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SCIENTIFIC AND TECHNICAL SUPPORT OF NEW CONSTRUCTION FOR HISTORIC BUILDINGS SAVING

Investigations results of technical state of bearing structures, bases and foundations of historical building in complicated conditions are presented. Stress strain state (SSS) of the «base – superstructure on piles – historical buildings» system was evaluated. Calculation by finite element method (FEM) using elastic perfectly-plastic Mohr – Coulomb soil model was applied. The most rational construction option taking into account the actual technical state of historical building was chosen. Test calculations have been made in order to determinate the possibility of loss of cultural heritage object of local significance due to three most likely accidents variants during operation of a new building. New building frame stability has been evaluated taking into account the local failure in case of emergency.

Keywords: *loess soil, historical building, new building influence, soil excavation, pile foundation, emergencies, modeling, finite element method, elastic-plastic problem, stress-strain state, additional settlements, cut-off wall.*

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НАУКОВО-ТЕХНІЧНИЙ СУПРОВІД НОВОГО БУДІВНИЦТВА ДЛЯ ЗБЕРЕЖЕННЯ ІСТОРИЧНОЇ ЗАБУДОВИ

Викладено результати досліджень технічного стану несучих будівельних конструкцій, їх основ і фундаментів історичної будівлі за умов лесових ґрунтів і несприятливих фізико-геологічних процесів. Розрахунком методом скінченних елементів (МСЕ) з використанням пружно-пластичної моделі ґрунту з критерієм міцності Кулона – Мора оцінено напружено-деформований стан (НДС) системи «основа – каркасна новобудова на палях – історична забудова» й вибрано найбільш раціональний варіант будівництва з урахуванням фактичного технічного стану історичної будівлі. Виконано перевірочні розрахунки з визначення можливості втрати об'єкта культурної спадщини місцевого значення у результаті трьох найбільш ймовірних варіантів аварій при експлуатації новобудови. Оцінено стійкість її каркаса новобудови з урахуванням локального руйнування у разі надзвичайних ситуацій.

Ключові слова*: лесовий ґрунт, історична забудова, вплив новобудови, котлован, пальовий фундамент, аварійна ситуація, моделювання, метод скінченних елементів, пружно-пластична задача, напружено-деформований стан, додаткові осідання, роз'єднувальний екран.*

Introduction. Investors' maximum attention to historical centers of old cities is a characteristic feature of modern construction. These are the places where the buying of a comfortable dwelling, offices, shopping areas, etc. is the matter of prestige. It is unfortunately that we have many negative examples of the new buildings, which affect the existing historical buildings [1 – 4]. Nowadays the influence of foundation technologies is crucial for urban development on loose and structurally unstable soils. It's followed by geotechnical designing and soil investigation mistakes. Until now, the possibility of cultural heritage object loss as a result of an emergency during new building exploitation isn't considered at all.

Geotechnical support is usually applied during designing and construction period for a new building. It allows minimizing risk of mistakes at designing stage and prevents negative impact during construction and installation works (CIW) [5]. Since new construction at protection zone of architectural monument could cause its loss at CIW stage as well as during new building exploitation. It is actual matter to conduct prediction of possible emergency at this area. It will allow constructive solutions and recommendations to be developed. Its fulfillment will provide the saving of historical building at all stages of life cycle.

Analysis of recent sources of research and publications. Construction in historical development environment put a number of requirements to geotechnical engineers. This requirements concern SSS analyzes of soil bases and consideration of its variation during further exploitation of new building. Naturally, design solutions should take into account parameters of bearing buildings structures, its bases and foundations as well as technical state of existing buildings [5 – 11].

Geotechnical prediction (evaluation) of new building influence on the change of surrounding soil massive SSS should be performed during designing of bases, foundations and underground parts of new buildings. It should include bases and foundations of adjacent buildings. It should be taken into account depending on category of technical state of the structure (see Table 1), based on conditions [5 – 11]:

$$S_d \leq S_{d.u}; \qquad (\Delta S/L)_d \leq (\Delta S/L)_u; \qquad i_d \leq i_{d.u}, \qquad (1)$$

where S_d is additional existing foundation settlements from a new building influence or existing building reconstruction, cm;

$S_{d.u}$ is limit value of additional settlements of existing building base, cm;

$(\Delta S/L)_d$ is designed value of differential foundation settlements from a new building influence or existing building reconstruction;

$(\Delta S/L)_{d.u}$ is limit value of differential settlements;

i_d is designed additional heeling of the existing building from a new building influence or existing building reconstruction;

$i_{d.u}$ is limit value of additional heeling of an existing building.

Protection methods of existing structures at construction state are being improved. These methods include installation of cut-off wall between existing structure and new building. It's made of steel sheet pilling, steel tubes, bored pile wall, diaphragm wall or soil-cement elements [12 – 15].

The effectiveness of each protection method for the existing buildings from new construction influence under specific soil conditions, buildings and structures parameters is usually being evaluated by FEM using elastic-plastic model for soil of the «soil base – new building – protective structure – existing building» system [16 – 21].

Actual technical state of the existing building has a significant influence on its protection method. There could be the situations when it is advised to take into consideration base soil strengthening as a result of its long-term compression under the footing of existing foundations. It might be conducted by the way of soil sampling from-under the footing and its laboratory investigation afterwards. Empiric expressions and mathematical modeling of long-term soil densification process might also be used for that purpose [22 – 24].

Table 1 – Ultimate limit additional deformation value of existing foundation

Structures types	Technical state category	Ultimate limit foundation deformations		
		Settlements, cm	Differential settlements	Tilt
1. RC and steel frame	Normal (I)	2,5/5** (6)	0,004/0,002** (0,004)	-
	Satisfactory (II)	1,5/3(4)	0,003/0,001 (0,002)	-
	inappropriate for normal exploitation (III)	1,0/2(3)	0,0007/0,0005 (0,001)	-
2. Rigid structures	I	1,5/5	0,0016/0,004	0,0040
	II	1,0/3	0,0010/0,002	0,0020
	III	0,5/2	0,0004/0,001	0,0010
3. Multistory buildings with bearing walls	I	2,0	0,0030	0,0040
	II	1,0	0,00070	0,0010
	III	0,5	0,0003	0,0005
3.1. Walls of large panels (according [2])	I	4	0,0016	0,004
	II	3	0,001	0,002
	III	2	0,0007	0,002
3.2. Walls of large blocks or masonry without RC	I	5	0,002	0,004
	II	3	0,0015	0,002
	III	2	0,001	0,002
3.3. Masonry walls with RC	I	6	0,0024	0,004
	II	4	0,0018	0,004
	III	3	0,0012	0,003

** In the numerator according to [6], in the denominator according to [2]

Identification of general problem parts unsolved before. Complicity of the evaluation of the «soil base – new building – protective structure – existing building» system lies in necessity of phased modeling. For example, the following phases might be used: existing building operation; protective structure installation (for example sheet piling); soil excavation to the designed level and installation of new building foundations; further erection and operation of new building. Also the same investigations but without a protective structure were carried out. Aside from that, a new building influence isn't investigated enough when it is a result of its collapsing according to possible emergencies predicting.

That is why the **goal** of this article is to evaluate SSS of the «soil base – superstructure on piles – historical buildings» system and to choose the most rational construction option taking into account the actual technical state of the historical building by the way of FEM modeling using elastic perfectly-plastic Mohr – Coulomb soil model and evaluation of possible influence from new building collapse.

Basic material and results. This work consists of the following steps: 1) site soil investigation; 2) technical state investigation of existing building; 3) foundation observe of existing building; 4) laboratory soil testing; 5) analysis of new building project; 6) FEM modeling of new building influence on technical state of existing building; 7) FEM modeling possible influence from new building collapse; 8) results analysis of this study.

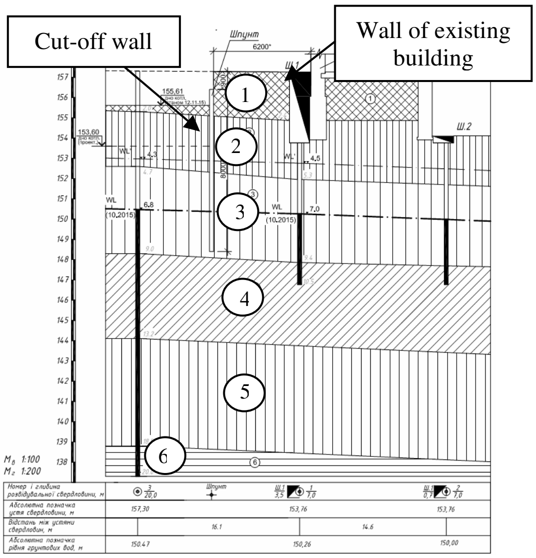


Figure 1 – Soil profile: 1 – unmade soil; 2 – yellow and light brown loess loam, semisolid, mildly plastic in water-saturated state, macro-porous, collapsing; 3 – light brown loess loam, yielding, macro-porous; 4 – grey and brown loam, semisolid; 5 – yellow loam, mildly plastic; 6 – red and brown clay, semisolid

Results of site soil investigation. Site situated in the Poltava loess plateau conditions. Thickness of loess soil is 9.4 m. Thickness of unmade soil is 2.4 m. The groundwater level is 7 m from ground level. There are filled underground workings at the construction site. Soil profile is presented in Fig. 1.

Strata 2 and 3 are very soft (weak) soil after water saturation. The deformation modulus of these soils in water saturated state is E=5000 kN/m^2. That's why the bearing strata lie approximately on 9 m from ground level.

Technical state investigation of existing building. A two-story building with basement (existing building) of specialized teaching and educational complex (STEC) №26 is the object of the investigations. It locates on Komsomolska st., 20 in the city of Poltava (Fig. 2). It was erected at the end of 19th century as the general's Petrash manor and it is an architectural monument of local significance (Fig. 3).

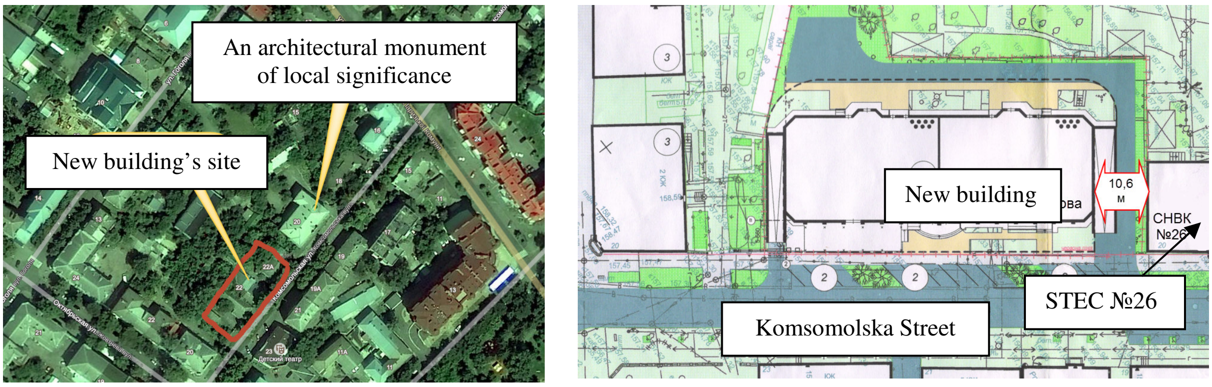
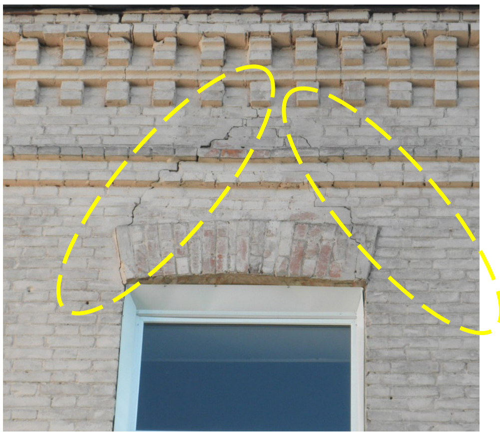


Figure 2 – Situation scheme of construction site and adjacent historical buildings

Figure 3 – General view of the existing building

Building constructive scheme – longitudinal and transverse brick bearing walls. The height of the floor is 3.6 m. Vertical and inclined cracks in walls and bridges, soakage and rotting of wooden construction of roof and flooring, damage of asphalt concrete paving on the perimeter of the building, frost-related damage of brickwork, mortar weathering from its joints, prestressed steel strands sagging, severe ageing of water supply and sewerage networks are the main damages emerged during years of exploitation. The most characteristic damages and defects of building are shown at Fig. 4 and Fig. 5. Technical state of the building is III (inappropriate for normal exploitation) according to regulations.

a

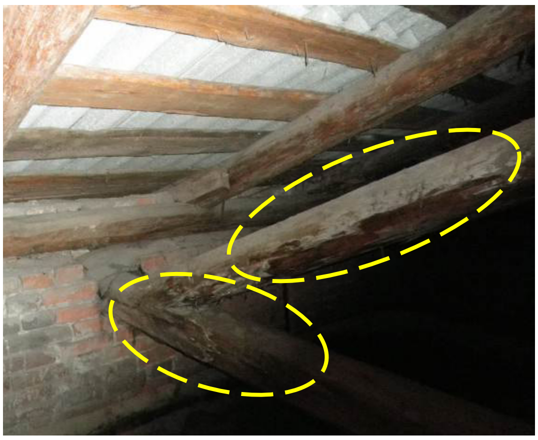


b

c

Figure 4 – The most characteristic wall damages and defects of architectural monument: *a* – inclined cracks in segmental arches; *b* – cracks in external walls; *c* – vertical crack at steel strand fixation point

a



b

Figure 5 – Soakage and rotting of wooden construction of roof and flooring (*a*) and corrosion of basement floor rails (*c*)

Foundation observe of existing building. Foundations of the building were inspected out of two pits (Fig. 6). It's strip and made of brick. Its depths is 3.35 m down from the Earth surface, the width of foundation strip beneath external walls is 0.71 and 0.84 m, and beneath internal walls is 0.8 m. Vertical or horizontal hydro isolation hasn't been noticed. There are no cracks in foundation. The base of foundations is strata 2. Constructive scheme of the building is not suited for collapsing soils environment. Differential settlements of foundations are caused by complex of unfavorable conditions. That led to origin and development of cracks in walls.

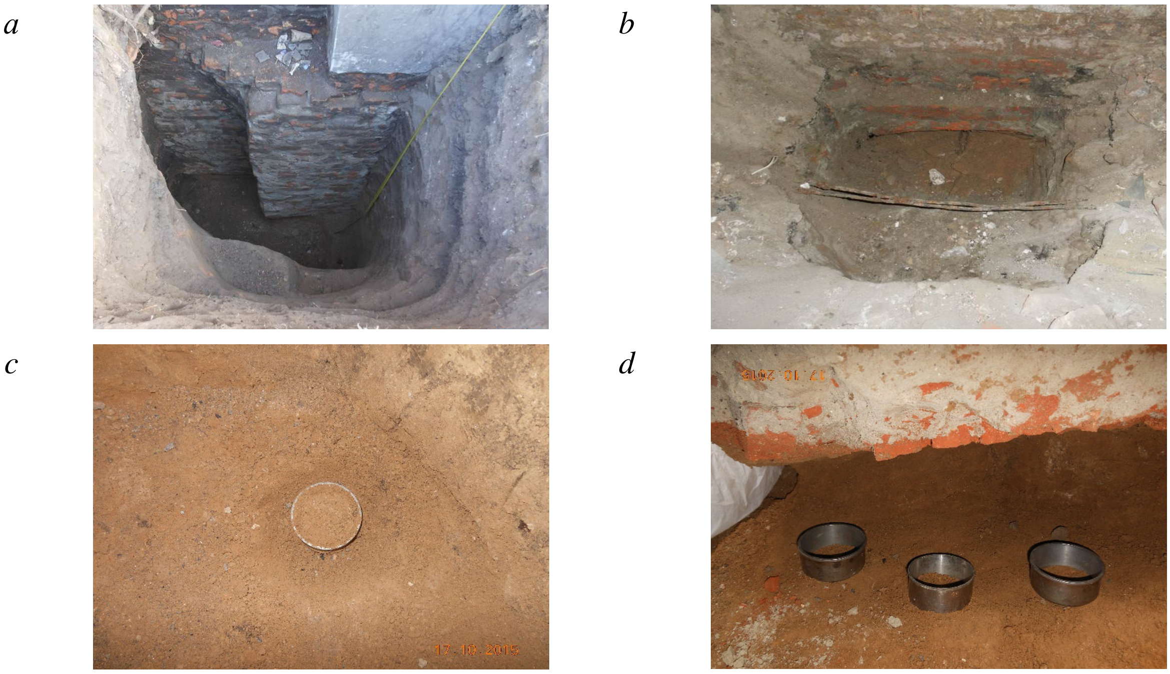


Figure 6 – Existing building foundations view out of pits (under external (*a*) and internal (*b*) walls) and a soil sampling (natural soil (*c*) and foundation base (*d*))

Analysis of new building project. On the 10.6 m distance from existing building a new building construction is planned. It's a residential multistory building with axial overall dimensions 31.6x65.1 m. The height of the building is 24.0 m. There is an underground parking with the 3.5 m height. There are 7 floors in the building, 3.6 m in height each. Constructive scheme of new building is frame with the 7.2 m step of majority of vertical bearing elements in longitudinal direction and 6.6 m in transverse direction. Foundation – preformed hydraulically jacked displacement piles (its section is 350x350 mm, length – 7.5 m). The height of piles cap is 800 mm.

Sheet piling cut-off wall is designed in order to minimize new building's influence on the existing building. Sheet piling cut-off wall is made of steel tubes Ø127x4 mm with 254 mm step on the 6.2 m distance from school's external wall, the length of the elements is 8 m.

FEM modeling of new building influence on technical state of existing building. FEM has been performed in order to evaluate new building's possible influence on existing building. The elastic perfectly-plastic Mohr – Coulomb soil model was applied for FEM modeling. Yield function is introduced as a function of stress and strain and can be presented as a surface in principle stress space. The elastic perfectly-plastic Mohr – Coulomb soil model is a constitutive model with a fixed yield surface, i.e. yield surface that is fully defined by model parameters and not affected by plastic straining. Parameters of soil model were determined by the way of laboratory soil testing. Geometry and boundary conditions of calculation FE scheme were assigned according to existing building and soil investigations, and according analysis of new building project.

FEM included following phases: 1) STEC exploitation (Fig. 7); 2) soil excavation (2 m depth) and installation of sheet piling cut-off wall (Fig. 8); 3) soil excavation (designed depth) and piles installation of new building (Fig. 9); 4) construction and exploitation of new building (Fig. 10). Also the same investigations but without installation of sheet piling disconnecting screening were carried out (Fig. 11).

It was determined that additional deformations of base of STEC building foundations would be 1...3 mm, and 2...4 mm without sheet piling.

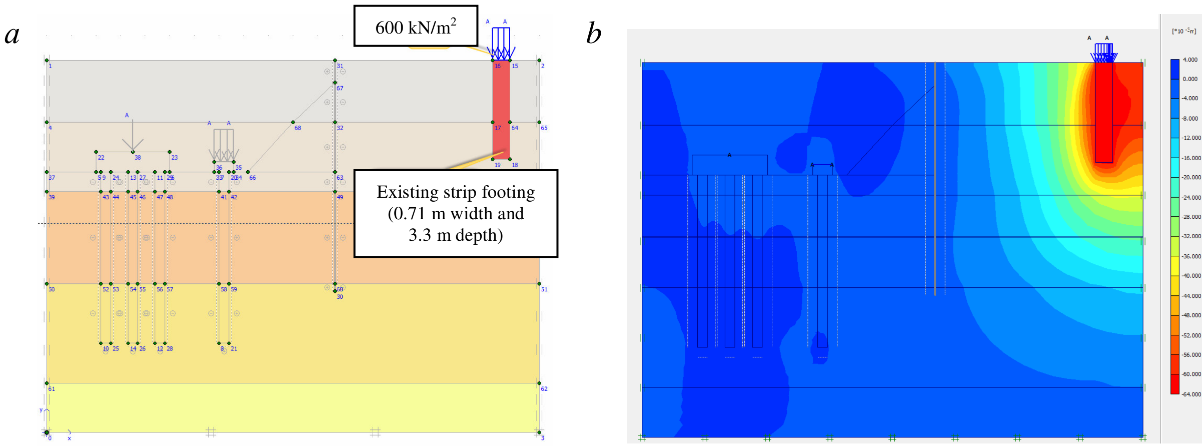


Figure 7 – Calculation scheme (*a*) of the first phase of modeling (existent building exploitation) and correspondent shadings of vertical deformations (*b*)

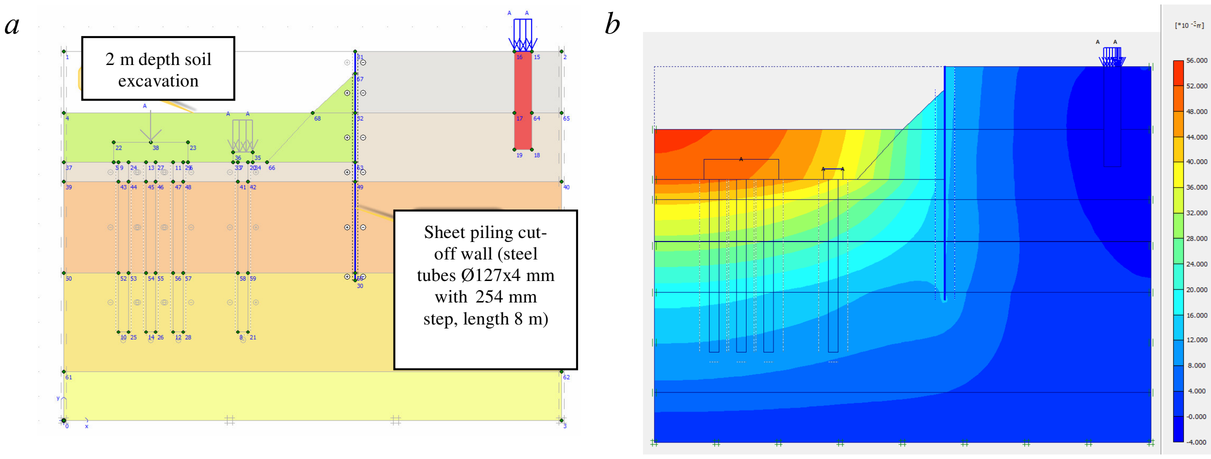


Figure 8 – Calculation scheme (*a*) of the second phase of modeling (sheet piling installation of steel tubes Ø127x4 mm with 254 mm step, length 8 m and 2 m depth soil excavation) and correspondent shadings of vertical deformations (*b*)

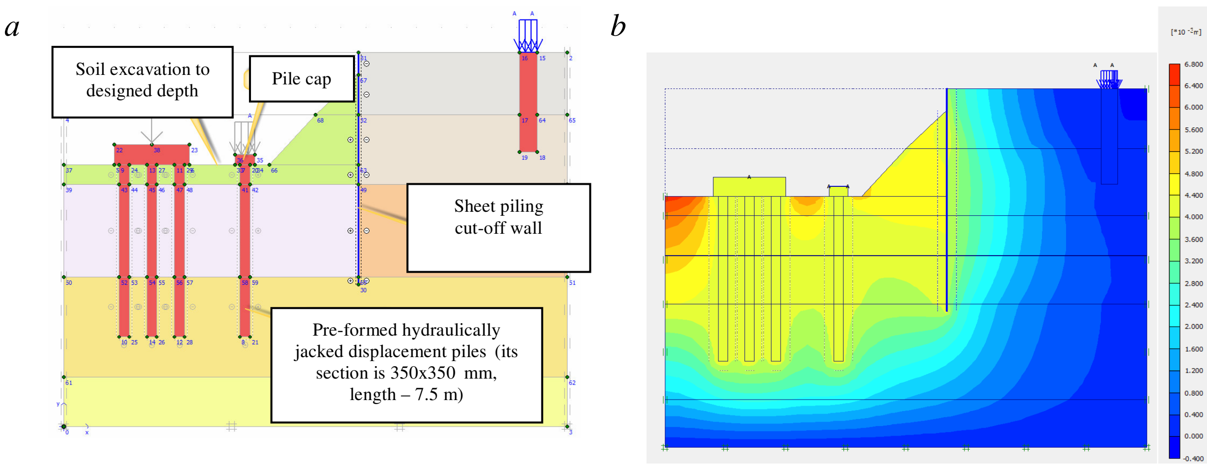


Figure 9 – Calculation scheme (*a*) of the third phase of calculation (soil excavation to designed depth and installation of pre-formed displacement piles of 35x35 mm in section and 7.5 m length, caps installation) correspondent shadings of vertical deformations (*b*)

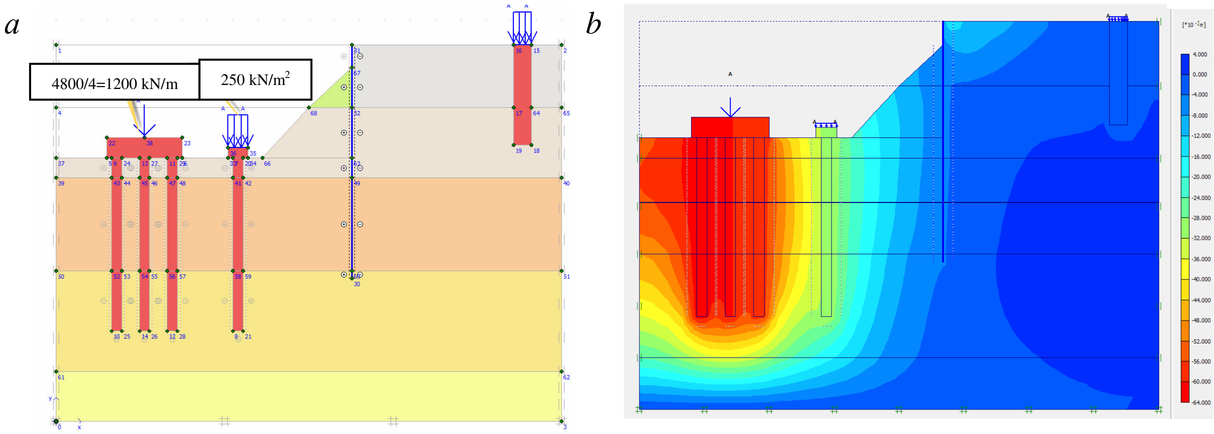


Figure 10 – Calculation scheme (*a*) of the fourth phase of modeling (construction and further exploitation of new building) correspondent shadings of vertical deformations (*b*)

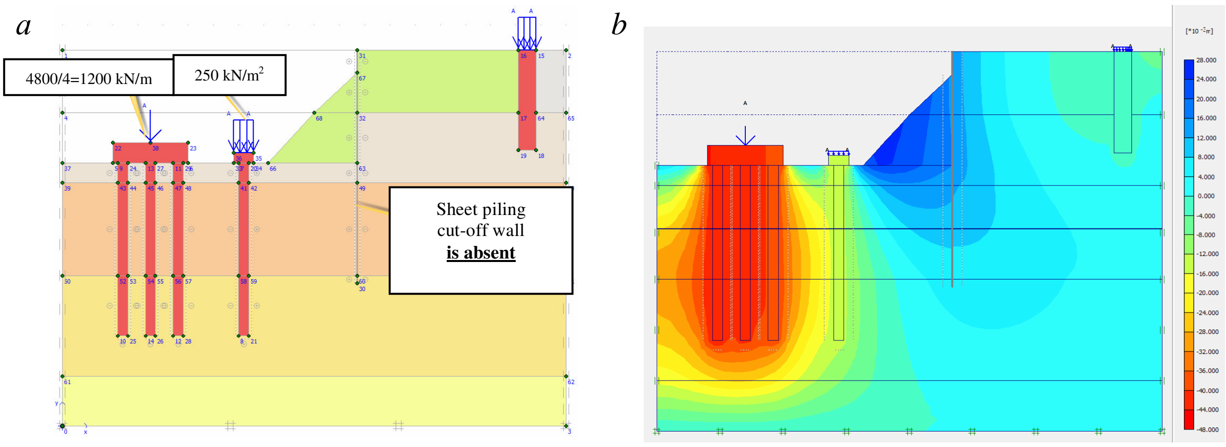


Figure 11 – Calculation scheme (*a*) of the fourth phase of modeling (construction and further exploitation of new building) without sheet piling installation between new and existing buildings and correspondent shadings of vertical deformations (*b*)

FEM modeling possible influence from new building collapse. There also was considered the possibility of loss of cultural heritage object of local significance as a result of emergency of new building (Fig. 12 – 14).

Basic models (mechanisms) of local collapse (progressive collapse) of new building's structures are considered by the means of FEM. These models are characterized by: 1) simultaneous gradual displacement of all vertical structures (or its parts), situated above the local collapse; 2) simultaneous turning of each structural part of the building situated above the local collapse around its rotation centers; this kind of displacement requires collapse of existent bonds of these constructions and untouched building elements; collapse of shift bonds of vertical elements and flooring; 3) condition of non-collapsing of part of flooring, located just above broken vertical structure and supported with it; 4) displacement of structures of a single floor, located just above broken vertical element; in this case there will be detachment of vertical constructions from flooring, located above them.

Man-made emergencies causes were considered during test calculations. It included: 1) explosions outside or inside of the buildings (domestic gas, explosive gas mixtures and fluids, bombs and other explosive devices); 2) fire; 3) transport accidents (traffic accident, cranes collapse); 4) local overloading of structures; 5) mistakes during manufacturing and installation.

There were following calculation situations considered: 1) middle pylon 11E collapse at parking level (Fig. 12); 2) face column 13E collapse and face pylon 13Д collapse at the first floor level (Fig. 13); 3) collapse of flooring plate fragment above the first floor on the area of local collapse with its loading with parking flooring debris (Fig. 14).

New building's frame stability condition is secured and progressing collapse of the building is unlikely. This was determined as a FEM result of geometric non-linear formulation. Non-linear features of concrete were taken into account. Cinematic method of limit balance theory was applied. Mechanisms of local collapse were considered. There is a possibility of local collapse of some structures but it can be avoided by some additional constructive solutions applying.

a *b*

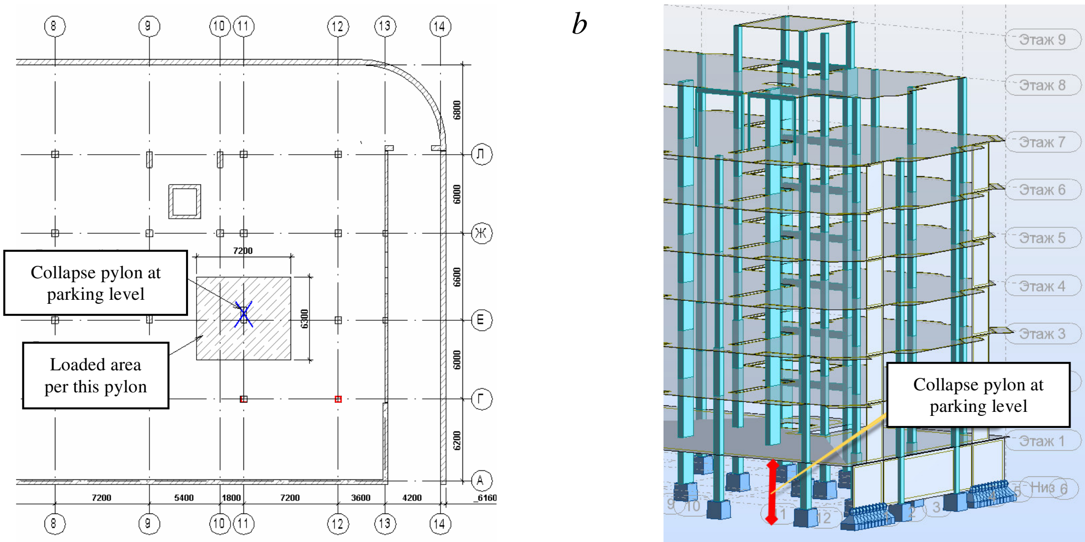


Figure 12 – Calculation scheme of emergency situation №1 – middle pylon 11E collapse at parking level: *a* – calculation scheme layout; *b* – finite-element scheme

a *b*

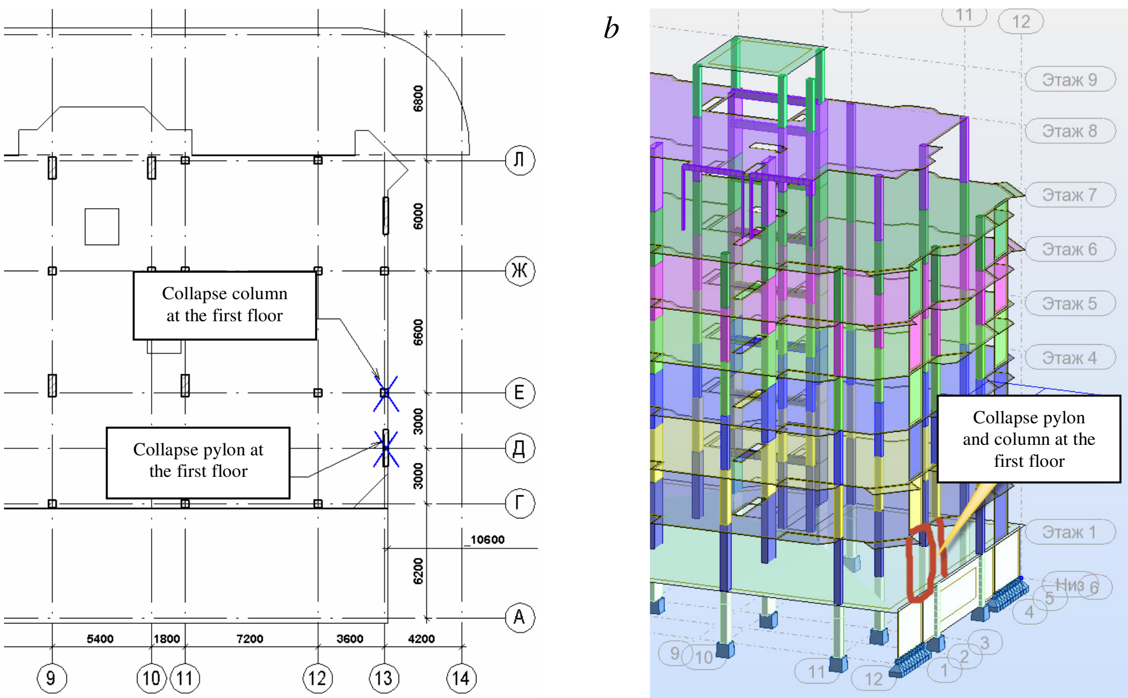


Figure 13 – Calculation scheme of emergency situation №2 – collapse column 13E and pylon 13Д at the first floor level: *a* – calculation scheme layout; *b* – finite-element scheme

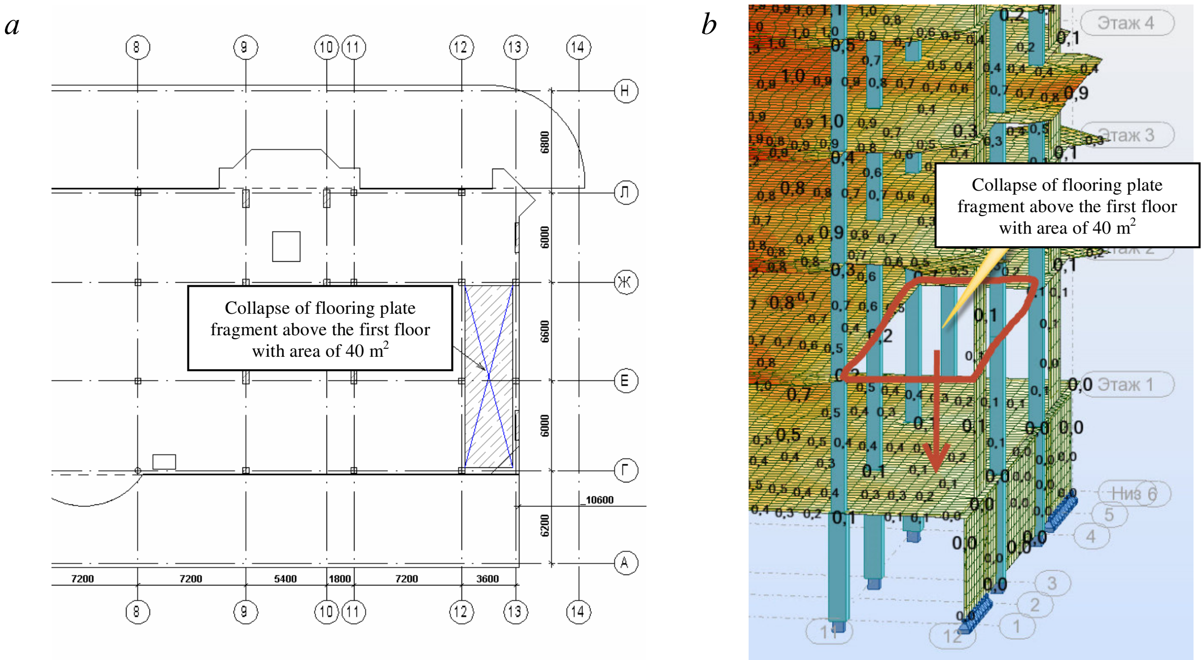


Figure 14 – Calculation scheme of emergency situation №3 – collapse of flooring plate fragment above the first floor with area of 40 m², that fell on the parking flooring:
***a* – calculation scheme layout; *b* – finite-element scheme**

Deformation marks were installed inside the socle of the building for further monitoring of the deformation process. The marks are the steel bars 20 mm in diameter and 150 mm in length. There was a geodesic monitoring (II accuracy class) conducted prior to construction process.

Conclusions. According to calculation of additional deformations of STEC foundations in case of new construction close to it are S_{du}=0,1…0,3 cm. These values do not exceed limit values S_{du}=0,5 cm (for an inappropriate state for normal exploitation). It has been proved that designed sheet piling wall is unnecessary. Aside from that the settlements which were derived through FEM will be checked by the way of geodesic monitoring. Necessary corrective amendments will be included to the design solutions.

Complete collapse of the building is unlikely according to the results of possible risks evaluation. Partial collapse will not cause additional negative influence on the existing building. Construction of multistory residential building with underground parking will not affect actual state of STEC and will not cause the loss of the object of cultural heritage of local significance.

References

1. Симагин В. Г. Проектирование и устройство фундаментов вблизи существующих сооружений в условиях плотной застройки / В. Г. Симагин. – М. : АСВ, 2010. – 128 с.

2. Улицкий В. М. Геотехническое сопровождение развития городов / В. М. Улицкий, А. Г. Шашкин, К. Г. Шашкин – С-Пб. : Геореконструкция, 2010. – 551 с.

3. Коновалов П.А. Основания и фундаменты реконструируемых зданий: монография / П. А. Коновалов, В. П. Коновалов. – М. : АСВ, 2011. – 384 с.

4. Проектирование и устройство подземных сооружений в открытых котлованах / Р. А. Мангушев, Н.С. Никифорова, В.В. Конюшков и др. – М., СПб. : АСВ, 2013. – 256 с.

5. ДБН В.1.2-5:2007. Система забезпечення надійності та безпеки будівельних об'єктів. Науково-технічний супровід буд. об'єктів. – К. : Мінрегіонбуд України, 2007. – 16 с.

6. ВСН 490-87. Проектирование и устройство свайных фундаментов и шпунтовых ограждений в условиях реконструкции промышленных предприятий и городской застройки. – М., 1988. – 35 с.

7. ТСН 50-302-96. Устройство фундаментов гражданских зданий и сооружений в Санкт-Петербурге и на территориях, административно подчиненных Санкт-Петербургу. – С-Пб., 1997. – 102 с.
8. ДСТУ-Н Б В.1.2-16:2013. Визначення класу наслідків (відповідальності) та категорії складності об'єктів будівництва. – К. : Мінрегіонбуд України, 2013. – 37 с.
9. ДБН В.2.1-10-2009. Основи та фундаменти будівель і споруд. Основні положення проектування. Зі змінами №1 і №2. – К. : Мінрегіонбуд України, 2009. – 161 с.
10. Нормативні документи з питань обстежень, паспортизації, безпечної та надійної експлуатації виробничих будівель і споруд. – К. : Державний комітет будівництва, архітектури та житлової політики України. Міністерство праці та соціальної політики України. Держнаглядохоронпраці України, 1997. – 23 с.
11. Справочник геотехника. Основания, фундаменты и подземные сооружения / под ред. В.А. Ильичева и Р.А. Мангушева. – М. : АСВ, 2014. – 728 с.
12. Зоценко М. Л. Ефективність роз'єднувальних стінок у ґрунті при захисті існуючих будівель від впливу новобудов / М. Л. Зоценко, О. В. Борт // Бетон и железобетон в Украине. – 2007. – № 1. – С. 24 – 27.
13. Piling Engineering / K. Fleming, A. Weltman, M. Randolph, K. Elson. – London and New York: Taylor and Francis, 2008. – 398 p.
14. Зоценко М. Л. Осідання будинку при послідовному зведенні секцій / М. Л. Зоценко, Ю. Л. Винников, А. В. Веденісов // Світ геотехніки. – 2015. – № 2 (46). – С. 24 – 30.
15. Kauther R. Back analysis of geotechnical models for a deep excavation in claystone based on monitoring data / R. Kauther, H. Montenegro, O. Stelzer // Proc. of the XVI ECSMGE Geotechnical Engineering for Infrastructure and Development. – Edinburg, 2015. – P. 607 – 612.
16. Plaxis 3D Foundation. Reference Manual. Version 1.5 / R. Brinkgreveat al. – Delft: Delft University of Technology. – 2006. – 152 p.
17. Парамонов В. Н. Метод конечных элементов при решении нелинейных задач геотехники / В. Н. Парамонов. – С-Пб.: Геореконструкция, 2012. – 264 с.
18. Шапиро Д. М. Теория и расчетные модели оснований и объектов геотехники: монография / Д. М. Шапиро. – Воронеж: Научная книга, 2012. – 164 с.
19. Расчет осадки свайных фундаментов высотных зданий в грунтовых условиях Астаны / А. Ж. Жусупбеков, С. Б. Енкебаев, Р. Е. Лукпанов, А. С. Серикова // Основания фундаменты и механика грунтов. – 2012. – № 3. – С. 14 – 17.
20. Chau K.T. Numerical Methods / K. T. Chau // Proc. of the 18th Intern. Conf. on Soil Mechanics and Geotechnical Engineering. – Paris, 2013. – P. 647 – 654.
21. Бойко І. П. Числове моделювання напружено-деформованого стану фундаменту різнорівневого висотного комплексу в м. Києві / І. П. Бойко, В. С. Носенко // Основи та фундаменти: міжвід. наук.-техн. зб. – К. : КНУБА, 2015. – Вип. 37. – С. 3 – 14.
22. Винников Ю. Л. Тривало обтиснені лесові основи фундаментів при підтопленні територій / Ю. Л. Винников, О. В. Семко, О. В. Гранько // Строительство, материаловедение, машиностроение: сб. науч. тр. – Д.: ПГАСА, 2009. – Вып. 50. – С. 104 – 109.
23. Zotsenko N. Designing the compacted subsoil's using mathematical simulation method / N. Zotsenko, Y. Vynnykov // Active Geotechnical Design in Infrastructure Development. – Proc. of the XIIIth Danube-European Conf. on Geotechnical Engineering. – Ljubljana, 2006. – Vol. 2. – P. 385 – 390.
24. Numerical simulation of consolidation problem / K. Edip, M. Garevski, V. Sheshov, J. Bojadjeva // Proc. of the XVI ECSMGE Geotechnical Engineering for Infrastructure and Development. – Edinburg. – 2015. – P. 3847 – 3850.

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