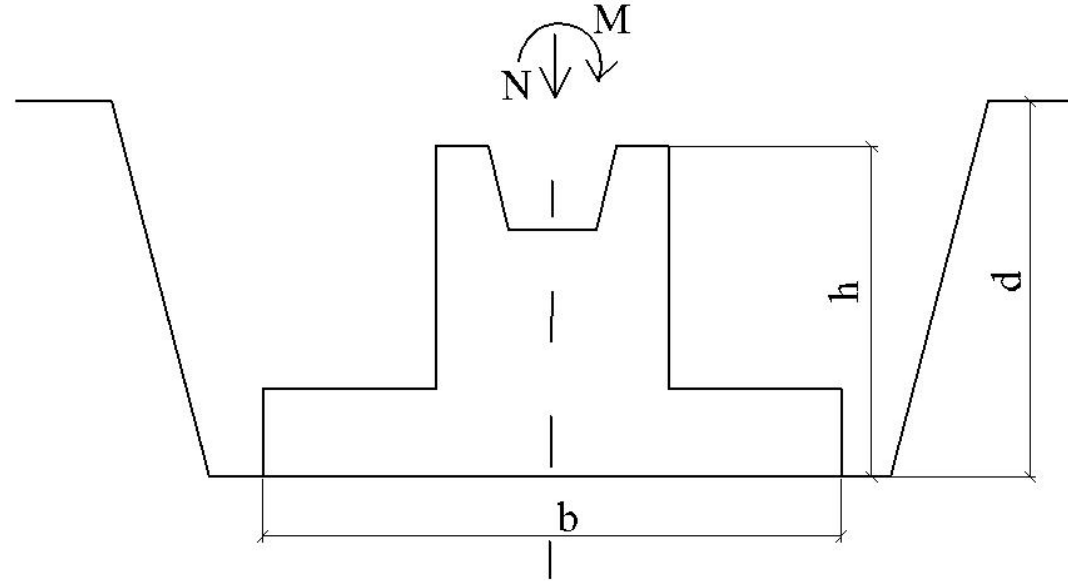


FOUNDATION ON WATER-SATURATED SUBSIDING SOIL



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.

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),

γ_{mt} – the average weight of the foundation and the soil on its edges is assumed to be 20 kN/m³,

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/m².

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 γ_{c1} γ_{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 (ϕ_{II} and c) are determined experimentally; k=1.1, if the characteristics of soil strength (ϕ_{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_{γ} , M_q и M_c - coefficients that depend on the angle of internal friction ϕ_{sat} of the soil and the shape of the foundation in plan;

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

γ_{II} γ'_{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 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 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. 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

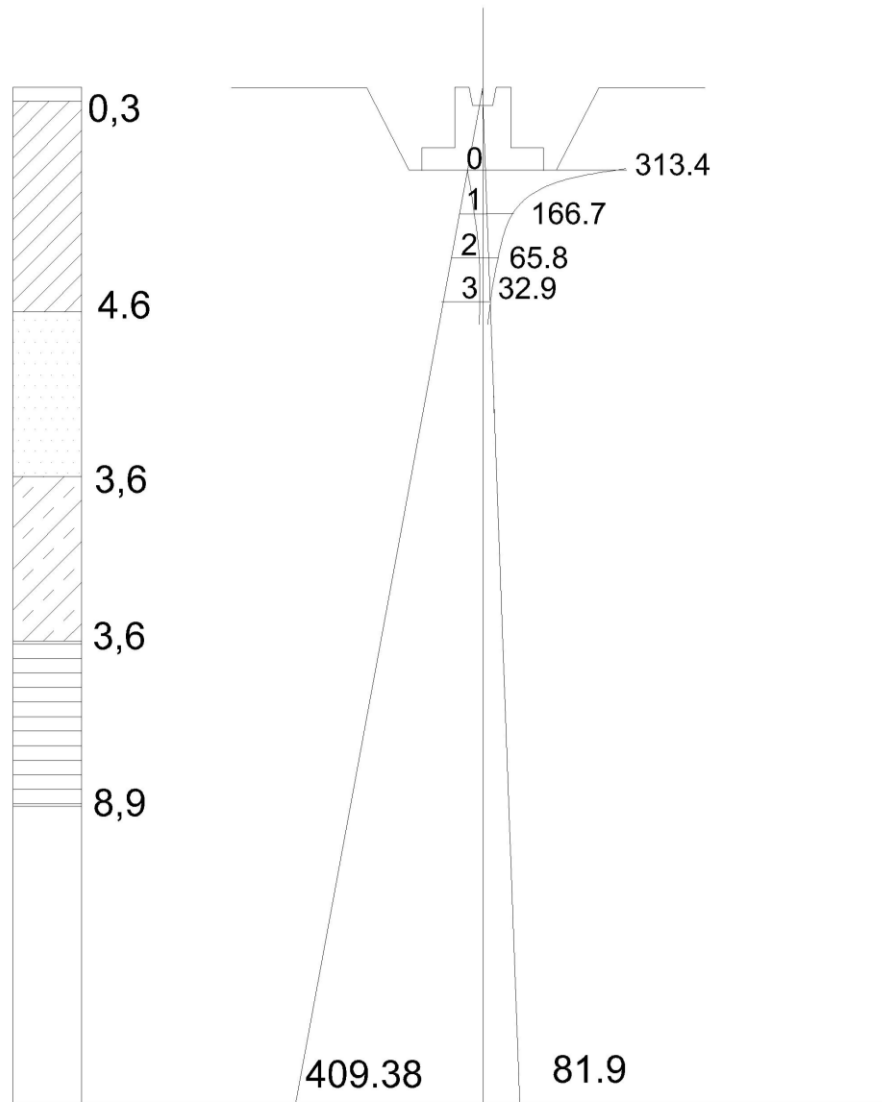
$$P_{\max} = \frac{1200}{3,4 \cdot 4,8} + 20 \cdot 1,8 + 20 + \frac{410}{13,056} = 160,9 \text{ kPa} < 230,9 \text{ kPa}$$

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

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

Conditions are met.

Determining the settlement by the method of layer-by-layer summation



The settlement is determined and is often more than permissible, as it is used in the calculation E_{sat}

The subsidence of the lower layer due to its own weight is not determined if the water saturation of the soil occurred before the construction of the house, and is determined if it occurs during operation.

$$P_{av} = \frac{2100}{3.4 \cdot 4.8} + 20 \cdot 1.8 + 20 = 184,7 \text{ kPa} < 192,4 \text{ kPa}$$

2. We determine the stress from the soil's own weight

$$\sigma_{zg,1} = \gamma_1 \cdot h_1 = 1.39 \cdot 10 \cdot 0.3 = 4,17 \text{ kN/m}^2$$

$$\sigma_{zg,2} = \gamma_1 \cdot h_1 + \gamma_2 \cdot h_2 = 4,17 + 1,93 \cdot 10 \cdot 4,6 = 92,95 \text{ kN/m}^2$$

$$\sigma_{zg,3} = \sigma_{zg,2} + \gamma_3 \cdot h_3 = 92,95 + 2,01 \cdot 10 \cdot 3,6 = 165,31 \text{ kN/m}^2$$

$$\sigma_{zg,4} = \sigma_{zg,3} + \gamma_4 \cdot h_4 = 165,31 + 1,98 \cdot 10 \cdot 3,6 = 236,59 \text{ kN/m}^2$$

$$\sigma_{zg,5} = \sigma_{zg,4} + \gamma_5 \cdot h_5 = 236,59 + 2,06 \cdot 10 \cdot 8,9 = 414,93 \text{ kN/m}^2$$

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

$$\sigma_{zg,0} = \sigma_{zg,1} + \gamma_2 \cdot h_d = 4,17 + 1,93 \cdot 10 \cdot 1,5 = 33,12 \text{ kN/m}^2$$

3. The soil layer under the foundation is divided into elementary layers with a thickness of h:

$$h \leq 0,4b$$

$$h = 0,4 \cdot 3,4 = 1,36 \text{ m}$$

Table - Settlement calculation

No layer	No	soil	h, m	z, m	$\zeta = \frac{2 \cdot z}{b}$	α	kPa $\sigma_{zp} = \alpha \cdot p$	$\sigma_{zp, cp}$	$\zeta_k = \frac{2 \cdot z}{B_k}$	α_k	kPa $\sigma_{z\gamma} = \alpha_k \cdot \sigma'_{zg, 0}$	$\sigma_{z\gamma, cp}$	E _i , kPa	$0,8 \cdot \frac{(\sigma_{zp, i, cp} - \sigma_{z\gamma, i}) \cdot h_i}{E_i}$	s _i , M
	0		0	0	0	1	184,7		0	1	33,12				
	1		1,36	1,36	0,8	0,848	156,63	170,66	0,62	0,91	27,118	30,119	6000	0,025485	
	2		1,36	2,72	1,6	0,532	98,26	127,44	1,24	0,682	20,3236	23,7208	6000	0,018808	
	3		0,36	3,08	1,81	0,118	21,79	60,03	1,40	0,607	18,0886	19,2061	6000	0,001959	
	4		1,36	4,44	2,61	0,2925	54,02	37,91	2,02	0,414	12,3372	15,2129	30000	0,000823	0,047

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