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CIRCULAR FOUNDATION PARAMETERS OPTIMIZATION BY METHOD OF BOUNDARY ELEMENTS

Alla Morgun, Ivan Met and Roksolana Malachkovska

Vinnytsia National Technical University, Faculty Building, Power Engineering and Gas Supply, Department of Construction, Municipal Engineering and Architecture, Vinnytsia, Khmelnytske shose95, Ukraine; alla@morgun.com.ua, vanmet@ukr.net, roksimalachkovska@gmail.com

ABSTRACT

The types of structures, for construction of which it is expedient to use circular foundations, are considered. The advantages of the circular foundations as compared with other types of foundations are determined. Applying the method of boundary element (MBE), the search of optimal ratio of the internal and external diameters of circular foundation is performed to obtain maximum carrying capacity of tower drier circular foundation. The comparison of the numerical studies with the experimental data is carried out, carrying capacity of tower drier circular foundation in case of rational relations of its internal and external diameters is determined. The technique of non-linear behaviour of the circular foundation under loading as the most economically efficient type of foundation construction for ring in plan buildings is developed.

KEYWORDS

Circular foundation, Stressed-strained state, Carrying capacity, Method of boundary elements (MBE)

INTRODUCTION

Foundations are structural elements which transmit load from the construction to the ground. For the reliable transmission of these loads the foundations must be designed in such a way that avoid their excessive subsidence and provide sufficient sliding and sloping stability [2].

Besides the most investigated foundations (strip foundations, rectangular foundations, ring foundations) circular foundations are more suitable and economically efficient to provide the support of axially-symmetrical constructions such as tower silo, water-cooling towers, chimneys, transmission towers, television aerials, radar installations, smoke stacks, piers, underground parkings, water towers, shaft storage facilities and storage tanks [4].

For such constructions circular foundations are better due to the complete usage of the carrying capacity of soil basis. They are often used for the building of large and high constructions to resist lateral loadings and increase the resistance to overturning. Besides, circular foundations enable to decrease the amount of the material, used for the construction and the cost of the construction that is also very important for the investor.

Ukraine also refers to the countries where circular foundations are used in construction sphere. Characteristic trend for modern agricultural brand of our country is the necessity to construct grain complexes – dryeration bins, where the circular foundations are used, as they have higher specific carrying capacity than the spread foundations [8].

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With the growing usage of such foundations in numerous important projects, the interest to their behaviours grew. Such behaviours comprise the response to loading and maximum carrying capacity. Distribution of stresses in the basis of foundations of circular shape has qualitative and qualitative differences from the analogue foundations with the continuance bottom (ring, rectangular, strip foundations). Stressed-strained state of structures foundations depends on the form of the foundations in the plan [4].

It was found that there is no sufficient literature where the results and methods of the design for the calculation of circular foundations carrying capacity are presented. The existing methods of circular foundations calculation do not have the reliable normative base, that substantially restricts the possibilities of their rational design and usage and restrain their wide implementation, although for certain structures (smoke stacks, water cooling towers, silvers, television towers, etc.) the application of circular foundations is most expedient.

Thus, the development of reliable, scientifically substantiated methods of their stressed-strained state determination is an urgent problem for foundation construction.

PROBLEM DEFINITION

The necessity of the solution of problems, connected with the assessment of the strength and soil deformability is dictated by the requirements of engineering practice. Deformative properties of the foundation, upper structure of the tower type and soil base have different order. The characteristic feature of such structures (elevator, smoke stacks, water towers, bridge piers) is extremely high rigidity of the above-foundation part, Figure 1. They do not bend and provide gradual settling as a single mass. Conditions of such structures operation greatly depend on the soil base. Nowadays foundations of greater part of circular structures are designed in the form of shallow depth foundations.

In the given research, more accurate preconditions for the description of circular foundations behaviour, taking into account matching deformation of the foundation and nonlinear deformations of the base complex engineering-geological conditions are suggested.

Calculations of circular foundation settling [Figure 1 b] are carried out, applying modern numerical method of boundary elements and latest achievements in the sphere of dispersive soils mechanics. Spring-plastic model, based on the plastic flow theory in the form of non-associative law was elaborated.

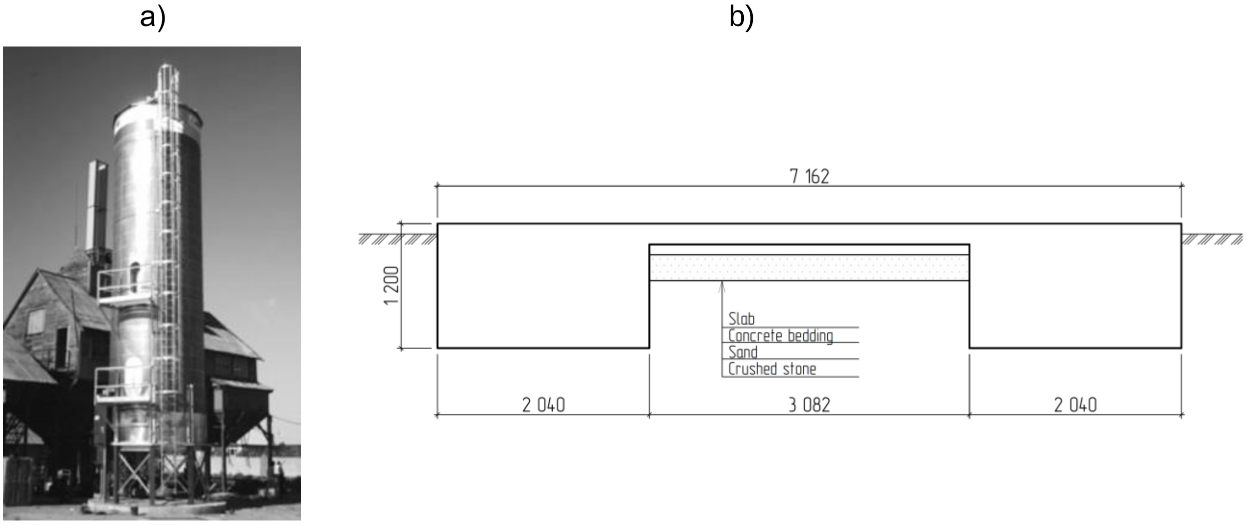

Fig. 1 – a) Tower drier; b) Geometrical characteristics of the circular foundation

Dilatancy relations of dispersive soil grounds of V.N. Nikolaevsky and I.P. Boiko, the procedure of step-by-step loading, applying the O.A. Ilushin method of spring solutions were used. As the criterion of soil transition into plastic state Mises-Shleiher-Botkin criterion was used. As the values of safe loading and boundary carrying capacity are formed by soil strength characteristics are used in the developed model, determination of these characteristics is performed by experimental standard triaxial studies of soil specimen: E=9800 kPa; ρ=1.96 t/m^3; ρ^{min}=1.64 t/m^3; ρ^{max}=2.21 t/m^3; ϑ=0.35; e=0.67; φ=26°; c=17.2 kPa; p_0=-1900 kPa.

According to the existing Building Regulations (1) carrying capacity of the circular foundation consists of the soil resistance under the footing, the first component in (1) and force of friction on the lateral surface, the second component in (1).

$$F=\gamma_c\cdot(R\cdot A\cdot\gamma_{cr}+U\Sigma f_i\cdot h_i\cdot\gamma_{cf}) \tag{1}$$

where R, f_i – is the calculated soil resistance under the footing and on the lateral surface, correspondingly; A – is the area of the foundation footing; $U\Sigma h_i$ – is the area of the lateral surface.

For determination of operating surfaces areas of the ring and circular foundations (Figure 2) the following dependences are used:

- for the ring foundation:

$$S=2\pi R\cdot H+\pi R^2, \tag{2}$$

where $A=\pi R^2,\ U\Sigma h_i=2\pi R\cdot H$.

for circular foundation carrying capacity was determined as the sum of lateral resistances on the internal and external lateral surfaces of the circular foundation and soil compression strength under the footing of the circular foundation:

$$S=2\cdot 2\pi R\cdot H+\pi R^2-\pi r^2 \tag{3}$$

where the area of the foundation footing A = $\pi R^2-\pi r^2$, area of the lateral surface $U\sum h_i=2\cdot 2\pi R\cdot H$.

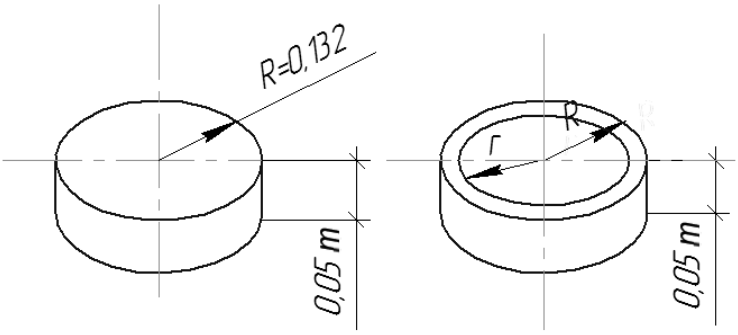

Fig. 2 – Schemes of the studied models of the circular foundation

THEORETICAL CALCULATIONS BY METHOD OF BOUNDARY ELEMENTS

Data for the calculation of working surfaces (lateral surfaces and footing) for the considered models of circular foundations are given in Table 1. For obtaining optimal ratio r/R method of gradient descent is used. Gradient of the ratio of total working surfaces of the circular foundations to the ring foundations increases to r/R = 0,4 and then decreases. Calculation data are given in Figure 3.

Tab. 1 – Data for calculation of the working surfaces of the circular foundations models

Ratio R/r	r (m)	R (m)	Area of lateral surfaces, (m^2)	Ratio to the ring foundation to lateral surfaces	Area of the point, (m^2)	Ratio to ring foundation to the point	Total working surface (m2)	Ratio of total working surfaces of the circular foundations to ring foundations
0		0,132	0,04147	1	0,0547	1	0,09617	1
0,2	0,0264	0,132	0,0497	1,198	0,05255	0,96	0,1023	1,15
0,4	0,0528	0,132	0,05806	1,4	0,04598	0,84	0,10404	1,176
0,6	0,0792	0,132	0,06635	1,6	0,03503	0,64	0,10138	1,024
0,8	0,1056	0,132	0,0747	1,8	0,1972	0,36	0,09443	0,648

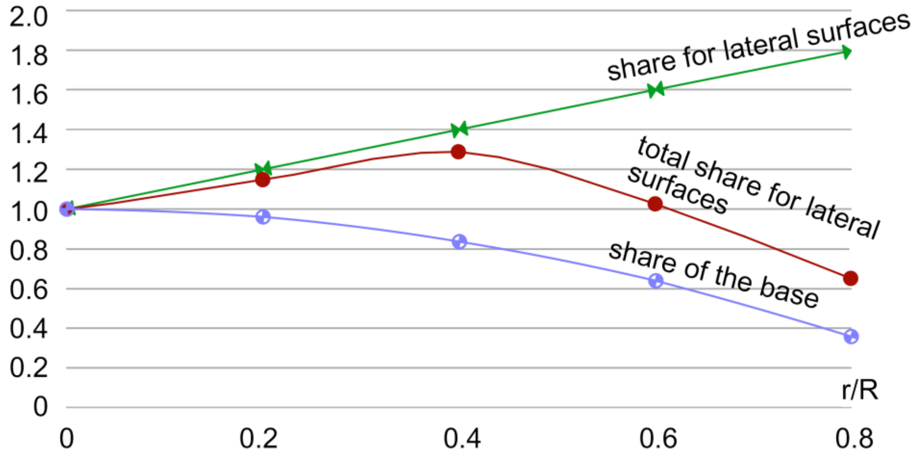

Fig. 3 – Dynamics of the indices of the circular foundation working surface change relatively the working surface of the ring foundation, depending on r/R

Elastic-plastic model, that was used, gave the basis the numerical analysis of the obtained data of the forecasting character of circular foundations deformation [5].

As the considered problem is non-linear, the step-wise iteration process is used, because step-wise procedure was and remains the integral part of finite element analysis. At each step linear problem was solved, applying O. A. Ilushin method of elastic solutions.

MBE reduces the calculation system of differential equations to the integral equation (Brebbia, 1987):

$$\left.\begin{array}{c}\sigma_{ij,j}+b_j=0\\ \varepsilon_{ij}=\frac{1}{2}(u_{i,j}+u_{j,i})\\ \sigma_{ij}=C_{ijkl}\varepsilon_{kl}\end{array}\right\}\Rightarrow C_{ij}(\xi)u_j(\xi)+\int_{\Gamma}p_{ij}^{*}(\xi,x)u_j(x)d\Gamma(x)=\int_{\Gamma}u_{ij}^{*}(\xi,x)p_j(x)d\Gamma(x), \qquad (4)$$

where $\sigma_{ij,j}+b_j=0$ are the static equilibrium equations; $\varepsilon_{ij}=\frac{1}{2}(u_{i,j}+u_{j,i})$ – are the geometrical equations; $\sigma_{ij}=C_{ijkl}\varepsilon_{kl}$ – are the physical equations of the environment.

In the process of the consideration of the non-linear problem integral equation obtained by K. Brebia [3] has the form:

$$c_{ij}u_j+\int_{\Gamma}\rho^{*}{}_{ij}u_{ij}d\Gamma=\int_{\Gamma}u_{ij}{}^{*}\rho_i d\Gamma+\int_{\Omega}\dot{\sigma}^{*}\,\dot{\varepsilon}_{jk}^{p}d\Omega \qquad (5)$$

where u – is the set vector of displacements on the contact boundary of the foundation construction; p – is the target vector of the stresses on the boundary; u^*, p^*, σ^* – are te kernels of the boundary equations (5) or MBE impact function, kernels are fundamental solutions of a boundary value problem corresponding to a source function given in the form of Dirac delta function [5]. In the boundary element method, this is R. Mindlin's solution for displacements and stresses due to the action of a unit force P = 1 in space and they are marked with an asterisk. Kernels of the integral equation characterize the studied environment: c_{ij} – is constant, it is determined from the conditions of the body motion as a whole, it appears in the process of the transition of the boundary problem to the integral equation (4) for the obtaining the single solution; Γ, ξ, x, Ω – are correspondingly boundary surface of the foundation construction, point of the disturbance, point of the observance and boundary of the triangle sections of active zone of the soil [3].

In the process of numerical realization (5) only the contact surface of the foundation and soil was discretized, contact boundary was divided into a number of boundary linear elements, expected active zone of the base deformation was discretized by the triangled sections.

ANALYSIS OF RESULTS

The results of the studies show that the most optimal from the point of view of carrying capacity must be the circular foundation with r/R=0.4, as it has the maximum total working surface.

For the verification of the obtained data, the calculation of the models of the circular and ring foundations, the dimensions of which are given in Table 1, is carried out by MBE, using the developed elastic-plastic model of the soil base. Calculation data and the comparison with model experimental studies are shown in Figures 4, 5.

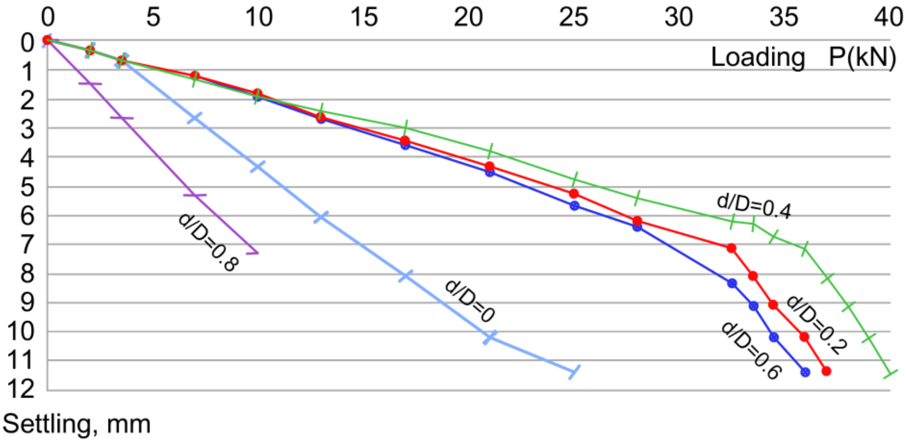

Fig. 4 – Data of the numerical forecast by MBE of carrying capacity of the ring and circular foundations with the same contact area

Analysis of the dependences in Figure 3 allows to make a conclusion that in case of the same contact surface minimal carrying capacity is inherent to the ring with d/D = 0,8, where, according to Table 1, total working surface is the smallest. Maximum value of carrying capacity has the test ring plate with d/D = 0,4 (43 kN), its total working surface (Table 1) is the largest. Proceeding from the obtained conclusions, the ratio d/D = 0,43 is suggested to be taken as the circular foundation of the tower drier (Figure 1b).

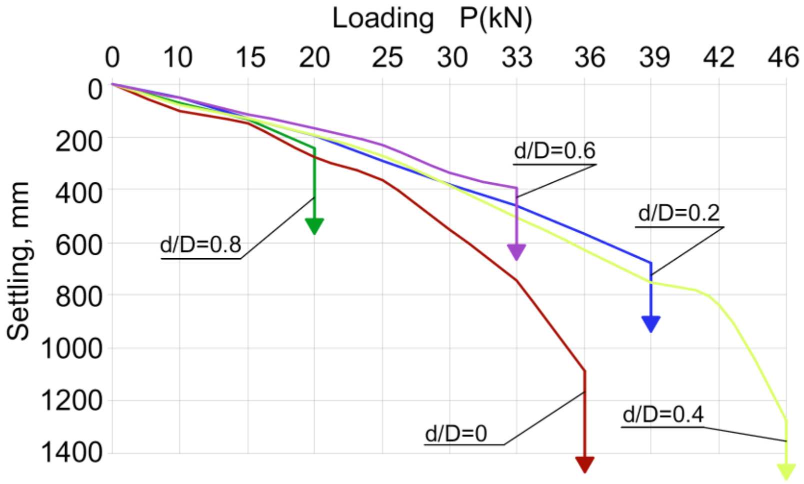

Fig.5 – Experimental studies of the test plates of the circular and ring forms with the same contact area and different d/D ratios

Modern calculations requirements comprise the requirements to provide the complete information regarding the functioning of the construction at all the stages of deformation, including the stage of destruction. Figure 6 shows the graph “loading-settling”, obtained by MBE, as the physical process of stressed – strained state change of the circular foundation construction of the tower drier.

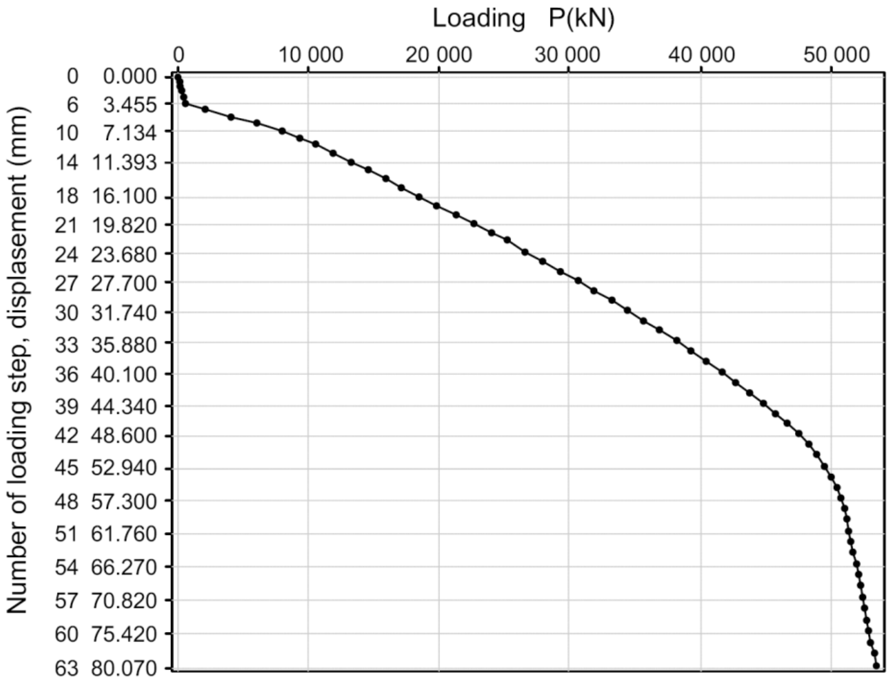

Fig. 6 – Graph “loading-settling” of the circular foundation of tower drier

When the tower drier of 5400 kN of the weight is loaded settling is 8 cm, it is less than admissible 10 cm. In the process of dryeration bin construction (Figure 1) and transmission on the foundation the loading of 5400 kN, the value of settling was 7,2 cm.

CONCLUSION

Displacement of foundation constructions in dispersive soil bases under the action of force impacts causes the change of its physical-mechanical properties, that influences their carrying capacity.

Non-linear model of soil base behaviour, developed by MBE, enables to describe the behaviour of the circular foundation with the sufficient for practical needs accuracy, providing economic effect.

The suggested dilatancy model and MBE enables at the stage of design to forecast geoengineering situation of circular foundation behaviour, state of foundation structure in the specific engineering-geological conditions that allows to improve the quality of design calculation, possibility to increase the terms of construction functioning by means of its stressed-strained state regulation.

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