The impact of slurry wall stiffness on settlements of neighboring buildings

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ABSTRACT

The authors studied the impact of the slurry wall stiffness, as well as the depth of embedment below the excavation bottom on additional settlement of the neighbouring buildings. The paper provides comparison of numerical calculations with the data of field monitoring of one actual construction site of St. Petersburg. The project involved the construction of a three-level parking in soft soils and restrained urban conditions. The present article shows that the usage of counter-forts increases by far the slurry wall stiffness which significantly lowers the settlements of the neighbouring buildings. Counterforts increase the bending stiffness of the retaining structure by an order, which leads to considerable decrease of settlements caused by the excavation works.

Keywords: finite element analysis, slurry wall, In-situ monitoring, additional settlement of neighboring buildings.

1 INTRODUCTION

New development in major cities involves the construction of underground parkings in new residential buildings, shopping centers, etc. When building such facilities in engineering and geological conditions of St. Petersburg, it is necessary to use retaining structures with considerable stiffness. The stiffness of slurry wall significantly exceeds that of a sheet piling wall or bored piling wall, which enables to excavate the pit down to 10 m or deeper in close proximity to neighbouring buildings (Mangushev et al, 2016).

Slurry wall technique includes construction of the walls of underground facilities (or retaining structures of the excavation) in narrow (0.4 - 1.2 m) and deep (occasionally exceeding 50 m) trenches. Hydrostatic pressure of bentonite slurry of high density prevents the vertical walls of trenches from collapsing. When subsequently the trench is filled with concrete, the slurry is displaced due to its lower density. The slurry wall construction is carried out in bays of 2 – 2.5 linear meters.

2 ESTABLISHING OF COMPUTATIONAL MODEL

GEOIZOL company has constructed a unique three-level underground parking of a new residential building in the center of the city in difficult engineering and geological conditions of St. Petersburg and in close proximity to the existing buildings. The project involved excavation of a pit using the top-down method. A 0.8 m thick slurry wall with counterforts (cross section of 0.8 × 2.5 m) erected with a 6.6 m spacing, was adopted as a retaining structure (compressive strength 39 MPa).

Geotechnical conditions on the site were typical for the central part of St. Petersburg. The residential building with the underground parking in question was being constructed adjacent to the historical existing buildings (Fig. 1).

The excavation was carried out down to the level of 10.2 m using the top-down method, and included three levels of reinforced concrete cross-beams constructed at the following levels: 0 m, -3.6m, -6.9m, and at the level of the foundation slab, i.e. -10.2m. The existing building discussed in this paper has the following characteristics: no basement, adjacent to the excavation pit with its long side, bearing walls are longitudinal. Foundation depth of the existing building is 3m. Pressure under the strip foundation was taken as 200 kPa. The distance between the de-signed slurry wall and the strip foundation totaled 3 m. Next to the existing building foundation there was a foundation of a previously demolished building. The ground water level is -3m, i.e. directly under the existing building foundation

The site characteristics shown in Table 1 are typical for the central part of the city: the sub-soil consists of saturated sandy silt, underlain by the heavy layer of soft saturated fluid loam, and only beginning from the level of 11.4 m there are layers of moraine loamy sand and loam with relatively high strength properties. Next is bedrock consisting of solid Proterozoic clays.

The behavior of soil during the excavation works was modeled using Plaxis software, Hardening Soil model. The soil properties that were used in the calculations are given in Table 1 (geological survey data).

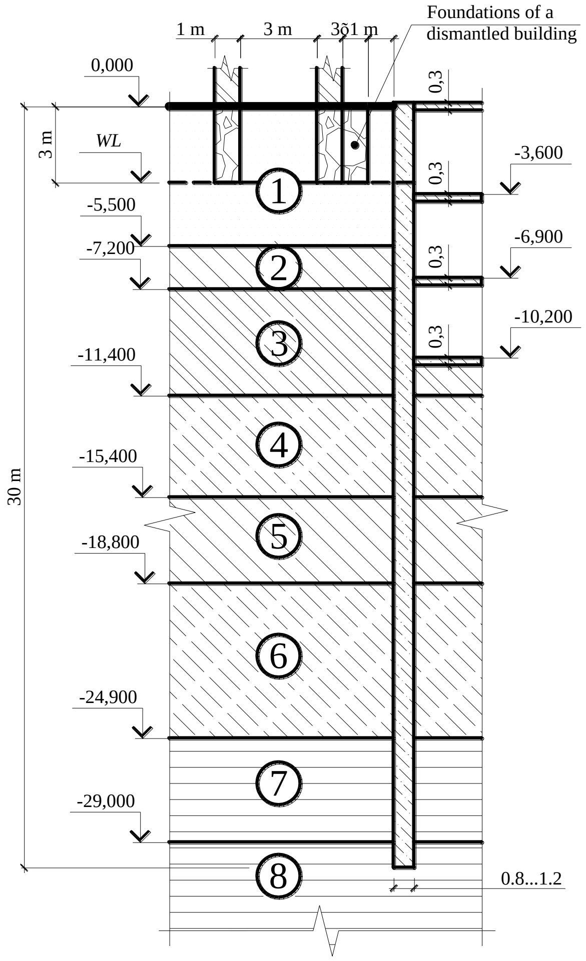

Fig. 1. Geotechnical conditions

Two calculations were carried out:

1) impact of the stiffness of retaining structure on the additional settlement of the adjacent buildings given the fixed depth of the retaining structure (approved in the design);

2) impact of the stiffness of retaining structure on the additional settlement of the adjacent buildings with consideration of various depth of embedment of the retaining structure below the excavation pit.

3 EVALUATION OF THE IMPACT OF THE STIFFNESS OF THE RETAINING STRUCTURE ON THE ADDITIONAL SETTLMENT OF THE NEIGHBOURING BUILDINGS GIVEN THE FIXED DEPTHTH OF THE RETAINING STRUCTURE

Four types of retaining structures were considered within the framework of the present task:

- 0.8 m thick slurry wall;
- 1 m thick slurry wall;
- 1.2 m thick slurry wall;
- 0.8 m thick slurry wall with 0.8×2.5 counterforts constructed with the spacing of 6.6 m (Fig. 2).

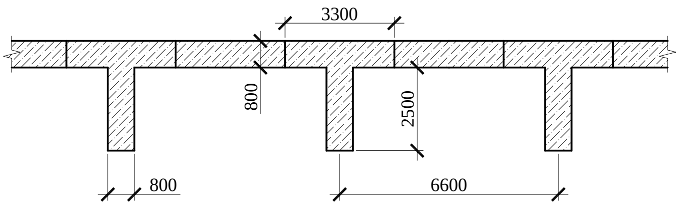

Fig. 2. Slurry wall with counterforts

The main property of an excavation retaining structure is its bending stiffness (EI). The graph presented in Fig. 3 show the comparison of the unit bending stiffness of the given types of retaining structures per one meter in cross-section. The stiffness of 2.1 m thick slurry wall was calculated for reference.

Pictures 4 show the constructed guiding walls and the excavated area of the slurry wall with counterforts.

The problem was calculated as two-dimensional one with PLAXIS 8 software. There have been developed a great number of approaches to solving the problem of retaining structures, however numerical methods turned out to be the most popular globally (Hosseinzadeh, 2015; Ramezani, 2017). A hardening soil model was selected for simulation; calculations were carried out in 8 stages shown in Fig. 5. The following features were simulated: loaded strip foundations of the existing buildings, alternately constructed floors and soil excavation down to the level of the next floor, etc.

Table 1. Physical and mechanical soil properties

№	Soil	γ, kN / m^3	E_{50}^{ref}, kN / m^3	E_{oed}^{ref}, kN / m^3	E_{ur}^{ref}, kN / m^3	c, kN / m^3	φ, degree
1	Loose sand	19,1	10 000	10 000	30 000	1	28
2	Fluid loam	18,9	5 000	5 000	25 000	11	16
3	Fluid loam	18,3	5 000	5 000	25 000	11	6
4	Soft sandy loam	21,7	14 000	14 000	42 000	34	24
5	Semi-solid loam	21,4	16 000	16 000	80 000	55	25
6	Soft loamy sand	22,0	18 000	18 000	90 000	44	31
7	Clay hard, dislocated	20,9	23 000	23 000	115 000	98	13
8	Clay hard, non-dislocated	21,4	26 000	26 000	130 000	104	17

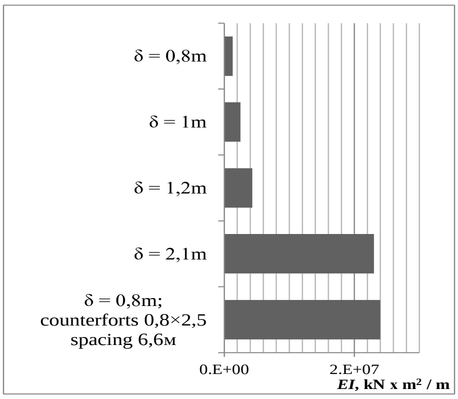

Fig. 3. Unit bending stiffness per 1m of the retaining structure

Fig. 4. Constructed guiding walls with counterforts

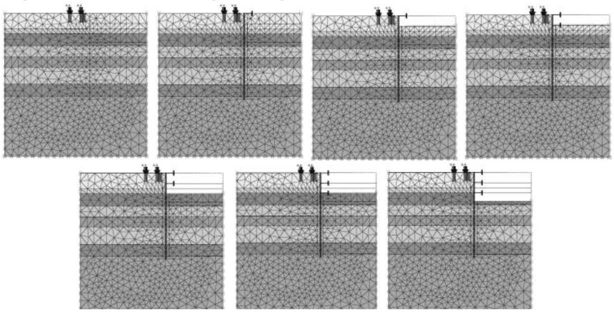

Fig. 5. Calculational stages of 2-D modeling

The results of the simulation are presented in Fig 6, and dependence of additional settlement of the adjacent buildings on bending stiffness of the retaining structure has been presented as a graph.

The results of the calculations evidence that the construction of 2.5×0.8 m counterforts with the spacing 6.6 m increases twentyfold the bending stiffness of the retaining structures which enables to reduce the additional settlements of the neighbouring buildings almost by half.

The dependence of the additional settlement on the bending stiffness of the retaining structure is described satisfactorily by formulae of power law and logarithmic relationship, presented in Fig. 6.

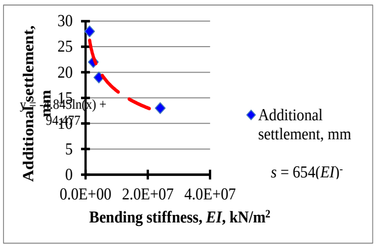

Fig. 6. The impact of bending stiffness of the retaining structure on additional settlement of the adjacent buildings given the fixed depth of the retaining structure

4 EVALUATION OF THE IMPACT OF THE STIFFNESS OF THE RETAINING STRUCTURE ON THE ADDITIONAL SETTLMENT OF THE NEIGHBOURING BUILDINGS

To estimate the interaction of the retaining structure stiffness and the depth of the embedment below the excavation bottom two types of slurry wall from the previous problem were considered: the most flexible one and the stiffest one. The depth of the retaining structure varied from 14.2 (4 m below the excavation bottom) to 26.2 m (16 m below the excavation bottom).

The calculations were carried out in accordance with the stages presented in Fig. 5 simulating the top-down excavation.

The results of the calculation are presented in Fig. 7.

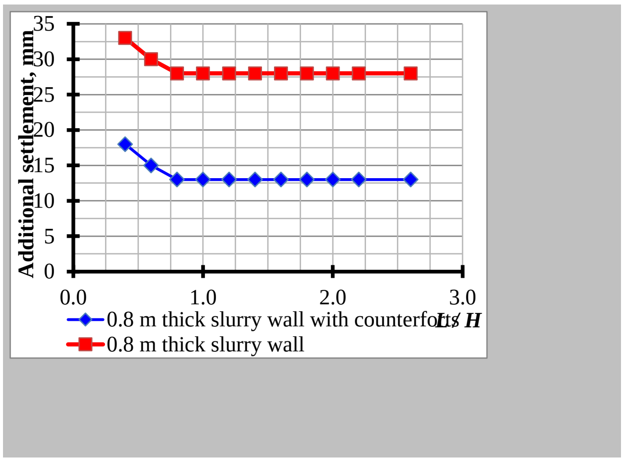

Fig. 7. The impact of bending stiffness of the retaining struc-ture on additional settlement of the adjacent buildings given the various embedement depth of the slurry wall below the excavation bottom

The obtained results evidence that regardless of the stiffness of the retaining structure, the increase of the embedment depth below the excavation bottom does not lead to significant decrease of settlements. Similarly, the type of sub-soil in which the slurry-wall is embedded does not have a significant influence.

5. COMPARISON WITH FIELD OBSERVATIONS

As mentioned above, the present calculations simulated a real project – construction of a residential building with three-level underground parking. The settlements of the neighboring buildings were monitored regularly. Modern geotechnical engineering methods of monitoring enable to collect the full scope of data for the evaluation of the situation by making back-analysis (Shi-Yu Xu, 2018; Shih-Heng Tung, 2013; Houhou, 2019).

Fig. 8 shows the part of the excavation site with the neighboring buildings and gives the benchmarks location.

Some results of the monitoring are presented in Table 2. The first stage of monitoring works corresponds to the execution of concreting of the slurry wall, the second stage was carried out after the completion of excavation works. Thus, the difference between the readings of two stages of monitoring is the settlement caused directly by the excavation works, without process-induced distortion which is significant in the conditions of soft soil regardless of the choice of geotechnology (Butterfield, 2017; Shulyatev, 2017).

In according with the monitoring data, the measured additional settlement of the neighboring buildings totaled 8-13 mm, while the calculated settlement for this kind of retaining structures and the depth of its embedment is 13 mm. Technological settlement totaled 13-26 mm. In the end, with allowance made for certain simplifications and assumptions made in calculations scheme, the reasonable correlation be-tween field data and calculated forecast is worth mentioning.

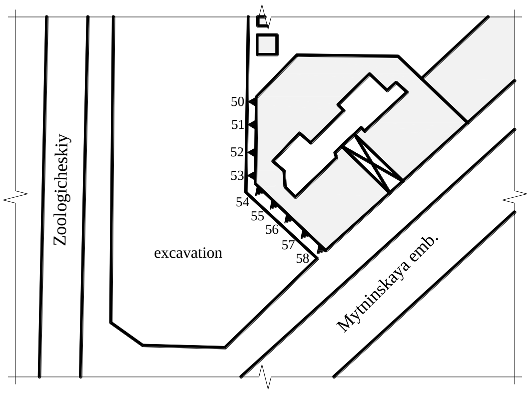

Fig. 8. The location of the benchmarks

6. MAIN CONCLUSIONS

Based on the numerical modeling of the slurry wall construction under the various calculations schemes it is possible to draw the following conclusions:

• counterforts increase the bending stiffness of the retaining structure by an order (in the given case study from 1.3×10^6 to 2.4×10^7), which leads to considerable decrease of settlements caused by the excavation works (in the case study from 28 mm down to 13 mm);

• regardless of the stiffness of the retaining structure, the increase of the depth of the embedment bellow the excavation bottom does not lead to significant reduction of the settlement;

• obtained numerical results are satisfactorily described by empirical formulae which have sufficient convergence.

Table 2. Monitoring data

№	Monitoring date	ΔΣ*h*, mm										
		50	51	52	53	54	55	56	57	58	58a	60
1	17.03.2010	-20,0	-22,0	-26,0	-24,0	-26,0	-24,0	-21,0	-19,0	-16,0	-15,0	-13,0
2	30.11.2010	утр.	утр.	-36,0	-37,0	-36,0	-32,0	-30,0	-29,0	-26,0	-25,0	-20,0
2 – 1		—	—	10,0	13,0	10,0	8,0	9,0	10,0	10,0	10,0	7,0

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