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Ruchkivskyi V.V., *post-graduate*
ORCID 0000-0001-8982-2884 ruchkivsky8@ukr.net
Kyiv National University of Construction and Architecture

INFLUENCE OF DISTANCE BETWEEN A RETAINING WALL AND THE EXISTING BUILDING ON STRESS-STRAIN STATE OF THE SYSTEM «RETAINING STRUCTURES – SOIL MASSIF»

The results of work research of engineering protective structures in a densely built–up area with difficult engineering–geological conditions have been presented. The modeling of the geotechnical problem of deep excavation protection using a three-tier retaining wall has been performed. The task of mutual influence of existing building and deep excavation with the change of distance between them is solved. The grafs of displacement's dependence several tiers of retaining walls from the distance to an existing building have been presented. According to these data, a plot of the dependence of displacements of separate tiers of retaining walls from the distance to an existing building is constructed. The problem is solved by the finite element method using a nonlinear model of a solid soil environment. The character of the formation of zones of potential slip surface slope is revealed. The dependence of bending moments of the retaining walls from the distance to the existing building is shown. A safe location of an existing building to a deep excavation has been substinated.

Keywords: *numerical modeling, engineering protective structures, finite element method, horizontal displacements, bending moments.*

Ручківський В.В., *аспірант*
Київський уаціональний університет будівництва та архітектури

ВПЛИВ ВІДСТАНІ МІЖ ПІДПІРНОЮ СТІНОЮ ТА ІСНУЮЧОЮ ЗАБУДОВОЮ НА НАПРУЖЕНО-ДЕФОРМОВАНИЙ СТАН СИСТЕМИ «УТРИМУЮЧІ КОНСТРУКЦІЇ – ҐРУНТОВИЙ МАСИВ»

Наведено результати дослідження роботи інженерних захисних конструкцій на щільно забудованій території зі складними інженерно-геологічними умовами. Виконано моделювання геотехнічної задачі захисту глибокого котловану за допомогою триярусної підпірної стіни. Розв'язано задачу взаємовпливу існуючої забудови та глибокого котловану при зміні відстані між ними. Подано графіки залежності переміщень окремих ярусів підпірних стін від відстані до існуючого будинку. Задачу розв'язано методом скінченних елементів із використанням нелінійної моделі суцільного ґрунтового середовища. Виявлено характер утворення зон потенційної поверхні ковзання схилу. Показано залежність згинальних моментів підпірних стін від відстані до існуючого будинку. Обґрунтовано безпечне розташування існуючого будинку до глибокого котловану.

Ключові слова: *числове моделювання, інженерні захисні конструкції, метод скінченних елементів, горизонтальні переміщення, згинальні моменти.*

Introduction. At the present stage of housing development, there is a prevalence of tendencies to increase the building density of historically formed districts of cities. Considering the density, the most rational in these conditions is the exploration of underground space, in which you can arrange engineering communications, parkings, warehouses, shopping and entertainment complexes, thus freeing the ground area. Thereby a number of urgent engineering problems arise due to the deepening the levels of basements of existing buildings and the excavation of pits to a depth of 10 – 15 m and more, and as a consequence, changes in the stress-strain state of neighboring buildings. In many cases, existing buildings undergo significant deformations (cracks in walls and foundations, structural distortions, etc.) that are caused by uneven subsidence that develops after the start of construction works of the zero cycle of new buildings and continue to evolve during the exploitation phase. Especially increases the risk of such deformations during construction on the bases, composed of weak soils. In these circumstances, the task of reducing the impact of new construction on the stress-strain state of the system «ground base – foundation – overground constructions» of existing buildings becomes of great importance.

Analysis of recent studies and publications. To date, a large number of methods for calculating the protective structures of deep excavation have been developed, but their use often leads to the receipt of significantly different, contradictory results to each other. The presence of surrounding buildings greatly complicates this process. Inaccurate calculation of the enclosure structure leads to unpredictable impact on surrounding construction. For solving the problem of predicting the impact of new construction on existing structures in densely built up area, the scientific works of M.L. Zotsenko [4], [5], Yu.L. Vynnykov [3], I.P. Boyko [7], P.I. Yakovlev [6], V.S. Nosenko [8], C. Capraru [9].

Definition unsolved aspects of the problem which the article covers. Construction of objects with underground facilities in a densely built up area requires the installation of a deep excavation, which should be from the conditions of preservation in the initial state of surrounding construction. To do this, it is necessary to fulfill the forecast of the impact of digging the foundation pit on the stress-strain state of this building. The difficulty in implementing such forecast lies in the fact that many initial data needs to be taken into account: the configuration and condition of the surrounding building, the parameters of the pit, the load from existing buildings, the uneven layering of soils, and the phased construction work. Simulation of such complex geotechnical processes requires simultaneous consideration of many factors, which can only be achieved by using the finite element method.

Formulation of problem. The purpose of this paper is to investigate the mutual influence of the installation of a deep excavation high-rise residential complex and existing buildings with varying the distance between them. To achieve the goal with the help of the finite element method, the modeling of the system of «retaining walls – a soil massive – existing building» was performed. The calculation was performed taking into account the formation of a strained-deformed state of the soil mass during the installation of retaining walls. At the same time, the soil array was considered as a solid nonlinear medium. The analysis of the formation of the strained-deformed state of the soil massif, protective fencing and foundation structures of the building is carried out. The horizontal movements of the top of the bearings of the retaining walls, the bending moments, as well as the vertical displacement of the foundation of the existing house were compared. The patterns of formation of the potential zone of sliding surface of slope and role in its formation of existing building with decreasing distance to the protective structure of the foundation pit are revealed. The rational arrangement of an existing building in relation to the deep excavation is established.

The main material. The object of construction is a multi–storey residential complex consisting of five sections located on a slope along the contour of Lake Glinka (Fig. 2), at the corner of the streets Filatov and Boulevard Druzhby Narodiv in Kyiv.

The surrounding building is represented by two five-section buildings located at a distance of 20 m from the fence of the pit (Fig. 1).

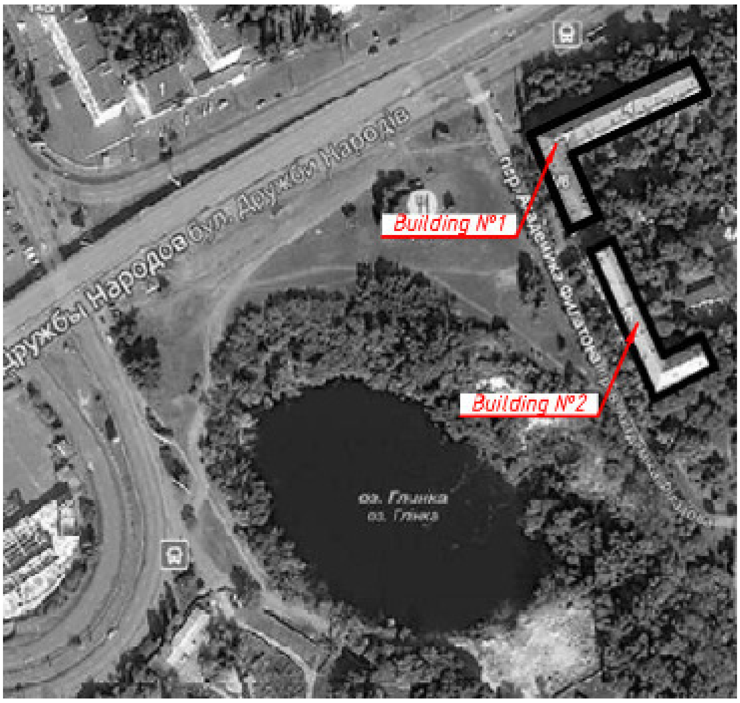

Figure 1 – Scheme of construction site

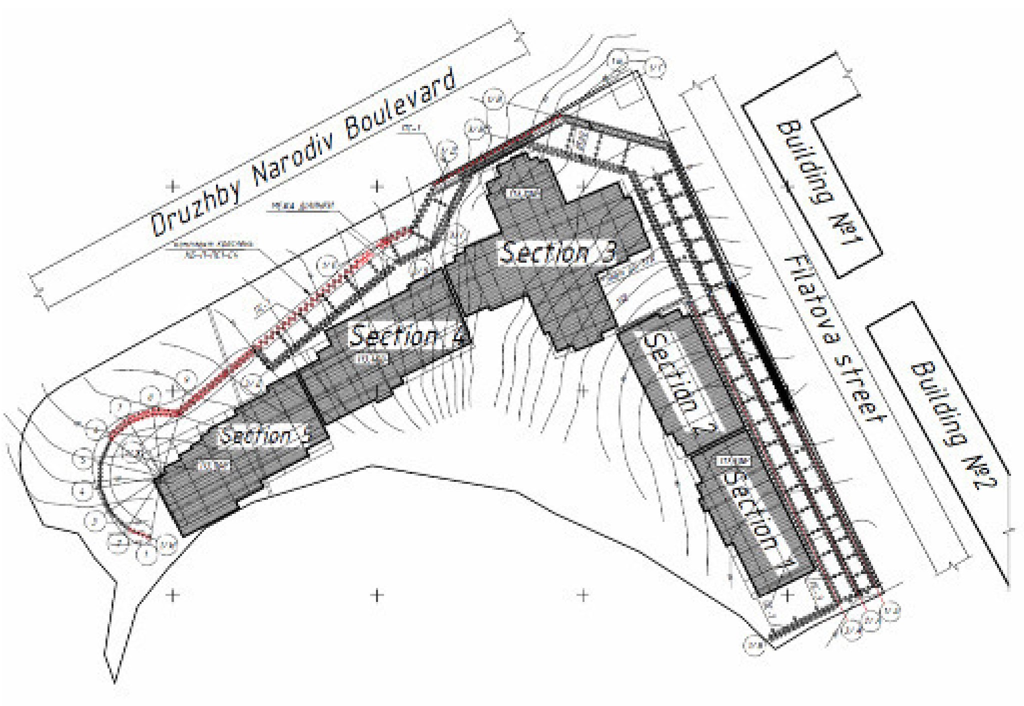

Figure 2 – Location plan of sections, retaining structures and surrounding buildings

Buildings are frameless with brick bearing longitudinal external and internal walls, on foundations of reinforced concrete basements, partially rubble, with basement, with prefabricated reinforced concrete overlap, enclosed on the longitudinal and inner walls. The stability of buildings in the longitudinal and transverse directions is ensured by the joint work of the external and internal walls, as well as prefabricated concrete slabs.

Before the construction was completed, a survey of the technical condition of the buildings was performed. The technical condition, established at the same time, is recognized as satisfactory. According to the report on the survey of buildings, a recommendation was made: when designing a deep excavation near the existing buildings, measures for protecting existing structures should be provided, by arranging the retain structures in the form of walls from bored piles [1]. Methods of these structures arrangement should exclude additional influences on existing objects (vibration, soaking, removal of soil from the basis of existing foundations, etc.).

As a complex of measures for engineering preparation and protection of the territory to ensure the stability of the slope on the site allocated for the construction of the project provides for the installation of a cascade of three levels of retaining walls (in separate sections of two and one row). Piles of all retaining walls are executed with a drilling diameter of 820 mm of variable length from 23 to 28 m with the reinforcement of round spatial reinforcement frames to the full depth. The class of piles concrete is C20 / 25.

The piles of the retaining wall RW–1 are arranged in a chess order with a distance between the piles in the row of 1,8 m and between the rows of piles 0,9 m. This provides for increasing the spatial rigidity of the design of the retaining wall and ensures the passage of groundwater between piles without raising the level of ground water behind the wall and the passage of groundwater between piles without raising the level of ground water behind the wall and the possibility of implementing measures for drainage of groundwater in the area of the retaining wall. In the upper part of the pile of the retaining wall are combined monolithic reinforced concrete grillage height of 1200 mm, which provides a compatible work of piles.

Between piles arranged monolithic reinforced concrete bracing. The maximum mark for the excavation of the pit is provided by the project after the installation of piles and grillages of RW–1 along the Druzhby Narodiv Boulevard is 117,50, and along the Filatov street 127,5.

After the installation of the retaining wall RW–1 on the site along the Filatov street, the supporting wall RW–2 is executed with an absolute mark of 127.5.

Piles of the supporting wall RW–2 are arranged in a chess order with a distance between the piles in the row of 1,8 m and between the rows of piles of 1 m. In addition, with a step of 6...7 m between the piles of retaining walls RW–1 and RW–2 arranged on 3 piles perpendicular to the main piles of retaining walls. In these piles, in the future, a wall–counterfort with a thickness of 500 mm, rests on the wall of the supporting wall RW–1, is arranged.

In the upper part of the pile of the retaining wall RW–2 are combined with reinforced concrete grillage in the thickness of 1200 mm, which provides a compatible work of piles. Between piles of RW–2 is a monolithic reinforced concrete wall–counerfort. Maximum mark for the excavation of the pit is provided by the project after the installation of piles and grillers RW–2 – 118.2.

After the excavation of the soil near the RW–1 and RW–2 along the Filatov street, the supporting wall RW–3 is executed with an absolute mark of 122.8, and along the Druzhby Narodiv Boulevard with a mark of 118.8. The walls of the supporting wall RW–3 are placed in two rows of the distance between the piles in the row is 1,2 m and between the rows of piles 1,2 m. The length of the piles is 23 m.

In addition, with a step of 6...7 m between the piles of retaining walls RW–2 and RW–3 piles arranged perpendicular to the main piles of retaining walls. In these piles, in the future, a wall-counterfort with a thickness of 500 mm is arranged.

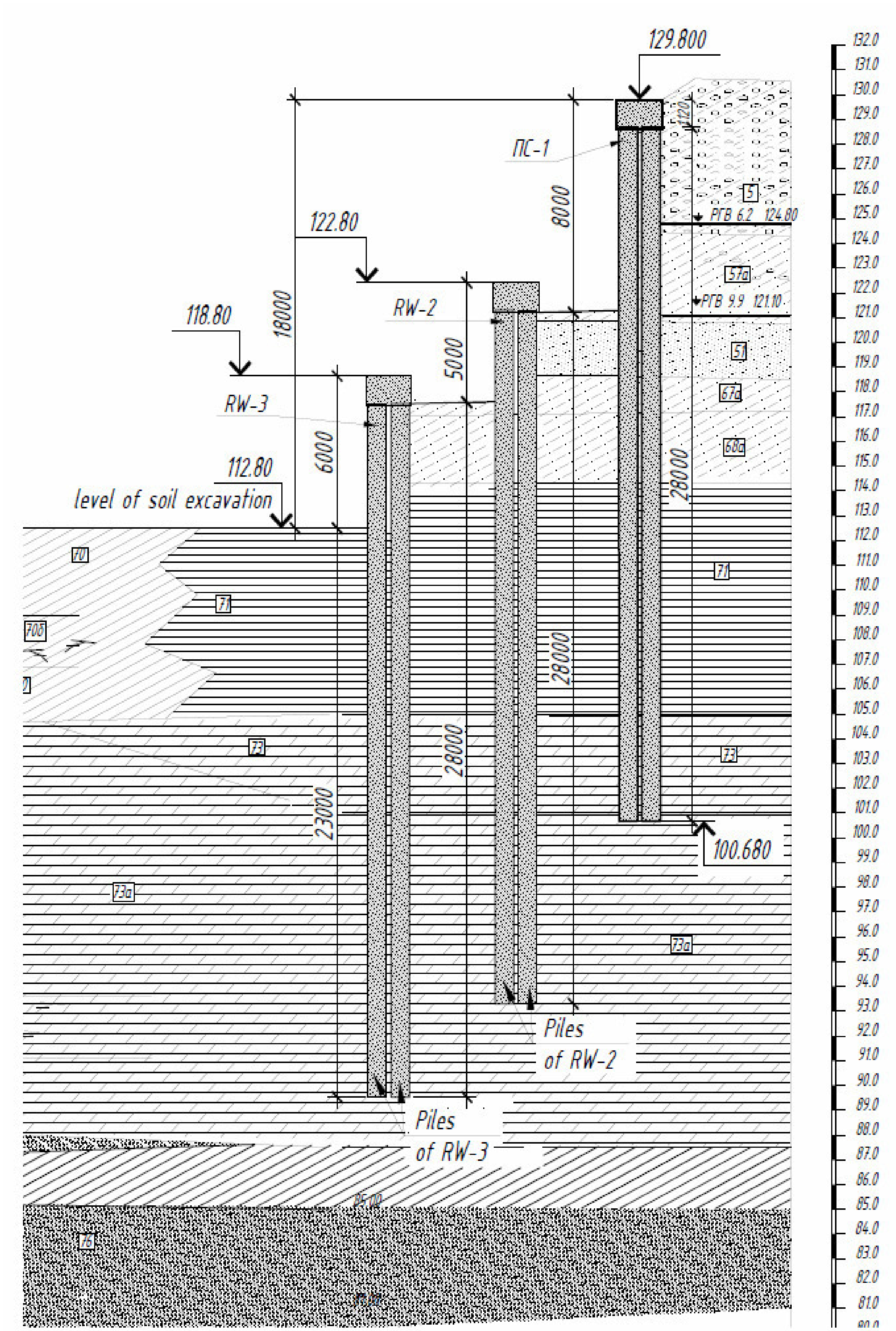

Figure 3 – Characteristic section on retaining walls

In the upper part of the pile of the retaining wall RW–3 are combined monolithic reinforced concrete grillage with a thickness of 1200 mm. Between piles of PS–3 is a monolithic reinforced concrete wall– counterfort.

The maximum mark for the excavation of the pit is provided by the project after the installation of piles and grills of RW–3 along the Filatov street of 117.5, and along the Druzhby Narodiv Boulevard is 113.70. The total depth of the pit makes 18m.

Engineering–geological site conditions are difficult (Fig. 4). According to the topographical plan and the report on engineering geological surveys, the maximum difference between the markings of the surface of the hilly part of the construction site is 12m. In the geological structure, from the surface of the territory prevail sandy soils of sandstone, loams with admixture of construction waste to 35 %, a significant soil–vegetation layer and peat. Below the bulk soil are sandy and sandy clay soils, marl clay and sand. Hydrogeological conditions of the construction site are characterized by the presence of several aquifers.

Within the construction site, there are active landslide processes that arise as a result of the suposonic washout of shallow rock particles when the first aquifer is inclined on the slopes of groundwater.

Before the beginning of work on planning of the territory, transfer of engineering communications and the arrangement of retaining walls, it is planned to organize monitoring of the stability of the slope, hydrological regime and the state of the surrounding building under a special program developed in the framework of scientific and technical support. On supporting elements (walls) of buildings is envisaged to fix geodetic observation marks and to arrange a system of rappers outside the building and its zone of influence.

Also, place the marks along the external retaining wall (RW–1) and on the slope with a step of 10 – 20 m and later on the grilliage of the retaining walls. It is also planned to organize a piezometric borehole system with a step of 20 – 25 m to monitor the level of groundwater.

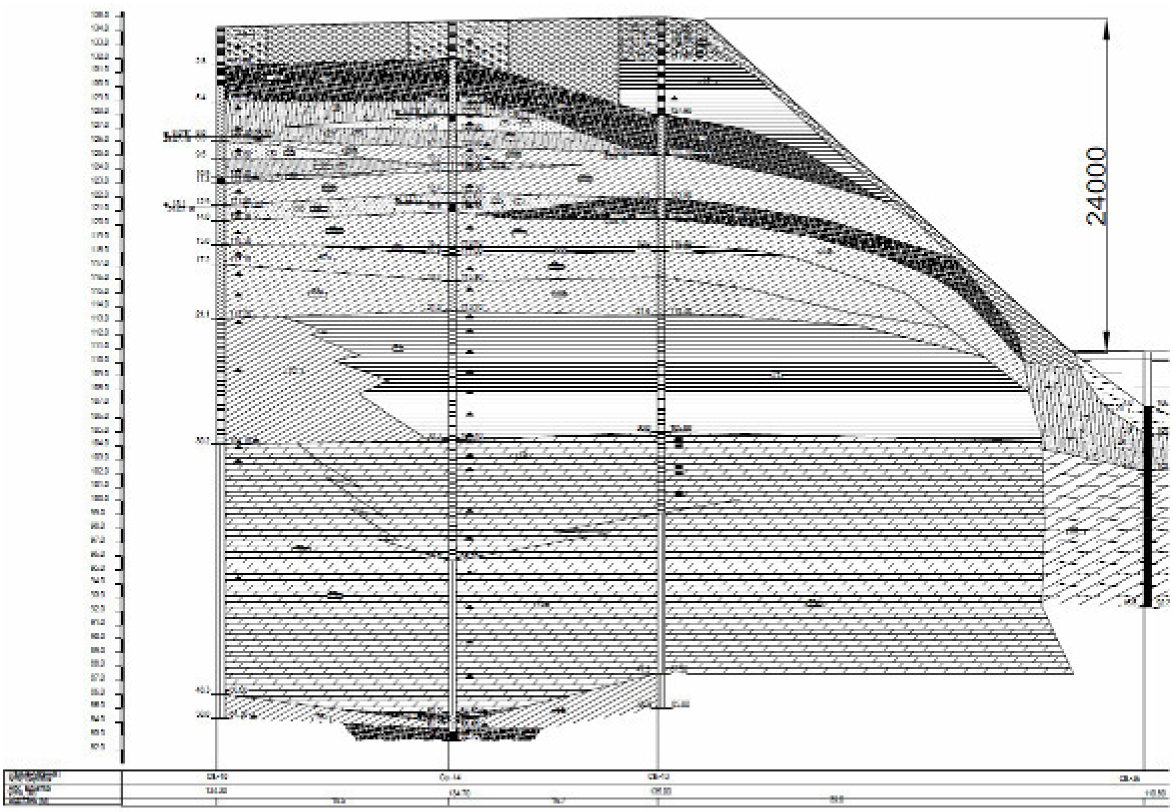

Figure 4 – Engineering-geological section

Table 1 – Physical and mechanical characteristics of soils

№ IGE	Soil description	Density, g/sm^3	Deformation module, MPa	Angle of internal friction, grad	Cohesion intercept, кPa	Filtration coefficient., m/day
14	Soil and vegetation layer	1.9	5	9	10	–
18	Peat of medium degree of decomposition	1.14	6	10	20	0.5
52	Sands of medium size	1.84	45	36	2	6
53	Large sand	1.84	40	37	1	7
55	Solid clay sand	2.0	19	28	17	0.5
56	Plastic clay sand	1.86	20	26	16	0.6
57a	Plastic clay sand	2.02	17	24	13	0.8
67a	Plastic clay sand	2.04	21	25	14	0.2
68a	Plastic clay sand	2.06	19	26	15	0.3
70	Semisolid loam	2.0	19	24	23	0.2
71	Semisolid clay	1.95	30	22	60	0.01
73	Semisolid clay	1.97	31	19	60	0.01

The numerical simulation of the stress-strain state of the protective structures of the deep excavation together with the soil mass was carried out using the finite element method, which enabled to take into calculation the complex properties of the soil, as well as to determine the stresses and displacements in all elements of the system at all stages of soil excavation. At the same time, the soil array was considered as a solid nonlinear medium. The task was solved in a two–dimensional setting. The calculation was carried out in 8 stages.

Fig. 6 shows the design scheme, which includes a ground base with a capacity of 50 m, three tiers of retaining walls (RW) with piles of step 1.2 m, length 28 m in RW–1 and PS–2, and 23 in PS–3, as well as the foundation of the existing buildings with reduced load from the superstructure. Characteristics of the rigidity of the piles of the retaining walls were calculated on the basis of 1m.p. The dimensions of the calculated area are 50×80 m. The lower part of the design circuit, at a distance of 20 m from the sole of the pile of the retaining wall, is limited by a plane that is fixed from the vertical displacements. On the lateral planes, on the basis is imposed ligature, which prevent only normal to the plane of displacement. For the retaining walls, the calculated stiffnesses are taken: $EI = 5.54 \cdot 10^5$ kN·m^2/m, EA = 1.73 kN/m.

4 variants of the task were solved:

V1 – retaining walls without surrounding building;

V2 – retaining walls with an existing building at a distance of 20m;

V3 – retaining walls with an existing building at a distance of 10m;

V4 – retaining walls with an existing building at a distance of 5m.

The calculation was made with taking into account the formation of the strained-deformed state of the soil mass during the installation of the retaining wall.

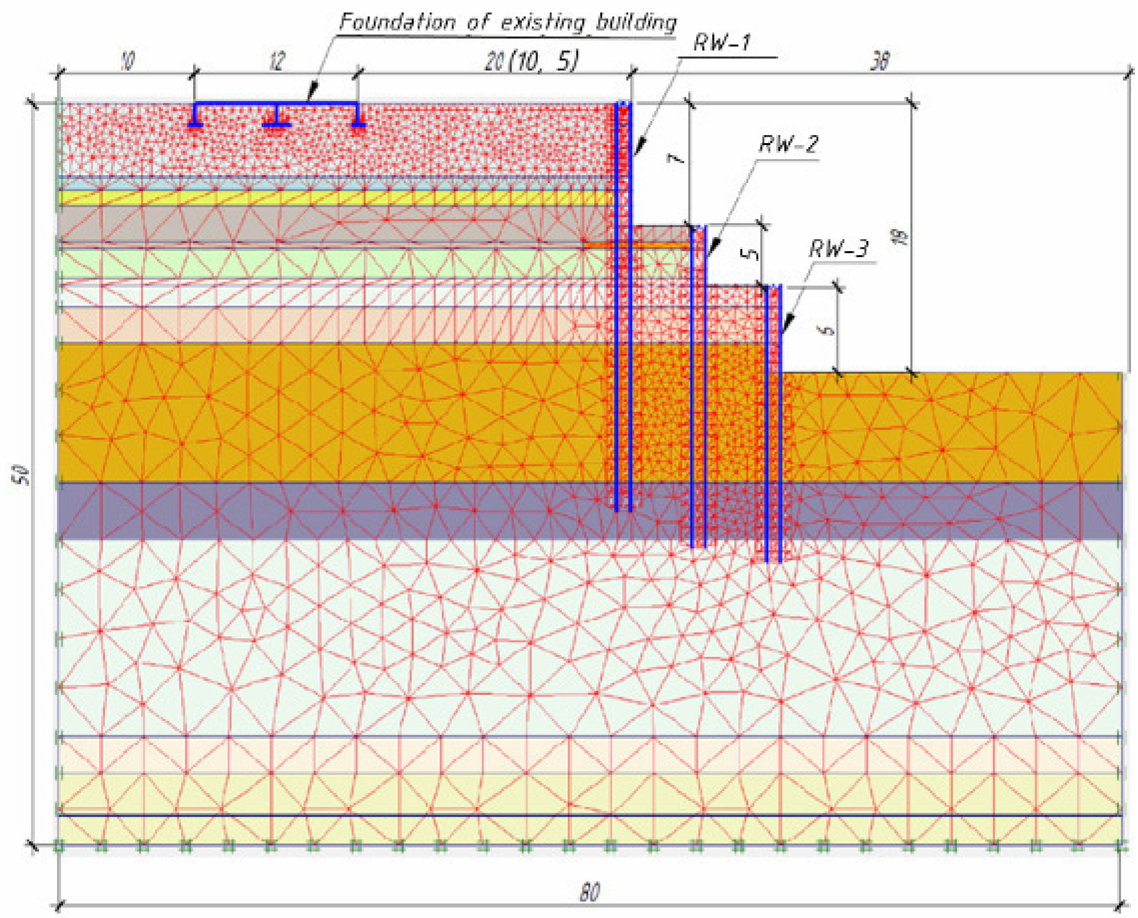

Figure 6 – Analytical scheme

In this case, horizontal displacements of the retaining wall's top, bending moments, and vertical displacement of the existing building's foundation were compared.

Fig. 7 indicates values of the horizontal displacements of the retaining walls top without building, in Fig. 8 – with building at a distance of 20, 10 and 5 m, respectively. Reducing the distance between the building and the retaining wall causes a significant change in horizontal displacement. In Fig. is 9 given a graph that showing changes in the displacement of the retaining wall tiers, depending on the distance to the building. The increase in displacement ranges from 12 to 70 %. The maximum value is observed in variant V4 at a distance of 5 m.

Analysis of the bending moments change indicates that the reduction of distance leads to both quantitative and qualitative change in the diagram of moments. This change is shown in fig. 10, which shows the diagrams of moments in the first pile to building at different variants for the location of the building. The same situation is observed in the piles of the other two tiers of retaining walls. So, with variants V3 and V4, bending moments increase by 2 and 60 % compared with V1 and V2. Insignificant change in the moments in variants V1 and V2 indicates that the existing building at a distance of 20 m from the pit is not in the zone of formation of the slope slip surface. With a decrease in the distance to 10 and 5 m, another picture is observed: the character of the diagram changes with the quantitative values of the moments, as well as their maximum values are formed on other marks. This is due to the fact that the close location of the building near the pit causes its entry into the zone of formation slide surface. This process is clearly observed in Fig. 8.

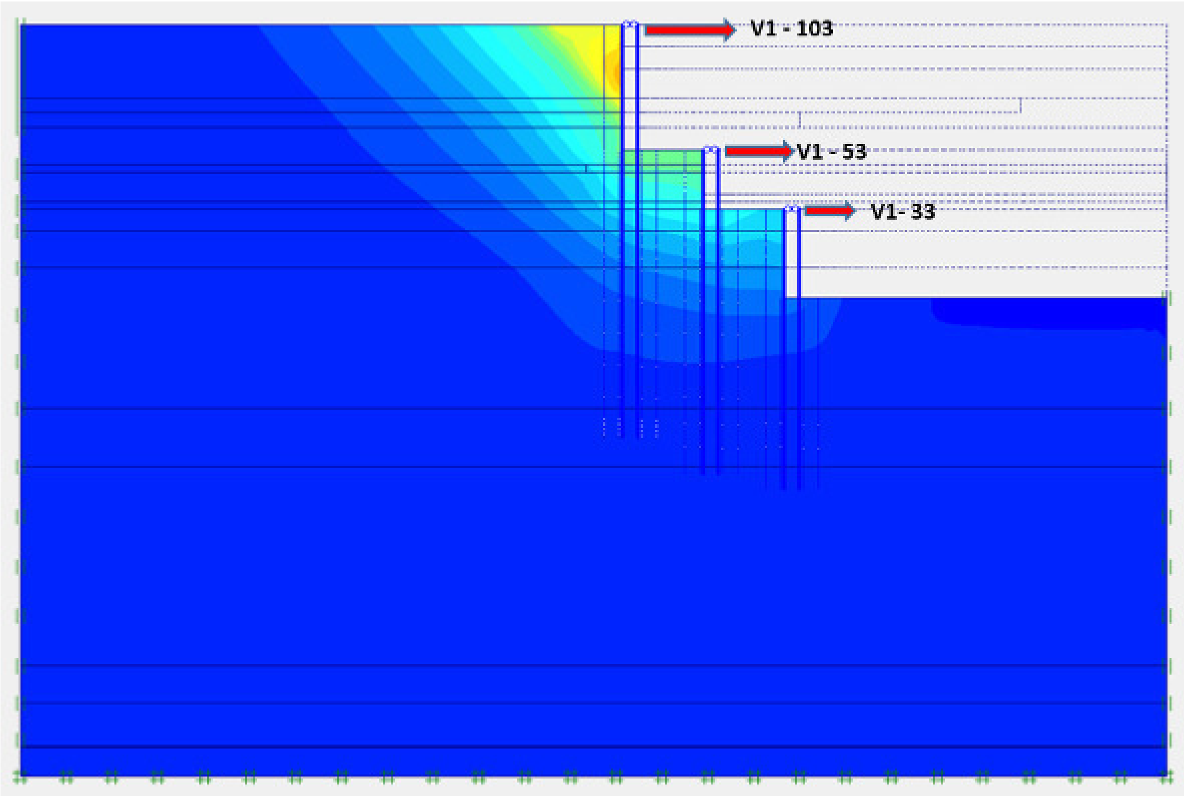

Figure 7 – Horizontal deformations of the retaining structure without building (mm)

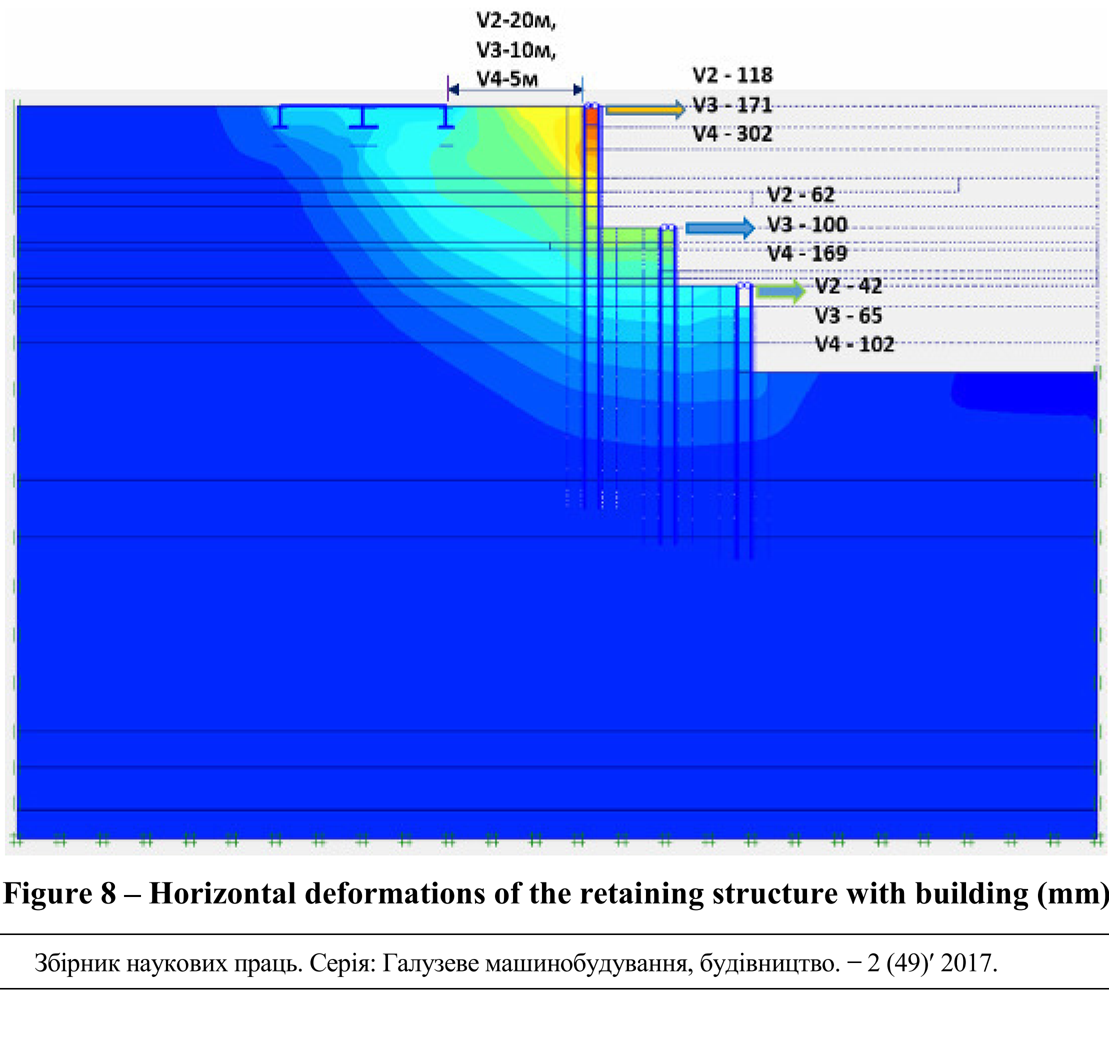

Figure 8 – Horizontal deformations of the retaining structure with building (mm)

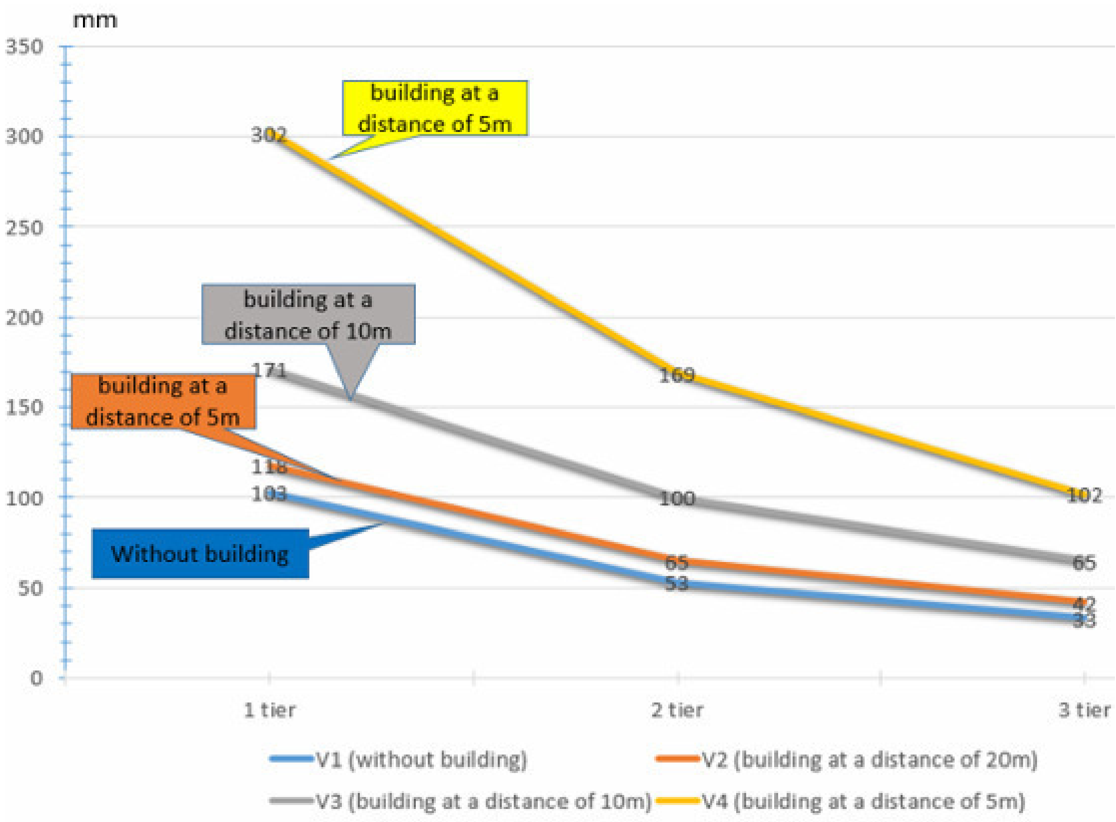

Figure 9 – Dependency graph of the retaining wall tiers displacement from the distance to the building

Analysis of the existing building's stress-strain state has shown that in the foundation structures, with a decrease the distance to the pit, the growth of additional sediments is fixed. There is an increase in vertical deformations by 30 – 40%. This situation requires additional measures to reduce the impact of the installation of the deep excavation.

Conclusions. It was revealed that taking into calculation the influence of existing building upon the installation of the deep excavation significantly changes the character of the soil massif and retaining structures stress-strain state, increasing the displacement of fence structures by 12 – 70%, depending on the distance to the building.

Discovered that bending moments in the fence structure with a decrease in the distance between the pit and existing buildings undergo quantitative and qualitative changes. Thus, the value of bending moments in piles with a decrease of the distance from 20 m to 10 m increases by 26 %, and in the case of a decrease of the distance from 10 to 5 m – by 45 %.

It is shown that reducing the distance between the existing building and deep excavation leads to additional sedimentations in the foundation structures of the existing building. Thus, vertical deformations at the location of the building at a distance of 5 m increase by 35 %, compared with the building at a distance of 20 m, which is explained by the fall of the building into the zone of slip surface slope.

It was revealed that the most rational location of the existing building is when the depth of the pit is equal to the distance between the building and the edge of the retaining wall, as the building does not fall into the zone of the new construction influence.

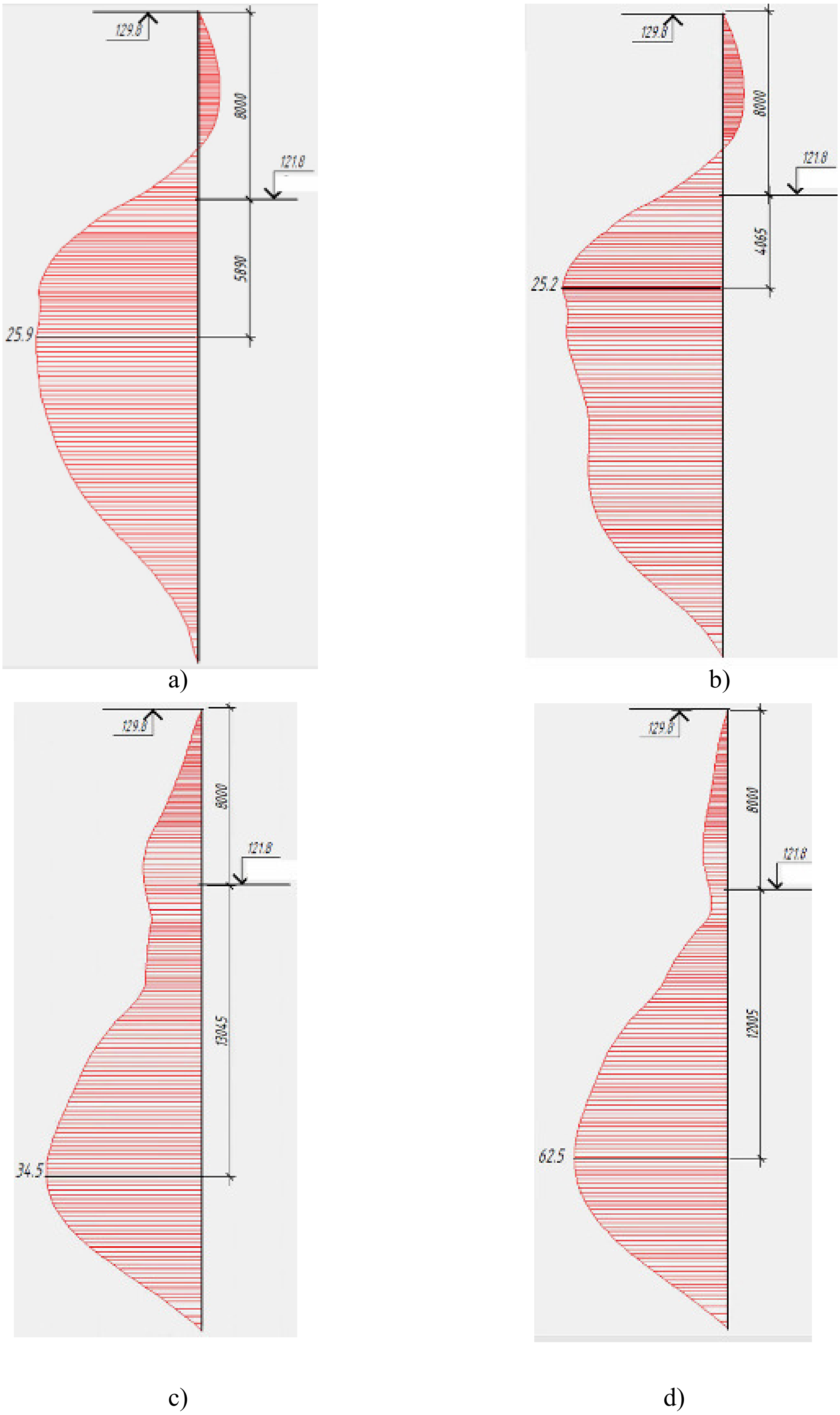

Figure 10 – Curves of bending moments in the first to building pile (t*m):
a) without building; b) building at a distance of 20m; c)building at a distance of 10m; d)building at a distance of 5m

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