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Assessing the impact of new construction for existing buildings

A. Shamov[1*], T. Irgibaev[1], A. Krasyuk[2]
[1]*Satbayev University, Almaty, Kazakhstan*
[2]*Institute of Mining named after N.A. Chinakal, Novosibirsk, Russia*
**Corresponding author:* *shamov09@gmail.com*

Abstract. In the context of the construction of buildings and structures in densely populated urban areas, a major construction concern is the potential impact of new construction on adjacent buildings. As excavations are carried out and buildings are subsequently erected, the soils experience additional stresses, which can lead to either additional pressure or relaxation. Consequently, nearby existing buildings are subject to additional settlement. Uneven settlement is of particular concern, as this unevenness can lead to excessive deformation and even failure of the building structure. Such deficiencies not only compromise the functionality of the structures, but also fail to meet the fundamental requirement of maintaining the mechanical integrity of the building. Therefore, the main goal is to accurately predict the area of influence associated with new construction activities.
Keywords: *geotechnical forecast, impact assessment, foundation deformation, sheet piling, numerical calculations, Midas GTS NX.*

1. Introduction

The work focuses on the relevance of consolidating existing buildings in the development of large cities, which leads to the construction of new buildings in close proximity to existing ones. This proximity significantly influences the nature of construction and poses challenges for designers to ensure the safety of existing buildings. The transfer of additional loads from newly erected structures to the soil foundation can cause deformations and non-standard settlement of existing buildings, especially low-rise buildings with shallow strip foundations. On the other hand, new high-rise buildings in central regions are built on slab foundations, which impose significant design loads and requirements for uniform settlement.

Considering the features of new construction in densely built-up urban areas, the following key factors can be identified that have a significant impact on the deformation of existing buildings in cramped conditions [1]:

1) the distance from the newly constructed building to the existing building;

2) the depth of the foundation of the newly erected building relative to the base of the foundation of the existing building;

3) pressure along the base of the foundation of an existing and newly constructed facility;

4) technology for constructing the underground part of a newly erected building;

5) with the open method of working - the depth of excavation of the bottom of the pit;

6) geological and hydrogeological conditions at the construction site;

7) the thickness of the compressible foundation soils;

8) design features of the existing and newly constructed buildings such as:

- number of floors in the building under construction and in the existing building,
- type of foundations used for both existing and newly constructed structures;
- structural diagrams of buildings;

9) category of condition of building structures of the existing building.

Thus, the occurrence of additional deformations in an existing building is the result of the influence of numerous hazardous factors associated with the initial stage of construction, as well as the static load created by the weight of the building under construction. Considering that the influence of technological factors can be mitigated through reasonable construction methods, this paper considers the process of deformation of an existing structure by transferring the load to its foundation from the weight of a newly constructed building as one of the most difficult geotechnical problems when constructing buildings in cramped conditions.

If we consider the process of constructing a new building next to the existing one at the stage of loading the soil mass with the weight of the new building, then the most significant construction factors include:

- pressure along the base of the foundation of an existing and newly constructed facility;
- the depth of the foundation of a newly constructed building relative to the base of the foundation of the existing building;
- the distance between the existing and the building under construction;
- geological conditions of the construction site;
- the thickness of the compressible foundation soils.

Accurate calculation of additional settlement of buildings and structures is important to ensure their stability and safety. Currently, many methods have been developed for determining settlement values, each of which is designed for specific geotechnical conditions. However, it is important to note that these methods should be used with caution as the results may not always be accurate due to differences in soil conditions and other site-specific factors. Therefore, testing and validation of existing methods in various geotechnical conditions remains a relevant and ongoing task for engineers and researchers. To ensure the safety and sustainability of the built environment, further research and development of innovative and reliable methods for calculating the settlement of buildings and structures under various conditions is necessary.

The expected results involve a generalization of dependencies and an exact methodology for calculating additional settlement of existing building foundations through numerical modeling and calculations. The immediate objectives of the research include developing a design scheme for the joint operation of a building under construction, the soil foundation and existing buildings, determining the influence of various factors on the behavior of the design scheme, and analyzing the results obtained.

Overall, the work addresses an important urban development issue and aims to provide practical solutions to minimize the negative impacts of constructing new buildings in close proximity to existing structures.

2. Materials and methods

In order to carry out a geotechnical forecast of buildings and structures located in the sphere of influence of new construction, a spatial model was developed using a software package.

The general view of the calculation model is presented in Figure 1.

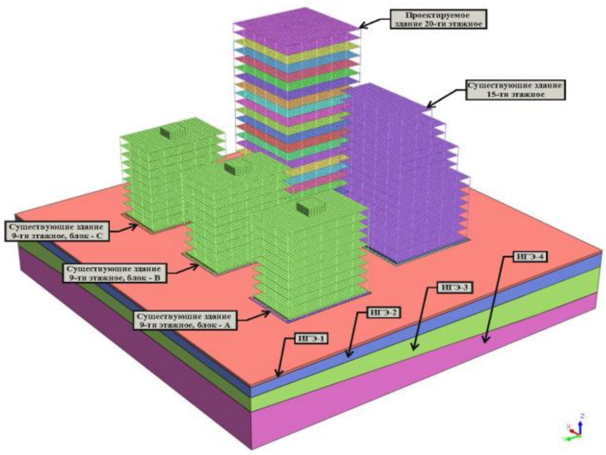

Figure 1. General view of the calculation model

To facilitate the transfer of building models to the MIDAS GTS NX PC, the following steps were performed:

- collection of data on current loads on buildings;
- determination of forces inside structural elements;
- calculations of structural elements, as well as the spatial frame of the building for various combinations of loads. These calculations and analysis of the spatial behavior of the structure were carried out using the LIRA-SAPR and SAPFIR software packages.

The creation of the model «building under construction - soil foundation - existing building» within the framework of the MIDAS GTS NX PC took place in several stages:

- formation of a foundation mass considering soil characteristics using the Hardening Soil Small model.
- creating an array of foundation slab points by projecting these points onto the surface of the foundation and the excavation site and assigning soil properties to the volumetric elements.
- formation of a finite element (FE) mesh for the foundation and pit mass.
- setting boundary conditions.

When solving the problem, calculations were carried out in 30 stages according to the following technological stages [2, 3]:

Stage 0 - loading the calculation area with the own weight of the soil and determining the initial stress-strain state of the soil mass;

Stage 1 - modeling of existing buildings by creating an appropriate stress-strain state;

Stage 2 - zeroing out the movements obtained at the previous stages;

Stage 3 - construction of a pit fencing, additional load from vehicles 50 kPa;

Stage 4 - excavation of the 1st stage of the pit;

Stage 5 - excavation of the 2nd stage of the pit;

Stage 6 - excavation of the 3rd stage of the pit;

Stage 7 - installation of the foundation slab of the new building;

Stage 8 to 29 - arrangement of underground and ground floors of the new building;

Stage 30 - application of operational loads to the new building.

The planned dimensions of the model were adopted in accordance with the preliminary boundaries of the zone of influence [4]. The depth of the model is 25 m from the actual ground level.

The building blocking scheme is shown in Figure 2.

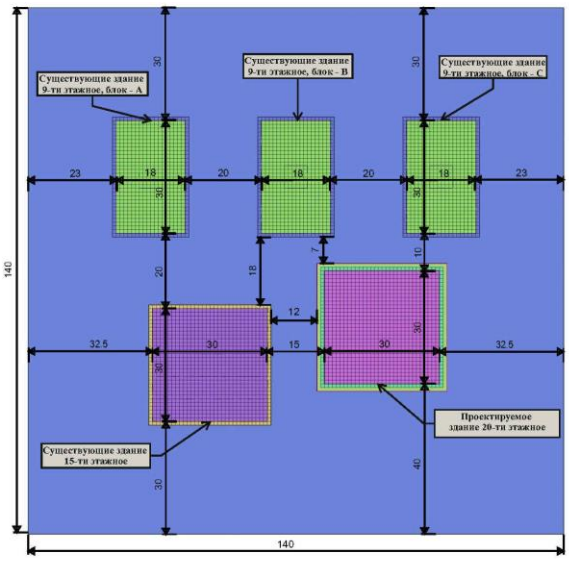

Figure 2. Building blocking scheme

Characteristics of soil models are presented in Table 1.

Table 1. Soil characteristics for the HSS model

Symbol	Unit measurements	Engineering-geological element			
		EGE-1	EGE -2	EGE -3	EGE -4
1	2	3	4	5	6
ν	-	0.35	0.35	0.35	0.4
c	kN/м^2	20	40	60	177
ϕ	degrees	21	21	30	
γ_{unsat}	kN/м^3	21.4	21.6	21.8	21.2
γ_{sat}	kN/м^3	22.5	22.7	22.5	22
ψ	degrees	9	9	0	3

E_{50}^{ref}	kN/м^2	7000	12000	16000	18000
E_{oed}^{ref}	kN/м^2	7000	12000	16000	18000
E_{ur}^{ref}	kN/м^2	21000	36000	48000	54000
m	-	0,5	0.5	0.5	0.5
K_0	-	0.641	0.641	0.5	0.546
G_0^{ref}	kN/м^2	136620	144098	149326	128411
$\gamma_{0,7}$	-	0.000248	0.000242	0.000258	0.000716

Characteristics of materials are presented in Table 2.

Table 2. Material characteristics

Name	E, kN/м^2	ν	γ, kN/м^3
Concrete	2.94E+07	0.2	24.5
Steel	2.06E+08	0.25	76.947

The existing development is presented in the form of four objects, three of which are residential 9-story buildings and one 15-story public building. During the design of load-bearing structures of buildings, loads and impacts, as well as their design combinations, are considered [5].

Structural solutions for residential 9-storey buildings, block: A; B; C.

The foundation is a monolithic strip, 600 mm thick, concrete class B25.

The basement walls are monolithic reinforced concrete, 300 mm thick, class B25 concrete.

Rigidity diaphragms - reinforced concrete monolithic t = 300 mm made of class B25 concrete.

Floor slabs and coverings are monolithic reinforced concrete, 200 mm thick, concrete class B25.

Columns are monolithic reinforced concrete, section 300×300 mm, class B25 concrete.

For the reinforcement of reinforced concrete structures, periodic profile reinforcement of class A400 is used according to GOST R 52544-2006.

Constructive solution for a 15-story public building.

The foundations are piles with a monolithic reinforced concrete grillage 800 mm thick, driven piles.

The basement walls are monolithic reinforced concrete, 400 mm thick, concrete class B25.

Rigidity diaphragms - reinforced concrete monolithic t = 400 mm made of class B25 concrete.

Floor slabs and coverings are monolithic reinforced concrete, 200 mm thick, concrete class B25.

Columns are monolithic reinforced concrete, section 400×400 mm, class B25 concrete.

For the reinforcement of reinforced concrete structures, periodic profile reinforcement of class A400 is used according to GOST R 52544-2006.

Constructive solution for the designed 20-story public building.

The foundation is in the form of a continuous monolithic slab, 1500 mm thick, concrete class B30.

The basement walls are monolithic reinforced concrete, 500 mm thick, concrete class B30.

Rigidity diaphragms - reinforced concrete monolithic t = 500 mm made of class B30 concrete.

Floor slabs and coverings are monolithic reinforced concrete, 200 mm thick, concrete class B30.

Columns are monolithic reinforced concrete, section 500×500 mm, class B30 concrete.

For the reinforcement of reinforced concrete structures, periodic profile reinforcement of class A500 is used according to GOST R 52544-2006.

Pit fencing.

The construction of the foundation of a newly constructed building below the established level of the existing one, especially when the foundations are close together, necessitates the need to secure the walls of the pit. To achieve this goal, a cost-effective approach is to use a tongue and groove made from Ø219 mm pipes with a metal belt made from a number 22 I-beam with a board pick-up. This method is considered the most economical type of pit fencing [6]. It turns out to be suitable for cases where excavation work is carried out in dry soils, which means groundwater lies below the bottom of the pit. Typically, used pipes are used for pipe sheet piles, which effectively minimizes the costs associated with pit fencing.

The use of sheet piling fencing of the pit allows the development of the pit to a depth of 3-10 m. This fastening method protects the surrounding buildings from the impact of the pit. The influence zone of a pit without sheet piles doubles. Excavations near existing buildings without sheet piling protection can lead to significant deformations and even potential collapse of the structure.

Loads and impacts.

During the design of load-bearing structures of buildings, loads and impacts, as well as their design combinations, are considered.

To calculate the bearing capacity, the following are used: design loads; for calculating suitability for normal operation - normative ones.

According to the duration of action, loads are divided into permanent and temporary (long-term, short-term, special).

The calculation of the spatial scheme in the Lira software package was carried out for the following loads:

- own weight of building structures - is set automatically, load reliability factor γ_t = 1.1;
- standard payload for office premises is 2 kN/m^2, for residential premises 1.5 kN/m^2, load safety factor γ_t = 1.1;
- standard payload for the rigidity core (elevator hall) 400 kg/m2, load safety factor γ_t = 1.1;
- standard load from the weight of the partitions, distributed over the entire area of the premises 2 kN/m^2, load reliability factor γ_t = 1.2;
- standard load from the weight of the roof fence is 1 kN/m, load safety factor γ_t = 1,1;
- standard snow load 1.77 kN/m^2, load safety factor γ_t = 1.4;
- standard wind load 0.76 kN/m^2, load safety factor γ_t = 1.4;
- pulsation component of the wind load, set automatically by the program, load reliability factor γ_t = 1.4;
- standard payload on technical floors is 2 kN/m^2, load safety factor γ_t = 1.2.

3. Results and discussion

MIDAS GTS NX is a program specifically designed for modeling interactions between structures and their foundations using the finite element method. GTS NX is used to perform step-by-step calculations of excavation, embankment, construction, loading and other impacts that have a direct impact on design and construction.

The program supports considering various conditions (soil characteristics, water levels, etc.) and various analytical methodologies for modeling real-world phenomena.

The calculation results at the stage of modeling the existing buildings are presented in Figures 3-8.

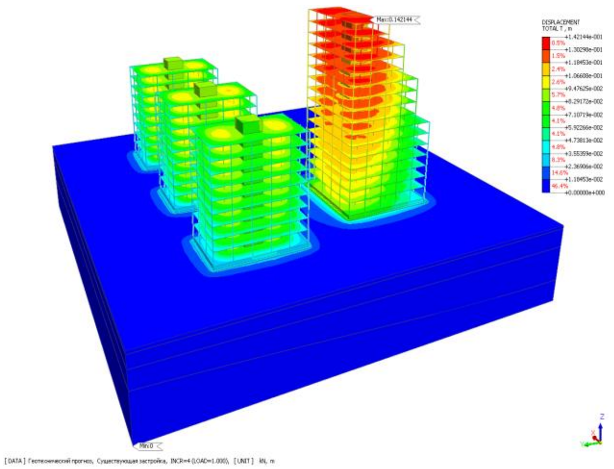

Figure 3. Deformed diagram of the existing building (Max 14.2 cm /Min 1.18 cm)

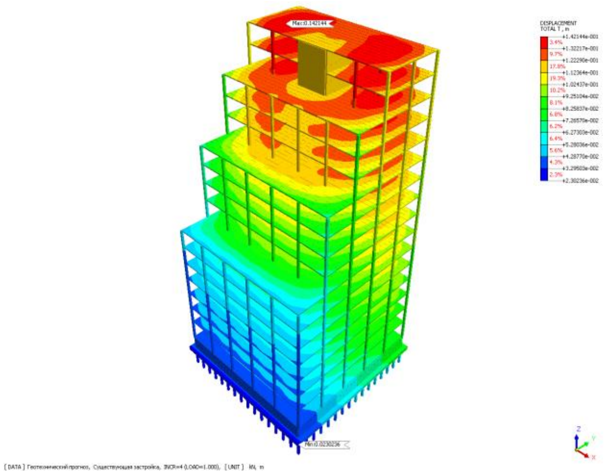

Figure 4. Deformed diagram of an existing 15-story public building (Max 14.2 cm / Min 2.3 cm)

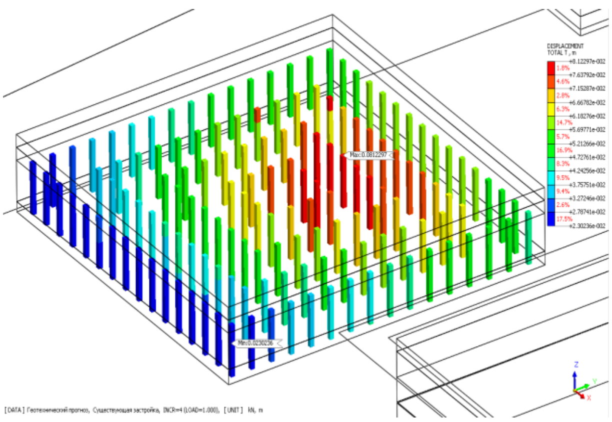

Figure 5. General deformations of driven piles under an existing 15-story public building (Max 8.12 cm / Min 2.3 cm)

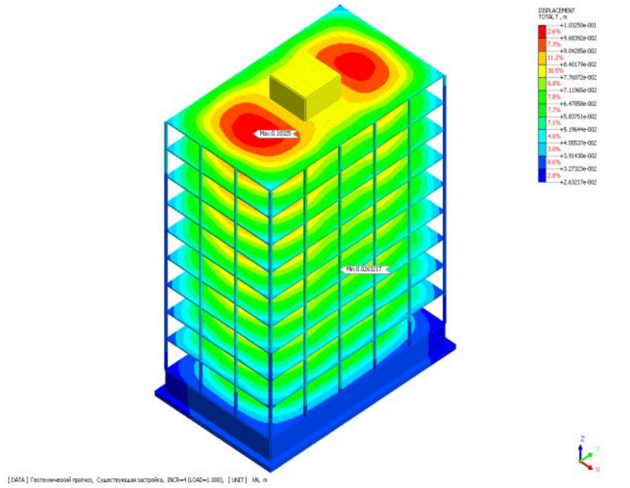

Figure 6. Deformed diagram of the existing 9-story building residential building, block A (Max 10.3 cm /Min 2.6 cm)

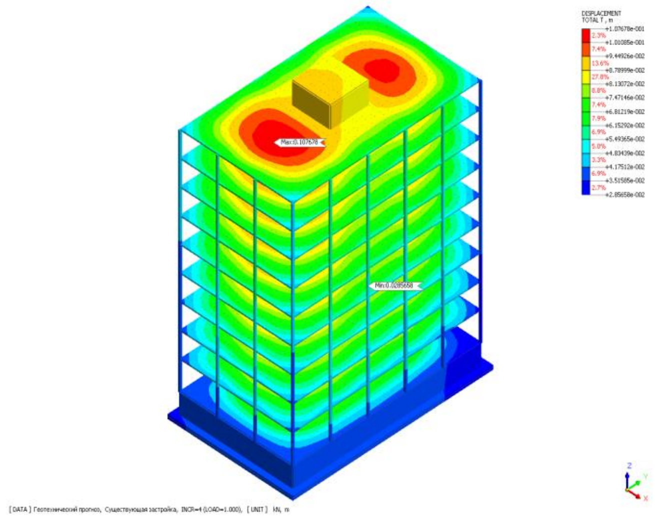

Figure 7. Deformed diagram of the existing 9-story building residential building, block B (Max 10.76 cm /Min 2.86 cm)

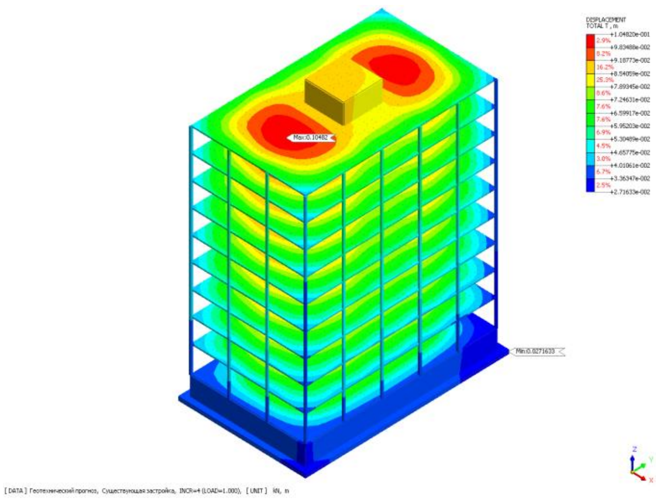

Figure 8. Deformed diagram of the existing 9-story building residential building, block C (Max 10.5 cm /Min 2.71 cm)

The calculation results for sampling the 3rd layer of soil with a depth of 5 m are presented in Figures 9 - 21.

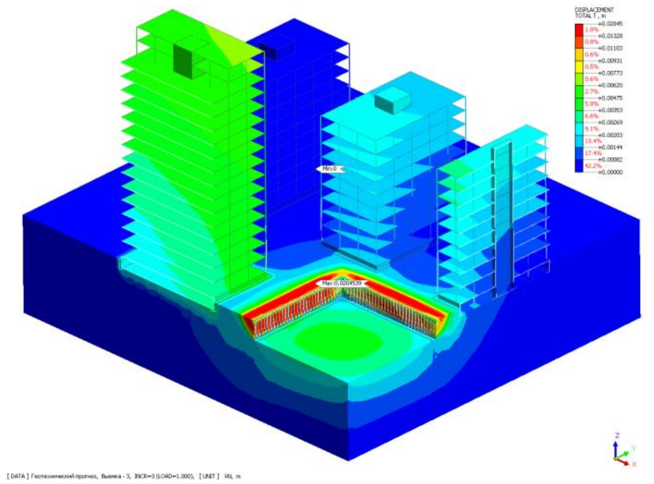

Figure 9. Deformed diagram when removing the 3rd layer of the pit (Max 2.0 cm /Min 0.17 cm)

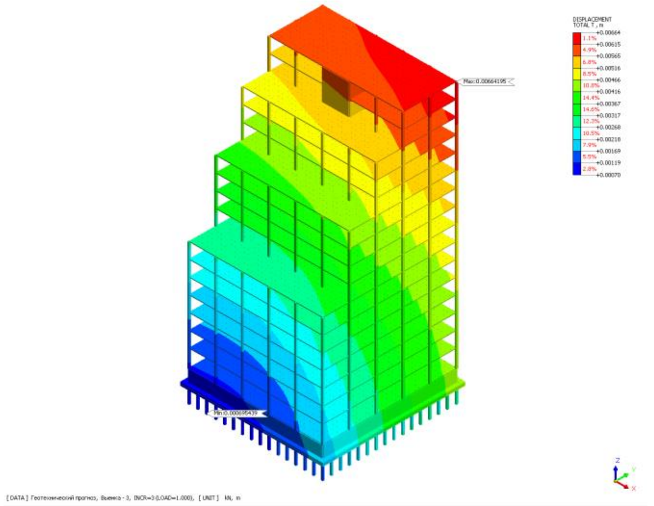

Figure 10. General deformations of an existing 15-story building when removing the 3rd layer of the pit (Max 0.66 cm / Min 0.07 cm)

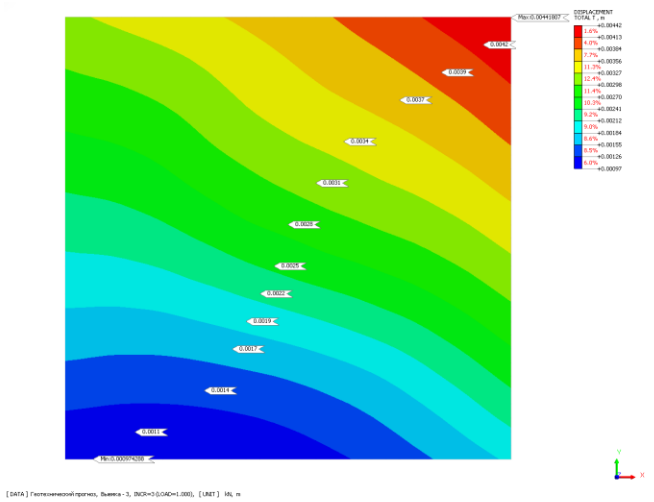

Figure 11. General deformations of the foundation of an existing 15-story building when removing the 3rd layer of the pit (Max 0.44 cm / Min 0.1 cm)

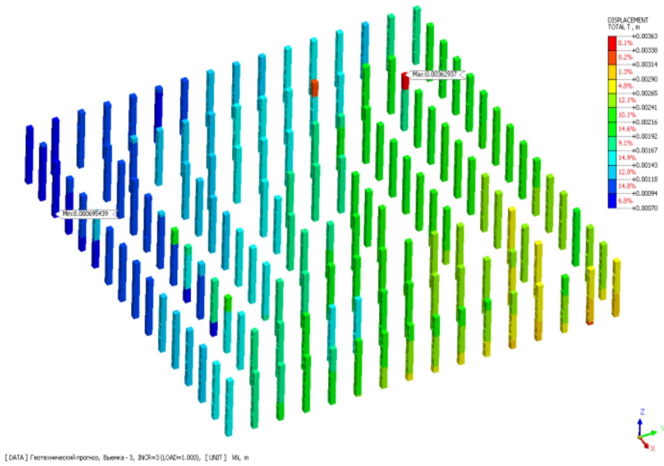

Figure 12. General deformations of piles of an existing 15-story building when removing the 3rd layer of the pit (Max 0.36 cm / Min 0.07 cm)

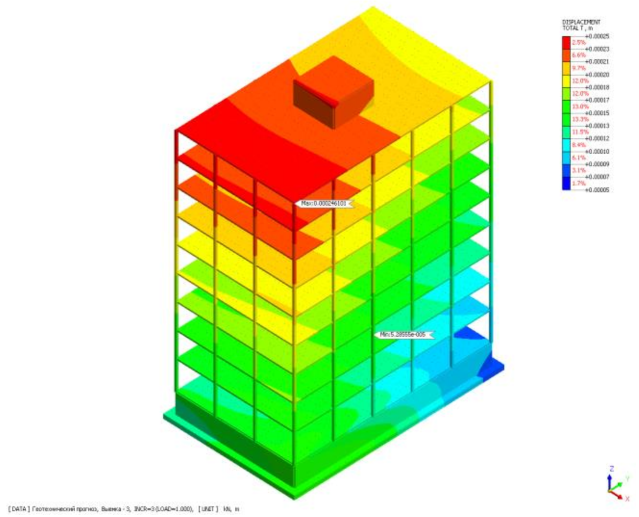

Figure 13. Deformed diagram of the existing 9-story building block A, when removing the 3rd layer of the pit (Max 0.025 cm / Min 0.005 cm)

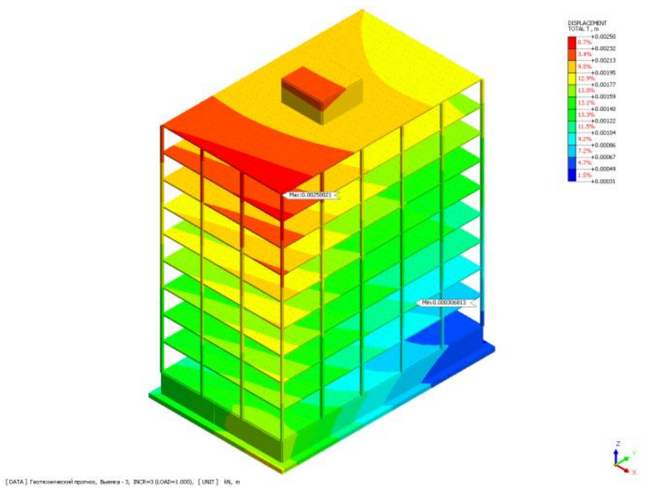

Figure 14. Deformed diagram of the existing 9-story building block B, when removing the 3rd layer of the pit (Max 0.25 cm / Min 0.031 cm)

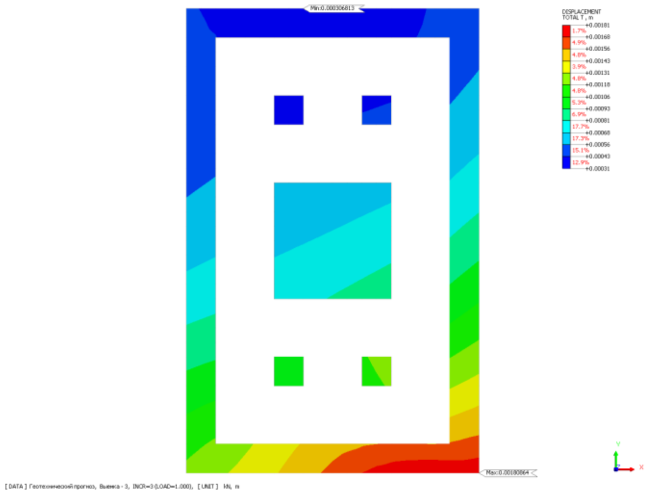

Figure 15. Deformed diagram of the foundation of an existing 9-story building block B, when removing the 3rd layer of the pit (Max 0.18 cm / Min 0.031 cm)

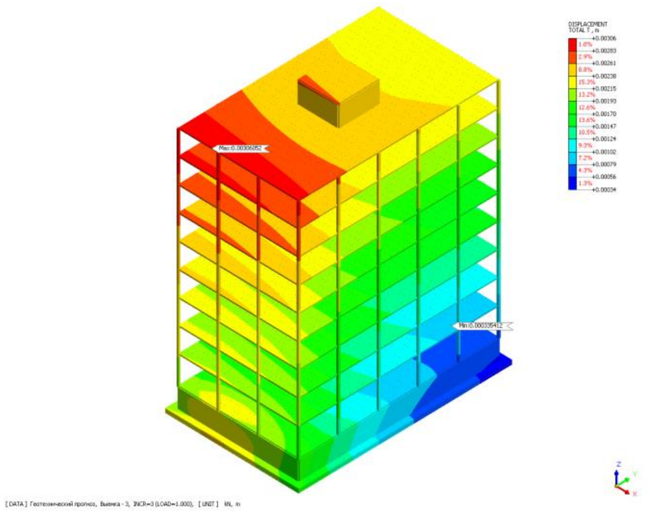

Figure 16. Deformed diagram of the existing 9-story building block C, when removing the 3rd layer of the pit (Max 0.31 cm / Min 0.034 cm)

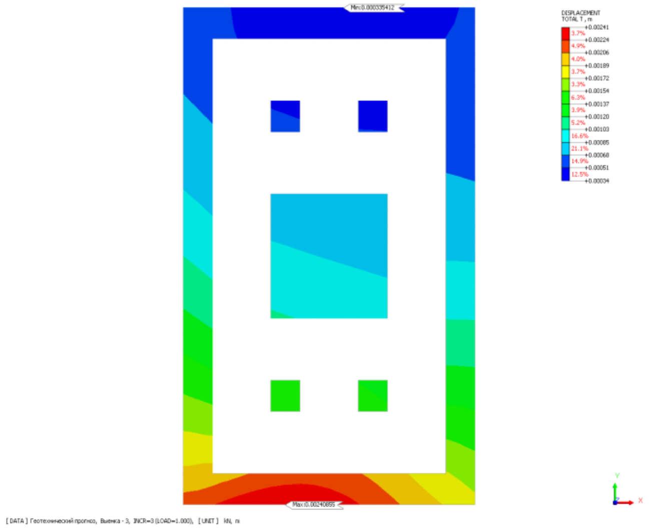

Figure 17. Deformed diagram of the foundation of the existing 9-story building block C, when removing the 3rd layer of the pit (Max 0.24 cm /Min 0.034 cm)

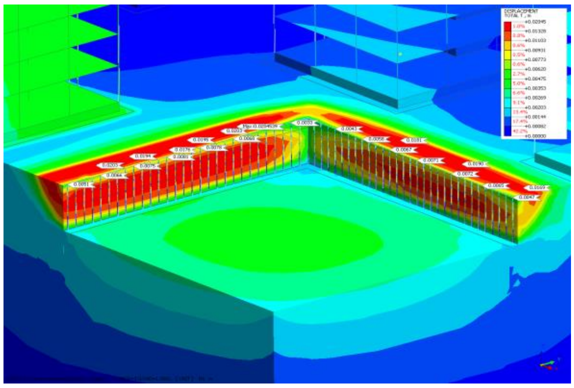

Figure 18. General movements of the pit sides during excavation 3rd layer of soil (Max 0.97 cm /Min 0.081 cm)

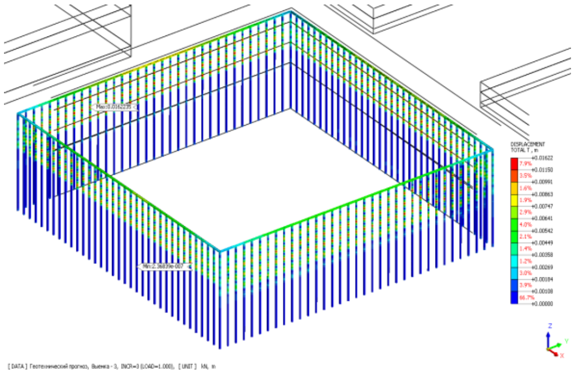

Figure 19. General deformations in sheet piles made from pipes Ø219 mm and belts from I-beam number 22 (Max 1.62 cm / Min 0.1 cm)

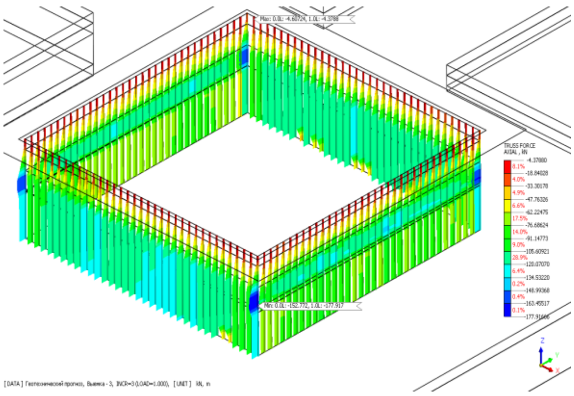

Figure 20. Axial force in sheet piles made of pipes Ø219 mm (Max -4.37 kN /Min -177.91 kN)

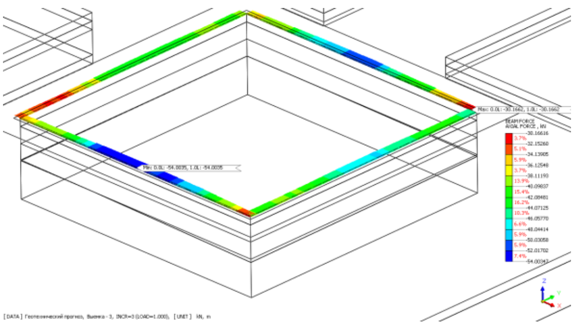

Figure 21. Axial force in the belt from I-beam number 22 (Max -30.17 kN /Min -54.0 kN)

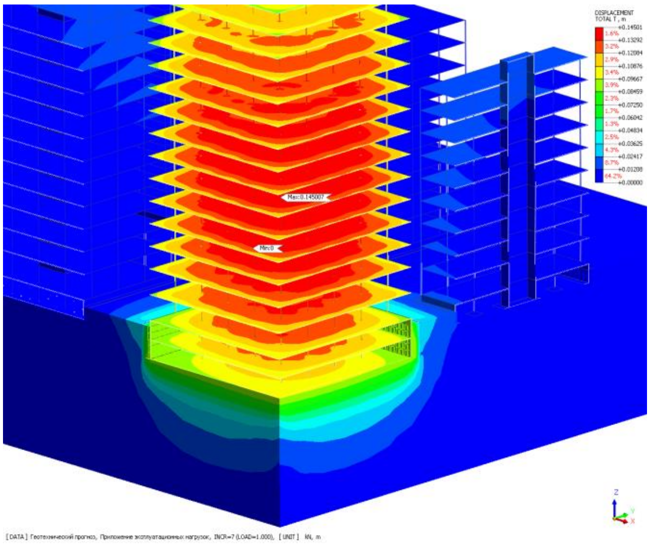

Figure 22. Deformed diagram at the stage of applying operational loads to the designed building (Max 14.5 cm / Min 1.2 cm)

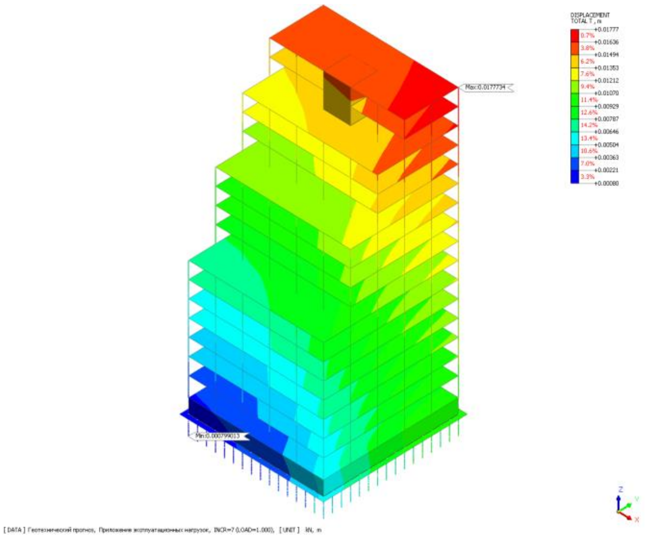

Figure 23. General deformations of an existing 15-story building at the stage of application of operational loads to the designed building (Max 1.77 cm /Min 0.08 cm)

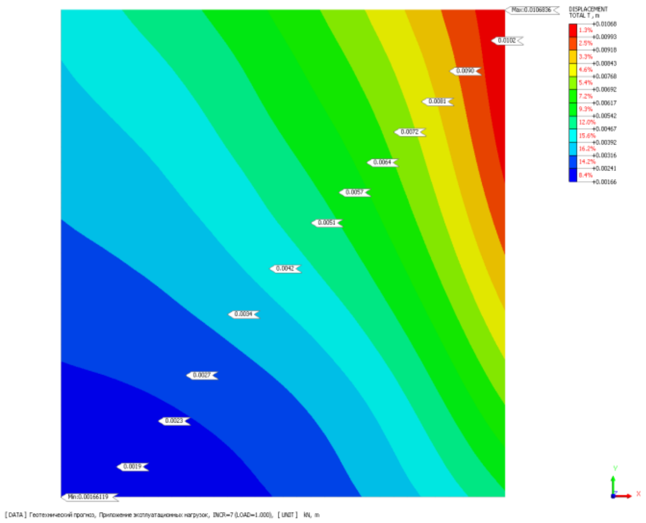

Figure 24. General deformations of the existing foundation 15-story building (Max 1.1 cm /Min 0.17 cm)

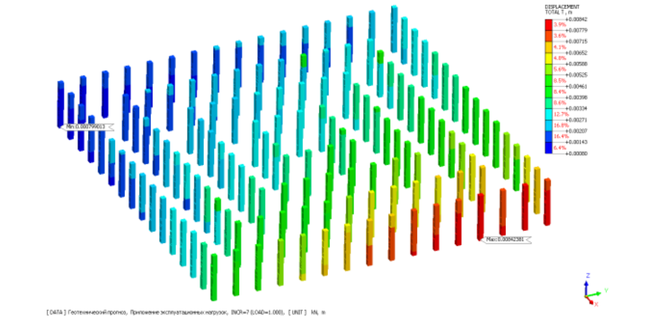

Figure 25. General deformations of driven piles under an existing 15-story public building (Max 0.84 cm / Min 0.08 cm)

Figure 26. Deformed diagram of the foundation of an existing 9-story building, block A (Max 0.043 cm / Min 0.01 cm)

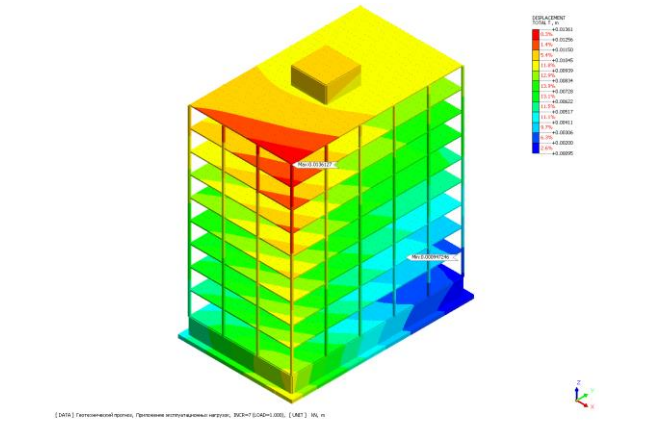

Figure 27. Deformed diagram of an existing 9-story building building, block B (Max 1.36 cm /Min 0.095 cm)

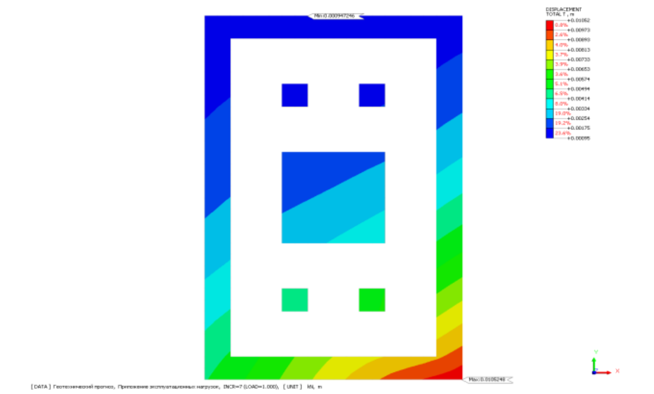

Figure 28. Deformed diagram of the foundation of an existing 9-story building, block B (Max 0.7 cm / Min 0.05 cm)

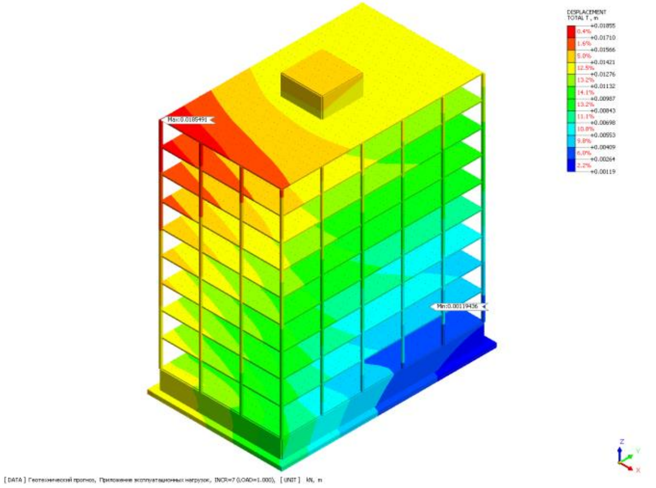

Figure 29. Deformed diagram of an existing 9-story building building, block C (Max 1.86 cm /Min 0.12 cm)

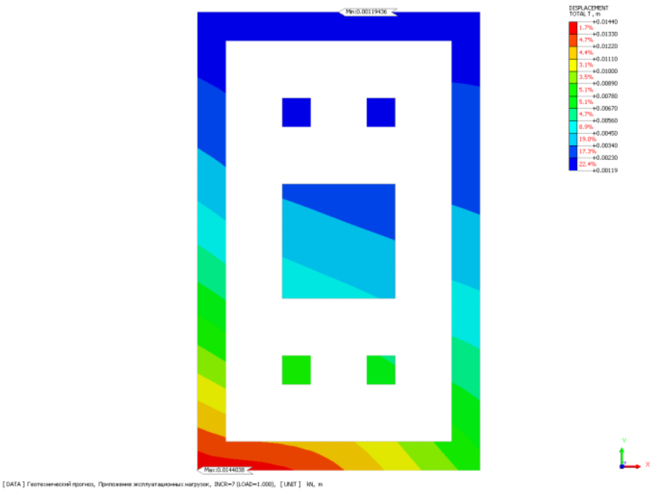

Figure 30. Deformed diagram of the foundation of an existing 9-story building, block C (Max 1.44 cm / Min 0.12 cm)

The calculation results for two stages in GTS NX MIDAS are presented in Table 3.

Table 3. Calculation results in GTS NX MIDAS

Stage	Deform. noun 15 storey buildings (Max/min), cm			Deform. noun 9 storey building (Max/min), cm					
	Constr.	Fund.	Piles	Block A		Block B		Block C	
				Constr.	Fund.	Constr.	Fund.	Constr.	Fund.
1	2	3	4	5	6	7	8	9	10
Notch 3	0.664/ 0.1	0.442/ 0.091	0.363/ 0.060	0.0208/ 0.0037	0.0130/ 0.0040	0.25/ 0.0250	0.180/ 0.0270	0.306/ 0.0312	0.240/ 0.0301
Operating load	1.777/ 0.175	1.07/ 0.166	0.842/ 0.080	0.0732/ 0.0111	0.0432/ 0.0106	1.361/ 0.104	1.052/ 0.0947	1.854/ 0.133	1.440/ 0.119

4. Conclusions

From the analysis of the calculation results, the following conclusions can be drawn:

1. The stability of the sides of the pit with additional load from transport (50 kPa) is ensured; the maximum deformation of the sheet piling when excavating a 5 m pit is 16.2 mm. The maximum force of a sheet pile made of metal pipes Ø219 mm is 152.77 kN.

2. The maximum deformation of the foundation of an existing 9-story residential building, block A, when operating loads are applied to the designed building is 0.43 mm, which does not violate the serviceability of the building and does not exceed the requirements of Appendix B, Table B.1, SP RK 5.01-102-2013.

3. The maximum deformation of the foundation of an existing 9-story residential building, block B, when operating loads are applied to the designed building is 10.5 mm, which does not exceed the requirements of Appendix B, Table B.1, SP RK 5.01-102-2013.

4. The maximum deformation of the foundation of an existing 9-story residential building, block C, when operating loads are applied to the designed building is 14.4 mm, which does not exceed the requirements of Appendix B, Table B.1, SP RK.

5. The maximum deformation of the foundation of an existing 15-story building when operating loads are applied is 10.7 mm, which does not exceed the requirements of Appendix B, Table B.1, SP RK 5.01-102-2013.

Acknowledgements

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Жаңа құрылыстың әсерін бағалау қолданыстағы ғимараттар үшін

А. Шамов[1*], Т. Иргибаев[1], А. Красюк[2]

[1]Satbayev University, Алматы, Қазақстан
[2]Н.А. Чинакал атындағы тау-кен институты, Новосибирск, Ресей
*Корреспонденция үшін автор: shamov09@gmail.com

Аңдатпа. Тұрғындар тығыз орналасқан қалалық аудандарда ғимараттар мен құрылыстарды салу жағдайында жаңа құрылыстың көршілес ғимараттарға ықтимал әсері құрылыстың негізгі мәселесі болып табылады. Қазба жұмыстары жүргізіліп, кейіннен ғимараттар тұрғызылғандықтан, топырақтар қосымша қысымға немесе релаксацияға әкелуі мүмкін қосымша кернеулерді бастан кешіреді. Демек, жақын жердегі бар ғимараттар қосымша қонистануға жатады. Біркелкі емес қондыру ерекше алаңдаушылық тудырады, өйткені бұл біркелкі еместік ғимарат құрылымының шамадан тыс деформациясына және тіпті бұзылуына әкелуі мүмкін. Мұндай кемшіліктер құрылымдардың функционалдығын бұзып қана қоймайды, сонымен қатар ғимараттың механикалық тұтастығын сақтаудың негізгі талаптарын қанағаттандырмайды. Сондықтан негізгі мақсат - жаңа құрылыс қызметімен байланысты әсер ету аймағын дәл болжау.

Негізгі сөздер: *геотехникалық болжам, әсерді бағалау, іргетастың деформациясы, қаңылтыр төсеу, сандық есептеулер, Midas GTS NX.*

Оценка влияния нового строительства на существующую застройку

А. Шамов[1*], Т. Иргибаев[1], А. Красюк[2]
[1]Satbayev University, Алматы, Казахстан
[2]Горный институт им. Н.А. Чинакала, Новосибирск, Россия
*Автор для корреспонденции: shamov09@gmail.com

Аннотация. В контексте строительства зданий и сооружений в густонаселенных городских районах основная проблема в области строительства заключается в потенциальном воздействии нового строительства на соседние здания. По мере проведения земляных работ и последующего возведения зданий грунты испытывают дополнительные напряжения, которые могут привести либо к дополнительному давлению, либо к релаксации. Следовательно, близлежащие существующие постройки подвергаются дополнительной осадке. Особое беспокойство вызывает неравномерная осадка, поскольку эта неравномерность может привести к чрезмерной деформации и даже разрушению конструкции здания. Такие недостатки не только ставят под угрозу функциональность конструкций, но и не отвечают фундаментальному требованию: поддержанию механической целостности здания. Следовательно, основная цель заключается в точном прогнозировании зоны влияния, связанной с новой строительной деятельностью.

Ключевые слова: *геотехнический прогноз, оценка влияния, деформации фундамента, шпунтовое ограждение, численные расчеты, Midas GTS NX.*

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