difference between b2 and b1, R2 and R1 is less than 10%, then we accept:

$$l_2 = 1,4b_2$$

Table 1 – Calculated resistances  $R_0$  of subsiding soils

| Sjils                                                                                                                                                                                                                                                                                                     | $R_0$ , kPa (kg/cm <sup>2</sup> ), soils                                       |                             |                                                                      |          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|-----------------------------|----------------------------------------------------------------------|----------|
|                                                                                                                                                                                                                                                                                                           | natural composition with<br>density in the dry state $p_d$ , $\tau/\text{M}^3$ |                             | compacted with density in<br>the dry state $p_d$ , $\tau/\text{M}^3$ |          |
|                                                                                                                                                                                                                                                                                                           | 1,35                                                                           | 1,55                        | 1,60                                                                 | 1,70     |
| Sandy<br>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)   |
| <p>Note: the numerator shows the values of <math>R_0</math>, which refer to non-soaked loamy soils with a degree of moisture <math>S_r \leq 0.5</math>; in the denominator - <math>R_0</math> values, which refer to the same soils with <math>S_r \geq 0.8</math>, as well as to soaked silty soils.</p> |                                                                                |                             |                                                                      |          |

Table 1– Coefficients of working conditions  $\gamma_{c2}$ ,  $\gamma_{c2}$

| soils                                                                                                                 | Coefficient<br>$\gamma_{c1}$ | 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  $\gamma_{c2}$  is assumed to be equal to one.

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

4 For loose sands  $\gamma_{c1}$  and  $\gamma_{c2}$  taken equal to 1.

Table 2 - Coefficients  $M_\gamma$ ,  $M_q$ ,  $M_c$ 

| Angle of internal<br>friction , deg. $\varphi_{II}$ | Coefficients |       |       | Angle of internal<br>friction $\varphi_{II}$ , deg. | Coefficients |       |       |
|-----------------------------------------------------|--------------|-------|-------|-----------------------------------------------------|--------------|-------|-------|
|                                                     | $M_\gamma$   | $M_q$ | $M_c$ |                                                     | $M_\gamma$   | $M_q$ | $M_c$ |
| 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                                         | $\rho_{II}$         | t/m <sup>3</sup>     | 1,39         | 1,72  | 2,01 | 1,98 | 2,06 |
| Solid Particle density                          | $\rho_s$            | t/m <sup>3</sup>     |              | 2,73  | 2,68 | 2,69 | 2,70 |
| Water content                                   | W                   |                      |              | 0,15  | 0,24 | 0,26 | 0,22 |
| Liquid limit                                    | W <sub>L</sub>      |                      |              | 0,35  |      | 0,28 | 0,40 |
| Plastic limit                                   | W <sub>p</sub>      |                      |              | 0,19  |      | 0,22 | 0,20 |
| Angle of internal friction                      | $\varphi_{II}$      | degree               |              | 21    | 33   | 20   | 15   |
| Specific cohesion                               | C <sub>II</sub>     | kPa                  |              | 25    | 1    | 12   | 80   |
| Modulus of Deformation                          | E                   | MPa                  |              | 20    | 30   | 15   | 50   |
| Relative subsidence under pressure p, MПа       | $\epsilon_{SL}$     | 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 <sub>II,sat</sub> | kPa                  |              | 5     |      |      |      |
| Modulus of Deformation water-saturated soil     | E <sub>sat</sub>    | MPa                  |              | 6     |      |      |      |

Soil classification indicators

| №<br>Layer | e     | $S_r$ | $I_p$ | $I_l$ | Soil properties                                  |
|------------|-------|-------|-------|-------|--------------------------------------------------|
| 1          |       |       |       |       | plant layer                                      |
| 2          | 0.825 |       | 0.16  | -1.25 | Subsidence soil<br>loam solid                    |
| 3          | 0.653 | 0.389 |       |       | Sand medium-sized low moisture<br>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. Accept  $R_0$  according to the table. 1

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

$$\rho_d = 1.35 \text{ t/m}^3 \quad R_0 = 180 \text{ kPa}$$

$$\rho_d = 1.55 \text{ t/m}^3 \quad R_0 = 200 \text{ kPa}$$

$$\rho_d = 1.496 \text{ t/m}^3 \quad R_0 = 180 + \frac{200-180}{1,55-1,35} (1,496 - 1,35) = 194,6 \text{ kPa}$$

2. Find  $b_0$  using the formula

$$b_1 = \sqrt{\frac{2100}{1,4 (194,6 - 20 \times 1.8 - 20)}} = 3,3 \text{ m}$$

3. Determine R1 by the formula:

$$R_{\text{sat}} = \frac{\gamma_{\text{c1}} \cdot \gamma_{\text{c2}}}{k} \cdot [M_{\gamma} \cdot k_z \cdot b \cdot \gamma_{\text{II}} + M_q \cdot d_1 \cdot \gamma'_{\text{II}} + (M_q - 1) \cdot d_b \cdot \gamma'_{\text{II}} + M_c \cdot c_{\text{sat}}]$$

$$\gamma_{\text{c2}} = k = k_z = 1 \quad d_b = 0 \quad \gamma_{\text{c1}} = 1,25 \quad c = 5 \text{ кПа}$$

$$\text{For } \varphi_{\text{sat}} = 19 \quad M_{\gamma} = 0,47 \quad M_q = 2,89 \quad M_c = 5,48$$

$$\gamma = \gamma_{\text{sat}} = 10 \cdot \rho_{\text{sat}} = 19,3 \text{ (кН/м}^3\text{)}$$

$$\gamma'_{\text{II}} = 10 \cdot \frac{\rho_1 \cdot h_1 + \rho_2 (d - h_1)}{d} = 10 \cdot \frac{1,39 \cdot 0,3 + 1,93 \cdot (1,8 - 0,3)}{1,8} = 18,4 \text{ (кН/м}^3\text{)}$$

$$R_1 = \frac{1,25 \cdot 1}{1} (0,47 \cdot 1 \cdot 3,3 \cdot 19,3 + 2,89 \cdot 1,8 \cdot 18,4 + 5,48 \cdot 5) = 191,3 \text{ кПа}$$

4. We specify the value of b1 at R1

$$b_1 = \sqrt{\frac{2100}{1,4 (191,3 - 20 \times 1,8 - 20)}} = 3,33 \text{ м}$$

5. We specify R2 according to the formula:

$$R_2 = \frac{1.25 \cdot 1}{1} (0.47 \cdot 1 \cdot 3,33 \cdot 19,3 + 2,89 \cdot 1.8 \cdot 18,4 + 5.48 \cdot 5) = 191,7 \text{ kPa}$$

6. We specify the value of b2 at R2

$$b_2 = \sqrt{\frac{2100}{1,4 (191,7 - 20 \times 1.8 - 20)}} = 3.33 \text{ m}$$

7. We find the difference between b2 and b1

$$\frac{3,33 - 3,33}{3,33} 100\% = 0\% < 10\%$$

Since the difference is less than 10%, we accept:

$$\mathbf{b} = 3,4 \text{ m}, \mathbf{l} = \boldsymbol{\eta} \cdot \mathbf{b} = 4,8 \text{ m}, \quad \mathbf{R}_{\text{sat}} = 192,4 \text{ kPa}, \quad \mathbf{1.2R} = \mathbf{1.2} \cdot 192,4 = 230,9 \text{ kPa}$$

8. Check the ultimate stresses, kPa:

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

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

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

$$W = \frac{b \cdot l^2}{6} = \frac{3,4 \cdot 4,8^2}{6} = 13,056 \text{ m}^3$$

1. N=2100 kN M=260kNm

$$P_{\max} = \frac{2100}{3,4 \cdot 4,8} + 20 \cdot 1,8 + 20 + \frac{260}{13,056} = 204,6 \text{ kPa} < 230,9 \text{ kPa}$$

$$P_{\min} = \frac{2100}{3,4 \cdot 4,8} + 20 \cdot 1,8 + 20 - \frac{260}{13,056} = 164,8 \text{ kPa} > 0$$

$$P_{av} = \frac{2100}{3,4 \cdot 4,8} + 20 \cdot 1,8 + 20 = 184,7 \text{ kPa} < 192,4 \text{ kPa}$$

2. N=1200 kN M=410kNm

$$P_{\max} = \frac{1200}{3,4 \cdot 4,8} + 20 \cdot 1,8 + 20 + \frac{410}{13,056} = 160,9 \text{ kPa} < 230,9 \text{ kPa}$$

$$P_{\min} = \frac{1200}{3,4 \cdot 4,8} + 20 \cdot 1,8 + 20 - \frac{410}{13,056} = 98,1 \text{ kPa} > 0$$

$$P_{av} = \frac{1200}{3,4 \cdot 4,8} + 20 \cdot 1,8 + 20 = 129,5 \text{ kPa} < 192,4 \text{ kPa}$$

Conditions are met.