УДК 624.15:69.05(075.8) DOI 10.33042/2311-7257.2023.109.1.3

Igor Shumakov[1], Vladyslav Basanskyi[2], Yuri Fursov[1], Svitlana Bratishko[1], Oleksandr Savchenko[1]

[1]*O.M. Beketov National University of Urban Economy in Kharkiv, Ukraine*
[2]*State Enterprise «Research Institute of Construction Production named after V.S. Balytskyi»*

DETERMINATION OF THE IMPACT ZONE OF ENABLING WORKS OF A NEW CONSTRUCTION ON THE SURROUNDING BUILDINGS

The methodology for graphical and analytical determination of the influence area of an excavation on the foundations of adjacent buildings is provided, depending on the type of enclosing structures and the depth of the excavation. The idealized model of the influence zone takes into account conditions under which the boundary of the influence zone of a new building can be limited to a distance where the calculated value of additional settlement of the soil mass of the existing structure does not exceed 1 mm.

Keywords: *underground construction, pit, concrete, piles, impact, modeling, optimization, parameters.*

Introduction

Modern construction is characterized by intensive development of underground space. Without it, the demographic, transport, and operational problems of large cities are impossible to solve. This leads to the emergence of multistorey underground parking garages, shopping centers, underground roads and interchanges as well as underground offices. For example, in the Tokyo metropolitan area with a population of almost 9 million people, each building has 3–4 underground floors [1].

Currently, the conditions of construction in large cities are such that the most intensive construction works are carried out in the central part of the city. This can be explained by the rational placement of objects in areas with developed infrastructure and the historical psychology of “prestigiousness” of real estate in the central districts of the city. According to the data of design and research organizations, it may be possible to place below ground surface up to 70% of the total volume of garages, up to 60% of storage facilities, up to 50% of archives, and up to 30% of cultural and public services in large cities [2]. It is also noted that energy savings in existing underground facilities amount to 74% in refrigerators, 20% in sports pools, 25% in shopping centers, and 31% in gyms. The consumption of heat energy in underground storage facilities is 23% lower than in the corresponding above-ground facilities. For example, the practice of many countries shows that the operating costs of maintaining underground public facilities account for only 30–50% of the costs of maintaining the corresponding above-ground structures [3–9].

It should be noted that the level of use of underground space is different for each city: it is necessary to consider the historical development, transport infrastructure, natural and climatic characteristics of the region, and the prospects for the development of the urban area as a whole. The city will inevitably move underground to reduce the density of development in historic centers. The environmental problem of air pollution can also be solved by moving the main traffic flows underground.

The goal is to determine the impact zone of the pit on the adjacent buildings, depending on the type of enclosing structures and the depth of the pit.

Analysis of Recent Research

Existing buildings located near the construction site fall within the impact zone of the new building. However, deformations of the structures of the adjacent buildings can be observed both during the construction of the above-ground part of the new building and during the period of enabling works. In the paper [10], it is determined that the impact zone is an area with a width of l = 60 m along the perimeter of a new building with an impact area S, which for a new construction object of rectangular shape is calculated by:

$$S = 2l\,(a + b + 2l), \qquad (1)$$

where S is the area of the impact zone, m^2;
a is the width of the constructed building, m;
b is the length of the constructed building, m;
l is the width of the impact zone, m.

However, the width of the impact zone of the new building is not substantiated and assumed to be the same for any conditions of the construction site and any stage of construction. Meanwhile, on the basis of the studies conducted [9, 11], a group of factors has been identified that must be considered when building next to nearby houses:

– characteristics of the soil base (presence of weak and unevenly compressed soils);

– high groundwater level;

– possibility of a water-saturated and plastic state of soils at the site, which may lead to their compaction or loss of stability under dynamic influences;

– depth of the foundations of adjacent buildings.

According to [9], the main causes of deformations during excavation of pits is an increase in stresses in the impact zone of the new construction.

At the same time, the author of [11, 12] argues that the deformations of buildings during the excavation of construction pits and trenches near said buildings occur due to a decrease in vertical and horizontal stresses in the soil mass below the bottom of the pit and next to it, which reduces the bearing capacity of the foundation due to full or partial elimination of lateral loading. As a result, plastic deformations of the soil may develop, with it being squeezed out from under the base of the foundation towards the pit. The intensity of the development of these deformations largely depends on the relative position of the base of the previously erected foundation and the pit being excavated.

If the depth of the pit is greater than the depth of the existing foundations, additional negative phenomena may arise: the development of active lateral pressure of the soil on the wall of the existing foundation; the formation of a downward slope with a limited stability; the effect of hydrodynamic forces caused by a decrease in the groundwater level in the soil mass, etc. Such phenomena often lead to an uneven rise in the bottom of the pit, which was mentioned in [13].

If the average pressure under the base of the existing foundation (in the case of a direct abutment) is lower than the design resistance, then usually the soil will not be squeezed out from under the base of the existing foundation, provided that the bottom of the pit is 0.5 m or more higher than the base of said foundation.

When creating foundations in the vicinity of previously constructed buildings, various negative impacts may occur, and the properties of soils may change, which tend to worsen during the construction and operation of buildings and structures. Therefore, for foundations that consist entirely of water-saturated clay soils and silty sands, it is important to take into account the possibility of a decrease in their strength and deformation characteristics due to the loosening and increase of soil moisture during the construction process [14, 16–18].

Formulation of the purpose of the article

The purpose of the research is to determine the area of influence of the pit on the adjacent buildings, depending on the type of enclosing structures of the pit and its depth. To do this, it is necessary to evaluate the types of fencing in terms of deformability and, within the idealized model of the influence zone, take into account the conditions when the calculated value of the additional settlement of the base of the existing building has minimal values.

Methodology and Results

In addition to the characteristics of the soil, the level of groundwater and the depth of the foundation, which may depend on the size of the zone of influence of the new pit, the depth and type of pit enclosure are also important. In order to verify this assumption, calculations of the influence zone were carried out during the development of the pit with the use of enclosing structures of the pit in the form of sheet pile walls, bored piles and diaphragm walls.

Calculations using the *Plaxis* program were carried out during the development of a pit with dimensions of 24×94 m. During calculations within the idealized model, the impact zone was determined based on the condition that it is allowed to limit the radius of the impact zone of a new construction by a distance at which the calculated value of the additional settlement of the soil mass or the base of the existing structure of the surrounding development does not exceed 1 mm. The total impact area minus the area in the middle of the pit enclosure was determined.

In the idealized model, the impact zones were determined when excavating the pit to a depth of 3.5 m; 7.0 m; and 10.5 m, which roughly coincides with the arrangement of one-, two-, and three-level underground floors.

To determine the effect of the stiffness factor *EI* (*E* – modulus of elasticity of the material; *I* – torque moment of inertia of the structure) of the pit enclosure, three types of pit enclosure structures with a cantilever restraint in the soil were used in the model:

– Larssen sheet piling (in the model, the stiffness characteristics are taken for the VL605 type of sheet piling, with stiffness parameters EI = 105,210 kN * m^2;

– pit enclosure made of bored piles with a diameter of 620 mm and a spacing of 1 m, with stiffness parameters EI = 216,677 kN * m^2;

– pit enclosure made using the diaphragm wall technology, with a width of 620 mm and stiffness parameters EI = 596,190 kN * m^2;

– with a pit depth of 10.5 m, the option of using an additional system with metal pipe struts was considered for each type of pit wall fastening structure.

The length of the pit enclosure structures was assumed the same for all types according to the recommendations of the “Danish Rules” [15]:

$$L_{pe} = 2.4 * H_{ed} \tag{2}$$

where L_{pe} is the length of the pit enclosure structures, m; H_{ed} is the depth of the pit excavation, m.

According to (2), the length of the pit enclosure structures at a pit depth of 3.5 m; 7.0 m; and 10.5 m is, respectively 9, 17, 26 m. Calculation models for pit excavation were created for a depth of 3.5 m; 7.0 m and 10.5 m (see example for Fig. 1).

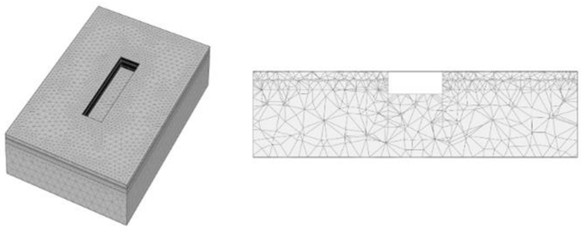

Fig. 1. Three-dimensional model of a soil mass with a pit that has a depth of 10.5 m

The plan of the site with isofields of deformations and the zone of influence (the outline is limited by an oval line) was built when excavation was carried out to a depth of 3.5 m; 7.0 m and 10.5 m for Larssen sheet piles, bored piles and slurry walls (see example in Fig. 2).

Overall deformations outside the pit are insignificant in all cases, up to 1 mm. Corresponding zones of influence of a pit excavated to different depths using different types of pit construction are graphically determined. The areas of the pit's influence zone are shown in Table 1.

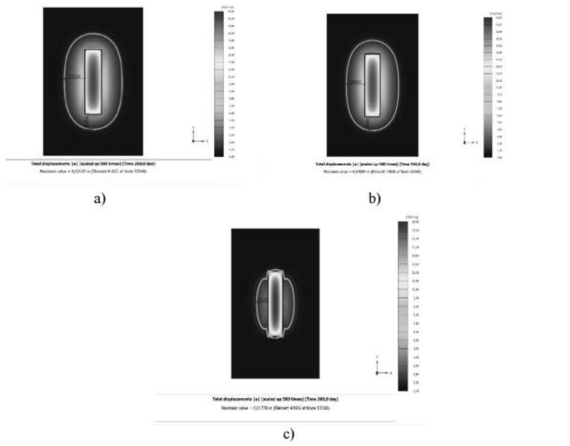

Fig. 2. An example of the construction of the influence zone of a pit with a depth of 3.5 m and a fence in the form of: a) Larssen sheet piling; b) bored piles; c) diaphragm walls

Discussion

It was found that, when excavating a pit to a depth of 3.5 m and 7.0 m, the impact zones show a nonlinear decrease when changing the structure of the pit enclosure, with a corresponding increase in the rigidity of the enclosure. Compared to the impact zone for a 3.5 m deep pit, the impact zone increases disproportionately for a 7.0 m deep pit. A 100% increase in excavation depth (from 3.5 m to 7.0 m) increases the impact zone by 24% for enclosures in the form of Larssen sheet piling and bored piles, and by 31% for a diaphragm wall. The overall deformations outside a 7.0 m deep pit in all cases increase compared to the deformations in case of a 3.5 m deep pit and are in the range of 10–15 mm.

Table 1

Impact zones when excavating a pit

Type of pit enclosure	Area of the impact zone, m^2, for a pit with the depth, m					
	without additional securing			with additional securing		
	3.5	7.0	10.5	3.5	7.0	10.5
Larssen sheet piling	7.321	9.515	8.320	-	-	8.034
Bored piles	6.971	9.093	7.726	-	-	7.808
Diaphragm walls	2.301	3.330	11.383	-	-	8.309

When the pit was excavated to a depth of 10.5 m, the impact zone decreased when using an enclosure in the form of Larssen sheet piling and bored pile wall compared to a diaphragm wall enclosure; there was also a significant increase (up to 200 mm) in large deformations in the Larsen sheet piling, and an increase in large deformations began in the bored pile enclosure as well. Compared to the impact zone for a 7.0 m deep pit, the impact zone increases disproportionately for a 10.5 m deep pit. A 50% increase in excavation depth (from 7.0 m to 10.5 m) increases the impact zone by 14% for enclosures in the form of Larssen sheet piling, by 17% for bored pile enclosures, and by 3.42 times for a diaphragm wall enclosure.

Due to the significant rigidity of the diaphragm wall, with increasing depth of excavation it continues to operate according to the rigid scheme with an increase in the zone of “small deformations” not exceeding 10 mm, and a slight increase in “large deformations” exceeding 10 mm.

Larssen sheet piling, in turn, at great depths provides a decrease in the zone of “small deformations” as well as a considerable increase in its own deformations and significant (up to 200 mm) deformations in the zone of “large deformations”. Such a change in the proportion of “small” and “large” deformation zones is due to the fact that, at a considerable depth, the Larssen sheet pile enclosure begins to function according to the flexible scheme, and with such deformations, destruction and collapse of the enclosure structures may occur.

From the point of view of the construction technology in the conditions of urban development, Larssen sheet piling is characterized by a number of positive and negative factors. The positive ones include the following: prefabricated sheet pile design with guaranteed geometry and rigidity characteristics and a low own weight; relatively high rate of construction; structural integrity in plan, which reduces the possibility of soil suffosion; reusability. The negative factors are as follows: limited rigidity and length characteristics; as a method of embedment, pile sinking, vibratory driving-in, and jacking are typically used, which may have a negative impact on the surrounding buildings in the zone of compacted urban development; possibility of groundwater filtration through the enclosure wall; possibility of the development of corrosion processes over time; possibility of distortions in the geometry of the wall structure (warping) if there is uneven occurrence of soils; high cost of the product.

In turn, the bored pile enclosure provides at great depths a decrease in the zone of "small deformations" as well as an increase in its own deformations and deformations in the zone of "large deformations". Such a change in the proportion of "small" and "large" deformation zones is due to the fact that, at a considerable depth, the bored pile enclosure begins to function according to the flexible scheme, but its rigidity is still sufficient to ensure the overall stability of the system.

From a technological point of view, the use of bored piles to make pit enclosures has a number of positive and negative factors as well. The positive ones are: relatively low cost of construction; variability in geometric parameters without significant limitation in length; high rate of construction when using certain construction technologies (CFA piles, jacked piles, etc.); absence of significant vibration (in most soil conditions); can be used in most soil conditions; can be used as a permanent structure, including the action of vertical loads; when using secant piles and bored piles with intermediate jet piles, it is ensured that groundwater filtration into the pit is prevented. The negative factors include the following: when using a symmetrical pile frame (the most common option), part of the reinforcement is used ineffectively, which leads to over-reinforcement; the quality of the pile is largely dependent on the quality of the equipment used and the qualifications of personnel; the mechanical properties of the soil around the pile may reduce; it is difficult to limit the groundwater inflow; it is necessary to create an additional structure to form the surface (horizontal sheeting); in watered soils, when using the CFA piling technology, decompaction of the soil mass around the piles may manifest itself to a great extent, which may lead to additional settlement of the surrounding buildings.

As a result of the analysis of changes in the functioning of the pit enclosure for the types under consideration, it was found that for the diaphragm wall such a depth of excavation can also be used, at which the enclosure will function according to the flexible scheme, resulting in similar processes as when using other enclosure types, namely, a decrease in the zone of "small deformations" and an increase in the zone of "large deformations".

When using the diaphragm wall as a pit enclosure, the following main positive and negative factors can be identified from a technological point of view. The positive ones include: wide variability in the geometric parameters of the enclosure structure, with the possibility of using it for a significant depth of submersion; possibility of ensuring considerable rigidity of the structure; effective use of reinforcement; low impact (which may include pressure, vibration loads, and deformations) on the soils and foundations of the surrounding buildings when installing enclosure structures using the diaphragm wall method; reliable watertightness; fast preparation of the finished surface; can be used in any soil conditions; can be used as a permanent structure, including the action of vertical loads. The negative factors include the following: high cost of construction; high requirements for the quality of equipment and personnel qualifications; the need to arrange a plant for the preparation of bentonite mixture on the construction site; relatively low rate of enclosure installation; inapplicability in the presence of cavities in the soil mass.

Conclusions

Calculations of the zone of influence during the development of the pit were carried out using such enclosing constructions of the pit as Larsen sheet piling, bored piles and diaphragm wall. It was established that the nature of the change in the influence zone is similar for different types of enclosure structures, and the transition from rigid to flexible operation of the pit enclosure depends on the ratio of the rigidity of the enclosure and the depth of the excavation. In the pit The analysis of the change in the deformation zone for a pit 10.5 m deep, for which additional fastening with metal pipe spacers is applied, shows that the transition to flexible operation of the pit enclosure and the increase of deformations over 1 mm occurs more slowly than without the use of additional fastening. Based on the results of the calculations, it was found that the area of the pit's influence zone, with other factors unchanged, depends on the type of construction of its enclosure and the depth of the pit. The results of the research can be used when choosing the type of enclosing construction of the pit to prevent the negative impact of the new construction on the surrounding buildings.

References

1. Токіо – місто, яке було відроджене двічі. https://transparentcities.in.ua/news/tokio--misto-yake-bulo-vidrodzhene-dvichi.

2. Han Admiraal, & Shipra Narang Suri. Think Deep: Planning, development and use of un-derground space in cities. Netherlands Drukkerij Aktief, Pijnacker. 59 p. https://isocarp.org/app/uploads/2015/05/FINAL_Think-Deep.pdf.

3. Ten amazing underground cities. http://www.factroom.ru/facts/wp-content/themes/platforma/js, last accessed 2023/01/20.
4. The history of the construction of the underground city of Montreal. Portal “La ville souterraine de Montréal”. http://record-absolu.pagesperso-orange.fr/construction/montrealreso/reso.htm.
5. Semenova, O.S., & Volkov, N.S. Urban planning methodology for the development of underground space at the intersection of the road network]/ Information portal “Underground urbanization concepts”. http://www.undergroundexpert.info.
6. Zhang, W., Gu, X., Zhong, W., Ma, Z., & Ding, X. (2022). Review of transparent soil model testing technique for underground construction: Ground visualization and result digitalization. *Underground Space*. 7 (4), 702–723. https://doi.org/10.1016/j.undsp.2020.05.003
7. Mandala, V., Patel, K.A., & Chavda, J.T. (2023). Numerical Investigations on Response of Multistorey Building Frames Subjected to Adjacent Unsupported Excavations. *Geotechnical and Geological Engineering*. 41, 1223–1245. https://doi.org/10.1007/s10706-022-02331-2
8. Chouhan, K., & Chavda, J.T. (2023). A Novel Approach to Simulate Cone Penetration Test Using Conventional FEM. *Geotechnical and Geological Engineering*. 41, 1439–1451. https://doi.org/10.1007/s10706-022-02346-9
9. Poulos, H. (2023). Analysis of Foundation Settlement Interaction among Multiple High-Rise Buildings. *Geotechnical and Geological Engineering*. 4. https://doi.org/10.1007/s10706-023-02429-1
10. Nadtochii, M. (2017). Doslidzhennia vplyvu orhanizatsiino-tekhnolohichnykh chynnykiv na nove budivnytstvo nadzemnoi chastyny monolitno-karkasnykh bahatopoverkhovykh budivel v ushchilnenykh umovakh [Investigation of the influence of organizational and technological factors on the new construction of the aboveground part of monolithic frame multistorey buildings in compacted conditions]. Dissertation of the Candidate of Technical Sciences: 05.23.08. Odesa State Academy of Civil Engineering and Architecture. Odesa, 2017, 145 p. (in Ukrainian).
11. Chouhan, K., & Chavda, J. (2021). A review on large deformation problems in geotechnical engineering. In: *Indian geotechnical conference*. Springer, NIT Trichy, India. https://doi.org/10.1007/978-981-19-6998-0_16
12. Augarde, C., Lee, S., & Loukidis, D. (2021). Numerical modelling of large deformation problems in geotechnical engineering: a state-of-the-art review. *Soils Found*. 61(6):1718–1735. https://doi.org/10.1016/j.sandf.2021.08.007
13. Zyliński, K., Korzec, A., Winkelmann, K., & Górski, J. (2020). Random field model of foundations at the example of continuous footing. *AIP Conf. Proc*. https://doi.org/10.1063/5.0007811
14. Shumakov, I., Pogrebniak, A., & Grinchuk, O. (2016). Aspects of supporting subsoil softening at excavation of deep foundation PITs. In: Contemporary achievements in civil engineering: conference proceedings 4th int. conf. 22 april 2016. Serbie, Subotiza: University of Novi Sad, pp. 529–537. https://doi.org/10.14415/konferencijaGFS2016.054
15. Denver, H., & Kellezi, L. (2016). Modelling of Earth Pressure from nearby Strip Footings on a Free & Anchored Sheet Pile Wall. In: Proc. of the 17th Nordic Geotechnical Meeting Challenges in Nordic Geotechnic, pp. 913–922, (2016). https://www.geo.dk/bibliotek/2011/earth-pressure-from-the-nearby-buildings-in-sheet-pile-walls/#t=article
16. Cui, K., Feng, J., & Zhu, C. (2018). A study on the mechanisms of interaction between deep foundation pits and the pile foundations of adjacent skewed arches as well as methods for de-formation control. *Complexity* 1:1–19. https://doi.org/10.1155/2018/6535123
17. Huang, M., Liu, Xr., & Zhang, Ny. et al. (2017). Calculation of foundation pit deformation caused by deep excavation considering influence of loading and unloading. *J. Cent. South Univ*. 24, 2164–2171. https://doi.org/10.1007/s11771-017-3625-3
18. Zhang, J., Xie, R., & Zhang, H. (2018). Mechanical response analysis of the buried pipeline due to adjacent foundation pit excavation. *Tunn Undergr. Space Technol*. 78:135–145. https://doi.org/10.1016/j.tust.2018.04.026

Автор: ШУМАКОВ Ігор Валентинович
доктор технічних наук, доцент, завідувач кафедри
Харківський національний університет міського господарства імені О.М. Бекетова
E-mail – igor.shumakov@kname.edu.ua
ID ORCID: http://orcid.org/0000-0002-1502-051X

Автор: БАСАНСЬКИЙ Владислав Олександрович
кандидат технічних наук, завідувач сектором
ДП «Науково-дослідний інститут будівельного виробництва імені В.С. Балицького»
E-mail – vladyslav.basanskyi@gmail.com,
ID ORCID: https://orcid.org/0000-0002-7850-7798

Автор: ФУРСОВ Юрій Васильович
кандидат технічних наук, доцент, професор кафедри
Харківський національний університет міського господарства імені О.М. Бекетова
E-mail – uafursov@gmail.com
ID ORCID: http://orcid.org/0000-0002-1386-2254

Автор: БРАТІШКО Світлана Миколаївна
доцент кафедри
Харківський національний університет міського господарства імені О.М. Бекетова
E-mail – svitlana.bratishko@kname.edu.ua
ID ORCID: http://orcid.org/0000-0002-4786-2375

Автор: САВЧЕНКО Олександр Іванович
кандидат економічних наук, доцент, доцент кафедри
Харківський національний університет міського господарства імені О.М. Бекетова
E-mail – oleksandr.savchenko@kname.edu.ua
ID ORCID: https://orcid.org/0009-0005-6687-0249

ВИЗНАЧЕННЯ ЗОНИ ВПЛИВУ ВИКОНАННЯ РОБІТ ПРИ НОВОМУ БУДІВНИЦТВІ НА НАВКОЛИШНЮ ЗАБУДОВУ

І.В. Шумаков[1], В.О. Басанський[2], Ю.В. Фурсов[1], С.М. Братішко[1], О.І. Савченко[1]
[1]Харківський національний університет міського господарства імені О.М. Бекетова
[2]ДП «Науково-дослідний інститут будівельного виробництва імені В.С. Балицького»

Для сучасного міського будівництва в ущільнених умовах забудови актуальним є питання стійкості ґрунтових масивів під існуючими будівлями. Інтенсивність розвитку можливих деформацій в значній мірі залежить від взаємного розташування основи раніше спорудженого фундаменту та котловану нової будівлі. У статті наведено методологію визначення зони впливу котловану на ґрунтові фундаменти суміжних будівель, залежно від типу обмежувальних конструкцій та глибини котловану. Зона впливу була розрахована для котловану з використанням захисних конструкцій у вигляді листових шпунтів Ларсена, свердловинних паль та діафрагмових стін. Відповідні зони впливу котловану на різні глибини, використовуючи різні типи конструкцій визначені графічно. Науковий результат може бути пояснений тим, що ідеалізована модель зони впливу враховує умови, при яких границя зони впливу нової будівлі може бути обмежена відстанню, на якій розрахункове значення додаткового осідання ґрунтового масиву або основи існуючої структури навколишньої будівлі не перевищує 1 мм. Розміри зон впливу визначаються на різних глибинах котловану, які приблизно відповідають розташуванню одно-, дво- та трирівневих підземних структур будівлі. Збільшення глибини котловану на два підземних поверхи збільшує зону впливу на 24-31% для розглянутих типів огородження котловану, а до трьох поверхів - на 14-17%. Встановлено, що характер зміни зони впливу схожий для різних типів конструкцій огородження, а перехід від жорсткого до гнучкого функціонування конструкції котловану залежить від співвідношення жорсткості огородження та глибини виробки. Як практичний результат дослідження його можна використовувати при виборі типу конструкції котловану для запобігання негативному впливу будівельних робіт нового будівництва на навколишні будівлі.

***Ключові слова**: підземне будівництво, котлован, бетон, палі, вплив, моделювання, оптимізація, параметри.*