Technological settlement due to protection of the existing buildings

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Abstract. Values of technological settlement caused by technological impacts during protective measures installation were obtained for existing buildings in the zone of deep excavation influence. Neglecting the technological part in settlement prediction of adjacent buildings can lead to their unserviceability. The technological settlement was determined by following methods: geodetic measurements of buildings settlements, numerical modelling and analogy method. The technological settlement was determined for 4 types of geological conditions that can be applied to geo conditions of Moscow and soft soils of St. Petersburg and Hanoi (Vietnam). The authors recommend values of technological settlement for the underpinning with micropiles, jet-grouting columns, the installation of a jet-grouting cut-off wall and changing a foundation type to a slab. A formula is given for the calculation of technological settlement along the building due to changes in a protection design. A satisfactory converge of predicted settlements of buildings in the influence zone of deep excavations considering technological part with geodetic measurements data was achieved for construction projects in Moscow and St. Petersburg. Obtained values of technological settlement made it possible to propose recommendations on choice of protection measures ensuring safety of adjacent buildings.

1. Introduction

Underground construction, including the construction of buried parts of buildings, in conditions of densely built up urban area involves usage of innovative technologies requiring an adequate assessment of additional deformations of adjacent buildings and structures. Construction experience shows that if the geotechnical forecast does not take into account the existence of technological impacts on the soil mass caused by building geotechnical structures, then as a result, you can get underestimated values of additional deformations leading to less effective design solutions and higher risks of failure [1,2].

In the process of underground works additional settlements of the adjacent buildings foundations caused by technological impacts (technological settlement) on average makes up 40 ... 60% of the total measured settlement of the building, and the largest fall on the installation of protective measures and the construction of excavation support [3].
Instructions on the need to consider additional settlement caused by technological impacts when predicting deformations of soil under adjacent buildings are contained in the current Russian standards.

The values of technological settlement caused by protective measures installation for buildings in the zone of underground construction influence are contained in the works of Nikiforova N. S. [4], Shulyatev O. A. [5], Mangushev R. A. [6,7], Razvodovskii D. E [8], Mirsayapov I. T. [9], Pinto A. [10] and other authors. However, the recommended values of such settlement for most protective measures types are not systematized or are lacking, thus allowing the designer to rely either on his own experience or on the results of recent research [2,6,11,12]. There is a need in recommendations on the value of technological settlement and the use of it in calculations to ensure adjacent buildings safety including architectural, cultural and historic monuments.

The article shows the result of technological impacts on the soil mass caused by installation of protective measures aimed at reducing additional settlement $S_{ad}$ for adjacent buildings in the zone of deep pits influence. The following types of protective measures are considered: the underpinning with micropiles, jet-grouting columns, the installation of a jet-grouting cut-off wall and changing a foundation type to a slab.

The research goal is to develop recommendations on how to consider technological impact of protective measures installation depending on their type. As a result of technological impacts on the soil mass, the part of additional settlement caused by them is studied. It is called technological settlement $S_t$.

2. Methods

The research used analytical, numerical methods, and the method of on-site observations. The technological settlement due to protection of existing buildings was determined by the use of geodetic measurements data and analysis of comparable work experience on sites with similar geological conditions. In particular, data from published sources and recommendations of regulatory documents, also based on geotechnical monitoring data, were analyzed.

The determined technological settlement was summed up with the settlement of adjacent buildings obtained by numerical modeling and the resulting settlement value was compared with measured on the construction site.

Due to the differences in the parameters of protective measures between construction cases for which monitoring data is available, as well as the complexity to determine the contribution of various factors to the amount of technological settlement, it was decided to define its average values depending on the type of protective measures and geological conditions.

For the arrangement of geological conditions the classification of soils types by Nikiforova N.S. [1] was used. The 4 types of geological conditions were considered (figure 1): I - dense and medium-density sands, II - clayey soils, with very stiff, stiff, firm-stiff consistency, III - soft soils (clayey soils with firm and soft-firm consistency (IIla) or loose sands (IIlb)). This classification of geo conditions could be used for Moscow and weak soils of St. Petersburg (type IIlb) and Hanoi in Vietnam (type IIlb) [13], but could also be applied to other cities with similar ground conditions. Geological conditions can be assigned to I-III a,b type, if the total capacity of the soil that determines it is more than 60% in the content of the soil mass that surrounds the pit. The physical and mechanical characteristics of soils of each type are presented in table 1.

3. Results and discussion

3.1. Technological settlements depending on the type of protective measures and geological conditions

3.1.1. Micropiles. In the world practice the use of micropiles as protective measures is illustrated in the works of Burland J.B. [14], Balossi Restelly A. [15] and other authors.
Table 1. The physical and mechanical characteristics of I-IIIa,b soil types.

| Geo conditions type | Soil                              | The physical and mechanical characteristics |
|---------------------|----------------------------------|---------------------------------------------|
|                     |                                  | c, kPa | φ, °  | E, MPa |
| I                   | anthropogenic soil               | 15     | 15    | 10     |
|                     | sand, medium, medium density     | 0-4    | 25-39 | 23-47  |
| II                  | anthropogenic soil               | 15     | 15    | 10     |
|                     | clayey soils, with very stiff, stiff, firm-stiff consistency | 10-40 | 14-25 | 18-40  |
| IIIa                | anthropogenic soil               | 15     | 15    | 10     |
|                     | silty sand, loose                | 0-4    | 18-20 | 11-12  |
| IIIb                | anthropogenic soil               | 15     | 15    | 10     |
|                     | clayey soils with firm, soft-firm consistency | 11-30 | 6-19  | 7-12   |

The main factors that affect the condition of foundations from the underpinning with micropiles are the technology of their installation and geological conditions.

In the paper [16], the authors determined the technological settlement for the installation of micropiles based on the geotechnical monitoring data of many construction objects. The piling method without compacting the soil around the boreholes was considered. It was determined that the amount of technological settlement due to underpinning of the existing buildings is 60% from calculated (predicted) settlement $S_{pm}$ (equation 1). This ratio was taken to account technological settlement in geo condition types I and II.

$$S_t = 0.6 S_{pm} ,$$

where $S_t$ is the technological settlement;

$S_{pm}$ – calculated (predicted with protection measure) settlement.

For weak soils of geo condition type III due to the lack of comparative data for determining technological settlement, the tables in article [5] could be used. According to this article the technological settlement during the installation of piles should be determined separately from drilling a borehole in a soil and from drilling the foundation body.

According to the tables in [5] the technological settlement value is 19 mm for type IIIa and 10 mm for type IIIb.

3.1.2. Jet-grouting columns. In the world practice jet-grouting columns for strengthening of soil under buildings foundations in the zone of deep excavation influence have been used in the United States (Morristown) [17], the Czech Republic (historic district of Prague) [18] and many other countries.

For strengthening a soil under foundations to protect buildings with jet-grouting columns, as shown in studies [8] and [19] conclusions, the averaged minimum value of technological settlement of foundations is up to 3 mm.

3.1.3. Jet-grouting cut-off wall. According to research by Nikiforova N. S. and Vnukov D. A. [1,20] for the type III of geo conditions (loose water-saturated sands and weak clay soils), the value of technological settlement of the buildings foundations from the installation of cut-off walls is 8 mm.

To consider the technological settlement in type I and II of geo conditions the analogy method was applied. Technological settlement from the cut-off wall installation to protect building at Gospitalnyj 8 (Moscow) was 3 mm [1,20].
3.1.4. Changing a foundation type to a slab. Practice indicates that in order for the foundation slab to come into operation, it must receive a settlement of up to 1 cm. The technological settlement of 1 cm can be assumed when changing a foundation type to a slab for protective reasons, since there is limited data to offer more accurate recommendations. An example of this protective measure is the foundations reconstruction of the building with underground part development on Nizhnyaya Krasnoselskaya street in Moscow [1].

3.1.5. Recommended values of technological settlement and their use in calculation. The values of technological settlement for 4 types of protective measures, depending on the type of geological conditions, are presented in table 2.

| Protective measure type | geological conditions type | technological settlement $S_t$ |
|-------------------------|---------------------------|-------------------------------|
| micropiles              | I                         | $S_t = 0.6 S_{pm}$            |
|                         | II                        | $S_t = 0.6 S_{pm}$            |
|                         | IIIa                      | 19 mm                         |
|                         | IIIb                      | 10 mm                         |
| jet-grouting columns    | I                         | 3 mm                          |
|                         | II                        |                                |
|                         | IIIa                      | 3 mm                          |
|                         | IIIb                      |                                |
| jet-grouting cut-off wall | I                       | 3 mm                          |
|                         | II                        | 3 mm                          |
|                         | IIIa                      | 8 mm                          |
|                         | IIIb                      | 8 mm                          |
| changing a foundation type to a slab | I         | $\leq 10$ mm                     |
|                         | II                        |                                |
|                         | IIIa                      |                                |
|                         | IIIb                      |                                |

The value of technological settlement must be added to calculated additional settlement of the building obtained from the results of the geotechnical forecast (equation 2).

$$S_m = S_t + S_{pm},$$  

where $S_m$ – additional settlement of the protected building considering the technology of protective measures installation.

$S_m$ depends on $x$ – the distance to the point along the length of the building away from the pit (figure 1). $S_m$ reaches the maximum value at the point closest to the pit ($x=0$) and the minimum value at the farthest point (where $x$ equals the length of the building). $S_t$ is not a constant for all values of $x$, because while moving away from a pit, design parameters of protective measures (for example, the length of micropiles) may change or becomes no need for their installation due to the fact that the resulting additional settlement doesn’t exceed the limit values.

It was assumed that $S_t \rightarrow 0$ at $x+L \geq r_{zi}$, where $L$ is the distance from the pit to the building, $r_{zi}$ is the radius of the zone of influence, which is determined within the geotechnical forecast, and also that $S_t$ decreases linearly from its table value at $x=0$ to the boundary of the zone of influence. Then, assuming $L < r_{zi}$, $S_t$ for a given value $x$ is determined by the equation 3.
\[ S_t(x) = \frac{S_t(r_{zi} - L - x)}{r_{zi} - L}, \]  

where \( S_t(x) \) is the technological settlement along the building.

**Figure 1.** Scheme of a protected building \((q – \text{the foundation pressure})\).

As the result of numerical research in Plaxis 2D software, authors suggested the method of settlement prediction for buildings and structures with protective measures in the zone of deep excavation impact [4]. The recommended values from table 2 were used to consider the technological impact. The technological settlement was summed up with the calculated additional settlement obtained by numerical modeling and statistical processing in Excel, and a 3D approximation was made to determine the settlement dependence on \( q, (x+L)/H_k \) (see figure 2).

**Figure 2.** Predicted settlements (with and without technological settlement consideration) of building underpinned with micropiles in a zone of deep excavation impact (geo conditions type I).

A comparison of the predicted additional settlement considering its technological part and measured on the construction site was made for the construction project in the center of Moscow (Figure 3) [8,19]. Forecasting using the recommended values of technological settlement allowed to obtain a satisfactory converge with the results of geodetic measurements.
Figure 3. Calculated, measured and predicted settlements for the construction project in the center of Moscow involving strengthening a soil under foundations with jet-grouting columns ($H_k = 12$ m, geo conditions type I).

The determined values of technological settlement allowed to develop recommendations for the choice of protective measures that ensure the safety of existing buildings. The recommendations were included in section 13.3 of the Geotechnical Engineer’s Handbook [21].

4. Conclusion

If the geotechnical forecast of soil deformations under buildings and structures in the influence zone of underground construction does not take into account the technological part of deformations, then as a result, you can get higher risks of failure, especially in difficult geological conditions. However, the technological settlement of existing buildings caused by installation of innovative underground construction technologies isn’t sufficiently studied.

Conducted research has determined values of technological settlement for existing buildings in the zone of deep excavation influence for 4 types of protective measures in 4 types of geological conditions. A formula is proposed for calculating the technological settlement along the length of the building away from the pit due to changes in the design of protective measures.

The recommended values of technological settlement were used in prediction method based on the results of numerical modelling. A satisfactory converge of predicted settlements of existing buildings with geodetic measurements data was obtained.

On the basis of determined values of technological settlement, results of numerical and on-site research, recommendations were suggested for the choice of protective measures that prevent excessive settlements of existing buildings. The recommendations were included in section 13.3 of the Geotechnical Engineer’s Handbook [21].

References

[1] Mangushev R A and Nikiforova N S 2017 Tekhnologicheskie osadki v zone vliyaniya podzemnogo stroitel’stva (Moscow: ASV)
[2] Mangushev R A and Nikiforova N S 2019 Prediction of technological settlements for existing buildings during underground construction The XVII European Conf. on Soil Mechanics and Geotechnical Engineering (Reykjavik), doi:10.32075/17ECSMGE-2019-019.
[3] Leushin V Y, Shishkin V Y, Karabaev M I and Konyuhov D S 2011 Byulleten’ Stroit. tekhniki 3 57–63
[4] Nikiforova N S and Konnov A V 2020 Protection of existing structures during underground development including problematic soils The 2nd Russia - USA Geo-engineering Symp. “Improvement of Design Codes”. ed J-L Briaud and V A Ilyichev (Moscow, St. Petersburg) pp 201–12
[5] Shulyatev O A, Mozgacheva O A, Minakov D K and Solovyov D Y 2016 Acad. Arhit. i Stroit. 4 129–40
[6] Mangushev R A, Gurskij A V and Sapin D A 2017 Inzhenerno-geologicheskie izyskaniya, proektirovanie i stroitel’stvo osnovanij, fundamentov i podzemnyh sooruzhenij (SPb) pp 9–22

[7] Mangushev R A and Sapin D A 2015 Zhilishchnoe Stroit. 9 3–7

[8] Razvodovskii, D.E. Chepurnova A A 2016 Promyshlennoe i grazhdanskoie Stroit. 10 64–72

[9] Mirsayapov I T, Hasanov R R and Safin D R 2017 Inzhenerno-geologicheskie izyskaniya, proektirovanie i stroitel’stvo osnovanij, fundamentov i podzemnyh sooruzhenij (SPb) pp 164–9

[10] Pinto A and Gourveia M 2003 Teatro Circo Underpinning of a centenary theatre the XIIIth European conf. on soil mechanics and geotechnical engineering. «Geotechnical problems with man-made and man influenced grounds. Main Session 4: Foundation in urban areas» (Prague) pp 329–34

[11] Ulitsky V M, Shashkin A G, Shashkin K G and Lisyuk M B 2014 Methodology and technology of underground floor construction underneath an historic building – Kamennootrosovskoy Theatre in St. Petersburg the 1st USA-Russia Geotechnical Engineering Workshop (Oakland, California: ASV) pp 110–9

[12] Macovetsky O A 2020 Evaluation of soil bases deformations induced by jet-grouting The Second Russia - USA Geo-engineering Symp. “Improvement of Design Codes”. ed J-L Briaud and V A Ilyichev (Moscow, St. Petersburg)

[13] Nikiforova N S, Van-Hoa N and Alekseev G V 2019 Measured and forecast settlements of buildings near deep pits in Vietnam J. Phys. Conf. Ser. 1425 012059, doi: 10.1088/1742-6596/1425/1/012059.

[14] Burland J B, Standing J R and Jardine F M 2001 Structural measures Building response to tunnelling. Case studies from construction of the Jubilee Line Extension, London (London: CIRIA) p 153

[15] Balossi Restelly A, Tornaghi R, Pettinarolli A and Rovetto E 2003 Reconstruction of La Fenice theatre in Venice. Foundation problems the XIIIth European conf. on soil mechanics and geotechnical engineering. “Geotechnical problems with man-made and man influenced grounds”. Main Session 4: Foundation in urban areas (Prague) pp 29–34

[16] Ilyichev V A, Nikiforova N S and Konnov A V 2017 A settlement calculation for neighbouring buildings with mitigation measures upon underground construction ICSMGE 2017 - 19th Int. Conf. on Soil Mechanics and Geotechnical Engineering (Seoul) pp 1789–92

[17] Armijo G E 2002 Jet-grouting underpinning of a building in the US 9th Int. Conf. on piling and deep foundations (Nice) pp 33–40

[18] Boudlik Z, Čuda R and Kubleš J 2003 Underpinning and support of a facade wall and former graveyard the XIIIth European conf. on soil mechanics and geotechnical engineering. «Geotechnical problems with man-made and man influenced grounds. Main Session 4: Foundation in urban areas» (Prague) pp 65–70

[19] Chepurnova A A 2014 Assessing the influence of jet-grouting underpinning on the nearby buildings J. Rock Mech. Geotech. Eng. 6 105–12, doi:10.1016/j.jrmge.2014.01.005

[20] Nikiforova N S and Vnukov D A 2012 Geotechnical Aspects of Underground Construction in Soft Ground 7th Int. Symp. “Geotechnical aspects of underground construction in soft ground” ed G Viggiani (Roma: CRC Press), doi: 10.1201/b12748

[21] Ilyichev V A and Mangushev R A 2016 Geotechnical Engineer’s Handbook. Footings, foundations,underground structures (Moscow: ASV)