SOIL MECHANICS

EXPERIMENTAL ANDTHEORETICAL RESEARCH ON THE BEARING CAPACITY OF RING-FOUNDATION BEDS

A. M. Karaulov
Siberian State Correspondence University.

UDC 624.131:624.15

Results are presented for solution of the problem of the limiting pressure of a ring foundation on a soil bed. Formulas and tables are given for practical calculations. Experimental data are cited for determination of the limiting pressure of an annular plate on a sandy bed. It is demonstrated that theoretical limiting-load values obtained on the basis of the proposed procedure do not exceed experimental values.

The theory of limiting equilibrium of soils is the basis for calculation of the bearing capacity of beds [1]. Berezantsev [2] has advanced this theory for axial symmetry. As a rule, axisymmetric problems are solved using the hypothesis of complete plasticity. Certain problems, however, cannot be solved within the framework of this hypothesis [3].

Karaulov [4] resolves the problem of the limiting pressure of an annular plate on a soil bed by the static method of the theory of limiting equilibrium of soils for axial symmetry. Here, a canonical system of equations in the cylindrical coordinate system rzθ (where z is the axis of symmetry in Fig. 1) was employed in the form

$$
\begin{aligned}
& dr = dz\tan(\alpha \pm \mu); \\
& d\sigma \pm 2\sigma \tan\varphi d\alpha = \\
& = \sigma \tan\varphi \frac{(m-1)(dr\cos\varphi \pm dz\sin\varphi) \pm dz}{r} + \\
& + \gamma(dz \pm dr\tan\varphi),
\end{aligned}
\tag{1}
$$

where α is the angle of incline of the first principal stress σ_1 to the z axis, $\sigma = (\sigma_z + \sigma_r)/2 + c\cot\varphi$ is the average reduced stress, γ is the unit weight of the soil, c and φ are the specific cohesion and angle of internal friction, respectively, and $m = 2(\sigma_\theta - \sigma_3)/(\sigma_1 - \sigma_3)$ is a parameter defining the relationship between the principal stresses.

The upper signs in (1) correspond to slip lines of the first family, and the lower signs to the second family.

Figure 2 is an example of the network of slip lines in the bed of an annuar plate (γ = 18 kN/m^3, φ = 15^o, and c = 10 kPa). The solution is achieved by integrating system (1) in the region of limiting equilibrium within the framework of corresponding boundary problems of the statics of a granular medium [4]. Here, the condition of incomplete plasticity with a varying parameter m is used in conformity with the conditions

Translated from Osnovaniya, Fundamenty i Mekhanika Gruntov, No. 2, pp. 2-4, March-April, 2006.
0038-0741/06/4302-0037 ©2006 Springer Science+Business Media, Inc.

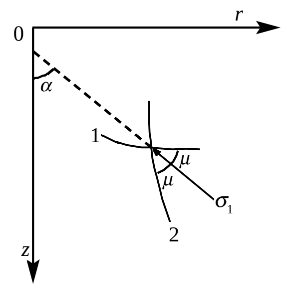

Fig. 1. Slip lines. 1 and 2) First and second families, respectively.

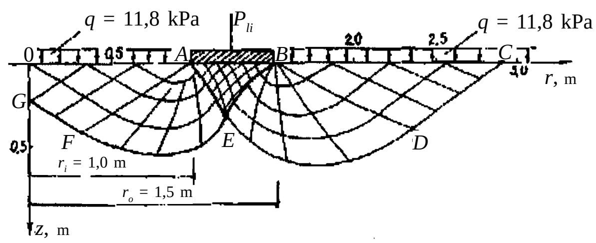

Fig. 2. Network of slip lines in bed of annular plate.

$$\begin{aligned} m &= m_0 && \text{when } \alpha \geqslant \pi/2; \\ m &= 2\alpha m_0/\pi && \text{when } 0 \leqslant \alpha \leqslant \pi/2; \\ m &= -4\alpha/\pi && \text{when } -\pi/2 \leqslant \alpha \leqslant 0; \\ m &= 2 && \text{when } \alpha \leqslant -\pi/2, \end{aligned} \tag{2}$$

where m_0 is the maximum value of m that will provide a solution to the problem.

Let us examine the average limiting pressure on a ring foundation

$$p_{li} = P_{li}/[\pi(r_o^2 - r_i^2)], \tag{3}$$

where r_o and r_i are the outside and inside radii.

Let us designate the width of the annular lower surface as $b = r_o - r_i$. It is obvious that when $r_i \to 0$, the pressure p_{li} will approach the average limiting pressure $p_{li,c}$ on a foundation with a circular lower surface of radius B. If, however, radius r_i increases without constraint, p_{li} will converge on the average limiting pressure $p_{li,s}$ of a strip foundation of width b. Let us express p_{li} as

$$p_{li} = p_{li,s} + k(p_{li,c} - p_{li,s}). \tag{4}$$

The value of $p_{li,c}$ can be calculated from the formula [4]

$$p_{li,c} = \gamma b N_\gamma + q N_q + c N_c, \tag{5}$$

where $N_\gamma = e^{10.73\varphi - 1.026}$; $N_q = e^{6.495\varphi + 1.114}$; $N_c = \cot\varphi\,(N_q - 1)$.

It is obvious that the coefficient k will depend on φ, the relative reduced surcharge $q' = (q + c\cot\varphi)/\gamma b$, and the ratio $\eta = r_i/b$. Average k values are given in [4]. We determined the k values for φ of 5, 10, 15, 20, 25, 30, 35, and 40°, and compiled tables. Table 1, which contains k values for φ of 5 (prior to slash) and 40° (after slash), can be cited as an example.

TABLE 1

η	k values for φ = 5 and 40° and q' of				
	2	4	6	8	10
0	1/1	1/1	1/1	1/1	1/1
0.4	–/1.433	0.363/–	0.406/–	0.397/–	0.404/–
0.8	–/1.095	0.204/1.345	0.214/1.554	0.210/1.562	0.210/1.562
1	–/1.939	0.184/1.196	0.193/1.361	0.191/1.371	0.193/1.376
3	–/0.241	0.096/0.326	0.104/0.384	0.102/0.394	0.105/0.405
5	–/0.142	0.064/0.188	0.071/0.217	0.070/0.221	0.073/0.227
∞	0	0	0	0	0

TABLE 2

Sand of medium density	Physico-mechanical characteristics				
	Soil density, tons/m^3	Density of soil particles, tons/m^3	Density factor	C, kPa	φ, deg
fine	1.58	2.66	0.68	0	29
coarse	1.64	2.66	0.62	0	37

The $p_{li,s}$ values were established from the formula cited in Construction Rule and regulation 2.02.01-83 [5].

Since the limiting pressure of an ring footing on a soil bed can be determined as a function of the bearing capacity of circular and strip footings, it is expedient to confirm experimentally the coefficient k characterizing the gradual transition from the circular to the strip footing in conformity with formula (5.20) in [5].

Experiments were conducted with ring textolite plates with an annuar width of 3 cm and different inside radii r_i: 0 (circular plate), 0.5, 1.0, 1.5, 2.5, and 4.5 cm. To create a roughened lower surface, a layer of sand was applied to the lower plane of the ring, which had been treated with an adhesive.

The experiments were conducted on two varieties of dry sandy soils (Table 2).

We conducted the experiments in the following sequence.

Sand was placed in a pan in layers each 5 cm thick, and compacted. To determine the density of the sand and its strength properties in the bed, the rings were set in the bed for the sampling of soil specimens. The strength parameters were determined in a shear device by the direct-shear method.

An annular plate was established on the prepared bed. The horizontal position of the plate was monitored with a level. A load was applied to the plate in steps of 1/10 the theoretical value of p_{li} via a loading device. Loading was continued to complete failure of the bed, which was characterized by collapse with lateral uplift of soil both from the outside and inside of the ring.

Only the limiting pressure P_{li}^{o} on the ring plate was determined as a result of the experiment. Three tests were conducted for each ring, as a result of which the average limiting pressure $P_{li,\mathrm{avg}}^{o}$ and limiting average load $p_{li}^{o} = (1/A)(P_{li,\mathrm{avg}}^{o})$ on the ring plate were determined, where A is the area of the ring.

The coefficient k was calculated from the formula

$$k = \frac{(p_{li}^{o} / p_c^{o}) - (p_s / p_c)}{1 - (p_s / p_c)}, \tag{6}$$

TABLE 3

r_i, cm	η	p^{o}_{li}, kPa	k	k_{teor}
0	0	14.5/61.7	1/1	1/1
0.5	0.167/0.167	14.6/76.7	1.01/1.37	0.96/1.12
1	0.333/0.333	15.9/84.1	1.15/1.56	1.07/1.21
1.5	0.5/0.5	12.6/78.2	0.80/1.41	0.76/1.17
2.5	0.833/0.833	9.84/64.1	0.47/1.06	0.46/0.89
4.5	1.50/1.50	7.1/53.1	0.21/0.78	0.19/0.55

where p^{o}_{c} is the experimental limiting load on the circular plate. The theoretical value of the ratio p_s/p_c for φ = 29 and 37° is ≅0.35. Accordingly, the expression for k was adopted as

$$k = \frac{(p^{o}_{li} / p^{o}_{c}) - 0.35}{0.65}. \qquad (7)$$

Results of tests of the impression of ring plates on fine (ahead of slash) and coarse (after slash) sands with φ = 29 and 37°, respectively, are presented in Table 3.

Comparison of the experimental and theoretical k values indicates that the theoretical are lower than the experimental values, and the discrepancy amounts to 30%.

Conclusions

1. The problem of the limiting pressure of a ring foundation on a bed can be resolved using condition (2).

2. Theoretical values of the limiting loads calculated on the basis of the proposed procedure do not exceed experimental data on the bearing capacity of the bed.

REFERENCES

1. V. V. Sokolovskii, *Statics of a Granular Medium* [in Russian], Fizmatgiz, Moscow (1960).
2. V. G. Berezantsev, *Density Analysis for Beds of Structures* [in Russian], Gosstroiizdat, Leningrad-Moscow (1960).
3. A. I. Kalaev, *Bearing Capacity of Beds Beneath Structures* [in Russian], Stroiizdat, Leningrad (1990).
4. A. M. Karaulov, *Bearing Capacity of Beds Beneath Axisymmetric Foundations* [in Russian], Izdatel'stvo Sibirskogo Gosudarstvennogo Universiteta Putei Soobshcheniya, Novosibirsk (2002).
5. *Construction Rule And Regulation 2.02.03-83, Beds of Buildings And Structures* [in Russian].