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Article

Ways to address the construction of new buildings in old urban areas

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Abstract. This paper deals with the problem of constructing new buildings in old urban areas, with emphasis on determining the actual dimensions of the active footprint of existing foundations. The study focuses on the problems associated with limited space for construction, geotechnical conditions, soil characteristics, as well as the features of near-surface foundations and methods for calculating their settlement. The paper proposes a methodology that, when applied, provides a more accurate and reliable determination of non-uniformity of base deformations of neighboring foundations. This is achieved by taking into account a number of factors, such as the sequence of erection, soil compaction, the size of the footings and the magnitude of loads. The proposed approach also substantiates the optimal spacing of the designed neighboring foundations, helping to reduce the negative impact on existing structures and ensuring the stability and durability of both new and existing structures. The results of this study represent a significant contribution to the development of effective construction solutions in limited urban spaces, and can be used by designers and builders to optimize construction processes and ensure the stability of buildings in complex geotechnical conditions.
Keywords: old urban areas, near-surface foundations, settlement calculations, geotechnical conditions, building design.

1. Introduction

In the design of new buildings in older urban areas where construction by superstructure or additions to existing buildings is envisioned, there is a need to determine the actual footprint of the existing foundation footprint [1]. This active zone includes changes in the compressibility characteristics of soils subjected to long-term compaction and local changes in the stress-strain state of the foundation due to the additional load on the area [2]. Foundations for new buildings in old urban or built-up areas are very demanding and are usually conditioned to eliminate impacts to the surrounding development. The presence of a vacant lot in an old urban area indicates the presence of unfavorable geotechnical conditions or any other problems on the site [3]. The presence of surrounding buildings and limited space for organizing the construction site represent the main problems in the design and construction of a new building. In recent years, intensive construction has started on one of the vacant areas near the center of the old town [4].

Traditional methods of settlement calculation, including those regulated by standards and based on the theory of linearly deformed bodies, cannot accurately predict the actual size of the active (compacted) zone of the foundation. These methods are designed to calculate a conventional, idealized soil, which leads to overestimated values of the results, the deviation of which may exceed 100%. In this regard, such methods are not acceptable for calculating settlement of foundations of buildings that are reconstructed in an urban environment, taking into account local changes in soil properties [5].

Therefore, for successful construction of buildings and structures in built-up areas, the results of studies of the behavior of closely spaced foundations are of particular importance. Special attention is paid to the formation of stress-strain zones and changes in physical and mechanical properties of soils subjected to long-term compaction during operation.

The purpose of the study is to analyze the influence of the stress zones of the new foundation on the formation of additional settlement of the existing foundation, taking into account the significant slope of the existing foundation under unilateral loading, and to determine the maximum allowable foundation spacing in accordance with the regulatory requirements.

2. Methods

The pattern of development of unequal settlement of adjacent foundations due to their mutual influence depends on several factors, such as the compressibility of soils, the sequence of load application and its magnitude, and the distance between adjacent foundations [6].

Unilateral impact on the foundation can lead to negative consequences such as tilt, roll, uneven settlement of foundations, distortion and misalignment of building structures [7]. Therefore, it is necessary to take this fact into account when designing, especially when calculating the deformation of the bases of closely located structures.

Let us assume that a new foundation F-2 is built next to an existing foundation F-1, under which the soil is partially compacted within the active zone 1 of the foundation (Figure 1). As a result, both foundations will undergo additional settlement, which will cause both foundations to tilt towards the newly constructed foundation. Taking these interactions into account is very important when analyzing the settlement development of their foundations in this case.

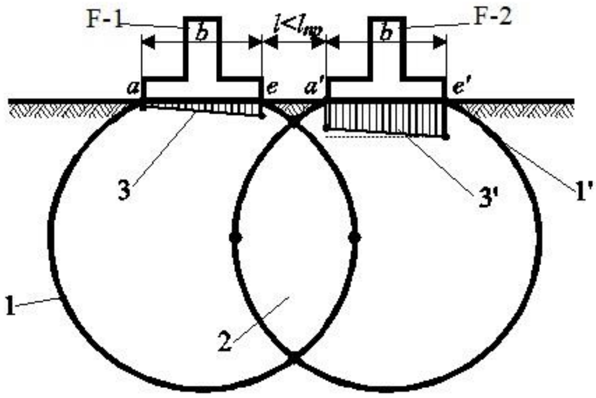

Figure 1 - Calculation diagram of the base of closely built foundations: 1 and 1' – boundaries of the active zones of the foundations F-1 and F-2; 2 – areas of overlap of active zones of bases; 3 – Estimated foundation settlement diagrams for foundations F-1 and F-2

In close proximity to the future structure is a residential building on Seyfullina Street in Astana, which is a five-story multi-family large-panel building, built around 1967 according to the project K-7 of the Mosproject Institute and belonging to the "Leningrad" series. The main load-bearing elements of this building are thin-walled reinforced concrete panels with thickened side ribs along the contour. The foundations of the house include columns of the cup type and reinforced concrete columns with cantilevers designed to support the basement panels. Basement waterlogging occurs due to the failure of the footings around the building and disturbance of the surrounding area. The strength of the concrete used in the structure is rated as B-25.

The construction site from a geological point of view is located on loam, which has light brown and brown colors. The soil has a different consistency, ranging from hard to soft-plastic. There are carbonate inclusions, as well as interlayers of sand and sandy loam up to 20 cm thick. The content of organic matter in the soil is up to 4.15%. The engineering-geological section at a depth of 15 meters is shown in Figure 2. The results of determinations of physical and mechanical properties of soils by engineering-geological elements are presented in Table 1.

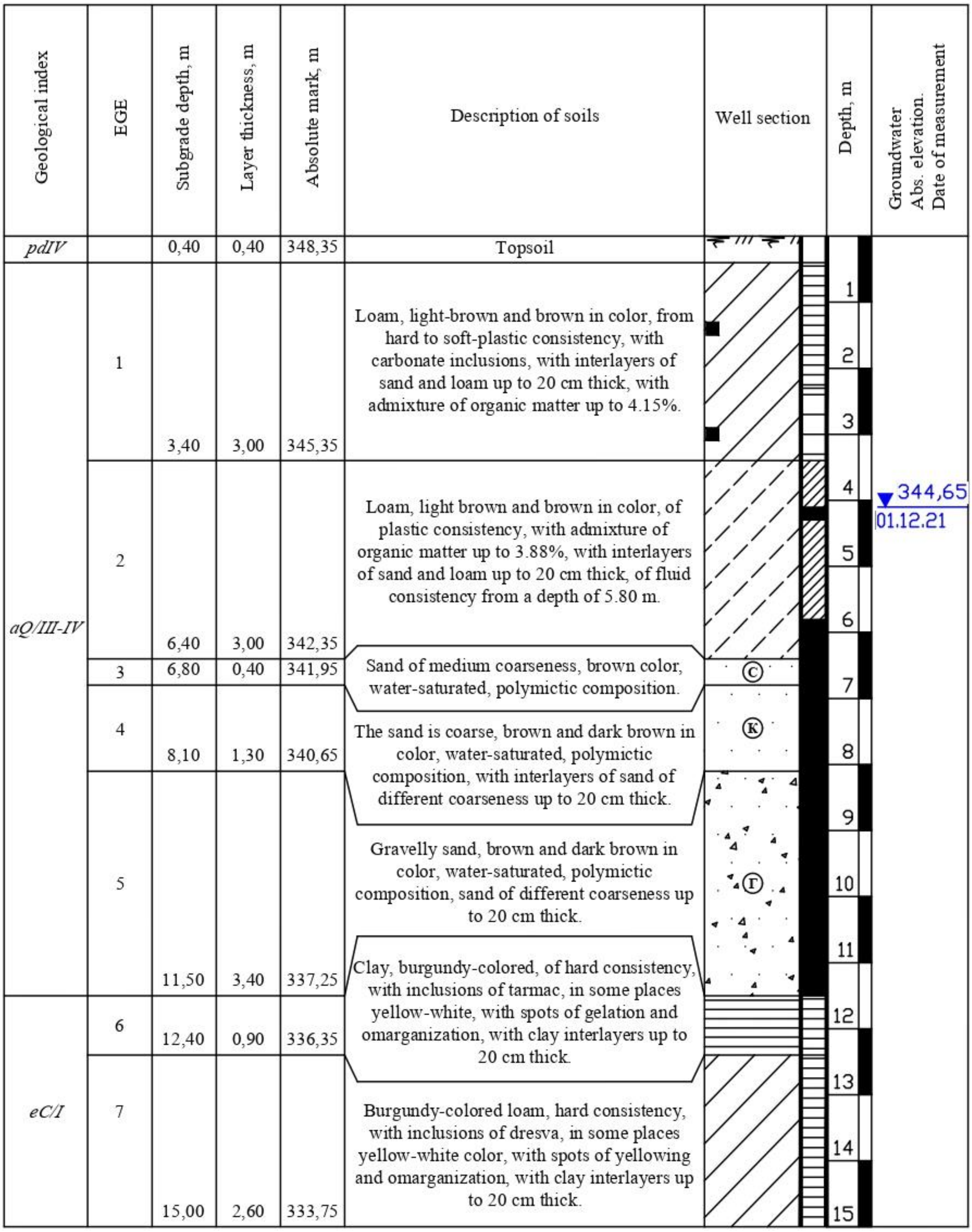

Figure 2 – Engineering-geological section

Table 1 – Results of determinations of physical and mechanical properties of soils by engineering-geological elements

№ of EGE	Name of soil	Natural humidity, *W*, %	Density natural, *ρ* g/cm^3	Density soil particle density, ρ_S g/cm^3	Porosity coefficient, *e*	Compression module at natural humidity, *Eк*, MPa	Angle of internal friction, *φ*, град.	Specific adhesion, *C*, MPa
№ 1 *aQ/III-IV*)	Loam, light brown to brown in color, hard to soft-plastic consistency	14.39	2.14	2.71	0.449	9.5	29.1	73
№ 2 (*aQ/III-IV*)	Loam, light brown to brown in color, solid to pourable consistency	23.28	2.04	2.70	0.636	5.5	12.8	38
№ 3 (*aQ/III-IV*)	Medium coarse sand, brown to dark brown in color, water saturated	14.83	1.56	2.3	0.650	30	35	1
№ 4 (*aQ/III-IV*)	Sand is coarse, brown and dark brown in color, water saturated	12.09	1.4	1.68	0.550	40	40	-
№ 5 (*aQ/III-IV*)	Gravelly sand, brown and dark brown in color, water saturated	9.79	1.46	1.75	0.650	30	38	-
№ 6 (*eC/I*)	Clay, burgundy in color, hard consistency	15.77	1.93	2.74	0.646	3.9	21.7	0.059
№ 7 (*eC/I*)	Loam, burgundy color, hard consistency	13.28	2.12	2.72	0.455	10.9	33.5	55

When planning new construction next to an existing building, both the maximum allowable additional deformations and the maximum allowable total deformations must be taken into account. Consequently, construction without preliminary determination of deformations in the existing building before the start of construction works, even if the recommendations on additional deformations are observed, does not guarantee protection against possible damage to the existing building. In this regard, it is planned to conduct a number of experimental studies to determine the allowable additional deformations, as well as to perform calculations using the finite element method.

Specialized dies were used to test adjacent dies. These rigid round disks with a flat sole or helical shape had sole areas ranging from 600 to 800 square centimeters. As part of the study, each die was loaded using a specialized design so that the pressure ranged from 0.01 to 0.1 MPa. The load at each level was kept centered and constant, and the total number of levels did not exceed 4. The duration of exposure at each level was the same, taking into account the conditional stabilization of ground rock deformation, which should not exceed 0.1 mm over a specified period of time according to state standard [8].

According to the state standard [9], the accuracy of settlement measurements when using deflection gauges was 0.1 mm. However, in some cases, more sensitive instruments such as IS and IP watch indicators were required, especially when studying compacted foundations of old built-up areas. The accuracy of measurements using these devices reached 0.01 mm.

Experiments conducted at both sites confirmed the relevance of the accepted working hypothesis of sequential effects on neighboring foundations. In the course of the experiments it became obvious that before the neighboring dies 2 (modeling new foundations) were subjected to loading, dies 1 (modeling old foundations) showed almost uniform settlement. The mutual influence of neighboring dies became more pronounced at the maximum load on die 2, which is due to a more complete overlap of the stress zones of the bases of both dies. Thus, the regularities of mutual influence of neighboring foundations established in the course of the experiment provide a basis for making appropriate corrections in the further improvement of soil investigation methods, as well as in the calculation and design of the geotechnical component of reconstructed buildings and structures.

The geotechnical model was analyzed by the finite element method using soil characteristics obtained from geotechnical investigations. When performing numerical studies on the settlement development of a foundation to be constructed in a built-up urban area, taking into account the compacted soils at the base, the calculation scheme presented in Figure 3 was used. The designed foundation F-2 is placed on the inhomogeneous, partially compacted base of the existing foundation F-1.

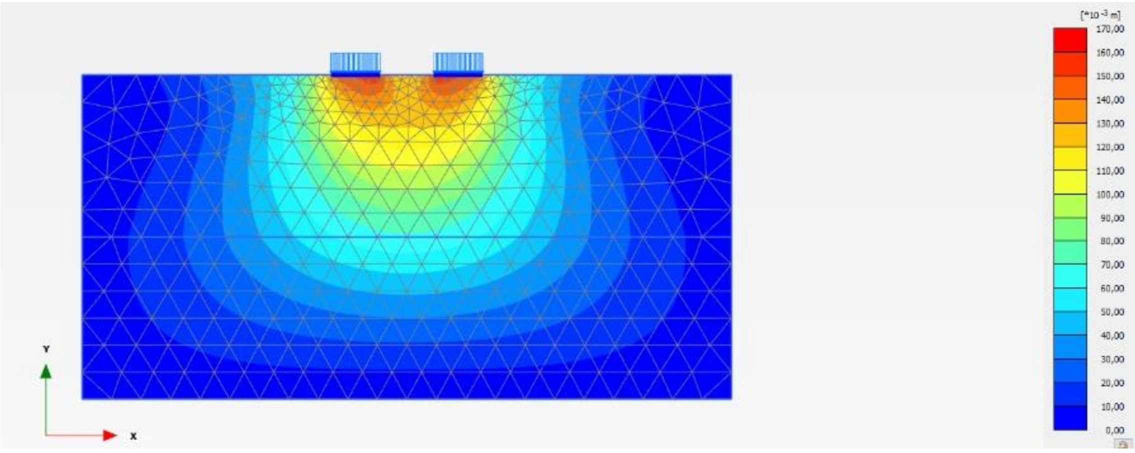

Figure 3 – Calculation scheme of neighboring foundations

3. Results and Discussion

Based on the results of both theoretical and experimental studies, we present a calculation model that assumes a pre-compaction of the soil to a state similar to the current state of the soil around the existing building. This model is based on the concept of volumetric compression of soils under the influence of maximum principal normal stresses, forming the actual deformed zone of the foundation footing. The use of a computer program is recommended for determining the volumes of complex-shaped overlay zones.

The new foundation F-2 is built next to the existing foundation F-1, under which the soil has already been compacted within the active zone 1 of the foundation, resulting in a significant reduction of its compressibility (Figure 4). In this case, the stresses caused by the loading of the new foundation F-2 in the overlap area 2 lead to additional compression of the already compacted foundation soil of the existing foundation F-1, which causes it to tilt towards the foundation to be erected. Thus, F-2 finds itself on a heterogeneous foundation, where on one side the soil is already compacted and on the other side it is in a natural state. It is obvious that, all other things being equal, the settlement of F-2, compared to an isolated foundation S built on naturally compacted soil, will be subject to change.

Settlement of the F-2 foundation built on inhomogeneous partially compacted basement will be less than:

$$S_{er.comp}^{imp} < S\,, \tag{1}$$

hence we can take:

$$S^{imp}_{er.comp} = S - S^{imp}_{dec.comp}\,, \tag{2}$$

where $S^{imp}_{er.comp}$ - settlement of the foundation being constructed, influenced by the neighboring existing foundation;

$S^{imp}_{dec.comp}$ - reduction of settlement of the foundation influenced by the neighboring existing foundation, the value of which is determined from the following condition:

$$S^{imp}_{dec.comp} = S^{imp}_{add.comp}\,, \tag{3}$$

where $S^{imp}_{add.comp}$ - additional settlement of the existing foundation resulting from full loading of the neighboring foundation under construction.

Consequently, uneven settlements (rolls) of the neighboring foundations occurring under stepwise loading are caused by preliminary soil compaction in the area of overlap (overlap) of the active zones of the base of both foundations.

For the design of neighboring foundations, the settlement values are $S^{imp}_{add.comp} = S^{imp}_{dec.comp}$ it is recommended to determine the volumetric settlement method using a compression curve reflecting the law of compression of previously compacted soil, taking into account the overlapping stress zones of the bases of the interacting foundations..

The calculation of the additional settlement $S^{imp}_{add.comp}$ of the existing foundation should be determined by the formula:

$$S^{imp}_{add.comp} = S^{imp}_{add.compI}, S^{imp}_{add.compII}, S^{imp}_{add.compIII}\,, \tag{4}$$

where $S^{imp}_{add.compI}, S^{imp}_{add.compII}, S^{imp}_{add.compIII}$ - components of additional settlement of the existing foundation (F-1) due to subsequent compression of compacted zones (I, II and III) of its foundation under the influence of unequally stressed zones ((I, II and III) appearing in the foundation of the neighboring foundation under construction (F-2) at full loading.

Further, the settlement *S* of the designed foundation (F-2) should be determined without taking into account the factor of mutual influence, as for a foundation made of natural structure soil, and the following settlement values should be accepted (Figure 4): $S_{a'}=S_{e'}=S$.

The elements of the additional settlement presented according to the calculation scheme shown in Figure 4 form a settlement matrix. This matrix takes into account the overlapping stress zones of the foundations and therefore reflects the mutual influence of neighboring foundations on their settlement. Using the results of the existing foundation calculation (F-1), evaluate the adverse effect of the effect of partial compaction of the foundation on the settlement of the newly constructed foundation (F-2).

The calculation of the relative unevenness of settlement is checked from the following condition

$$\frac{S_{e'} - S_{a'}}{b} = \frac{S^{imp}_{dec.comp}}{b} \le i_{marg}\,, \tag{5}$$

where $S_{e'} = S; S_{a'} = S - S^{imp}_{dec.comp}$.

And the distance between the designed foundations l should be checked based on the condition:

$$l \ge l_{marg}, \tag{6}$$

where l_{marg} – the maximum permissible distance between neighboring foundations at which the requirements of the normative document are met [10].

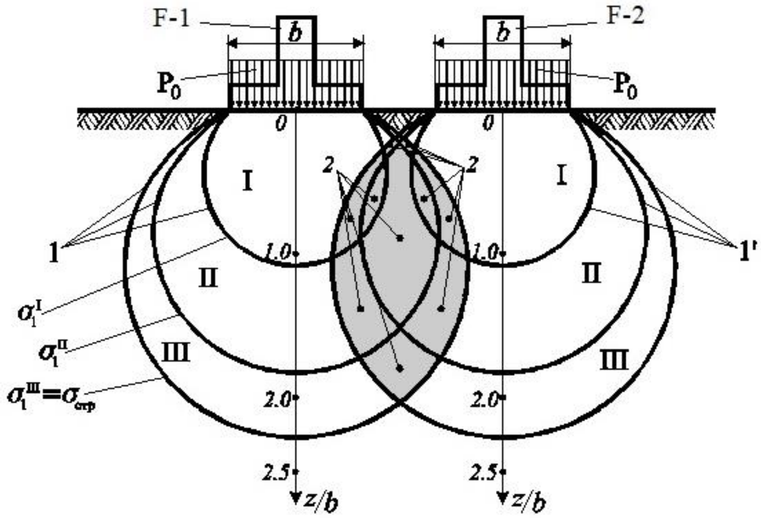

Figure 4 - Calculation scheme of the base of closely built foundations: 1 and 1' - boundaries of different stress zones I, II, III of the foundations F-1 and F-2; 2 - areas of overlapping stress zones of the foundations, taken into account in the calculation of settlements

Thus, the proposed methodology, in comparison with traditional methods of settlement calculation, provides a more accurate and reliable determination of unevenness of deformations of the bases of neighboring foundations. This is done by taking into account the sequence of erection, soil compaction, footing dimensions and the magnitude of loads. Thus, the proposed approach justifies the optimal distance between the designed neighboring foundations.

4. Conclusions

Analysis of the results of the calculations of additional settlement of the bases of closely located foundations allows us to identify the following regularities:

- the formation of additional settlement of the existing foundation is significantly influenced by the most stressed inner zones (I, II) of the base of the newly attached foundation, covering less compacted outer zones (I, II) of the base of the existing foundation;
- the less compacted exterior zones (II, III) of the existing foundation, where most of the additional settlement occurs, are more affected by the neighboring foundation;
- the additional settlement due to the one-sided base load results in a significant tilting of the existing foundation. This aspect should be taken into account in the final determination of the maximum allowable spacing between neighboring foundations, adhering to the limits on the unevenness of their settlement in accordance with the requirements of the standards.

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Nurgul Alibekova – data collection, resources, testing.

Aleksej Aniskin – interpretation, editing.

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