ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ
АКАДЕМИЯСЫ» РҚБ

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

ХАБАРЛАРЫ

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
КАЗАХСТАН»

NEWS

OF THE NATIONAL ACADEMY
OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN

SERIES

OF GEOLOGY AND TECHNICAL SCIENCES

3 (471)

MAY – JUNE 2025

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, hydrogeology, geography, mining and chemical technologies of oil, gas and metals*
Periodicity: 6 times a year.
http://www.geolog-technical.kz/index.php/en/

«ҚР ҰҒА» РҚБ Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).

Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *Геология, гидрогеология, география, тау-кен ісі, мұнай, газ және металдардың химиялық технологиялары*

Мерзімділігі: жылына 6 рет.

http://www.geolog-technical.kz/index.php/en/

«Известия РОО «НАН РК». Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: *геология, гидрогеология, география, горное дело и химические технологии нефти, газа и металлов*

Периодичность: 6 раз в год.

http://www.geolog-technical.kz/index.php/en/

CONTENTS

Geology

NEWS of the National Academy of Sciences of the Republic of Kazakhstan
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 3. Number 471 (2025), 39–54

https://doi.org/10.32014/2025.2518-170X.509

UDC 624.131.522.33

© K.S. Dosaliev[1], M.I. Karabaev[2], F.Kh. Aubakirova[1], A.M. Karabaeva[3], Ya.B. Kunanbayeva[1*], 2025.
[1]M. Auezov South Kazakhstan University, Shymkent, Kazakhstan;
[2]Moscow Geomechanics Engineering Group (MGEG) LLC, Moscow, Russia;
[3]TOO "Archcon", Astana, Kazakhstan.
E-mail: aira.kunaeva@mail.ru

STRESS-STRAIN STATE CALCULATIONS FOR THE SOIL BASE OF THE SLAB FOUNDATION OF A HIGH-RISE BUILDING

Dossaliyev Kanat Serikuly — PhD, Department head of the Department "Industrial, civil and road construction", South Kazakhstan University named after M. Auezov, Shymkent, Kazakhstan, E-mail: dosaliev_k@mail.ru, https://orcid.org/0000-0002-5423-9231;
Karabaev Muldash Ismailovich — candidate of technical sciences, Director, Moscow Geomechanics Engineering Group (MIGG) LLC, Moscow, Russia, E-mail: karabaev@mail.ru, https://orcid.org/0009-0007-1155-899X;
Aubakirova Farida Khabievna — candidate of technical sciences, associate professor of the Department "Industrial, civil and road construction", South Kazakhstan University named after M. Auezov, Shymkent, Kazakhstan, E-mail: faraub1011@mail.ru, https://orcid.org/0000-0002-4687-1528;
Karabayeva Aigerim Muldashevna — director, Archcon LLP, Astana, Kazakhstan, E-mail: aika5@mail.ru, https://orcid.org/0009-0004-7294-2029;
Kunanbayeva Yairakhan Bekaidarovna — PhD, associate professor, of the Department "Industrial, civil and road construction", South Kazakhstan University named after M. Auezov, Shymkent, Kazakhstan, E-mail: aira.kunaeva@mail.ru, https://orcid.org/0000-0001-9465-6980.

Abstract. One of the important challenges in the design of high-rise buildings is the accurate assessment of deformations in foundation structures that transmit heavy loads to the underlying soils. These loads engage soil layers at considerable depths, often with significantly different physical and mechanical characteristics. Slab foundations for high-rise buildings represent a complex engineering structure with a large footprint and deep embedment. The load from the building is not only massive but also highly non-uniformly distributed across the foundation area. To analyze the interaction between the slab foundation and the underlying soil, design studies were conducted using GEO-MIGG software. The stress-strain behavior of the soil foundation was simulated in a three-dimensional spatial formulation (3D). For detailed analysis, solid-state and finite-element models of the "soil foundation

– slab foundation” system were developed using the ANSYS software package. The results of simulations showed that the settlement of the foundation slab occurs unevenly during construction. The maximum settlement (S = 53 mm) is predicted in the central zone of the slab. However, the calculated values of total settlement (53 mm) and relative differential settlement (4.23×10^{-4}) do not exceed the allowable limits for such structural systems (100 mm and 0.002, respectively). The proposed design methodology can be effectively applied for analysis and design of foundations for high-rise buildings in complex geotechnical conditions.

Key words: slab foundation, heterogeneous geological structure, soil deformation nonlinearity, design modeling, the ground

© К.С. Досалиев[1], М.И. Қарабаев[2], Ф.Х. Аубакирова[1], А.М. Қарабаева[3], Я.Б. Құнанбаева[1*], 2025.

[1]М. Әуезов атындағы Оңтүстік Қазақстан университеті, Шымкент, Қазақстан;
[2]«Мәскеу геомеханиктерінің инженерлік тобы (МИГГ)» ЖШҚ, Мәскеу, Ресей;
[3]«Архкон» ЖШС, Астана, Қазақстан.
E-mail: aira.kunaeva@mail.ru

БИІК ҒИМАРАТТЫҢ ПЛИТАЛЫҚ ІРГЕТАСЫНЫҢ ТОПЫРАҚ НЕГІЗІНІҢ КЕРНЕУЛІ-ДЕФОРМАЦИЯЛАНҒАН КҮЙІН ЕСЕПТІК ЗЕРТТЕУ

Досалиев Қанат Серікұлы — PhD, М. Әуезов атындағы Оңтүстік Қазақстан университетінің «Өнеркәсіптік, азаматтық және жол құрылысы» кафедрасының меңгерушісі, Шымкент, Қазақстан, E-mail: dosaliev_k@mail.ru, https://orcid.org/0000-0002-5423-9231;
Қарабаев Молдаш Исмаилұлы — техника ғылымдарының кандидаты, «Мәскеу геомеханиктерінің инженерлік тобы (МИГГ)» ЖШҚ директоры, Мәскеу, Ресей, E-mail: karabaev@mail.ru, https://orcid.org/0009-0007-1155-899X;
Аубакирова Фарида Хабиевна — техника ғылымдарының кандидаты, М. Әуезов атындағы Оңтүстік Қазақстан университетінің «Өнеркәсіптік, азаматтық және жол құрылысы» кафедрасының доценті, Шымкент, Қазақстан, E-mail: faraub 1011@mail.ru, https://orcid.org/0000-0002-4687-1528;
Қарабаева Әйгерім Молдашқызы — «Архкон» ЖШС директоры, Астана, Қазақстан, E-mail: aika5@mail.ru, https://orcid.org/0009-0004-7294-2029;
Құнанбаева Яйрахан Бекайдарқызы — PhD, М.Әуезов атындағы Оңтүстік Қазақстан университетінің «Өнеркәсіптік, азаматтық және жол құрылысы» кафедрасының доценті, Шымкент, Қазақстан, E-mail: aira.kunaeva@mail.ru, https://orcid.org/0000-0001-9465-6980.

Аннотация. Биік ғимараттарды жобалау кезінде күрделі міндеттердің бірі негіз топырақына үлкен жүктемелер беретін іргетас конструкцияларының деформацияларын дұрыс айқындау болып табылады. Іргетас конструкцияларынан түсетін үлкен жүктемелерге байланысты бірлескен жұмысқа едәуір тереңдікте орналасқан және әртүрлі физикалық-механикалық қасиеттерге ие топырақтар тартылады. Биік ғимараттардың плиталық іргетастары үлкен тереңдікке тереңдетілген үлкен ауданы бар күрделі құрылыс конструкциясы болып табылады. Биік ғимараттардың салмағынан іргетастарға түсетін жүктемелер едәуір ғана емес, сонымен қатар аудан бойынша өте біркелкі бөлінбейді. Бұл міндетті шешу үшін есептеудің сандық әдістері қолданылады. Түпкілікті элементтер әдісі мен топырақтың математикалық модельдерін пайдалануға негізделген әдістер неғұрлым кең таралған. «Топырақ негізі - плиталық іргетас» жүйесінің бірлескен жұмысының есептік зерттеулері «GEO-MIGG» бағдарламасын пайдалану арқылы орындалды. Топырақ негізінің күрделі кернеулі-деформацияланған жай-күйін есептік модельдеу кеңістіктік қойылымда (3D) орындалды. «Топырақты негіз - плиталық іргетас» жүйесінің үш өлшемді қатты денелі және міндетті-элементтік үлгілерін әзірлеу «ANSYS» бағдарламасы бойынша жүзеге асырылды. «Топырақты негіз - плиталық іргетас» жүйесінің бірлескен жұмысының есептік зерттеулерінің нәтижелері бойынша биік ғимаратты тұрғызу кезінде іргетас плитасының шөгуі біркелкі жүрмейтіні анықталды. Максималды шөгу (S = 53 мм) іргетас плитасының орталық бөлігінде болжанады. Бұл ретте плиталық іргетастың шөгінділерінің (53 мм) және шөгінділердің салыстырмалы айырмашылығының (4,23x10-4) болжамды шамалары құрылыстардың осы класы үшін рұқсат етілген шамалардан (10 см және 0,002) аспайды. Бұл әдістемені күрделі инженерлік-геологиялық жағдайларда биік ғимараттар мен құрылыстардың іргетастарын жобалау тәжірибесінде табысты қолдануға болады.

Түйін сөздер: плиталық іргетас, біртекті емес геологиялық құрылым, топырақтың деформациясының сызықтық еместігі, есептік модельдеу, топырақ

© К.С. Досалиев[1], М.И. Карабаев[2], Ф.Х. Аубакирова[1], А.М. Карабаева[3], Я.Б. Кунанбаева[1*], 2025.

[1]Южно-Казахстанский университет им. М. Ауэзова, Шымкент, Казахстан;
[2] ООО «Московская инженерная группа геомехаников (МИГГ)», Москва, Россия;
[3]ТОО «Архкон», Астана, Казахстан.
E-mail: aira.kunaeva@mail.ru

РАСЧЕТНЫЕ ИССЛЕДОВАНИЯ НАПРЯЖЕННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ ГРУНТОВОГО ОСНОВАНИЯ ПЛИТНОГО ФУНДАМЕНТА ВЫСОТНОГО ЗДАНИЯ

Досалиев Канат Серикович — PhD, заведующий кафедрой «Промышленное, гражданское и дорожное строительство» Южно-Казахстанского университета имени М. Ауэзова, Шымкент, Казахстан, E-mail: dosaliev_k@mail.ru, https://orcid.org/0000-0002-5423-9231;

Карабаев Мулдаш Исмаилович — кандидат технических наук, директор ООО «Московская инженерная группа геомехаников (МИГГ)», Москва, Россия, E-mail: karabaev@mail.ru, https://orcid.org/0009-0007-1155-899X;

Аубакирова Фарида Хабиевна — кандидат технических наук, доцент кафедры «Промышленное, гражданское и дорожное строительство» Южно-Казахстанского университета

имени М. Ауэзова, Шымкент, Казахстан, E-mail: faraub1011@mail.ru, https://orcid.org/0000-0002-4687-1528;
Карабаева Айгерим Мулдашевна — директор ТОО «Архкон», Астана, Казахстан, E-mail: aika5@mail.ru, https://orcid.org/0009-0004-7294-2029;
Кунанбаева Яйрахан Бекайдаровна — PhD, доцент кафедры «Промышленное, гражданское и дорожное строительство» Южно-Казахстанского университета имени М. Ауэзова, Шымкент, Казахстан, E-mail: aira.kunaeva@mail.ru, https://orcid.org/0000-0001-9465-6980.

Аннотация. При проектировании высотных зданий одной из сложных задач является достоверное определение деформаций фундаментных конструкций, передающих большие нагрузки на грунты основания. Ввиду больших нагрузок от фундаментных конструкций в совместную работу вовлекаются грунты, расположенные на значительной глубине и обладающие разными физико-механическими свойствами. Плитные фундаменты высотных зданий представляют собой сложную строительную конструкцию, имеющую огромную площадь, заглубленную на большую глубину. Нагрузки на фундаменты от веса высотных зданий не только значительные, но и распределяются крайне неравномерно по площади. Для решения этой задачи применяются численные методы расчетов с ьзованием современных нелинейных математических моделей грунтов. Наибольшее распространение получили методы, основанные на использовании метода конечных элементов и математических моделей грунта. Расчетные исследования совместной работы системы «грунтовое основание – плитный фундамент» выполнялись с использованием программы «GEO-MIGG». Расчетное моделирование сложного напряженно-деформированного состояния грунтового основания выполнялось в пространственной постановке (3D). Разработка трехмерной твердотельной и конечно-элементной моделей системы «грунтовое основание – плитный фундамент» осуществлялась по программе «ANSYS». По результатам расчетных исследований совместной работы системы «грунтовое основание – плитный фундамент» было установлено, что осадка фундаментной плиты происходит неравномерно. Максимальная осадка (S = 53 мм) прогнозируется в центральной части фундаментной плиты. При этом прогнозируемые величины осадок (53 мм) и относительной разности осадок ($4,23x10^{-4}$) плитного фундамента не превышают допустимых величин для данного класса сооружений (10 см и 0,002). Методика может успешно применяться при проектировании фундаментов высотных зданий и сооружений в сложных инженерно-геологических условиях.

Ключевые слова: плитный фундамент, неоднородное геологическое строение, нелинейность деформирования грунтов, расчетное моделирование, грунт

Introduction. When designing high-rise buildings, one of the complex tasks is to reliably determine the deformations of foundation structures that transfer large loads to the base soils. Due to the large loads from foundation structures, soils located at a considerable depth and having different physical and mechanical properties are involved in the joint work. In addition, slab foundations of high-rise buildings are a complex building structure with a huge area buried at a great depth. At the same time, the loads on the foundations from the weight of high-rise buildings are not only significant, but also distributed extremely unevenly over the area.

The aim of the study is to develop and advance calculation methods for determining the settlement of slab foundations, taking into account the nonlinearity of deformation of foundation soils under the influence of uneven loads from the weight of high-rise buildings.

Materials and methods

The paper presents the results of computational studies of the stress-strain state (hereinafter SSS) of the "soil base - slab foundation" system, conducted taking into account nonlinear soil deformation.

A solid slab with 6.0 m thickness was considered as the foundation of a 600 m high-rise building designed on site No.17 on the territory of the Moscow International Business Center (hereinafter MIBC) "Moscow-City". In mathematical modeling, the solid slab and enclosing wall were reproduced in real sizes. The computational studies were carried out using the finite element method in a spatial setting, taking into account the heterogeneity of the geological structure of the foundation and the action of loads from the dead weight of the high-rise building.

During the work, a simplified calculation scheme was adopted, characterized by the complete development of a pit under the entire area of the site under consideration, instantaneous construction of the building, modulated by applying loads from the weight of the overlying building structures to the foundation slab.

When designing foundations for high-rise buildings, both traditional and modern calculation methods are widely used (Feng, et al., 2023; Tsytovich, 1973; Feng,1923; Shulyatyev, 2020; Segerlitz, 1979; Nikolaevsky, 1987; Kachanov, 1969; Drucker, 1952; Zaretsky, et al., 2003; Karabaev, 2004; Massond, 1973). At the same time, today, calculation methods based on the application of the finite element method and the use of mathematical models, based on the results of soil tests in laboratory conditions, are more widely used (Ibragimov, et al., 2023; Brovko, et al., 2020; Brovko, et al., 2017; Basile, 2015; Nasrollahi, et al., 2019).

The calculation studies were carried out using the methodology developed under the supervision of Professor Yu.K. Zaretsky (Zaretsky, 1989) and allowing one to determine the stress-strain state of the soil massif and slab foundation during construction taking into account the heterogeneity of the geological structure of the base and the uneven impact of loads from the building's own weight. The methodology is based on a joint numerical solution using the finite element method of a system of differential equilibrium equations and equations of soil state. The algorithm for solving the problem of nonlinear soil deformation is based on the use of an iterative procedure using the "fictitious" forces method. The developed methods and algorithm are implemented in the “GEO-MIGG” computational program (Abstract collection).

A mathematical model developed within the framework of the theory of plastic flow with hardening is used to describe the nonlinear mechanical behavior of soils (Zaretsky, 1989). The parameters of this model were determined from the “passports” of triaxial soil tests performed within the framework of engineering and geological surveys. When developing the soil base model, materials from previously conducted engineering and geological surveys were used.

In order to conduct computational studies of the stress-strain state of the soil base of the slab foundation of a high-rise building, a general mathematical model of the “soil base - slab foundation” system was developed, consisting of:

a mathematical model of the mechanical behavior of the soil, developed within the framework of the theory of plastic flow with strengthening;

a solid model of the soil base, the enclosing walls of the pit and the slab foundation of the high-rise building; a finite element model of the computational domain, obtained by breaking down the solid model of the computational domain into volumetric finite elements;

a geomechanical model of the soil base, developed on the basis of the results of engineering and geological surveys, with the allocation of computational geological elements (hereinafter referred to as CGE) in the soil massif and the assignment of their computational physical and mechanical characteristics;

boundary conditions specified at the boundaries of the computational domain in the form of displacements and loads from the building.

Solid model of the “soil base - slab foundation” system. For computational studies of high-rise building structures, a solid model was developed together with the soil base, which included the soil base, the slab foundation of the building and the enclosing structures (diaphragm wall). The general view of the developed solid model and its fragments is shown in Figure 1.

In the work, when modeling the “soil base - slab foundation” system, it was accepted:

- the enclosing “diaphragm wall” has a thickness of 0.9 mm, a length of 68.3 m (absolute marks of the top - 133.2 m, bottom - 64.1 m);

- the foundation slab is solid and has a constant thickness of 6.0 m, (absolute marks of the top - 86.1 m, bottom - 80.1 m);

- the foundation slab has a depression, and the absolute marks of the top of the depression are 81.1 m, the bottom – 74.1 m.

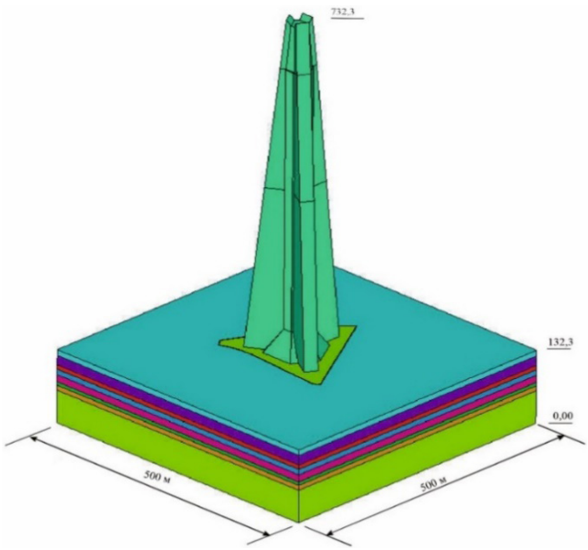

Figure 1 - General view of the solid model of the “soil base – slab foundation” system

Finite element model of the computational domain. To conduct computational studies by breaking down the developed solid model into volumetric elements, a finite element model of the entire computational domain was developed (Figure 2). In this case, the approximation of the computational domain was performed by spatial 4-node finite elements (tetrahedrons). In this case, the total number of finite elements and nodes of the mesh of the computational domain breakdown was: 833 124 and 145 296, respectively, with 435 888 unknowns.

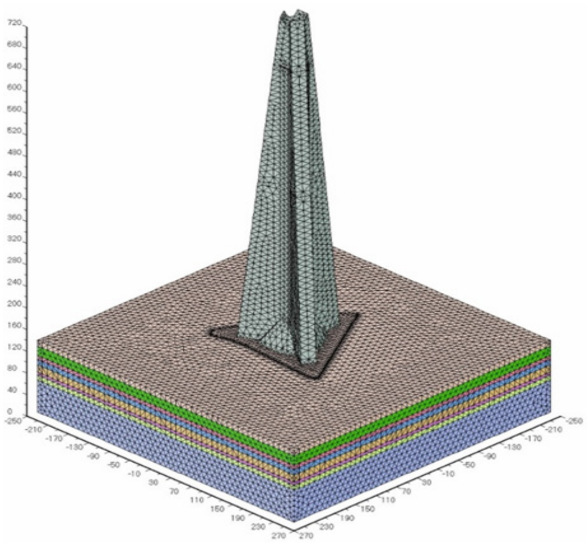

Figure 2 – General view of the finite element model of the computational domain

Geomechanical model of the soil foundation. The properties of the rock mass were studied using geophysical (seismic tomography) and pressuremetry methods. Pressuremetry was performed in a limited volume and, for technical reasons, limited to a depth of 35-40 m, geophysical studies were performed for the entire depth of the foundation exploration, up to 90 m. In laboratory conditions, soil samples were tested in the depth range of the entire explored massif, the number of which exceeded 300.

In addition to standard laboratory tests of samples, deformation and strength properties of rocks in a triaxial stress state were determined at this facility, modeling the behavior of the "soil base - slab foundation" system under different load combinations. A total of 42 such determinations were made, covering all types of soils lying at the base of the designed high-rise building.

Based on the survey results, an engineering-geological model of the massif was created, represented by a set of engineering-geological elements (hereinafter EGE). In accordance with GOST 20522-96, EGE have the same origin and type, provided that the soil properties are very close. For mathematical modeling of the interaction of the "soil base - slab foundation" system, a geomechanical model of the soil is created, which is a set of EGE. These elements can consist of one or more EGE, not necessarily of the same origin, and differ in that the soil characteristics within them can be constant or change according to the conditions of the calculation method.

In total, 8 EGEs are distinguished in the soil massif. Two of them, located in the upper part of the thickness to a depth of 30 m, are not considered as the foundation of the structure and were not studied in triaxial compression devices. Table 1 shows their generalized design characteristics, since when calculating the SSS of the "soil base - slab foundation" system, they act as an additional load. When calculating the stability of pits and retaining structures, the calculated values of the properties of each of the EGEs are used.

Table 1. Standard values of characteristics of computational-geological elements (CGE)

CGE	EGE	Brief description of rocks	CGE sole mark, m	Density, t/m^3	Porosity coefficient	Strength		
						$R_{compr.}$ MPa	c, MPa	φ, grad
1	1, 2	Fill soil, sand and loam in native bedding	128	1,96	0,67	-	0,011	31
	5	Heavy, plastic, rare semi-hard, slightly swelling, loose clay	122	1,84	0.89		0.024	22.1
2	3,4,6-11	Interbedding of clays, dolomites, and low-strength limestones	105	2,30	0,33	-	0,3	24
3	12	Hard clay with layers of weak marl	96	2,12	0,57	-	0,205	29-

4	13-14	Medium strength limestone, non-softening	88	2,31	0,32		1,8	48
5	15-16	Limestone of low strength, less often of medium strength with layers of marl	74	2,36	0,36	16	1,2	48
6	15	Low-strength limestone	68	2,27	0,41	10	1,5	46
7	15-16	Limestone of low strength, less often of medium strength with layers of marl	59	2,38	0,34	18	1,5	52
8	16	Medium strength limestone, dolomotised	0	2,43	0,30	35	2,2	53

The features of deformation and destruction of rocks in a volumetric (triaxial) stress state are described graphically in the form of strength "passports" in accordance with GOST 12248-96 "Soils. Methods of laboratory determination of strength and deformability characteristics". By analyzing and processing the results of triaxial soil tests for each CGE using a special method, strength "passports" are developed, which are used in calculation studies as initial data. An example of the design of calculated strength "passports" is shown in Figure 3.

Figure 3 – Example of the design of a strength "passport"

Soil studies in triaxial compression devices were conducted at three levels of horizontal stresses. The results corresponding to the minimum horizontal load (the first branch of the strength "passport") were used as the calculation results. After the pit is opened, the natural stresses are unloaded, as a result of which the soil massif becomes looser. In the calculation studies conducted, it is the first branch of the strength "passport" that models this state.

It should be noted that the values of the general soil deformation moduli in this case are closest to the values obtained by the geophysical method.

Methodology and sequence of calculation stages. To conduct calculation studies by breaking down the developed solid model into volumetric finite elements, a finite element model of the calculation domain was developed. In this case, the approximation of the calculation domain was performed by spatial 4-node finite elements (tetrahedrons) taking into account the nature of the strike of the EGE slab foundation of the high-rise building of the multifunctional complex, as well as the enclosing "diaphragm walls". In this case, the total number of finite elements and grid nodes of the calculation domain breakdown was: 574,073 and 101,967, respectively.

In the work, the following sequence of calculation stages was adopted for representative modeling of the entire construction process: modeling of the natural stress-strain state of the soil foundation; modeling of the device of the enclosing wall in the ground; modeling of the excavation pit; modeling of the device of the slab foundation; modeling of the construction of a high-rise building.

In the work, the calculation stages were modeled as follows:

Stage 1. Modeling the natural stress-strain state of the soil mass. At this calculation stage, the area under consideration consists of 8 CGE. The stress-strain state of the soil mass is formed only from the soil's own weight.

Stage 2. Modeling the enclosing wall device. At this stage, the physical and mechanical characteristics in the finite elements corresponding to the "wall in the ground" are replaced by the characteristics determined for concrete.

Stage 3. Modeling the excavation pit. In this case, some of the finite elements corresponding to the excavation pit being developed are excluded from further consideration. Thus, a pit consisting of an "empty" finite element is formed in the calculation area.

Stage 4. Modeling the device of the pile-slab foundation. At this stage, as well as at the 2^{nd} stage, the characteristics in the corresponding finite elements of the calculation area are replaced. As a result of such a replacement, a pile-slab foundation with the corresponding physical and mechanical characteristics is formed in the calculation area.

Stage 5. Modeling the construction of a high-rise building. At this stage, an external load from the overlying structures of the high-rise building is applied to the surface of the foundation slab.

Boundary conditions. The impact of the building itself on the foundation structures is modeled by applying loads from the building's own weight to the corresponding areas on the surface of the slab foundation. For this object, the total load on the foundation slab was 757 796 tons.

At this stage of the calculation studies, the construction of a high-rise building was modeled using a simplified method, the building was erected instantly.

At the lower boundary of the calculation area, a complete absence of displacements was specified, i.e. all calculation points located on this plane are motionless (Ux = Uy = Uz = 0).

At the four vertical boundaries of the calculation area, displacements were fixed in directions perpendicular to this plane. On the plane XoУ: Uz = 0; on the plane ZoY: Ux = 0.

Results

Stage 1. Modeling the natural stress-strain state of the soil massif. At this stage, the process of forming the stress-strain state of the soil foundation in its natural state was considered. For this purpose, the problem of compression from the soil's own weight without the possibility of lateral expansion is solved. At this stage, the stress-strain state of the massif in its natural state before the start of construction is formed from the action of its own weight.

The results of this stage are used at the next stage, when the construction of a high-rise building of a multifunctional complex on site No.17 of the Moscow-City International Business Center is considered as initial conditions. It should be noted that the reliability of forecasts of the interaction of the foundations of buildings and structures with a nonlinearly deformable base largely depends on the conditions for forming the stress-strain state. Thus, the main goal of this stage is to form a reliable initial condition.

Stage 2. Modeling the enclosing wall device. In the calculations for modeling the enclosing wall device, the concrete characteristics are set in the elements corresponding to the enclosing "wall in the ground". As a result of such a replacement, a zone is formed in the soil massif that corresponds in its geometric parameters and mechanical characteristics to the real enclosing wall in the ground. According to the calculation results, at this stage of the calculation studies, no noticeable changes in the stress-strain state occur in the soil massif due to the construction of the concrete enclosing wall.

Stage 3. Modeling of excavation. According to the calculation results, during excavation the soil mass is unloaded and there is a slight rise of the bottom. The maximum rise (24 mm) is expected in the middle part of the excavation under the high-rise towers. It is evident from the figure that the influence of excavation practically does not extend to the surrounding soil mass within the boundaries of the calculation area. The unloading of the soil mass that occurs as a result of excavation is illustrated in Figure 4 by isolines of vertical displacements Uy.

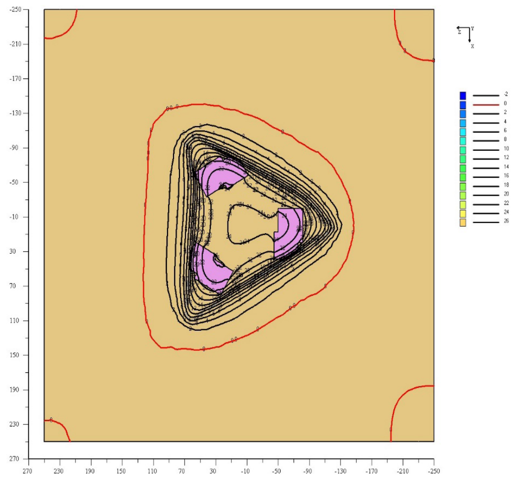

Figure 4 - Isolines of vertical displacements of the soil base Uy in mm

Stage 4. Modeling the slab foundation device. At this stage of the calculation studies, the device of the foundation slab is modeled. For this purpose, the characteristics are changed in the corresponding spatial finite elements of the calculation domain, i.e., the characteristics of reinforced concrete are specified in these elements instead of the soil characteristics. As a result, the foundation slab is modeled in the calculations, operating as a linearly deformable structure. The deformability modules of these elements are specified taking into account the concrete grade.

As a result of the device of a solid monolithic foundation slab with a thickness of 6.0 m, an additional load on the soil base occurs. As a result, additional subsidence of the soil mass directly under the base of the foundation slab to 5.2 mm occurs and the pressure on the base increases (Figures 5 - 6).

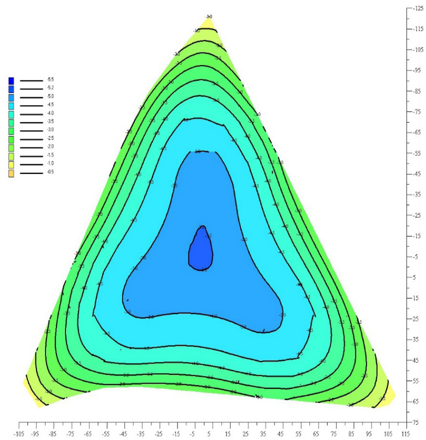

Figure 5 - Isolines of settlement of the base of the foundation slab from its own weight Uy in

mm

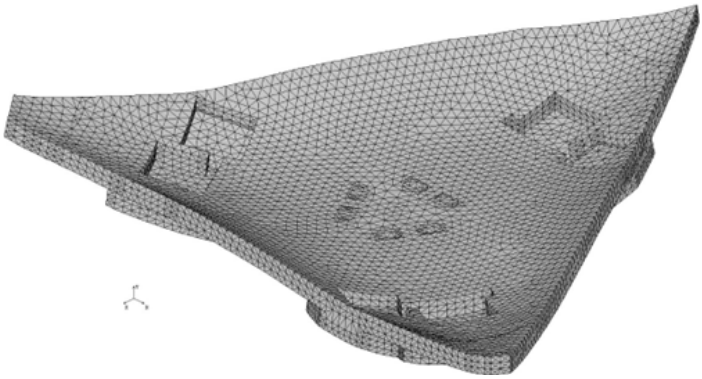

Figure 6 - Deformed state of the foundation slab

Stage 5. Modeling the construction of a high-rise building. As the results of the conducted calculation studies have shown, during the construction of a high-rise building, the loads on the slab foundation increase, and as a result, the stress-strain state of the entire soil base changes.

As the calculation results show, due to the significant deepening of the enclosing wall in the soil, additional movements of the soil base occur directly under the foundation slab. The settlement of the foundation slab develops unevenly. The maximum settlement of 53 mm is expected in the center of the foundation slab. The smallest settlements are expected under the corner points of the slab - less than 5 mm (Figure 7). The deformed state of the foundation slab, constructed at a scale of 50:1, is shown in Figure 8.

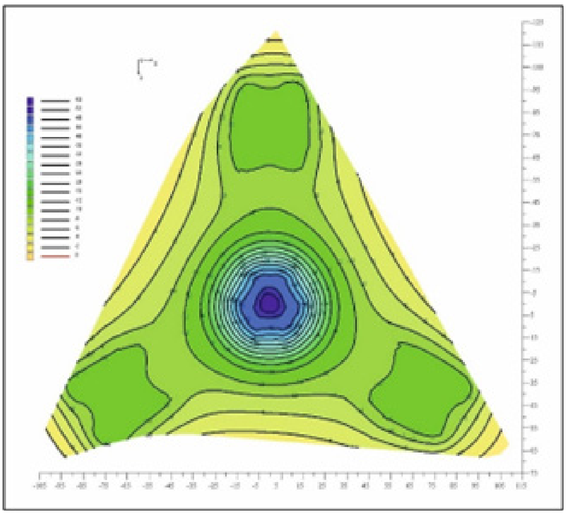

Figure 7 - Isolines and isofields of foundation slab settlement Uy (in mm)

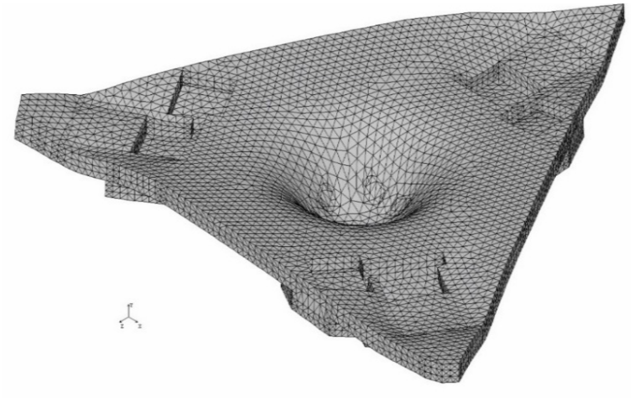

Figure 8 - Deformed state of the foundation slab

As a result of the foundation slab loading, vertical stresses increase in the soil mass directly under the slab, exceeding the natural value, i.e. in addition to the natural pressure from its own weight. In this case, the pressure on the soil under the slab is distributed unevenly. Under the most loaded part of the foundation slab (in the center), the maximum pressure value is observed, equal to 1.2 MPa (Figure 9).

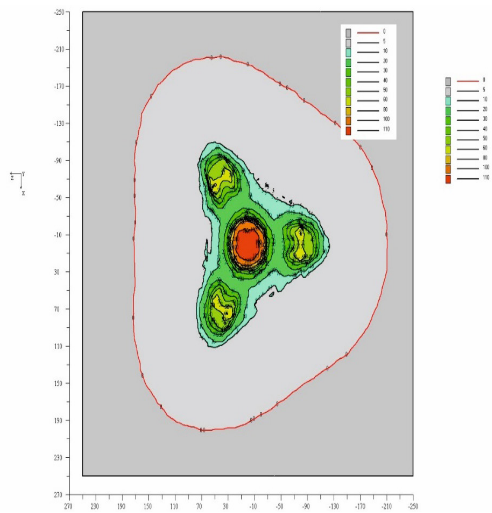

Figure 9 - Isolines of additional vertical stresses $\Delta\sigma_y$ (in t/m^2) under the base of the foundation slab.

Discussion

The calculation method and the mathematical model used to describe the nonlinear mechanical behavior of soils, developed within the framework of the theory of plastic flow with strengthening, allow us to take into account many factors that directly affect the behavior of the “soil base - slab foundation” system:

- nonlinearity of soil deformation;

- high-rise building construction technology (sequence of work);
- dependence of soil deformation on the loading sequence;
- occurrence of a limit state region in the soil massif under various cases of load (impact) changes.

The main advantage of the used mathematical model of soils is the determination of nonlinear parameters of the model from the results of real triaxial soil tests carried out in the load range from the natural stress-strain state to the limit state of soils.

The use of linear unloading deformation modules in calculations, in addition to nonlinear loading ones, allows us to reliably simulate the process of developing deep pits, which are widely used at the present stage of high-rise building construction.

Conclusion

The analysis of the results of the calculation modeling of the construction of a high-rise building on site No.17 of the Moscow-City International Business Center allowed us to formulate the following main conclusions:

- with a given load on the slab foundation, the limit state zones do not appear in the soil massif, which indicates the presence of a reserve of the bearing capacity of the soil base;
- the settlement of the foundation slab during the construction of a high-rise building occurs unevenly. At the same time, the maximum settlement is predicted in the middle of the foundation slab and is - 53 mm. The predicted value of settlement (53 mm) and the relative difference in settlement (4.23x10-4) of the slab foundation does not exceed the permissible values for this class of structures (10 cm and 0.002). In general, this design solution for the foundation slab meets the requirements of existing standards.

References

Abstract collection (2003) Rossijskie programmy dlya EVM [Russian computer programs]. Certificate of state registration of computer programs No.0217 – 01.1.0 RUS, series B, dated 24.01. 2001 (in Russian)

Basile F. (2015). "Non-linear analysis of vertically loaded piled rafts," Comput. Geotech., 63, –P.73–82. https://doi.org/10.1016/j.compgeo.2014.08.011 (in Eng.).

Brovko I.S., Baibolo, K.S., Ibragimov K.I., Kunanbayeva Y.B. (2017). The results of modeling and field studies of the interaction of large piles with ground subsidence. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 6(426), –P. 246–254 https://doi.org/10.32014/2020.2518-170X.129 (in Eng.).

Brovko I.S., Kunanbayeva Y.B., Brovko E.I., Baibolov K.S. (2020) Experimental substantiation of soil selection in reconstruction of a main gas pipeline. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 6(444), –P. 41–49 https://doi.org/10.32014/2020.2518-170X.129 (in Eng.).

Drucker O.C., Prager W. (1952). Soil Mechanics and Plastic Analysis of Limit Design, "Quart Appl. Mech.", 10, 157, pp. l57-165. (in Eng.).

Feng D.L., Xiao X.-L., Liang S.-H. (2023). A multiscale Drucker–Prager strength criterion based on microscopic physical soil analysis. «Soil Mechanics and Foundation Engineering", vol. 60, No. 5, –P. 444-451 (in Eng.).

Feng Sh., Lei H. (2023). A Structured Cam-Clay model with a damage variable «Soil Mechanics and Foundation Engineering", vol.60, No.5, –P. 425-431(in Eng.).

Ibragimov, K., Ussenkulov, Z.A., Yerimbetov, B.T., ... Kunanbayeva, Y.B., Ussenkulova, S.Z. (2023) Strength and deformability of large-scale clastic soils. *Smart Geotechnics for Smart Societies*, –P.862–866 (in Eng.).

Kachanov L-M. (1969). Osnovy teorii plastichnosti [Fundamentals of the Theory of Plasticity]. Moscow; Nauka. 420 p. (in Russian).

Karabaev M.I. (2004). Raschetnoye modelirovaniye stroitel'stva podzemnoy avtostoyanki na ploshchadi Revolyutsii *(g. Moskva)* [Calculation modeling of the construction of an underground parking lot on Revolution Square (Moscow)]. Journal "Yestestvennyye i tekhnicheskiye nauki" [Natural and Technical Sciences], Moscow, No.1, –P.136-138. ISSN 1684-2626 (in Russian).

Massond M. (1973) On the Relation Between the Factor of Safety and Realibility, Journal of Engineering for Industry, Transactions of ASTM, paper № 73 WA/DE-1. –P. 700-721 DOI: 10.1061/(ASCE)1090-0241(2001)127:8(700) http://dx.doi.org/10.1061/(ASCE)1090-0241(2001)127:8(700) (in Eng.).

Nasrollahi S. M., Hosseininia E. Seyedi. (2019). "A simplified solution for piled-raft foundation analysis by using the two-phase approach," C. R. Méc., 347, –P. 716–733. (in Eng.).

Nikolaevsky V.N. (1987). Mekhanika geomaterialov. Uslozhnennyye modeli [Mechanics of Geomaterials. Complex Models]. Itogi nauki i tekhniki: Mekhanika deformiruyemogo tverdogo tela [Results of Science and Technology: Mechanics of a Deformable Solid Body]. VINITI. Issue 19. – P. 48-182. (in Russian)

Segerlitz S. (1979). Primeneniye metoda konechnykh elementov [Application of the finite element method]. Moscow: Mir, 92 p. (in Russian)

Shulyatyev O. A. (2020) Osnovaniya i fundamenty vysotnykh zdaniy [Foundations and bases of high-rise buildings]. Moscow: ACB, 442 p. (in Russian)

Tsytovich N.A. (1973). Mekhanika gruntov [Soil mechanics]. ML: Vysshaya shkola, 280p. (in Russian).

Zaretsky Yu.K. (1989). Lektsii po sovremennoy mekhanike gruntov [Lectures on modern soil mechanics]. RSU Publishing House, 608 p. (in Russian)

Zaretsky Yu.K., Karabaev M.I. (2003). Otsenka vliyaniya proyektiruyemogo podzemnogo perekhoda na osadki gostinitsy «Moskva» [Assessment of the influence of the designed underground passage on the settlement of the "Moscow" Hotel]. Proceedings of the int. conf. on geotechnics "Reconstruction of historical cities and geotechnical construction", St. Petersburg, vol. 2, –P. 323-327. (in Russian)

Publication Ethics and Publication Malpractice in the journals of the National Academy of Sciences of the Republic of Kazakhstan

For information on Ethics in publishing and Ethical guidelines for journal publication see http://www.elsevier.com/publishingethics and http://www.elsevier.com/journal-authors/ethics.

Submission of an article to the National Academy of Sciences of the Republic of Kazakhstan implies that the described work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see http://www.elsevier.com/postingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The National Academy of Sciences of the Republic of Kazakhstan follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct (http://publicationethics.org/files/u2/New_Code.pdf). To verify originality, your article may be checked by the Cross Check originality detection service http://www.elsevier.com/editors/plagdetect.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the National Academy of Sciences of the Republic of Kazakhstan.

The Editorial Board of the National Academy of Sciences of the Republic of Kazakhstan will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайтах:
www:nauka-nanrk.kz
http://www.geolog-technical.kz/index.php/en/
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Директор отдела издания научных журналов НАН РК *А. Ботанқызы*
Редакторы: *Д.С. Аленов, Ж.Ш.Әден*
Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 15.06.2025.
Формат 70x90$^{1}/_{16}$. Бумага офсетная. Печать – ризограф.
14,5 п.л. Заказ 3.

РОО «Национальная академия наук РК»
050010, Алматы, ул. Шевченко, 28, т. 272-13-19