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GEOTECHNICAL BARRIER OPTIONS WITH CHANGED GEOMETRIC PARAMETERS

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ABSTRACT: The study has been aimed at development of a new method of constructing a geotechnical barrier (enclosing structures) when excavating pits, being more rigid compared with a sheet pile and a wall made of bore-secant piles and having less labor content and less cost than a diaphragm wall. The method is mainly aimed at ensuring the stability of the walls of the pit and protecting the adjacent territory from surface settlement during its excavation. It is proposed to use two rows of piling walls connected by means of specialized expanding anchors. The resulted geotechnical barrier is a 3D shoring characterized by significant stiffness due to soil between the walls. The main advantages of the proposed method are its low complexity and fast speed of building compared with the diaphragm wall, the ability to retrieve the barrier after completion of work, as well as greater rigidity of the shoring structure compared with the sheet piling. Numerical simulation of the proposed method has been carried out in order to obtain geomechanical assessment of its efficiency. The calculations have been performed in the Plaxis software package. Initial data required for simulation have been described in details. Various options for the implementation of the geotechnical barrier with the change in the distance between the walls and different angles of inclination of the external wall have been considered. Their comparison allowed choosing the most rational option for specific conditions. The results of numerical modeling show the effectiveness of the proposed method for constructing a geotechnical barrier.

Keywords: Piling, Geotechnical barrier, Surface settlement, Underworking of structures, Protection of buildings and structures

1. INTRODUCTION

Deep excavations are required for building of underground and partially-in-ground structures, arrangement of foundations of above-ground structures, etc. Excavation dimensions are determined by project specifications. Numerous various factors are taken into account at design stage: engineering geological conditions, groundwaters, surrounding structures and the like. Particular attention regarding deep excavations should be paid to hydrogeology since variations of hydrogeological regime of locality can lead to substantial negative consequences [1]. Building activity in permafrost regions is accompanied by significant difficulties [2]. In such case it is required to maintain certain temperature regime of soils in order to preserve their initial structure [3].

In order to provide stability of excavation slopes as well as to decrease negative impact on surrounding structures, various engineering and technological solutions and protective measures are applied. Herewith, neighboring structures can be affected not only by open excavating technologies but also by arrangement of underground facilities [4]. Herewith, the assessment methods of underground building activity regarding impact on existing structures can be adopted for above-ground building [5].

Pile shoring in combination with spacers or anchors is widely applied. These are the simplest and the less expensive solutions, though, characterized by certain limitations with regard to engineering and geological conditions, excavation widths and depths, sometimes they do not provide required stability.

When it is impossible to apply piles, a wall of tangent piles or jet-grouting piles is installed. Sometimes in the case of deep excavations a diaphragm wall is made as a shoring which is the most stiff and reliable, though rather expensive design [6].

The stability of the walls of the pit directly depends on the thickness of the enclosing structures (Fig. 1). As can be seen from the scheme, the sheet pile wall has the least rigidity, and the proposed geotechnical barrier – the highest one. The stability of the wall can also be improved by the use of other design solutions (buntons, anchors, back-legs, etc.). However, their use is not always possible.

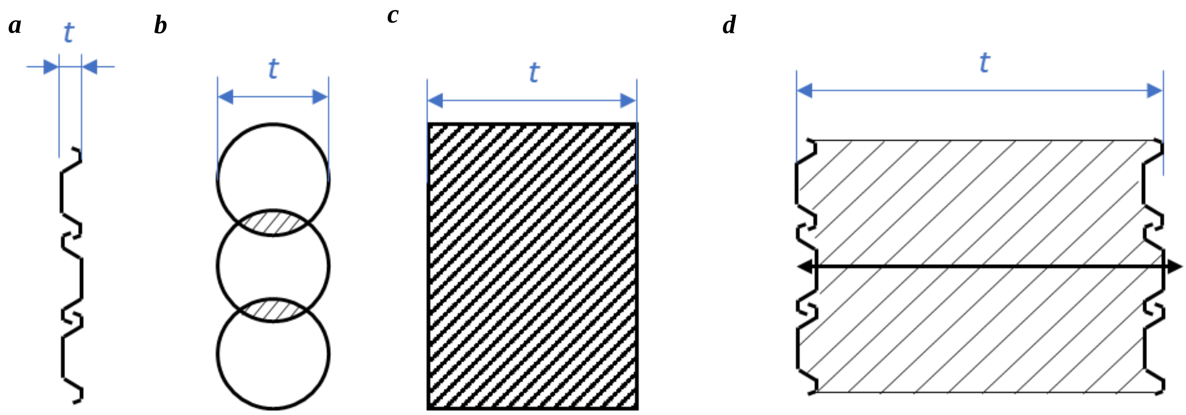

Fig.1 Comparative scheme of enclosing structures, a – sheet piling; b – a wall made of bore-secant piles; c – diaphragm wall; d – proposed design

In certain cases protective geotechnical barriers are used based both on chemical soil fixation by various additives, and on compensation grouting [7-10]. These measures result in significant elongation of time limits and increase in building costs [1]. Estimations of efficiency of compensation grouting in combination with other specialized methods of fixation and stabilization of soil array (chemical fixation, freezing, cementation) are described in [10]. High cost of protective structures requires for development of new design solutions, which stipulates the urgency of this work.

2. METHOD

As mentioned above, there are various engineering and technological solutions of excavation shoring. Fig. 2 illustrates general classification of excavation shoring [11].

Proposed method of geotechnical barrier construction is comprised of creation of two rows of shoring elements in soil between newly constructed and existing structure, one of which is made of pile shoring at the depth not exceeding the depth of the newly erected structure, and assembling of newly erected structure under protection of shoring elements. The second internal shoring element is installed along the external contour of the erected structure in the form of pile shoring at the depth equaling to the depth of the first shoring element. While excavating soil, the shoring elements are contracted by anchors. The anchors compact the soil between the shoring elements 1 and 2 making it solid, thus increasing its resistance against displacement towards excavation pit. Positioning the anchors at various angles to planes of shoring elements increases their bending resistance towards excavation pit and spatial stiffness of structures.

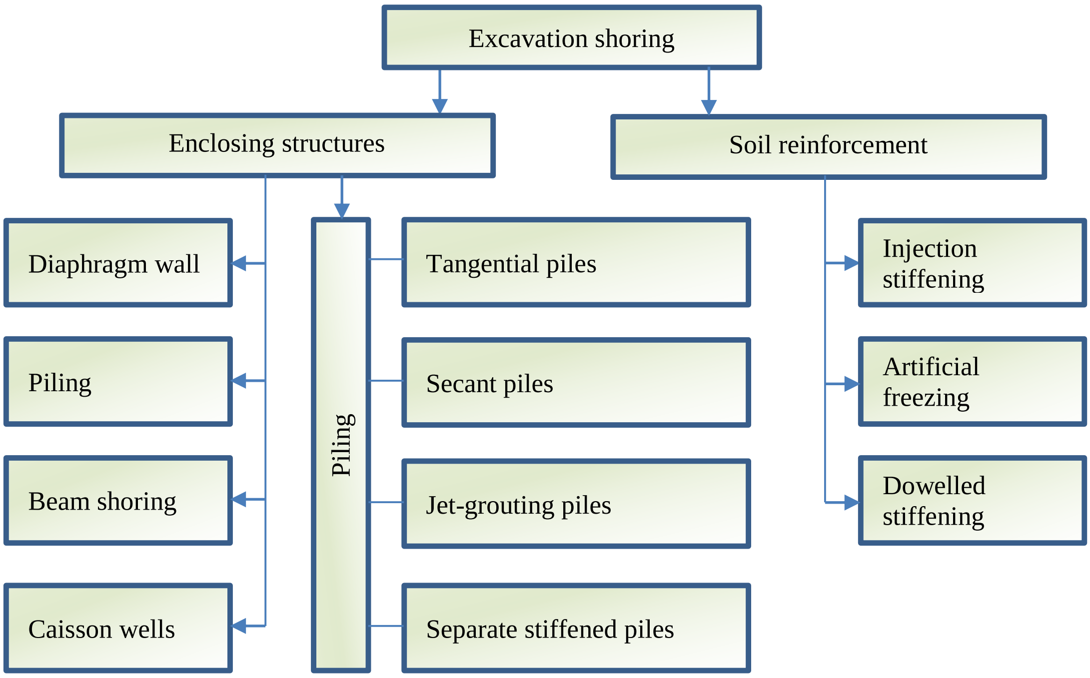

Fig.2 General classification of excavation shoring

The progress of this method during soil excavation (Fig. 3) and contraction of shoring elements (Fig. 4) are illustrated below.

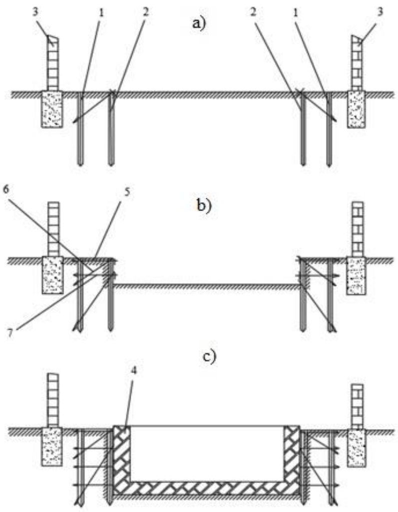

Fig.3 Schematic view of building and wall shoring of partially-in-ground structure: a – before soil excavation; b – partial soil excavation; c – complete soil excavation; 1 – external shoring; 2 – internal shoring; 3 – existing structure; 4 – newly erected structure; 5-7 – anchors

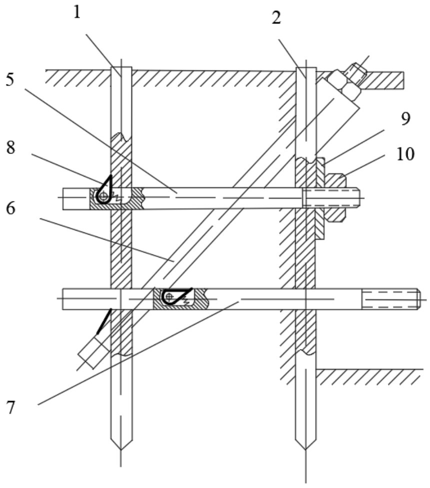

Fig.4 Schematic view of shoring connections: 1 – external shoring; 2 – internal shoring; 3 – existing building; 4 – building under construction; 5–7 – anchors; 8 – spring jaw; 9 – base plate; 10 – tension nut

The proposed geotechnical barrier significantly improves building quality due to decrease in soil migration from under foundations of existing structures under constrained city conditions, as well as increases stiffness of shoring, thus permitting to increase excavation depth, or, at moderate depths, to eliminate the use of spacers or soil anchors.

A new design of expanding anchor was developed for implementation of the proposed excavation shoring (Fig. 5).

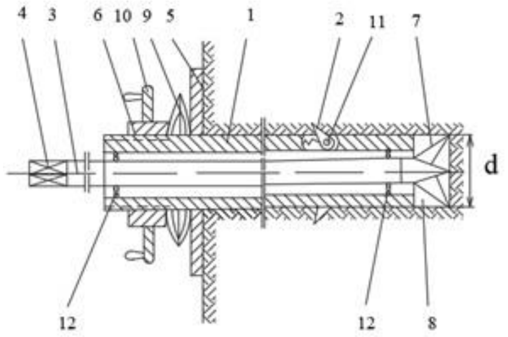

Fig.5 Schematic view of expanding anchor: 1 – hollow cylinder; 2 – pivoting cams; 3 – rod; 4 – coupler; 5 – base plate; 6 – tension nut; 7 – boring bit; 8 – borehole; 9 – spring; 10 – wheel; 11 – cam axles; 12 – holders

The expanding anchor is comprised of the hollow cylinder 1 equipped with expanding lock in the rom of pivoting cams 2, the rod 3 with the coupler 4 for rotary drive (not shown), the base plate 5 installed in the cylinder 1, and the tension nut 6.

The anchor can be equipped with the boring bit 7, fixed on the rod end 3 from the opposite side of the coupler 4. The base plate 5 and the tension nut 6 are installed on the cylinder 1. The diameter d of the borehole 8 made by the boring bit 7 equals to the outer diameter of the cylinder 1. The rod 3 is installed in the cylinder 1 with the gap providing output of fines. Rotary drive (not shown) is made in the form of standard drilling rig. Without boring tip, the design is simpler and the anchor (Fig. 5) is installed into preliminary made borehole.

The spring 9 can be installed between the base plate 5 and the tension nut 6. The nut 6 can be rotated by the wheel 10 rigidly connected with the nut. The pivoting cams are installed on the axles 11 and are spring loaded towards the borehole wall 8. The rod 3 is held along the cylinder 1 by the holders 12, for instance, in the form of spider wheels so that not to prevent output of fines.

2.1 Model Description

Efficiency of the proposed method was estimated by finite element simulation. The simulation was carried out in 2D formulation using Plaxis 2D software. Numerical experiments were also oriented at revealing regularities of surface settlement and horizontal displacement of wall upon variation of parameters of excavation shoring structures.

The following geometrical sizes of the model were used: width 400 m, height 40 m. The following displacements of elements are prohibited in the model: bottom – along Y axis; side – along X axis.

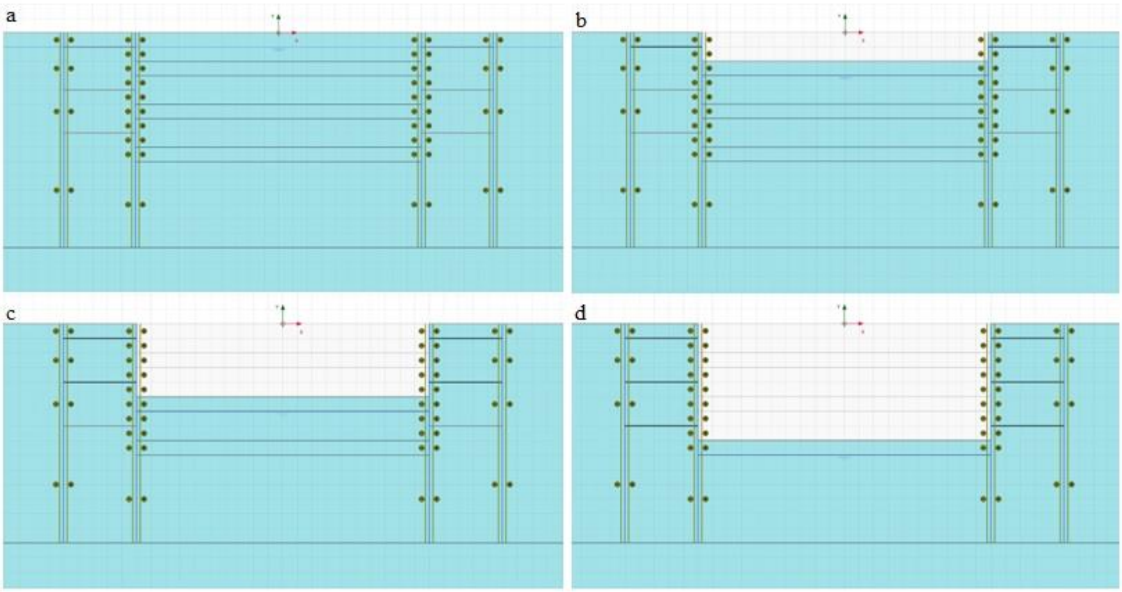

Fig.6 Simulation flowchart of building stages: a – first building stage; b – second building stage; c – third building stage; d – fourth building stage

2.2 Description of Construction Stages

Simulation of building stages is illustrated below (Fig. 6). At the first stage, installation of pile shoring is simulated. Then, at next stages, soil is sequentially excavated with installation of anchors at each level. The distance between the first and the second pile walls varied from 3 to 10 m. The level height is 3 m. The grid of anchor installation is 3×3 m.

Computations were carried out with Larssen sheet piling 5-U with the following properties per wall linear meter: cross section area – 289.78 cm^2, inertia moment –76,437 cm^4, moment resistance – 3,555 cm^3, weight per linear meter –227.5 kg. A pipe with outer diameter of 5 cm and wall thickness of 1 cm was taken for anchor simulation.

2.3 Description of Soils

Clay soils were selected as enclosing soils. Their physicomechanical properties peculiar for St Petersburg are summarized in Table 1.

Table 1 Physicomechanical properties of model with clay soils

γ_{unsat}, kN/m^3	γ_{sat}, kN/m^3	e_0	E_{50}, MPa	E_{oed}, MPa	E_{ur}, MPa
18.5	21	0.85	11	11	44
m	c, kPa	φ, º	ψ, º	$\gamma_{0.7}$	G_0, MPa
0.9	18	19	0	$0.15 \cdot 10^{-3}$	44

Remarks: γ_{unsat} – specific weight of soil at natural moisture content; γ_{sat} – specific weight of water saturated soil; e_0 – initial coefficient of porosity; E_{50} – soil deformation modulus; E_{oed} – odometric soil deformation modulus; E_{ur} – soil elasticity modulus; m – variable accounting for the influence of average stresses on soil deformation properties; c – effective cohesion; φ – effective angle of internal friction; ψ – dilatancy angle.

2.4 Soil Model Description

In order to account for deformation nonlinearity at the branch of unloading/repeated loading, the Hardening Soil Small-strain model (HSS) was used which presets additional hyperbolic dependence (in comparison with HS model) between stresses and deformations at low relative deformations ($\varepsilon_1 < 10^{-3}$). The HSS model is widely applied for solution of problems of soil interaction with supporting walls, cyclic loading with accumulation of displacements, etc. Verification of this geomechanical model by Russian and foreign researchers demonstrated that the proposed geomechanical model provided more accurate results for clay soils [12].

Predictions were made for nondrained soils with accounting for natural filtration rate and distribution of pore pressure.

3. RESULTS

In the initial model, the pile was installed vertically with the distance between internal and external walls equaling to 7 m. Horizontal displacements are illustrated below (Fig. 7). At the excavation depth of 8 m, the maximum horizontal displacements are 16 cm. It should be mentioned that the wall without anchors does not provide stability of the walls of the pit for such depth.

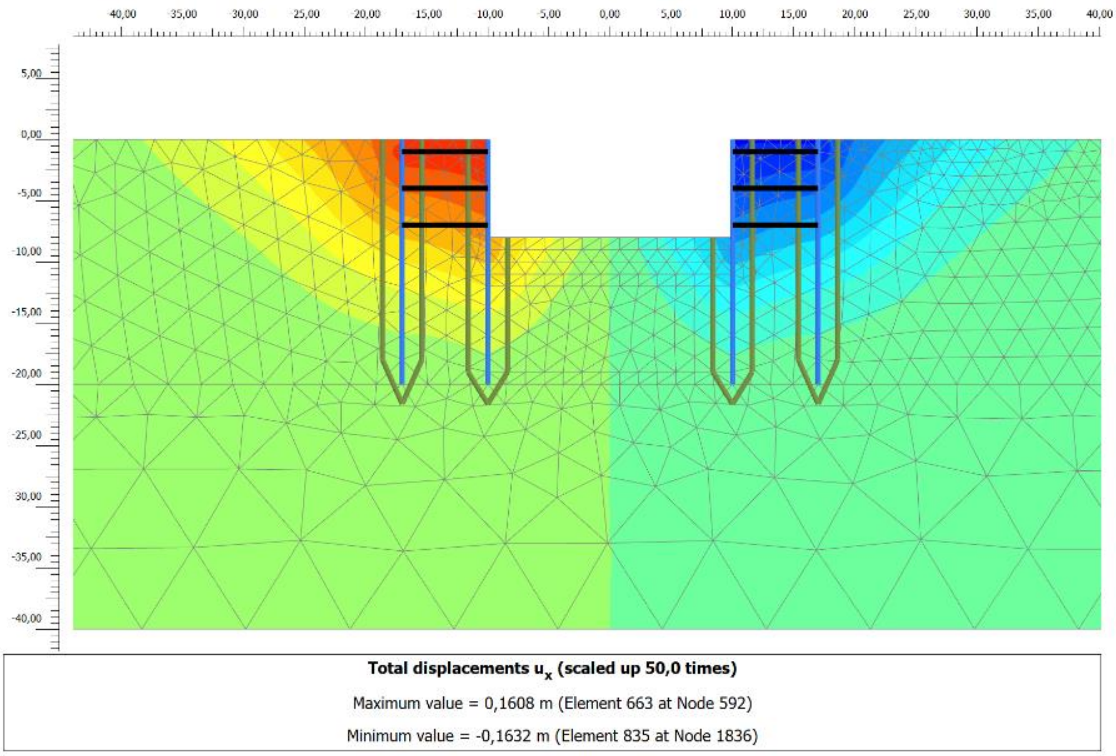

Fig.7 Horizontal displacements U_x, vertical pile is installed at the distance of 7 m

It is obvious that the stiffness of 3D structure formed by two walls connected by expanding anchors depends on the width of the obtained geotechnical barrier. Therefore, numerical experiments were carried out with variation of distances between internal and external pile walls.

When the distance increases from 3 to 5, 7, and 10 m, the horizontal displacements decrease from 28.3 cm to 21.2 cm (by 25%), 16.3 cm (by 42%), and 12.4 cm (by 56%), respectively (Fig. 8).

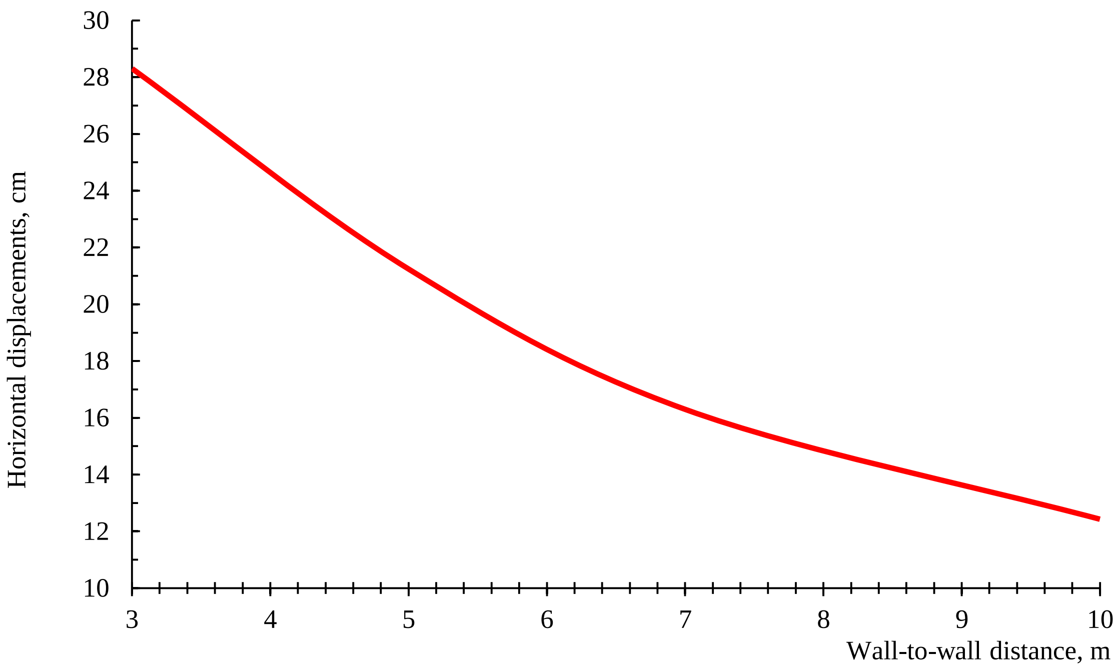

Fig.8 Horizontal displacements of internal pile wall as a function of wall-to-wall distance

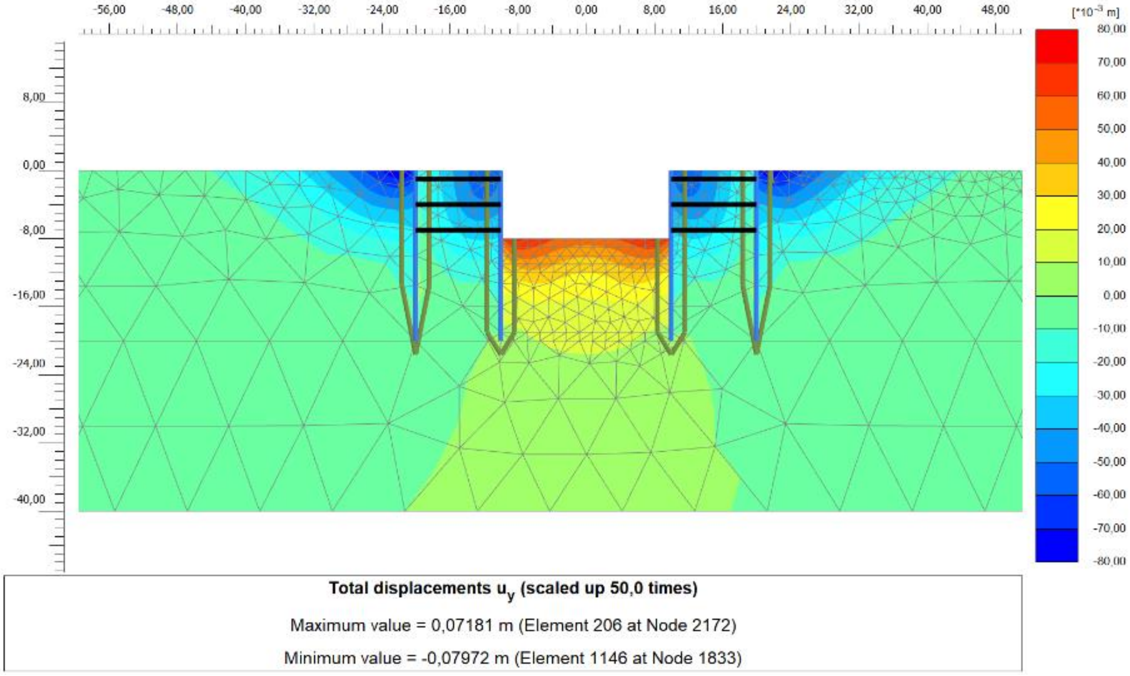

Fig.9 Vertical displacements U_y, vertical pile is installed at the distance of 10 m, mm

Surface displacements, when using geotechnical barrier with the width of 10 m, are illustrated below (Fig. 9). It can be seen that two concentration zones of vertical displacements are formed near pile. It should be mentioned that maximum concentration of U_y is observed at the distance of 1.5 m from external wall. At the distance of 5 m, the vertical displacements decrease to 5 cm.

Using inclined wall instead of external vertical pile wall will significantly increase stability of structures under horizontal load under soil pressure. Herewith, horizontal displacements significantly decrease by about 27% from 12.2 cm to 8.8 cm (Fig. 10). The external wall is inclined at the angle of 24°.

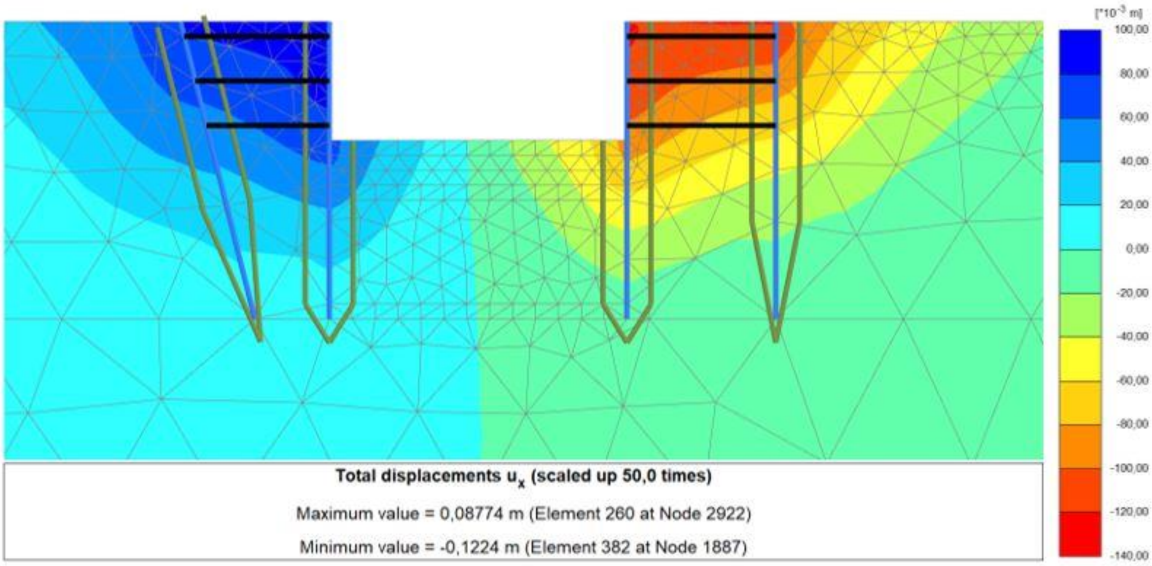

Fig.10 Horizontal displacements U_x, pile is installed at the distance of 10 m, mm: left – inclined pile; right – vertical pile

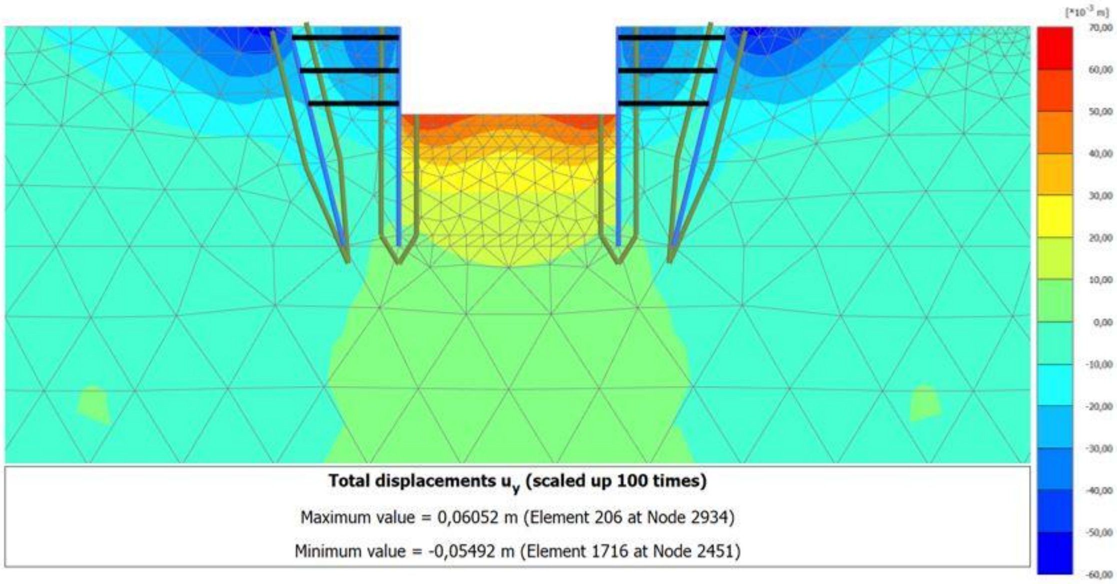

Fig.11 Vertical displacements U_y, pile is installed at the distance of 10 m, mm

Surface settlement in the case of inclined external wall is significantly lower in comparison with vertical wall. Maximum vertical displacement U_y is 6 cm (Fig. 11). The width of excavation influence area does not exceed 20 m. Herewith, no single subsidence trough is formed requiring for significant pile digging-in.

For specific engineering and geological conditions, it is necessary to establish optimal angle of inclination of the external wall and the distance between the walls.

4. DISCUSSION

In the world practice, for the construction of deep pits, as a rule, a diaphragm wall is used since the sheet piling does not ensure the stability of the walls [13,14]. The diaphragm wall construction method is quite time-consuming and expensive. The proposed method of the geotechnical barrier construction allows it to be used for the construction of deep pits with significantly lower costs. Here, when constructing the enclosing wall, the need for excavation works under the protection of clay mud, reinforcement, concreting, etc. is excluded. Material consumption is reduced due to the use of soil between the walls.

5. CONCLUSION

It should be mentioned that the proposed construction method of geotechnical barrier (shoring) using two pile walls connected by expanding anchors, is sufficiently efficient. Its implementation is less expensive in comparison with diaphragm wall. In order to increase local stability, it is possible to use bore-secant piles instead of walls of sheet pile.

If structure stiffness and its stability should be increased, it is possible to tension anchors and orient them at different angles. In addition, the proposed method can be used in combination of girders and soil anchors.

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