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# DIAGNOSING THE PERFORMANCE OF A RING FOUNDATION BY THE BOUNDARY ELEMENT METHOD

*Using the boundary element method, prediction of the bearing capacity of ring and round foundations for critical structures has been conducted as well as comparison of their performance. A more expedient variant of the foundation structure is substantiated.*

***Keywords:*** *boundary element method, ring and round foundation structures, nonlinear stage of soil behavior.*

## Introduction

Ring and round foundations are the most common foundation structures for such critical constructions as bunkers, chimneys, tanks.

The results of monitoring the settlement of buildings show significant discrepancies between actual and calculated values. This is due to the conventionality of design schemes, neglection of the soil stabilization processes.

Prediction of the stress-strain state of a “ring foundation – base” system is possible with orientation to the new computation technologies with the use of numerical simulation means based on scientific platforms, which have been actively developed and allow to raise the level of adequacy.

In this paper simulation procedure is based on the boundary element method (BEM). The property of ring foundations to realize bearing capacity both along inner and outer lateral surfaces and the edge provides significant advantage to ring foundations.

## Problem statement, defining relationships

The paper investigates special characteristics of the deformation process and bearing capacity of the ring foundation as well as conducts comparison with the performance of round foundation of the same dimensions (Fig. 1).

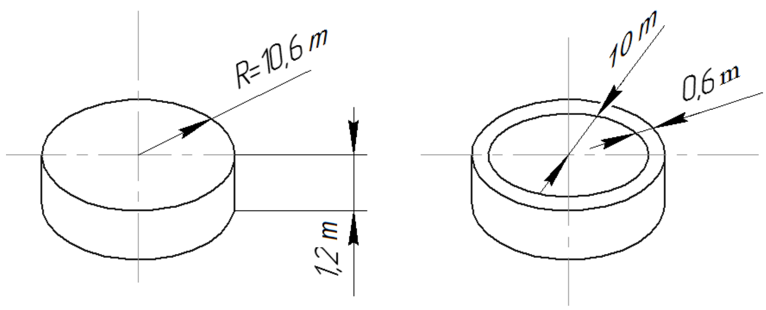


Fig. 1.Designs of the round and ring foundations

Design integral equation of the behavior of foundation structure in soil was obtained by C. Brebbia [1]:

$$c_{i,j}(\xi)u_j(\xi)+\int_{\Gamma} p^*_{i,j}(\xi,x)u_j(x)d\Gamma(x)=\int_{\Gamma} u^*_{i,j}(\xi,x)p_j(x)d\Gamma(x), \tag{1}$$

where $p_i(x)$ - the required stress vector at the object boundary; $u_i(\xi)$ - the specified displacement vector at the boundary of the object; $p^*_{i,j}(\xi,x), u^*_{i,j}(\xi,x)$ - fundamental functions of R. Mindlin.

For numerical solution of the problem BEM is used as well as mechanics of continuous and porous media. Simultaneous presence of the soil zones that work both in elastic and plastic stages requires application of the theory of elasticity and plasticity.

Calculation of the round foundation has been carried out according to the model of solving a nonlinear problem of soil mechanics based on the nonlinear dilatancy model [2,3]. Matrix notation of the integral boundary equilibrium equation [1] for the limit node has the form of:

$$HU = GP + DE^P, \tag{2}$$

where $H = \int_S \rho^* \Phi d\Gamma$; $G = \int_S U^* \Phi d\Gamma$ – integrals for each boundary element of the lateral surface and the lower surface that are calculated by the schemes of numerical integration of two-dimensional Gaussian quadrature, $G$ – influence matrix of BEM; $U^*, \rho^*$ – kernels of the boundary equation, Green's influence matrix, in this paper – fundamental singular solutions of R. Mindlin; $\Gamma, \xi, x$ – boundary, disturbance point, the point of supervision respectively;

$D = \int_\Omega \sigma^* \Phi^T d\Omega$ - integrals comprising inelastic deformations correspond to matrix $D$.

Generalized criterion of Mises – Schleicher – Botkin is adopted as a criterion of transition to limit state.

$$f = \begin{cases} \tau_{oct} + \sigma_{oct} tg\psi - \tau_s = 0 \;\; for\, \sigma_{oct} > \rho_0; \\ \tau_{oct} + \rho_o tg\psi - \tau_s = 0 \;\; for\, \sigma_{oct} < \rho_0. \end{cases} \tag{3}$$

where $\tau_{oct}, \sigma_{oct}$ – intensity of tangential stresses and hydrostatic pressure on the octahedral plane, $\rho_0$ – point of transition from the cone to the cylinder in the Mises – Schleicher – Botkin condition, $\tau_s$ – tangential stresses for $\sigma_{oct} = 0$.

To determine the amount of plastic deformation the non-associated law of plastic flow is used [4].

$$d\dot{\varepsilon}^p = d\lambda \frac{\partial F}{\partial \sigma_{i,j}}, \;\; F \neq f, \tag{4}$$

where $d\varepsilon^p$ – increment of the tensor of soil plastic deformation; $d\lambda$ – scalar factor; $F$ – plastic potential, function of deformation history; $\sigma$ – tensor of stresses; $f$ – load surface.

In order to find increment of the volumetric deformation tensor, dilatancy ratio of V. M. Nikolayevskiy and I. P. Boyko are used [2, 3]:

$$d\varepsilon^p_{layer} = \Lambda(\rho) d\gamma^p \tag{5}$$

where $d\varepsilon^p_{layer}$ – scalar equivalent of the soil volumetric deformation increment (inelastic volumetric deformation); $d\gamma^p$ – intensity of the plastic shear deformation increment; $\Lambda(\rho)$ – dilatancy coefficient, that depends on soil density ρ and can take both positive (dilatancy) and negative (contractancy) values [2,3].

Fig. 2 shows a numerical prediction of the round foundation behavior under load by BEM.

Weighted average indicators of engineering-geological surveys serve as the input parameters of the model:

Table 1

**Weighted average characteristics of the soil layers**

| E, *MPa* | φ, ° | $\rho^{min}$, $t/m^3$ | $\rho^{max}$, $t/m^3$ | $\rho$, $t/m^3$ | $\upsilon$ | C, *KPa* | *e* |
|---|---|---|---|---|---|---|---|
| *18* | *19* | *1.2538* | *2.0428* | *1.895* | *0.35* | *27.81* | *0.7952* |

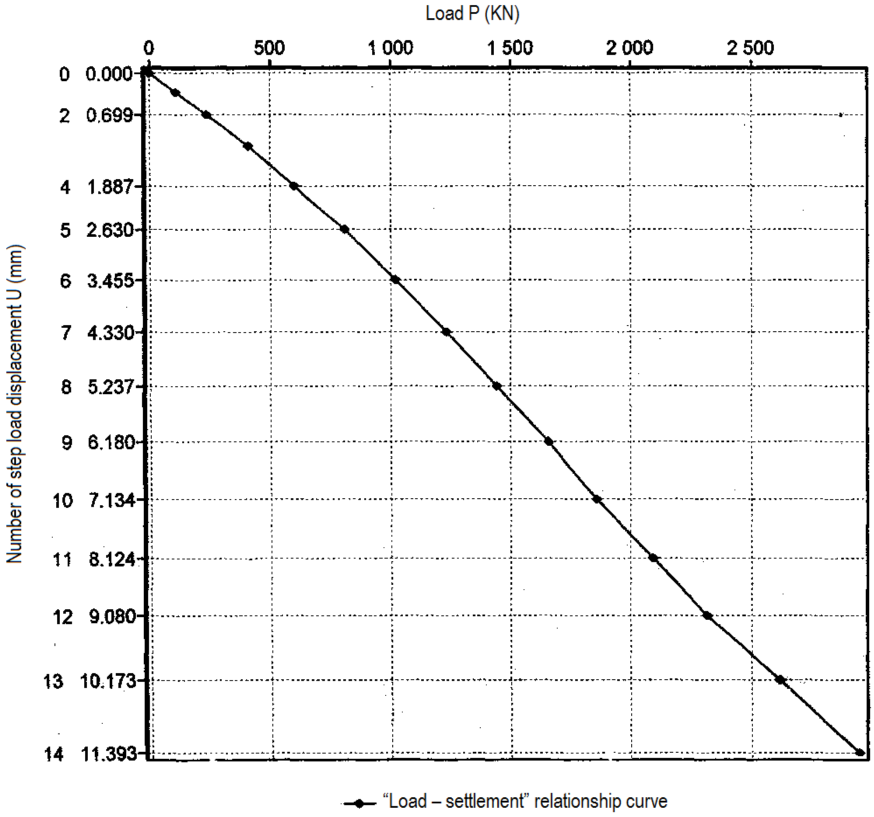


Fig. 2. "Load – settlement" relationship curve for the round foundation

To determine bearing capacity of the ring foundation (Fig. 1) by BEM, a program was written in the algorithmic language Delphi. Lateral surfaces of the ring foundation contact with the soil and the base were discretized by constant boundary elements.

Calculation boundary equation of BEM that links $\sigma - \varepsilon$ at the boundary (foundation contact surface with the soil) has the form of:

$$cU + \int_S UG^* d\Gamma = \int_S qU^* d\Gamma, \tag{6}$$

where $U, q$ - displacements and stresses at the foundation boundary; $U^*, G^*$ - fundamental solutions of R. Mindlin for an elastic half-plane; *c* – coefficient equal to 1/2 for constant boundary elements.

Matrix formulation of the design boundary equation of equilibrium has the form:

$$A \cdot \vec{\Upsilon} = F, \tag{7}$$

where *F* – vector of displacements, $\vec{\Upsilon}$ – vector of the required forces at the boundary of foundation structure ($\tau_{s1}, \tau_{s2}$ – tangential stresses at the external and internal lateral surfaces of the ring foundation and $\sigma_e$ – normal stresses along its base); *A* – BEM influence matrix that was composed from the solutions of R. Mindlin for an elastic half-plane.

Matrix $|A|$ for the ring foundation was composed from 9 submatrices formed from fundamental solutions of R. Mindlin:

$$\begin{vmatrix} KS1S1 & KS2S1 & KBS1 \\ KS1S2 & KS2S2 & KBS2 \\ KS1B & KS2B & KBB \end{vmatrix} \bullet \begin{vmatrix} \tau_{S1} \\ \tau_{S2} \\ \sigma_e \end{vmatrix} = \begin{vmatrix} 0{,}01 \\ 0{,}01 \\ 0{,}01 \end{vmatrix}, \tag{8}$$

where KS1S1, KS2S1, KBS1 – displacements of the node points of boundary elements (BE) at the external lateral surface from unit values $\tau_{s1}, \tau_{s2}, \sigma_e$;

KS1S2, KS2S2, KBS2 – displacements of the node points of BE at the ring foundation internal lateral surface from unit values $\tau_{s1}, \tau_{s2}, \sigma_e$;

KS1B, KS2B, KBB – displacements of the node points of the base BE from the unit values $\tau_{s1}, \tau_{s2}, \sigma_e$.

Vector F (right side of equation (7)) was defined for 0,01m displacement of the foundation.

By BEM, bearing capacity of the ring foundation for the settlement of 1cm is 2185 KN. According to the data of predicted settlement of the round foundation by BEM, for s = 1 cm. bearing capacity will be 2600 KN (see Fig. 2). It should be noted, however, that contact area at the base of the round foundation is 353 m$^2$ and that of the ring foundation – only 38.83 m$^2$, i. e. it is considerably (≈ 9,09 times) larger, bearing capacity of the ring foundation being only 16% smaller.

## Conclusions

The paper has further developed the method for analyzing deformation state of the ring and round foundations. The method takes into account nonlinear behavior of the soil.

When the expediency of choosing one or the other foundation structure is substantiated, it should be taken into account that the ring foundation will provide significant economy of material consumption, bearing capacity being practically the same.

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