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Experimental and analytical studies of the seasonal temperature effect on the "excavation – soil" system

Etudes expérimentales et analytiques de l'influence des variations saisonnières de température sur le système "fosses de fondation – le terrain"

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ABSTRACT: The excavation construction in the conditions of the seasonal changes in the temperature requires consideration of the impact of this factor on the stress-strain state of the excavation shoring system. The paper presents the results of laboratory experiments that assess the effect of changes in the temperature on the struts of system "soil – shoring – support system of excavation". The paper presents the results of the field and analytical studies, as well as the results of the laboratory investigation of the strut system, providing the detection of the seasonal temperature effect on excavation shoring structures.

RÉSUMÉ : La construction de la fosse dans des conditions de variations saisonnières de température oblige à prendre en compte l'influence de ce facteur sur le changement d'état contrainte-déformation dans les structures de fixation de la fosse. L'article présente les résultats d'études sur le terrain et analytiques pour identifier la dépendance de l'augmentation de la température sur la structure de la clôture de la fosse aux résultats d'expériences en laboratoire dans le système d'espacement.

KEYWORDS: thermal stress in the shoring system, seasonal temperature effect, bending moments in the enclosure.

1 INTRODUCTION.

Various temperature factors affect building structures, but climatic effects may be eventually attributed to the main ones.

Actually, it takes a year to arrange an underground substructure of a modern building with a multi-level parking lot. Therefore, it is necessary to consider seasonal temperature effect on the stress-strain state of the "excavation-soil" system. It should be noted, that seasonal changes in the temperature of the supporting struts that are free from thermal insulation could achieve 60°C. If supporting struts are installed in colder periods, they evidently expand under increasing thermal load in warmer periods, and stress in the struts, that results from the resistance of the surrounding soil mass, increases. On the contrary, struts mounted in summer contract in winter, thus causing eventual horizontal displacements of excavation enclosure, as well as settlements of the adjacent structures.

1.1 *Analysis of the world experience*

Effect of the thermal load on reinforced concrete, metal, stone and reinforced masonry structures during construction and operational periods has been appropriately studied and widely covered in world scientific literature and regulatory documents. However, the temperature effect on excavation enclosure and surrounding soil mass has not been sufficiently studied yet.

Results of the native (Panteleev & Bezgemmer 2014; Buadze et al. 2014; Shapiro & Korovkin 2008) and international studies (Moormann 2002) and (Zaremba 2007) also show the necessity to take into consideration seasonal temperature effect on the excavation supporting systems. For example, in Frankfurt-am-Main, when the ambient temperature raised by 20°C in the 16 meters deep excavation with four strut rows, stress in the struts increased by 60%. In the city of Pert, a 13 meters deep excavation was supported with three rows of struts made of 23,5 meters long steel pipes with a diameter of 406x9,5 mm and 1016x16mm. When the ambient temperature increased by 25 °C, an additional stress in the struts of the upper row increased by 30%.

Presently, the strut response to the thermal effect is usually calculated via a rigid support scheme without consideration of the soil compliance. However, the earlier performed by the authors numerical experiments (Khritin 2016) have discovered that due to the deformation of the soil massive behind the excavation walls the additional stress in struts is 2,5 times lower. Consequently, the material considered in the design essentially exceeds its required amount

2 THE EXPERIMENTAL EXCAVATION.

The actual behavior of the excavation supporting system was studied in summer, 2017, at the experimental site of the NIIOSP named after N.M. Gersevanov, where a largescale physical model of the excavation enclosure was constructed in a 14x4x6 meters metal box filled with sand.

In-situ modeling showed adequate experimental results and kept the physical nature of the studied phenomenon for a chosen prototype. With respect to the prototype, it was a 6 meters deep excavation with the retaining wall made of steel pipes. The 426x8 mm hollow circular steel pipes were installed at a spacing of one meter. At a depth of 1,5 meters, a row of struts was arranged for supporting the excavation wall. The struts were made of 426x8 mm steel pipes and were placed at a spacing of 4,5 m.

The model of the excavation-prototype was constructed in the aforementioned metal box at a scale of 1:3. The scale factor, as well as stiffness of the retaining wall and struts were chosen based on the simple similarity between the relative design deformations of the model and excavation – prototype (figure 1).

A B

Figure 1. Calculated horizontal displacements (diagrams) of the enclosing walls of the excavation prototype (A) (the maximum value is $5{,}4 \cdot 10^{-3}$ m; the minimum value is $0{,}02419 \cdot 10^{-3}$ m) and the excavation

model (B) (the maximum value is 0,6399·10^{-3} m; the minimum value is 0,01632·10^{-3} m).

As a result, the adopted natural model comprised a 2 meters deep and 3 meters wide excavation with the retaining wall made of steel pipes. Circular hollow steel pipes of 89 mm in diameter were installed at a spacing of 0.2 meters. The supporting struts made of the similar pipes were arranged at a depth of 0.5 meters. Wales were made of universal beams No 12 welded in a box (figure 2 and 3).

The performed experiment dealt with two types of retaining walls: solid wall and wall made of individual elements. For the purpose, a half of the excavation wall comprised steel pipes. The soil between the pipes was retained by lagging in the form of steel plates located at the external side of the wall (zone A). The other half of the wall was arranged without lagging (zone B).

Pipes were pushed into the ground under static load together with lagging to prevent the soil softening on the pipe-lagging contact.

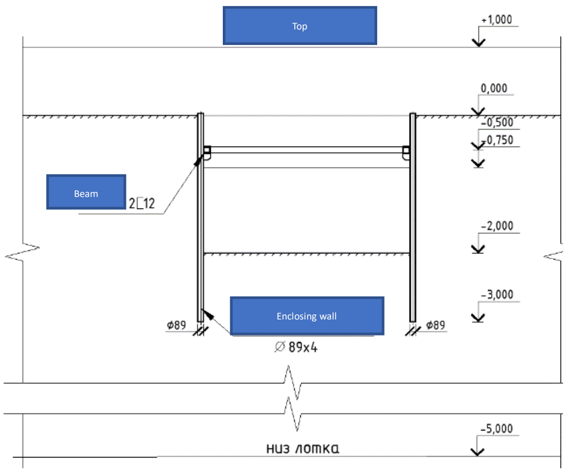

Figure 2. The layout of the excavation with steel shoring

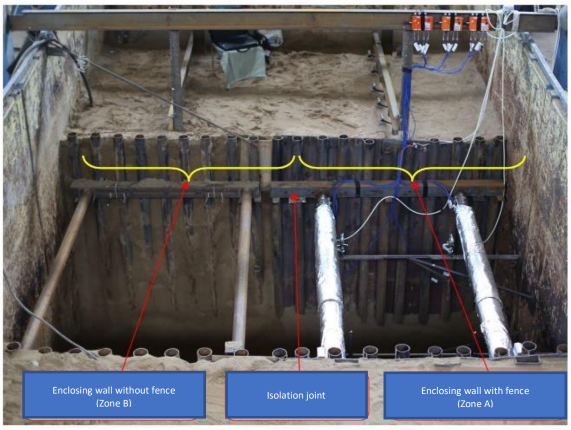

Figure 3. General view of the excavation (experimental) model.

The heating cable twisted on each strut provided the temperature effect. Thermal insulation made of basalt-cardboard material protected the struts together with the heating cable. Relay and temperature sensors installed on each strut regulated the heating mode to the maximum 60 °C.

Additional modeling of the struts expansion to the length exceeding their actual length (15 m) within the same range of temperature was performed using hydraulic jacks.

The struts were heated simultaneously and incrementally, with the temperature increments of 10 °C. The strut expansion simulation was made through jacking. The load was applied with the increments of 1.8 mm. This corresponded to the actual expansion of the strut under the temperature drop of 10°C.

Each experimental stage was accompanied with stress control in struts and shoring, monitoring of the horizontal displacement of the retaining wall, as well as monitoring of the vertical displacement of the soil behind the wall.

A stress-control automatic system designed on the base of SITIS equipment (Russia) was used for monitoring stress in the excavation shoring. The readings were taken both on demand (in real-time) and at a specified time interval. The monitoring system comprised string strain gauges, IGLA data loggers, a laptop, software and wireless network module. Each strut was equipped with three strain gauges evenly distributed around the circumference in the same cross section for 4, 8 and 12 hours. Four strain gages were mounted on the retaining wall at the level of a maximum designed moment. This included one strain gauge on opposite sides of the excavation in alignment with each strut. For taking into account the thermal deformations of the working strain gauge string and associated inaccuracy, control strain gauges without load were installed, when strain in structures was defined.

Vertical displacements of the adjacent soil surface were recorded from settlement benchmarks measuring 50x50x4 mm by means of dial indicators installed with the increment of 0,4 m in the direction transverse to the excavation enclosure.

The horizontal wall displacements of the experimental excavation were measured by the electronic (PSK-MG4) and analog (6PAO) deflectometers.

Figure 4 shows the measuring equipment installed in the experimental excavation.

Figure 4. The measuring equipment (general view).

3 NUMERICAL MODELING.

The performed experiments allowed authors to determine the dependence of the additional stresses in the excavation enclosure on the temperature increase in struts.

Based on the experimental data, a 3D numerical modelling of the stress-strain state of the excavation enclosure was performed via PLXIS software (fig. 5).

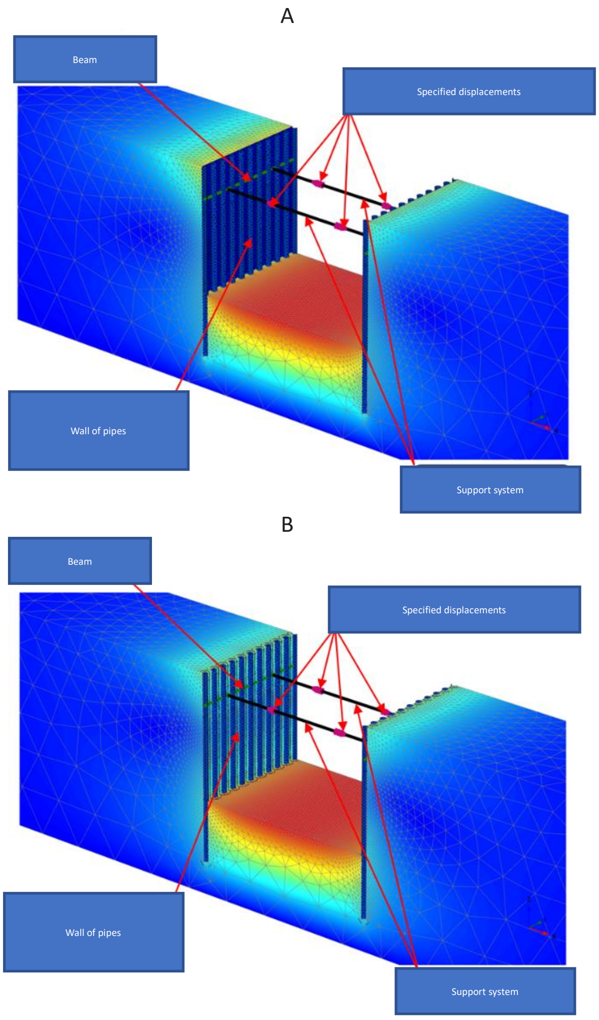

Figure 5. The design scheme for enclosing walls: a - solid; b – the wall made of individual elements.

Comparing experimental results and numerical simulation has shown that, on average, stress of the excavation enclosure sustaining static loads increases with the increase in the strut temperature as follows: by 50% - longitudinal stress in struts, and by 10% - bending moments of the excavation enclosure. It is worth mentioning, that stress in struts makes up to a 0,14 part of designed values defined through a rigid support scheme. The data obtained from the experiment has confirmed the fact, that discontinues wall has greater compliance than rigid wall has in the same conditions. Thermal forces in struts of discontinues enclosing wall are 15-20 % lower (fig. 6-7).

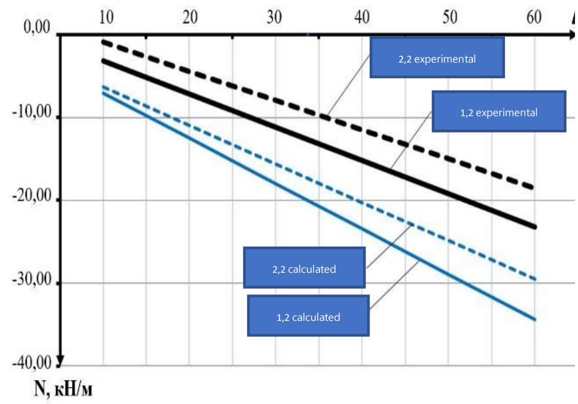

Figure 4. Relations of efforts in spacers with increasing temperature for the enclosing walls: 1.2 - solid; 2.2 - discrete.

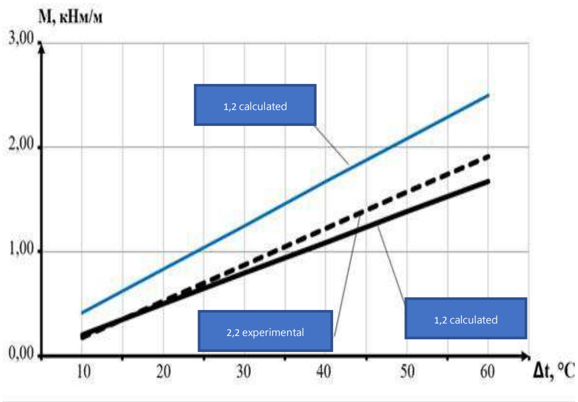

Figure 5. Relations of the bending moments in the fence when the strut temperature for the enclosing walls changes: 1.2 - solid; 2.2 - discrete

4 CONCLUSION

The experimental studies has provided the data characterizing stress-strain state of the excavation enclosing structure subjected to thermal impacts, and confirmed the necessity to consider additional “Thermal” forces in the strut system and enclosure of the excavation.

The experimental results confirm the fact, that additional stress in struts, that considers the soil deformation behind the excavation retaining wall, significantly lower than the stress defined through the rigid-support scheme that is currently utilized in calculations.

Stress in excavation steel shoring structures subjected to temperature effect and defined via modern software systems considers the behavior of the “excavation – soil” system and provides the opportunity to improve the design quality and significantly reduce the material consumption and the volume of construction and installation work during the excavation construction.

5 REFERENCES

Buadze I.E., Gagnidze I.Sh. Ksenidi V.S. About features of calculation of large-panel buildings on temperature effects // Stroitelnaya mekhanika i raschet sooruzheniy. – 2014. No. 3. – pp. 39–42.

Khritin I.V. Experimental studies of the effect of seasonal temperature changes on the efforts in the foundation pit fence structures // Vestnik grazhdanskikh inzhenerov. – 2017. – No.2. – pp. 154-162.

Khritin I.V. Seasonal changes in efforts of excavation shoring // Promyshlennoe i grazhdanskoe stroitelstvo. – 2016. – No.10. – pp. 85-89.

Moormann Ch. In-situ monitoring and analysis of braced excavations

with irregular shape // Geotechnical Aspects of Underground Construction in Soft Ground, Kastner, Emeriault, Dias, Guilloux (eds), Lyon, 2002.
Panteleev N.N. Bezgemmer D.A. Investigation of the stress-strain state of cylindrical buildings under temperature influences // Izvestiya vysshih uchebnyh zavedeniy. – No.11. – pp. 105-112
Petrukhin V.P., Pospekhov V.S., Shuliatev O.A. Experience in designing and monitoring a deep foundation pit // Collection of scientific papers NIIOSP named after N.M. Gersevanov. – 2008 – Issue 99. – pp. 139-148.
Petrukhin V.P., Shuliatev O.A., Mozgacheva O.A. Experience in designing and monitoring the underground part of the Turkish Trade Center // Osnovaniya i fundamenty. – 2004. – No.5. – pp. 2-8.
Petrukhin V.P., Shulyat'ev O.A., Mozgacheva O.A. The construction features of the Turkish Trade Center // Osnovaniya i fundamenty. – 2003 – No.2. – pp.6-8.
Shapiro G.I., Korovkin V.S. On the problem of stressed-deformated state of residential and public buildings under thermal effect. // Promyshlennoe i grazhdanskoe stroitelstvo. – 2008. – No.12. – pp. 5–8.
Shuliatev O.A., Pospekhov V.S. Analysis of the strut system operation of the deep foundation pit fence in conditions of temperature changes // Promyshlennoe i grazhdanskoe stroitelstvo. – 2017. – No.4. – pp.50-54.
Shuliatev O.A., Pospekhov V.S., Shuliatev S.O. From the practice of design of an enveloping structure and a foundation plate of the administrative complex of buildings with a four-level underground parking lot // Zhilishchnoe stroitelstvo. – 2012. – No.9. – pp. 50-53.
Zaremba N. L. Experiences in strut load monitoring in excavations for the new metrorail city project. School of Civil and Resource Engineering / The University of Western Australia, 2007.