Research of the additional building influence on the foundation in a stress superposition existing along the radius zone

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Abstract. The comprehensive studies’ results of the soil environment stress-strain state from the loaded and unloaded foundation model action are considered and compared:
1. Laboratory experiments with foundation models were carried out, on the basis of which a numerical SSS soil foundation analysis was carried out, empirical relationships between the influencing parameters and the foundations’ additional settlement amount due to their mutual influence on each other were obtained.
2. Numerical modeling of foundations located in the mutual influence zone by the finite element method of numerical research using the software package Plaxis 3D was performed.
3. A numerical analysis of the influence of the distances between the stamps’ axes on the additional stresses’ values from the loaded foundation is given using the method of angular points, as a method recommended by the current regulatory documentation [13]. These results can be used to refine the existing calculation methods. The difference between the results of numerical and experimental modeling is noted.

Introduction
In a tight urban environment, high-rise buildings are often constructed in close proximity to the existing buildings. Mutual influence zone size clarification of the foundations for different schemes of their loading is a very urgent topic. The soil located in the building load area is a part of the building-foundation system, it is an integral structural element of this system. The influence zone size depends on numerous factors [1, 3 ... 9, 12], for example: the size and shape of objects, their location, the depth of the underground part, climatic engineering-geological and hydraulic conditions, the magnitude of loads and impacts, the presence of unfavorable processes (for example, landslide), structural, planning and technological (construction and operation) features of the facility under construction [9, 10]. In addition, taking into account the influence of one or a number of factors is rather complicated due to the calculation schemes and models’ conventionality, numerous mistakes at all stages of the building construction life cycle, low quality of work and materials. In some cases, scientific support for design and construction is used [2, 6, 11].

Unilateral axial loading can cause adverse consequences: inclination, additional settlement, horizontal displacement, curvature and distortion of the building, provoke rheological processes (creep). BC 22.13330.2010 [13] in such cases requires a geotechnical forecast (assessment) of the construction...
impact on the change in the stress-strain state of the surrounding soil mass. Influence zone radius \( r_{iz} \) starts from the boundaries of the projected pit and is allowed to be limited by the distance at which the calculated value of the additional soil mass settlement or the surrounding building existing structure base does not exceed 1 mm.

**The problem formulation**

The purpose of the study was an experimental-theoretical study of the mutual influence of foundations, the determination of functional dependencies between the movements of closely located foundations, the distances between them, loading schemes, the study of the foundations' stress-strain state.

**Numerical modeling and calculations** soil deformations were performed using the program *Plaxis 3d* finite element method. Fine sand with physical and mechanical characteristics typical to Neogene deposits in the central part of Tambov was taken as the base soil (Table 1).

**Table 1.** Physical and mechanical characteristics of the sandy soil model fine sand with characteristics:

| \( c_s \), kgf/cm\(^2\) | \( \phi_s \), ° | \( E \), MPa | \( \rho \), g/cm\(^3\) | Porosity coefficient \( e \) |
|----------------|------------|--------|-------------|----------------|
| 0.02            | 32         | 28     | 1.5-1.55    | 0.65           |

After constructing the above-mentioned models of the "basement-foundation" system, a number of iterations were made in the calculation program with varying parameters of influencing factors, which are reflected in the Table 2.

**Table 2.** Variability of influencing parameters

| No. | \( D \), mm | \( \bar{L} = L / D \) | \( \rho \), g/cm\(^3\) |
|-----|------------|----------------|-------------|
| 1   | 200        | 2.5            | 1           |
| 2   |            | 3              | 1.5         |
| 3   |            | 3.5            | 1.55        |

The results of the foundation soil displacements calculations are reflected in the diagrams (Figure 1). In addition, the movements of the foundation models’ control points were observed, which made it possible to compare the calculated data with the results of field observations.

Based on the calculated data, the dependences of displacements on varied influencing factors are plotted, reflected in the summary Diagram 7.

In order to verify the calculated data, the authors carried out an experiment, in which the factors reflected in the above-mentioned calculations were varied in steps. The experiment was carried out in a steel tray with the dimensions: 180 - 100 - 85. As models of shallow foundations, rigid steel round dies with a diameter \( D_{st} \), equal to 200 mm (Figures 1, 3). In the experiments, the parameters were investigated according to Table 2. To ensure the sand-sand friction coefficient, the lower contact surfaces of the models are pasted over with sand.

![Diagram 1](image1.png)

![Diagram 2](image2.png)
On the models’ top, rigid steel plates with grooves are welded to fix the position of the cylindrical hinges. The load on the model was transferred in steps of approximately 1/10 ... 1/15 of the breaking load. Each stage of loading was maintained until the conditional stabilization of deformation equal to 0.1 mm for 1 hour of observation. In some experiments, the load was increased after 1 hour of observation. The experiment replication was 2-3.

The experimental observations’ results of the settlement and foundation models roll are shown in Figure 3.
Figure 3. Results of the foundation models’ displacements observations when changing load patterns and distances L from each other: a) loading scheme and changing the distance between foundation models; b) the foundation models’ settlement value when the distance is changed; c) the corresponding empirical functions of settlement of the models obtained; horizontal displacements of the centers of gravity of the dies base for loads F, (kN): 4.2; 7.2; 10.2; 12.

The foundations mutual influence zones’ determination using the method of corner points by BC 22.13330.2010 [13]
The calculation of the bases for structures’ deformations of the surrounding buildings located in the influence zone of new construction or reconstruction is performed from the condition

\[ s_{ad} \leq s_{ad,us} \]

where \( s_{ad} \) - is an additional settlement of the foundation base (joint additional deformation of the foundation and structure), determined taking into account the totality of effects associated with new construction or reconstruction;
\( s_{ad,us} \) - limit value of additional foundations settlement [13].

The settlement of the foundation base \( s \), cm, using a design scheme in the form of a linearly deformable half-space is determined by the method of layer-by-layer summation according to the formula:

\[ s = \beta \sum_{i=1}^{n} \frac{\sigma_{zp,i} \times h_i}{E_i} \]

where \( \beta \) - is a dimensionless coefficient equal to 0.8;
\( \sigma_{zp,i} \) - is average value for vertical normal stress.

The total load on the base from the maximum loading step \( N = 12 \) kN (1.224 tf). Depth of laying \( d = d_s = 0 \) m. The dimensions of circular foundation models in plan Ø200 mm the size of an alternative square foundation of the same area is 17.72×17.72 mm = 314 cm² = 0.0314 m². In our case, the total pressure under the foundation base from an external load for 4 stages of loading is:

\[ p_1 = \frac{N_1}{S} = \frac{4.2}{0.0314} = 133 \text{ kPa} = 1.33 \text{ kgf/cm}^2, \]

And loading \( p_2 = 2.29; p_3=3.24; p_4=3.82 \text{ kgf/cm}^2 \), respectively.
The values $\sigma_{zp,M}$ along the loaded foundation $F_1$ axis, we obtain by summing the stresses $\sigma_{zp,1}$ from pressure $p_0$ under the foundation itself and additional stress $\sigma_{zp,2}$ from the foundation $F_2$ influence. The latter is determined by the method of corner points as the algebraic sum of stresses at the considered depth at the corner point $M$ four loaded areas (fictitious foundations): $MLAT$ and $MNDL$ with positive pressure $p_0$ and $MKBLU$ $MNCK$ - with negative (see Figure 5). The aspect ratios of the indicated rectangular foundations are equal:

**Table 3.**

| Foundation spacing options | $\eta_3$ | $\eta_2$ | $\eta_1$ |
|-----------------------------|---------|---------|---------|
| MKBJ and MNCK               | 1.8     | 3.8     | 1       |
| MLAJ and MNDL               | 2.4     | 4.4     | 1       |
| Option II                   | 2.95    | 4.95    | 1       |
| Option IV                   | 3.5     | 5.5     | 1       |

![Additional stresses from the adjacent foundation, option I](image_url)
Figure 4. Calculation by the method of corner points of additional stresses in the soil from the adjacent foundation pressure influence. Variants with different spacing between the foundation models: I (L*=100 mm), II (L*=200 mm), III (L*=300 mm).

* After bringing round foundations to square foundations, the L values changed: I (L*=146 mm), II (L*=246 mm), III (L*=346 mm).
The lower boundary of the compressible base stratum is taken at the depth \( z = H_c \), where the condition is satisfied \( \sigma_{zp} = 0.2\sigma_{zp} = 8.4 \text{ m} \) (here \( \sigma_{zp} \) is additional vertical stress).

It takes into account the load effect from the F-2 foundation. Coefficient \( \alpha \): \( \alpha = \alpha_1 + \alpha_4 \)

External load voltages \( \sigma_{zp,1},\sigma_{zp,2},\sigma_{zp,nf} \) calculated by the formulas:

\[
\sigma_{zp} = \alpha P_{h1}; \quad \sigma_{zp,c} = \frac{\alpha P_{h1}}{4},
\]

The result of our research is a summary diagram in Figure 6, where it is possible to evaluate the results of the applied methods for the numerical assessment of the loaded die effect on an adjacent foundation located in the mutual influence zone.

**Figure 5.** Summary graph of the indicator die additional displacements from the load on the main die according to the results of experiments, computer modeling and calculations by the method of corner points.

**Summary**

1. Based on the analysis of the summary graph (figure 5), it can be seen that the experimental modeling results are significantly lower than the calculated data obtained by the method of corner points. This can be explained by an error caused by the experimental tray geometry. The thickness of the soil being compressed in it is 1000 mm, and according to the calculations, the depth of the compressed soil at the maximum loading step is 8400 mm.

2. The additional displacements’ calculation of the foundations from mutual influence by the method in corner points used in the current regulatory documents is based on the outdated method of calculating the foundations settlement by the method of layer-by-layer summation.

3. The functions of various parameters’ influence (distance between the foundations, eccentricities of force application, the soil foundation density).

4. Computer simulation by the FEM method gives the results that are very close to the experimental values, since the edge effect of the tray is taken into account.

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