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CALCULATIONS OF THE BEARING CAPACITY OF THE MULTILAYER FOUNDATION BASE

MALYSHEV, M.V. and NIKITINA, N.S.

Moscow Civil Engineering Institute, Moscow, USSR

SYNOPSIS

To estimate the foundation bearing capacity the Terzaghi three-component formula is used. The bearing capacity of multilayer foundation base is found using the coefficients derived for homogeneous foundation bases by any available or earlier approved design methods. With these coefficients used, the zone of bulging is built outlined from below by two intersecting planes. The pattern is generalized for the case of multilayer foundation bases, the number of layers being unrestricted. Simple formulas are derived for averaging bearing capacity coefficients envolving the effect produced by all the layers in the bulging zone. The paper presents an example of such a design pattern.

To define the values of ultimate pressure on the soil adequate to the foundation bearing capacity the Terzaghi (1943) three-component formula is usually used

$$q = \frac{1}{2} N_\gamma \gamma B + N_q \gamma' D + N_c c \qquad (1)$$

where N_γ, N_q, N_c - bearing capacity coefficients with their values depending on the angle of internal friction φ, γ - a mean value of the unit weight of the foundation base soils, γ' - a mean value of the unit weight of soils at the sides of the foundation of B width, D - the foundation depth. N_q and N_c coefficients are usually defined by the formulas obtained from Prantl solution and N_γ by numerical integrating. The tables of these coefficients, including are given by Vesić (1975).

The Prandtl design solution as well as other engineering schemes have been developed as applied to the foundation base of homogeneous soils. But in reality, foundations comprising soils of different strength properties and strongly pronounced laminated bedding are often encountered.

The design of the bearing capacity of multilayer foundation bases is usually made by the method based on using round cylindrical surfaces of sliding. Following it the coefficients for two-layer foundation bases have been tabulated. The authors considered it necessary to develop such a pattern of designing foundation bearing capacity which would be based on a simple design scheme and in case of a homogeneous foundation base could yield the same coefficient values as defined by more accurate but more complicated design techniques. As such a simplification, a design pattern was adopted in which the bulging zone for a homogeneous foundation base was restricted by two intersecting planes. This solution simplifies the Prandtl scheme (Fig.1), which gives quite definite values of angles of enterance $\varepsilon + \varphi$ and outlet ε where $\varepsilon = \frac{\pi}{4} - \frac{\varphi}{2}$

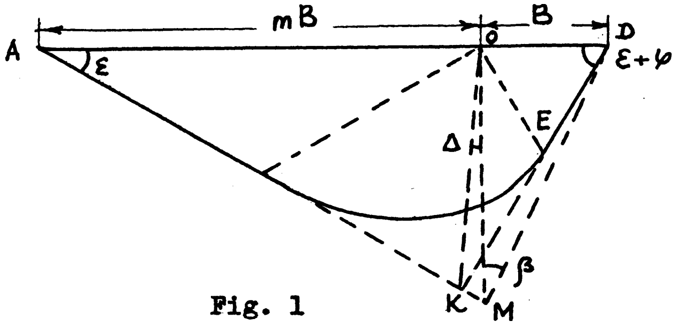


Fig. 1

If these two lines are extended to an intersection OK line will turn out to be inclined at Δ angle with respect to the vertical OM and Δ angle is defined from the relationship

$$\frac{\cos(\varepsilon-\Delta)}{\sin(\varepsilon+\varphi-\Delta)} = \frac{\cos\varepsilon}{\sin(\varepsilon+\varphi)} e^{\frac{\pi}{2}tg\varphi} \qquad (2)$$

and for $\varphi = 30°$ it is equal to $\Delta_{30°} = 36.34°$. The relative length of the bulging zone accord to Prandtl solution is equal to

$$m = e^{\frac{\pi}{2}tg\varphi}\, ctg\varepsilon \qquad (3)$$

Applying angle $\Delta \neq 0$ in the design pattern makes further derivation more complicated, therefore in the pattern adopted OM vertical is introduced instead of OK line and the angle of inclination $\angle$ ODK $= \varepsilon + \varphi$ is substituted by angle $\angle$ ODM $= \frac{\pi}{2} - \beta$ and thus $\angle$ OMD $= \beta$. In this case β angle turns out to be a function of m and is equal to

$$\beta = arcctg\,(m\, tg\varepsilon) = arcctg\; e^{\frac{\pi}{2}tg\varphi} \qquad (4)$$

The zone of bulging for laminated foundation may be drawn in a similar way as it is done for a homogeneous foundation base (Fig.2)

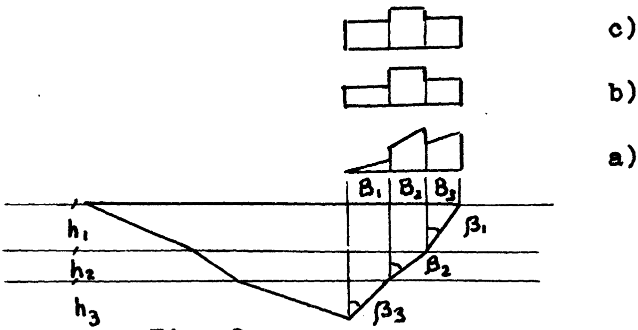


Fig. 2

The greatest diffilty is caused by the calculation of an average value of coefficient N_γ^{av}. As concluded from the theory of ultimate equilibrium of loose media the graph of loads in this case will be of triangulsr shape. Proceeding from the concept that the bearing capacity, that is, the resultant of pressure graphs of a homogeneous foundation bases with averaged characteristics indices must be equal to the bearing capacity of a laminated foundation we obtain according to the scheme (Fig.2,a)

$$\gamma_{av} N_\gamma^{av} = \sum_{i=1}^{n} \gamma_i N_\gamma^{(i)} \left(\frac{B_i}{B}\right)^2 + 2 \sum_{i=2}^{n} \left(N_q^{(i)} - 1\right) \left(\sum_{K=1}^{i-1} \gamma_K \frac{h_K}{B}\right) \frac{B_i}{B} \qquad (5)$$

and for a two-layer foundation base -

$$\gamma_{av} N_\gamma^{av} = \gamma_1 N_\gamma' \left(\frac{B_1}{B}\right)^2 + \gamma_2 N_\gamma'' \left(\frac{B_2}{B}\right)^2 + 2\left(N_q'' - 1\right) \gamma_1 \frac{h_1}{B} \cdot \frac{B_2}{B} \qquad (6)$$

Also we have

$$B_{i-1} = \frac{N_q^{(i)} - 1}{N_\gamma^{(i)}} h_{i-1} \; ; \qquad \sum_{1}^{n} \frac{B_i}{B} = 1 \qquad (7)$$

Here h_{i-1} - the thickness of (i - 1) - layer. The relative design thickness of the lower layer is obtained from the relationship

$$\frac{h_n}{B} = \left(1 - \sum_{i=1}^{n-1} \frac{N_q^{(i+1)} - 1}{N_\gamma^{(i+1)}} \cdot \frac{h_i}{B}\right) \operatorname{Ctg} \beta_n \qquad ,(8)$$

The β_n angle could be determined by formula (4).
For N_q coefficients the average value of N_q^{av} is obtained according to Fig.2,b

$$\mathcal{N}_q^{av} = \sum_{i=1}^{n} \mathcal{N}_q^{(i)} \frac{B_i}{B} \qquad (9)$$

and for the item added to the cohesion values (Fig.2,c)

$$c_{av} \mathcal{N}_c^{av} = \sum_{i=1}^{n} c_i \mathcal{N}_c^{(i)} \frac{B_i}{B} \qquad (10)$$

Formulas (9) and (10) for two-layer foundation yield give

$$\mathcal{N}_q^{av} = \mathcal{N}_q'' + \left(\mathcal{N}_q' - \mathcal{N}_q''\right) \frac{B_1}{B} \qquad (11)$$

$$c_{av} \mathcal{N}_c^{av} = c_2 \mathcal{N}_c'' + \left(c_1 \mathcal{N}_c' - c_2 \mathcal{N}_c''\right) \frac{B_1}{B} \qquad (12)$$

The values, derived from formulas (5),(9) and (10) for multilayer foundation base or from (6),(11) and (12) for two-layer foundation base are substituted into the formula (1) as average values, and in this way the bearing capacity of a laminated foundation is calculated as the bearing capacity of a one layer foundation base.

Consider an example of the design. Find the influence of a weak layer 0.5 m thick with a foundation width of B = 2 m. The soil characteristics and the dimensions are evident from Fig.3. Consider several values h_1 with thickness h_3 rather great. The data according to formula (4) and to Vesić(1975) are given in Table I.

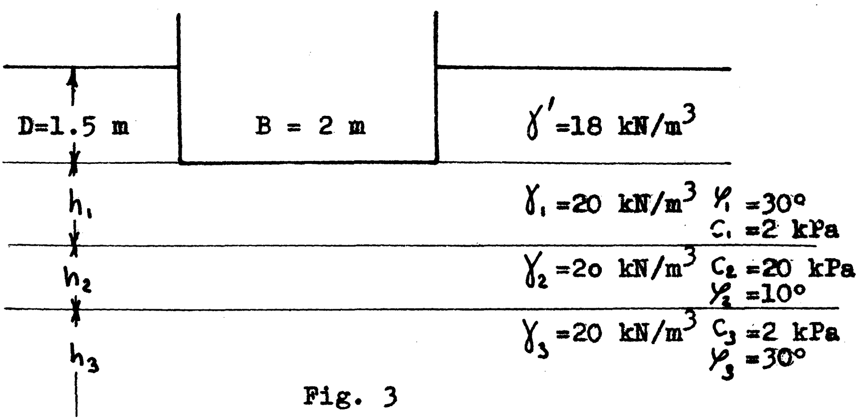


Fig. 3

Table I

φ°	$\mathcal{N}_\gamma$	$\mathcal{N}_q$	$\mathcal{N}_c$	ε°	β°	$tg\,\beta$
10	1.22	2.47	8.35	40	37.16	0.7579
30	22.40	18.40	30.14	30	21.99	0.4038

For different values of h_1/B with h_2/B =0.25 the data derived from formulas (7) and (8) are tabulated in Table II.

Table II

h_1/B	B_1/B	B_2/B	B_3/B
0	0	0.1895	0.8105
0.5	0.2019	0.1895	0.6086
1.0	0.4038	0.1895	0.4067
1.5	0.6057	0.1895	0.2048
2.0	0.8076	0.1895	0.0029
2.5	1	0	0

For three-layer foundation base formula (5) is

$$\gamma_{av} N_\gamma^{av} = \gamma_1 N_\gamma' \left(\frac{B_1}{B}\right)^2 + \gamma_2 N_\gamma'' \left(\frac{B_2}{B}\right)^2 + \gamma_3 N_\gamma''' \left(\frac{B_3}{B}\right)^2 + \tag{13}$$

$$+ 2\gamma_1 \left(N_q'' - 1\right) \frac{h_1}{B} \frac{B_2}{B} + 2\left(\gamma_1 \frac{h_1}{B} + \gamma_2 \frac{h_2}{B}\right)\left(N_q''' - 1\right) \frac{B_3}{B}$$

and formulas (9) and (10) yield

$$N_q^{av} = N_q' \frac{B_1}{B} + N_q'' \frac{B_2}{B} + N_q''' \left(1 - \frac{B_1}{B} - \frac{B_2}{B}\right) \tag{14}$$

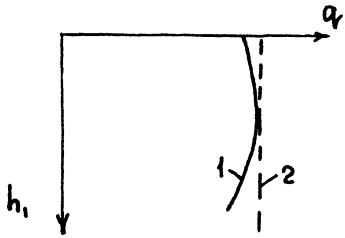
$$c_{av} N_c^{av} = c_1 N_c' \frac{B_1}{B} + c_2 N_c'' \frac{B_2}{B} + c_3 N_c''' \left(1 - \frac{B_1}{B} - \frac{B_2}{B}\right) \tag{15}$$

The results of the calculations are tabulated in Table III as well as pressure q derived from formula (1).

Table III

h_1, m	h_1/B	$\gamma_{av} N_\gamma^{av}$, kN/m^3	N_q^{av}	$c_{av} N_c^{av}$, kPa	q, mPa
0	0	436.2	15.4	80.5	0.93
1	0.5	508.3	15.4	80.5	1.00
2	1.0	513.0	15.4	80.5	1.01
3	1.5	450.2	15.4	80.5	0.95
4	2.0	319.9	15.4	80.5	0.85
5	2.5	448.0	18.4	60.3	1.00

Thus the greatest bearing capacity will occur when the weak streak is in the middle portion of the zone of repture. The design data are presented in Fig.4.



1 - with weak layer
2 - without it

Fig. 4

CONCLUSIONS

Simple formulas for the averaging bearing capacity coefficients N_γ , N_q and N_c for the multi-layer foundation bases are derived. It is possible to calculate them by formulas, which were given above.

REFERENCES

Terzaghi K. (1943). Theoretical Soil Mechanics. J.Wiley & Sons, New York.

Vesić A. (1975). Bearing Capacity of Shallow Foundations. In: Foundation Engineering Handbook, by H.F.Winterkorn and Hsai-Yang Fang. Van Nostrand Reinhold Co. New York