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THE BEARING CAPACITY OF LAYERED SUBSOIL

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Abstract: Various methods for calculation of the bearing capacity of a layered subsoil are analyzed. The values obtained are compared with the values calculated by means of PLAXIS Version 8, the latter being considered the correct ones. It is shown that Polish Standards and proposition modified by the authors are admissible to use only in the case of subsoil with a weak cohesionless lower layer, with small angle of friction. In engineering calculations, the bearing capacity of layered subsoil can be obtained based on a classic Terzaghi formula and average parameters of homogeneous subsoil.

Streszczenie: Analizowano różne metody obliczania nośności granicznej podłoża warstwowego. Otrzymane wyniki porównywano z wynikami otrzymanymi przy użyciu programu PLAXIS Version 8. Wykazano, że stosowanie Polskiej Normy i uproszczonej autorskiej modyfikacji jest dopuszczalne jedynie w przypadku, gdy dolną warstwę podłoża stanowi słaby grunt niespoisty o małej wartości kąta tarcia wewnętrznego. W obliczeniach inżynierskich dopuszcza się obliczanie nośności granicznej podłoża warstwowego z wykorzystaniem klasycznej formuły Terzaghiego i uśrednionych wartości parametrów geotechnicznych.

Резюме: Проведен анализ разных методов расчета предельной несущей способности слоистого основания. Полученные результаты были сравнены с результатами, полученными с использованием программы PLAXIS Version 8. Было обнаружено, что применение Польских Стандартов и упрощенной авторской модификации допустимо лишь в случае, когда нижний слой основания составляет слабый неплотный грунт низкого значения угла внутреннего трения. В инженерских вычислениях допустим расчет предельной несущей способности слоистого основания с использованием классической формулы Терцаги и усредненных значений геотехнических параметров.

LIST OF SYMBOLS

H – thickness of the subsoil,
h – thickness of the surface layer,
γ – unit weigh of soils,
E – Young's modulus,
ν – the Poisson ratio,
c – cohesion,
Φ – friction angle,
Ψ – dilatancy angle,
B – width of foundation,
L – length of foundation,
D – depth of embeddement,
B' – width of substitute foundation,
L' – length of substitute foundation,

ρ – bulk density,
g – gravitational acceleration ,
N_C, N_D, N_B – bearing capacity factors,
EA – normal stiffness,
EI – flexural rigidity,
R – radius of circle foundation,
R' – radius of substitute foundation,
Q_f – bearing capacity of shallow foundations,
σ_z – vertical stress,
σ_z' – vertical additional stress.

1. INTRODUCTION

In many practical engineering causes, it may be necessary to lay shallow foundations on stratified deposits. A layer of deposits below shallow foundation which influences the bearing capacity is called a subsoil. A simplified analysis shows that the thickness of the subsoil can be expressed by

$$H = \frac{B}{2}\tan\left(45^0 + \frac{\Phi}{2}\right),$$

where B is a width of a shallow foundation, and Φ is the angle of soil internal friction (BOWLES [1]). In the engineering practice, it is usually assumed that $H = 2B$ (PN-81/B-03020 [7]). The subsoil displays a layered structure if the thickness of the deposit surface layer is less than H. In the most practical problems, the subsoil is two-layered. Two general types of surface layer have been recognised:

1. Surface layer weaker than lower layer.
2. Surface layer stronger than lower layer.

In the first case, the bearing capacity is usually calculated for the soil strength parameters of the surface layer and reaches lower, safer values. In the second case, some modifications are necessary. The first proposition for multi-layered clays was presented by BUTTON [3], who used a circular arc to find an approximate minimum bearing capacity value. It was suggested that the proposed method of a circular arc is limited to cases where the strength ratio $c_r = c_2/c_1$ is in the order of $0.6 < c_r \le 1.3$. Similarly, REDDY and SRINIVASAN [9] considered cylindrical failure surfaces of two purely cohesive layers. BROWN and MEYERHOF [2] using the model test results for two-layered clays proposed a modified value N_c for calculation of bearing capacity based on the Therzaghi formula as a function of the thickness of layer in order to wide the foundation and to increase the strength ratio c_2/c_1. Model tests show that when the surface layer is very soft it tends to squeeze out from beneath the base. The soil may squeeze from beneath the foundation when the unit load q exceeds $q_u = 4c + \overline{q}$, where c is the cohesion of a very soft clay and $\overline{q}$ stands for the unit load of embedded soil.

PURUSHOTHAMARA at al. [8] presented the solution for two-layered cohesive-friction soils and gave a number of charts of bearing capacity factors. Based on their results it was suggested to obtain the modified Φ and c values and to use them for calculation of the bearing capacity of shallow foundations.

In practice, the bearing capacity of foundations on soft clay can be improved by a layer of compacted sand or gravel. The bearing capacity of such an inhomogeneous subsoil is difficult to obtain. Exact solutions (KENNY and ANDRAWES [5]) allow development of a simple method to solve this problem.

This paper deals with the problem of bearing capacity of strip and square foot foundations laid on two-layered subsoil. The bearing capacity is calculated by means of various methods and compared with the bearing capacity values obtained using finite element method (PLAXIS Version 8 [6]) treated as correct values. We show that the use of average values of strength parameters of homogeneous subsoil to calculate the bearing capacity by traditional Terzaghi's formula is appropriate for engineering practice.

2. THE GEOMETRY AND BASIC ASSUMPTIONS

This paper deals with the strip foundations whose width B = 1.0 m and the square foot foundations of $B = L$ = 1.0 m laid on two-layered subsoil (figure 1).

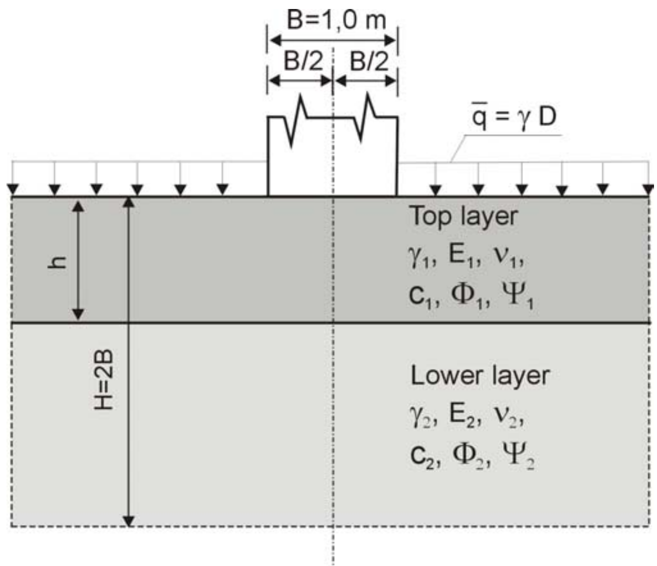

Fig. 1. Geometry of the problem

Very flexible and rough foundations are embedded in soil whose surface layer depth $D = B/2$, so traditionally in calculation, such foundations are treated as laid on the surface layer loaded with the unit load $\bar{q} = \gamma_1 D$, where γ_1 is the unit weight of the surface layer soil. Generally, four types of subsoil called: A, B, C and D are considered. They are a combination of dense and loose sands as well as strong and week clays (table 1).

Table 1

The layers of subsoil

Subsoil type	Surface layer	Lower layer
A	Strong clay	Loose sand
B	Dense sand	Loose sand
C	Dense sand	Weak clay
D	Strong clay	Weak clay

The physical and mechanical parameters of soils, i.e. γ – the unit weigh of soils, E – Young's modulus, ν – the Poisson ratio, c – the cohesion, Φ – the angle of friction and Ψ – the dilatancy angle of the surface and lower layers of soils, are given in table 2.

Table 2

Physical and mechanical parameters of soils

Subsoil	Surface layer						Lower layer					
	γ_1	E_1	ν_1	c_1	Φ_1	Ψ_1	γ_2	E_2	ν_2	c_2	Φ_2	Ψ_2
	kN/m^3	kN/m^2	–	kN/m^2	[°]	[°]	kN/m^3	kN/m^2	–	kN/m^2	[°]	[°]
A	21.0	21 000	0.3	18.0	15.0	0.0	16.0	32 000	0.3	1.0	29.5	0.0
B	17.0	76 000	0.3	1.0	32.0	2.0	16.0	32 000	0.3	1.0	29.5	0.0
C	17.0	76 000	0.3	1.0	32.0	2.0	22.0	11 000	0.3	9.0	10.0	0.0
D	21.0	21 000	0.3	18.0	15.0	0.0	22.0	11 000	0.3	9.0	10.0	0.0

The thickness of the surface layer is in the range of $0 \le h \le 2B$. It is assumed that water table is deeper than $2B$ and has no influence on the bearing capacity of foundations.

3. BEARING CAPACITY OF LAYERED SUBSOIL

3.1. ANALYSIS OF FINITE ELEMENT METHOD

The PLAXIS Version 8 finite element package [6] is used for analysis of bearing capacity of two-layered subsoil loaded with strip and square foundations whose width B = 1.0 m. The foundations are very flexible ($EA = 300000$ kN/m, $EI = 1000$ kN/m^2)

and very rough (no soil sliding in their base). The PLAXIS Version 8 is intended for the two-dimensional analysis of deformation and stability in geotechnical engineering.

Table 3

Bearing capacity calculated by means of PLAXIS

h/*B*	Subsoil							
	A		B		C		D	
	Foundation							
	Strip	Square	Strip	Square	Strip	Square	Strip	Square
	kN	kN	kN/m	kN	kN/m	kN	kN/m	kN
0	317.8	512.6	261.9	428.0	112.2	142.2	117.9	142.0
0.5	316.6	396.0	318.5	529.6	149.1	250.9	174.4	270.9
0.8	291.3	362.9	333.3	544.8	180.7	376.9	203.7	345.4
1.0	279.0	359.5	352.2	609.7	194.2	444.6	223.6	364.4
1.5	270.4	359.0	381.1	610.4	237.4	493.1	266.1	369.2
2.0	264.0	358.0	399.6	611.5	317.2	621.4	273.9	370.4
∞	256.1	357.5	425.7	613.0	391.4	655.2	274.5	372.1

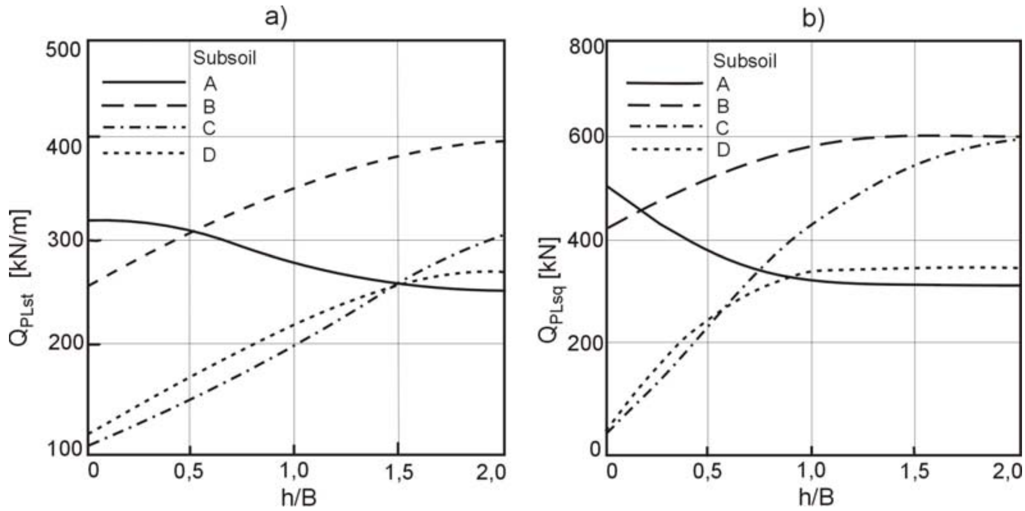

Fig. 2. Bearing capacity of foundations calculated by means of PLAXIS:
a) strip foundation, b) square foundation

The square foundation is treated as a circle foundation with this same base area (radius $R = B/\sqrt{\pi} = 0.564\,B$). The elastic-plastic Mohr–Coulomb model involves five parameters, i.e. E and ν representing for soil elasticity, Φ and c representing soil plasticity (strength) and Ψ as an angle of dilatancy. The values of those parameters accepted in this paper are shown in table 2. The authors of PLAXIS suggested $c > 0.2$ kPa for cohesionless sands so it is assumed $c = 1$ kPa for sands in this paper and $\Psi = \Phi - 30^\circ$ for the soils with $\Phi > 30^\circ$, and $\Psi = 0$ for the soils with $\Phi < 30^\circ$. The influence of elastic parameters on the bearing capacity is very small, while the strength parameters and angle of dilatancy considerably affect the bearing capacity. The angle of dilatancy of dense sand is greater than that suggested by authors of PLAXIS. The values of the bearing capacity of strip Q_{PLst} and square Q_{PLsq} foundations at this dilatancy angle assume minimum (safer) values. They are shown in table 3 and figure 2.

The values calculated at $h/B = \propto$ are also shown in table 3. The values obtined at $h/B = 2$ and $h/B = \propto$ for the subsoils of the types A, B and D are almost equal to each other, so $h/B = 2B$ is sufficient to consider the bearing capacity of a two-layered subsoil. For the subsoil of the type C the values of bearing capacity at $h/B = \propto$ are 1.23 and 1.05 times higher than at $h/B = 2$ for strip and square foundations, respectively. The subsoil of the type C is characterised by the surface layer made of dense sand (very strong) and the lower layer made of a weak clay (very weak). Generally, we can conclude that for the layered subsoil only layers in $h/B < 2$ influence the bearing capacity of the foundations.

3.2. PROPOSITION OF POLISH STANDARD

According to Polish Standards [7] the bearing capacity (Q_f) of shallow foundations loaded symmetrically and vertically is calculated from the following equation

$$Q_f = BL\,\{(1 - 0.3\,B/L)N_c c_u + (1 + 1.5B/L)N_D \rho\, g\, D_{\min} + (1 - 0.25B/L)N_B \rho\, gB\}\,, \quad (1)$$

where:

B, L – the width and length of foundation,
ρ – the bulk density,
g – the gravitational acceleration,
$D_{\min}$ – the depth of embeddement,
N_C, N_D, N_B – the bearing capacity factors,

$$N_D = e^{\pi \tan\Phi} \tan^2\left(\frac{\pi}{4} + \frac{\Phi}{2}\right), \quad (2a)$$

$$N_C = (N_D - 1)\,\mathrm{ctan}\Phi\,, \quad (2b)$$

$$N_B = 0.75(N_D - 1)\tan\Phi\,. \quad (2c)$$

The bearing capacity factors are exclusively the functions of the angle of internal friction.

If the weaker soil is deeper than 2*B* below foundation base, then the ultimate limit state has to be checked for the substitute foundation width *B*′ and length *L*′ placed on the surface of a weaker layer [7]. In this paper, the dimensions of substitute foundations proposed in Polish Standards [7] are denoted by

$$B'_n = B + 2\,h/m\,, \tag{3a}$$

$$L'_n = L + 2\,h/m\,, \tag{3b}$$

where for cohesive soils

$$m = 8 \quad \text{if} \quad h \le B\,, \tag{4a}$$

$$m = 6 \quad \text{if} \quad h > B \tag{4b}$$

and for cohesionless soils

$$m = 6 \quad \text{if} \quad h \le B \tag{5a}$$

$$m = 3 \quad \text{if} \quad h > B\,. \tag{5b}$$

The authors propose

$$B'_p = B + 2\,h/n\,, \tag{6a}$$

$$L'_p = L + 2\,h/n\,, \tag{6b}$$

where $n = 6$ for all soils (figure 3).

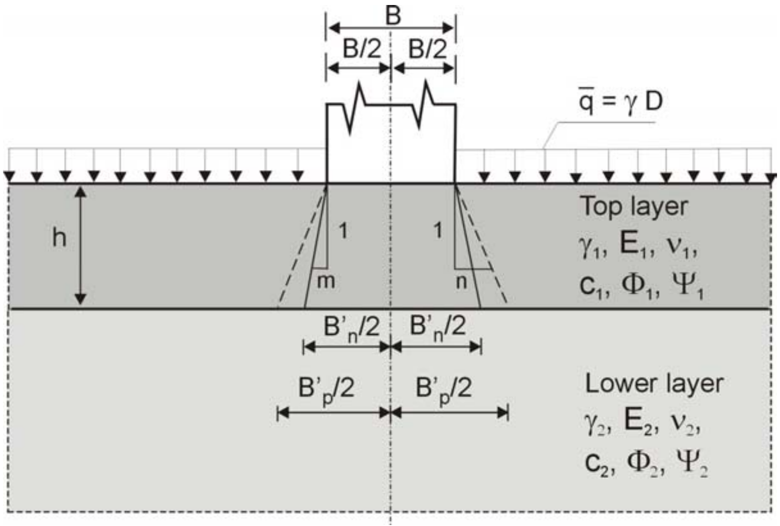

Fig. 3. Geometry of standard proposition

The bearing capacity values calculated from equation (1) for substitute strip and square foundation proposed in Polish Standards [7] marked with Q_{nst}, Q_{nsq}, respectively, and proposed by authors as Q_{pst} and Q_{psq} are shown in table 4.

Table 4

The values N' and Q' for substitute foundations

h/B	m	n	B'_n	B'_p	$\overline{q}$	N'_{nst}	N'_{nsq}	N'_{pst}	N'_{psq}	Q'_{nst}	Q'_{nsq}	Q'_{pst}	Q'_{psq}
	–	–	m	m	kN/m^2	kN/m	kN	kN/m	kN	kN/m	kN	kN/m	kN
Subsoil A													
0	8	6	1.00	1.00	10.5	318.0	440.7	318.0	440.7	294.7	540.7	294.7	540.7
0.5	8	6	1.13	1.17	21.0	267.8	330.6	278.0	345.4	556.0	1287.6	580.8	1385.0
0.8	8	6	1.20	1.27	27.3	216.3	251.9	226.6	264.7	731.3	1855.2	783.8	2087.5
1.0	8	6	1.25	1.33	31.5	191.5	218.0	210.0	236.9	861.0	2305.1	927.1	2621.4
1.5	6	6	1.50	1.50	42.0	156.2	128.7	156.2	128.7	1348.2	4394.2	1348.2	4394.2
2.0	6	6	1.67	1.67	52.5	132.1	90.4	132.1	90.4	1837.8	6760.4	1837.8	6760.4
Subsoil B													
0	6	6	1.00	1.00	8.5	273.4	395.5	273.4	395.5	259.9	453.7	259.9	453.7
0.5	6	6	1.17	1.17	17.0	349.1	494.8	349.1	494.8	499.3	1146.9	499.3	1146.9
0.8	6	6	1.27	1.27	22.1	410.7	437.7	410.7	437.7	668.9	1722.6	668.9	1722.6
1.0	6	6	1.33	1.33	25.5	391.0	397.6	391.0	397.6	788.3	2159.8	788.3	2159.8
1.5	3	6	2.00	1.50	34.0	422.2	389.8	393.1	311.2	1631.2	6588.0	1139.4	3611.2
2.0	3	6	2.33	1.67	42.5	466.4	335.5	396.0	231.1	2331.2	11099.2	1547.2	5507.4
Subsoil C													
0	6	6	1.00	1.00	8.5	178.0	141.9	178.0	141.9	102.2	155.9	102.2	155.9
0.5	6	6	1.17	1.17	17.0	181.2	189.2	181.2	189.2	145.3	286.7	145.3	286.7
0.8	6	6	1.27	1.27	22.1	181.8	237.1	181.8	237.1	174.4	390.0	174.4	390.0
1.0	6	6	1.33	1.33	25.5	175.2	278.7	175.2	278.7	194.3	457.8	194.3	457.8
1.5	3	6	2.00	1.50	34.0	262.5	321.0	215.0	236.3	340.6	1274.0	252.2	713.0
2.0	3	6	2.33	1.67	42.5	309.6	321.2	254.0	206.7	449.7	2023.9	317.5	1033.6
Subsoil D													
0	8	6	1.00	1.00	10.5	117.9	139.6	117.9	139.6	107.1	168.4	107.1	168.4
0.5	8	6	1.13	1.17	21.0	131.6	205.1	132.4	216.0	151.4	299.3	156.9	321.1
0.8	8	6	1.20	1.27	27.3	144.8	227.5	152.8	264.2	180.0	394.6	190.9	442.4
1.0	8	6	1.25	1.33	31.5	147.2	223.4	156.4	247.6	200.9	496.4	214.3	531.9
1.5	6	6	1.50	1.50	42.0	162.4	168.9	162.4	168.9	282.1	825.51	282.1	225.5
2.0	6	6	1.67	1.67	52.5	163.2	102.4	163.2	102.4	359.2	1208.0	359.2	1208.0

The distribution of an additional stress

$$\sigma'_z = \sigma_z - \gamma h \tag{7}$$

on the surface of lower layer calculated based on PLAXIS [6] is shown in figure 4.

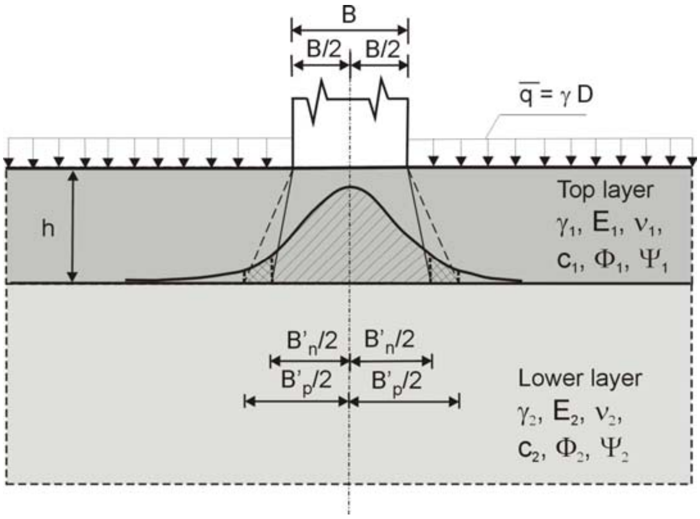

Fig. 4. Vertical additional stress σ'_z on the surface of lower layer

The vertical force acting on the substitute strip foundation base is calculated from the following equations

$$N'_{nast} = 2\int_0^{B'_n} \sigma'_z \, dB \,, \tag{8a}$$

$$N'_{pst} = 2\int_0^{B'_p} \sigma'_z \, dB \tag{8b}$$

for Polish Standards B'_n and authors' B'_p width of substitute foundations. Using PLAXIS Version 8 the bearing capacity of square substitute foundations were calculated as the radii of circle foundations

$$R'_n = \frac{B'_n}{\sqrt{\pi}} \,, \tag{9a}$$

$$R'_p = \frac{B'_p}{\sqrt{\pi}} \,. \tag{9b}$$

The values

$$N'_{nsq} = 2\pi\int_0^{R'_n} \sigma'_z \, r \, dr \,, \tag{10a}$$

$$N'_{psq} = 2\pi \int_0^{R'_p} \sigma'_z \, r \, dr \tag{10b}$$

were calculated and given in table 4.

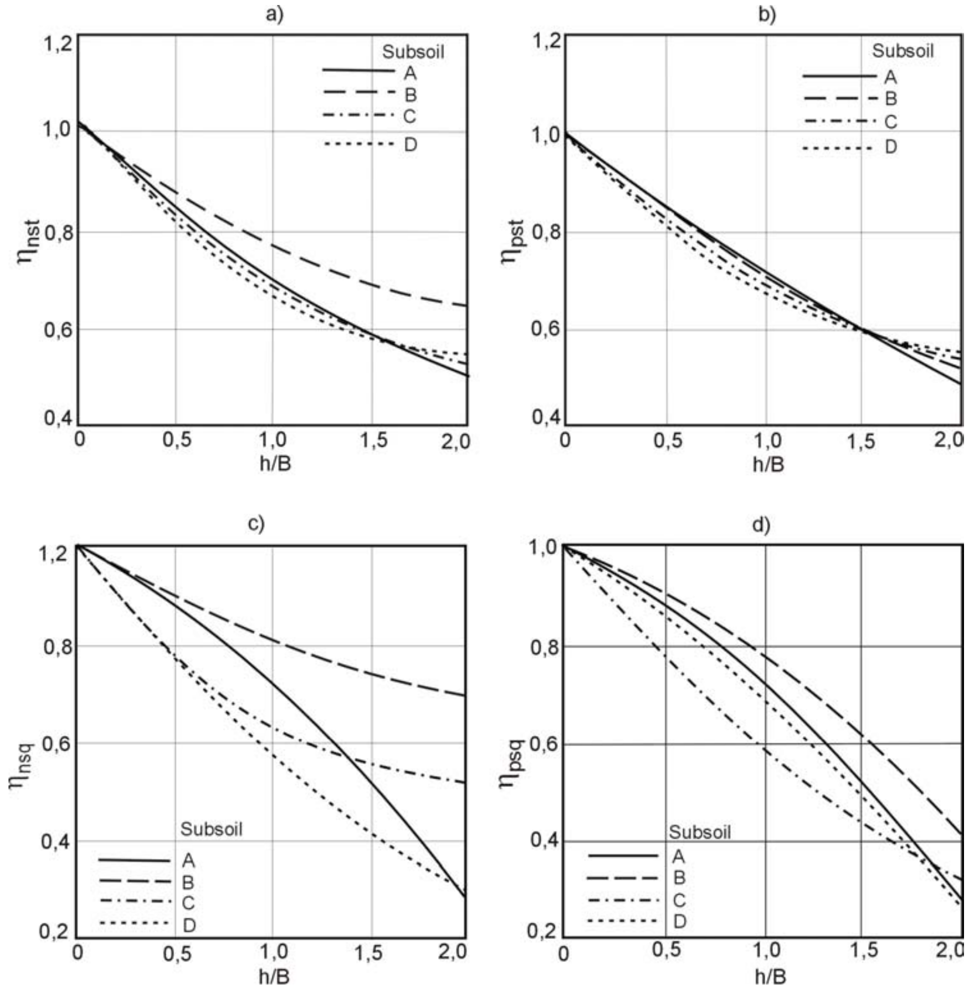

Fig. 5. Dependence of η on h/B

The factors

$$\eta_{nst} = \frac{N'_{nst}}{Q_{PLst}}, \tag{11a}$$

$$\eta_{pst} = \frac{N'_{pst}}{Q_{PLst}}, \tag{11b}$$

$$\eta_{nsq} = \frac{N'_{nsq}}{Q_{PLsq}}, \tag{11c}$$

$$\eta_{psq} = \frac{N'_{psq}}{Q_{PLsq}} \tag{11d}$$

that illustrate a real participation of the substitute foundation (N') in the bearing capacity of real foundation (Q_{PL}) are shown in figure 5.

The values of the factor η increase slower along with an increase of h/B. It is evident that the substitute foundation is only a virtual foundation in calculating the bearing capacity of layered subsoil. The evident difference between η_n and η_p was not revealed so from this point of view both propositions are equally suitable.

In figure 6, the following factors

$$\omega_{nst} = \frac{Q_{nst}}{Q_{PLst}}, \tag{12a}$$

$$\omega_{pst} = \frac{Q_{pst}}{Q_{PLst}}, \tag{12b}$$

$$\omega_{nsq} = \frac{Q_{nsq}}{Q_{PLsq}}, \tag{12c}$$

$$\omega_{psq} = \frac{Q_{psq}}{Q_{PLsq}} \tag{12d}$$

that affect h/B are shown.

It can be seen that the values ω approach unity at $h/B < 1.5$ in strip foundations and $h/B < 1$ in square foundations, but only in the case of the subsoils C and D. In the subsoil of types A and B, the values ω are much higher than unity, so the proposition of the substitute foundation in ultimate limit state of shallow foundations is not correct. The use of the substitute foundation in ultimate limit state is admissible only to the subsoil C at $h/B < 1$ and the subsoil D. These limitations are not given in Polish Standards [7].

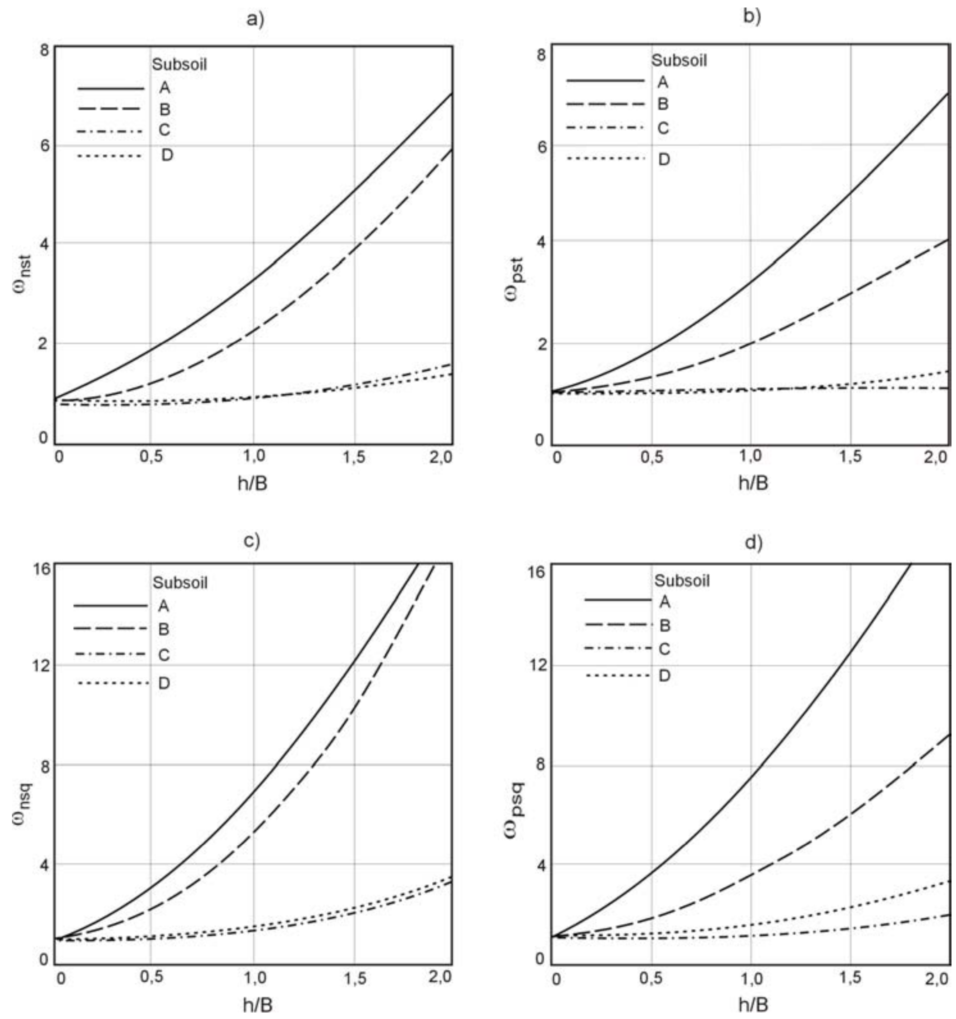

Fig. 6. Dependence of ω on h/B: a) ω_{nst}, b) ω_{pst}, c) ω_{nsq}, d) ω_{psq}

3.3. THE HOMOGENEOUS SUBSOIL

The bearing capacity of multi-layered subsoil can be calculated based on the average values of γ , c and Φ [1] (equation (1)), typical of a homogeneous subsoil. The average values of γ and c of multi-layered subsoil are calculated from the equations:

$$\gamma_{av} = \frac{\gamma_1\ h_1 + \gamma_2\ h_2 + \ldots + \gamma_n\ h_n}{\sum h_i}, \tag{13a}$$

$$c_{av} = \frac{c_1\ h_1 + c_2\ h_2 + \ldots + c_n\ h_n}{\sum h_i} . \tag{13b}$$

In this paper, two procedures for calculating the average values of Φ are considered. They are as follows:

- a direct procedure

$$\Phi_{av} = \frac{\Phi_1\ h_1 + \Phi_2\ h_2 + \ldots + \Phi_n\ h_n}{\sum h_i} , \tag{14}$$

- an indirect one

$$\tan\ \Phi_{av} = \frac{\tan\ \Phi_1\ h_1 + \tan\ \Phi_2\ h_2 + \ldots + \tan\ \Phi_n\ h_n}{\sum h_i} . \tag{15}$$

The values Φ_{av} calculated from equation (15) are denoted by Φ^*_{av}. The values of the bearing capacity of two-layered subsoil, where $h_1 = h$ and $h_n = h_2 = H - h$ at $H = 2B$ calculated for the average values of γ_{av}, c_{av} (13) and Φ_{av} calculated from equation (14) and Φ^*_{av} calculated from equation (15), are denoted by Q_h and Q^*_h, respectively. The values of Q_{hst}, Q^*_{hst} for strip foundations and Q_{hsq}, Q^*_{hsq} for square foundations are given in table 5.

The factors

$$\alpha_{hst} = \frac{Q_{hst}}{Q_{PLst}} , \tag{16a}$$

$$\alpha_{hsq} = \frac{Q_{hsq}}{Q_{PLsq}} , \tag{16b}$$

$$\beta_{hst} = \frac{Q^*_{hst}}{Q_{PLst}} , \tag{16c}$$

$$\beta_{hsq} = \frac{Q^*_{hsq}}{Q_{PLsq}} , \tag{16d}$$

representing the difference between the values of the bearing capacity of homogeneous subsoil calculated from equation (1) and the bearing capacity calculated by PLAXIS programme, treated as a correct value, are shown in figure 7.

Table 5

The values of bearing capacity of homogeneous subsoils

h/B	γ_{av}	c_{av}	Φ_{av}	Φ^*_{av}	Q_{hst}	Q_{hsq}	Q^*_{hst}	Q^*_{hsq}
	kN/m^3	kN/m^2	[°]	[°]	kN/m	kN	kN/m	kN
Subsoil A								
0	16.0	0.0	29.5	29.5	294.7	540.7	294.7	540.8
0.5	17.3	4.5	25.9	26.2	289.7	486.8	299.8	503.3
0.8	18.0	7.2	23.7	24.1	282.3	457.5	293.7	475.6
1.0	18.5	9.0	22.3	22.7	278.6	440.6	290.1	459.7
1.5	19.8	13.5	18.6	19.0	267.6	405.2	272.4	414.2
2.0	21.0	18.0	15.0	15.0	248.0	364.5	248.0	364.5
Subsoil B								
0	16.0	0.0	29.5	29.5	250.9	453.7	250.9	453.7
0.5	16.3	0.0	30.1	30.1	283.6	489.4	283.6	489.4
0.8	16.4	0.0	30.6	30.5	303.6	520.7	300.3	515.4
1.0	16.5	0.0	30.8	30.8	313.6	535.7	311.1	535.7
1.5	16.8	0.0	31.4	31.4	341.5	577.4	341.5	577.8
2.0	17.0	0.0	32.0	32.0	374.0	625.6	374.0	625.6
Subsoil C								
0	22.8	9.0	10.0	10.0	102.2	156.0	102.2	156.0
0.5	20.7	6.7	15.5	16.1	115.6	194.0	137.2	211.8
0.8	20.0	5.4	18.8	19.6	147.0	236.0	157.0	250.9
1.0	19.5	4.5	21.0	21.8	167.1	270.2	180.1	291.2
1.5	18.2	2.2	26.5	27.2	235.4	390.4	255.5	422.0
2.0	17.0	0.0	32.0	32.0	377.4	625.6	374.0	625.6
Subsoil D								
0	22.0	9.0	10.0	10.0	107.2	168.4	107.2	168.4
0.5	21.7	11.3	11.3	11.3	137.2	210.3	137.2	210.3
0.8	21.6	12.6	12.0	12.0	156.8	237.9	156.8	237.9
1.0	21.5	13.5	12.5	12.5	168.4	253.7	168.4	253.7
1.5	21.2	16.8	13.8	13.8	216.6	321.9	218.7	321.9
2.0	21.0	18.0	15.0	15.0	248.0	364.5	248.0	364.5

It can be noticed see that at $h/B = 0$ and $h/B = 2$ (homogeneous subsoil) the values of α and β are close to unity. The biggest difference emerges at $h/B = 1$. Generally, we can say that the values of β are close to those of α and two procedures of calculating the average values of Φ are effective. So the use of the average parameters of homogeneous subsoil in equation (1) is simple and correct procedure from engineering point of view for calculation of the bearing capacity of layered subsoil.

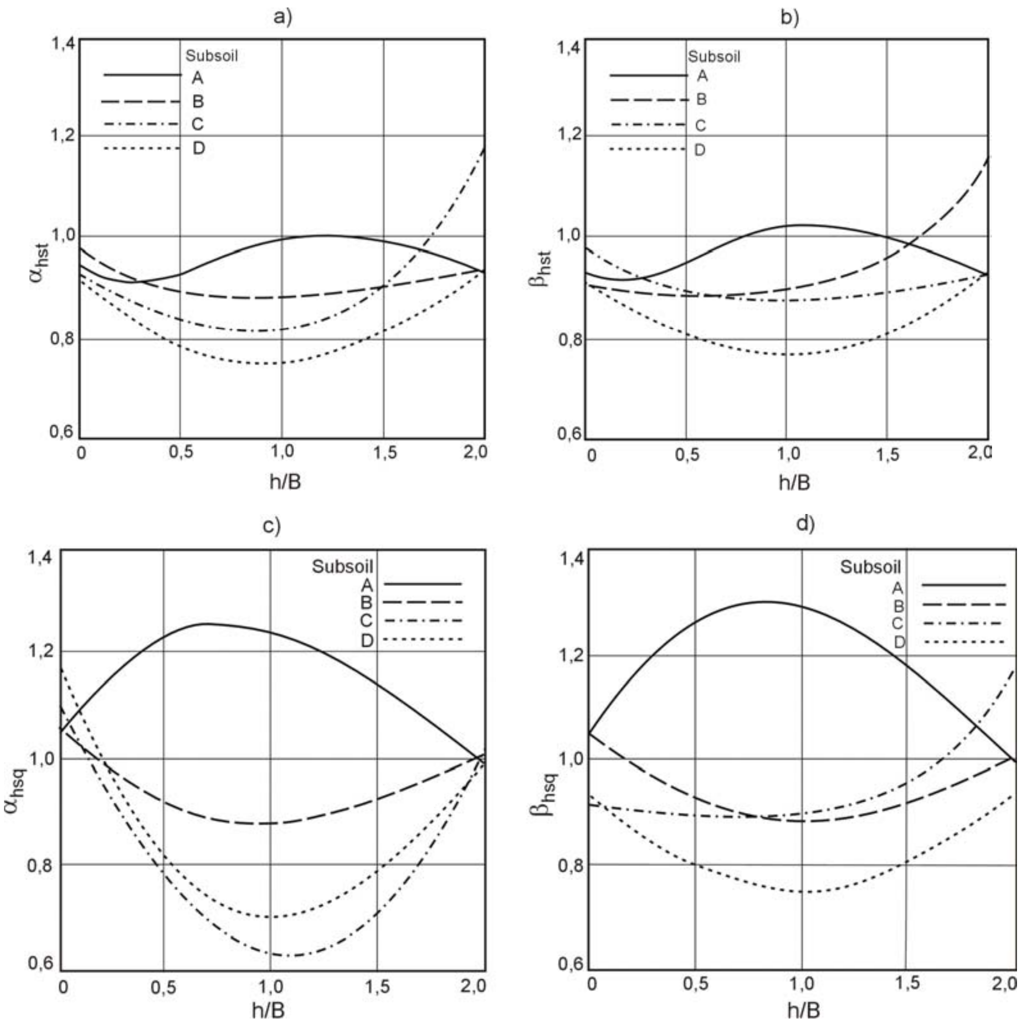

Fig. 7. Dependence of α and β on h/B:
a) α_{hst}, b) β_{hst}, c) α_{hsq}, d) β_{hsq}

4. CONCLUSIONS

From the engineering point of view only the layer thickness $H = 2B$ influences the subsoil bearing capacity. Accordingly to the Polish Standards the substitute foundation can be laid only on the top of a very weak cohesionless lower layer. The simpler authors' modification of the Polish Standards proposition for that case is also correct. The most general, simple and correct calculation of the bearing capacity of layered subsoil is done based on the Terzaghi formula with average parameters of homogeneous subsoil. There is no big difference in the bearing capacity if we use a direct formula for calculating the average angle of friction or indirect formula. In this paper, the investigation was carried out only for strip and square foundations of the width $B = 1.0\ \mathrm{m}$ loaded symmetrically and vertically. In authors' opinion, similar conclusions are correct for other loaded foundations of different size and shape.

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