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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
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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.

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ФРАТТИНИ Паоло, PhD, ассоциированный профессор, Миланский университет Бикокк (Милан, Италия), https://www.scopus.com/authid/detail.uri?authorId=56538922400 **НУРПЕИСОВА Маржан Байсановна** – доктор технических наук, профессор Казахского Национального исследовательского технического университета им. К.И. Сатпаева, (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=57202218883, https://www.webofscience.com/wos/author/record/AAD-1173-2019

РАТОВ Боранбай Товбасарович, доктор технических наук, профессор, заведующий кафедрой «Геофизика и сейсмология», Казахский Национальный исследовательский технический университет им. К.И. Сатпаева, (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=55927684100, https://www.webofscience.com/wos/author/record/1993614

РОННИ Берндтссон, Профессор Центра перспективных ближневосточных исследований Лундского университета, профессор (полный курс) Лундского университета, (Швеция), https://www.scopus.com/authid/detail.uri?authorId=7005388716 , https://www.webofscience.com/wos/author/record/1324908

МИРЛАС Владимир, Факультет химической инженерии и Восточный научно-исследовательский центр, Университет Ариэля, (Израиль), https://www.scopus.com/authid/detail.uri?authorId=8610969300, https://www.webofscience.com/wos/author/record/53680261

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Institute of Seismology of the Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan.
E-mail: ahrorhs1980@gmail.com

DETERMINATION OF CHANGES IN SOIL PARAMETERS USING THE PLAXIS 3D PROGRAM USING REINFORCEMENT OF BORED PILES

Ismailov Vakhithan — Doctor of geological mineralogical Sciences of the Institute of Seismology of the AS RUz, Tashkent, Uzbekistan, E-mail: vakhit.mbm@gmail.com, https://orcid.org/0000–0002–7893–1556;
Bozorov Jonibek — Seismology Institute of Sciences, AS RUz, Tashkent, Uzbekistan, E-mail: j.bozorov1968@gmail.com, https://orcid.org/0009-0008-5676-0144;
Khusomiddinov Akhror — Doctor of Philosophy in Geological and Mineralogical Sciences (PhD); Seismology Institute of Sciences, AS RUz, Tashkent, Uzbekistan, E-mail: ahrorhs1980@gmail.com, https://orcid.org/0000–0001–6970–3482;
Yadigarov Eldor — Doctor of Philosophy in Geological and Mineralogical Sciences (PhD), Seismology Institute of Sciences, AS RUz, Tashkent, Uzbekistan, E-mail: eldoradigarov@gmail.com, https://orcid.org/0000–0002–2305–279X;
Mansurov Azizjon — Seismology Institute of Sciences, AS RUz, Tashkent, E-mail: mazizjon876@gmail.com, https://orcid.org/0009-0007-9807-6925.

Abstract. The present study aims to assess the efficiency of engineering preparation at the "Labzak Park City" construction site, located in Tashkent—a region characterized by high seismic activity. The site features complex engineering-geological and seismotectonic conditions, being situated within active fault zones and historically exposed to earthquakes with intensities of up to 7–8 on the MSK-64 scale. The main objective of the study was to quantitatively evaluate the dynamic response of the soil mass before and after the implementation of reinforced bored piles. Numerical analysis was conducted using Plaxis 3D, a modern geotechnical modeling program based on the finite element method (FEM). The computational model comprised 10,468 finite elements and 24,231 nodes, ensuring a high level of detail and reliability. An accelerogram from a real earthquake (magnitude M = 5.2), recorded near the study site in 2020, was used as the input seismic motion. The modeling results demonstrated a substantial reduction in seismic impact parameters following engineering preparation of the foundation. Specifically, the maximum acceleration at the key calculation node decreased by 41.53%, velocity by 16.91%, and displacement by 11.29%. These findings indicate the high efficiency of reinforced bored piles in damping seismic waves, particularly in loess-like, subsidence-prone soils. The results support the feasibility and effectiveness of this technology for enhancing the stability and reliability of foundations in seismically active areas.

Keywords: seismic impact, seismicity, seismic intensity, acceleration, velocity, displacement, peak acceleration of soil

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Өзбекстан Республикасы Ғылым Академиясының Сейсмология институты, Ташкент, Өзбекстан.

E-mail: ahrorhs1980@gmail.com

PLAXIS 3D БАҒДАРЛАМАСЫ АРҚЫЛЫ БҰРҒЫЛАНҒАН ҚАДАЛАРДЫ АРМАТУРАЛАУ НЕГІЗІНДЕ ТОПЫРАҚ ПАРАМЕТРЛЕРІНІҢ ӨЗГЕРІСІН АНЫҚТАУ

Исмаилов Вахитхан — ӨР ҒА Сейсмология институтының геология–минералогия ғылымдарының докторы, Ташкент, Өзбекстан, E-mail: vakhit.mbm@gmail.com, https://orcid.org/0000–0002–7893–1556;

Бозоров Жонибек — Сейсмология ғылымдары институты, ҒА, Ташкент, Өзбекстан, E-mail: j.bozorov1968@gmail.com, https://orcid.org/0009-0008-5676-0144;

Хусомиддинов Ахрор — геология–минералогия ғылымдарының философия докторы (PhD), Сейсмология ғылымдары институты, ҒА, Ташкент, Өзбекстан, E-mail: ahrorhs1980@gmail.com, https://orcid.org/0000–0001–6970–3482;

Ядигаров Эльдор — геология–минералогия ғылымдарының философия докторы (PhD), Сейсмология ғылымдары институты, ҒА, Ташкент, Өзбекстан, E-mail: eldoradigarov@gmail.com, https://orcid.org/0000–0002–2305–279X;

Мансуров Азизжон — Сейсмология ғылымдары институты, ҒА, Ташкент, Өзбекстан, E-mail: mazizjon876@gmail.com, https://orcid.org/0009-0007-9807-6925.

Аннотация. Бұл зерттеу жоғары сейсмикалық белсенділікпен сипатталатын Ташкентте орналасқан «Лабзак Парк сити» құрылыс алаңындағы инженерлік дайындықтың тиімділігін бағалауға бағытталған. Учаске күрделі инженерлік-геологиялық және сейсмотектоникалық жағдайларға ие, белсенді бұзылу аймақтарында орналасқан және MSK-64 шкаласы бойынша 7-8 қарқындылығымен тарихи жер сілкінісіне ұшыраған. Зерттеудің негізгі мақсаты топырақ массасының күшейтілген бұрғылау қадаларын салуға дейін және одан кейінгі динамикалық реакциясын сандық бағалау болды. Сандық талдау соңғы элементтер әдісіне (FEM) негізделген заманауи геотехникалық модельдеу бағдарламасы Plaxis 3D арқылы жүргізілді. Есептеу моделі егжей-тегжейлі және сенімділіктің жоғары деңгейін қамтамасыз ететін 10 468 соңғы элемент пен 24 231 түйінді қамтыды. Кіріс сейсмикалық қозғалыс ретінде 2020 жылы зерттеу алаңының жанында тіркелген нақты жер сілкінісінің акселерограммасы (магнитудасы M = 5,2) пайдаланылды. Модельдеу нәтижелері іргетастың инженерлік дайындығынан кейін сейсмикалық әсер ету параметрлерінің айтарлықтай төмендеуін көрсетті. Нақтырақ айтсақ, негізгі есептеу түйініндегі максималды үдеу 41,53%-ға, жылдамдық 16,91%-ға, орын ауыстыру 11,29%-ға төмендеді. Бұл нәтижелер сейсмикалық толқындарды, әсіресе лесс тәрізді, шөгуге бейім топырақтарда, сейсмикалық толқындарды сөндіретін арматураланған қадалардың жоғары тиімділігін көрсетеді. Нәтижелер сейсмикалық белсенді аймақтардағы іргетастардың тұрақтылығы мен сенімділігін арттыру үшін осы технологияның орындылығы мен тиімділігін қолдайды. Мақала пайдалану кезінде сейсмикалық әсердің өзгеру ерекшеліктеріне арналған бұрғылау қадаларын күшейту шөгінді топырақтарда көп қабатты ғимараттар салу кезінде, сондай-ақ, Plaxis 3D компьютерлік бағдарламасының көмегімен сейсмикалық әсер ету кезінде кеңістіктегі топырақта болатын динамикалық өзгерістерді анықтауға болады, атап айтқанда жылдамдық, үдеу және сырғанау.

Түйін сөздер: сейсмикалық әсер, сейсмикалық, сейсмикалық қарқындылық, үдеу, жылдамдық, орын ауыстыру, топырақтың ең жоғары үдеуі

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Институт сейсмологии Академии наук Республики Узбекистан,
Ташкент, Узбекистан.
E-mail: ahrorhs1980@gmail.com

ОПРЕДЕЛЕНИЕ ИЗМЕНЕНИЯ ПАРАМЕТРОВ ГРУНТА С ПОМОЩЬЮ ПРОГРАММЫ PLAXIS 3D С ИСПОЛЬЗОВАНИЕМ АРМИРОВАНИЯ БУРОНАБИВНЫХ СВАЙ

Исмаилов Вахитхан — доктор геолого–минералогических наук, Институт сейсмологии АН РУз, Ташкент, Узбекистан, E-mail: vakhit.mbm@gmail.com, https://orcid.org/0000–0002–7893–1556;

Бозоров Жонибек — Институт сейсмологии АН РУз, Ташкент, Узбекистан, E-mail: j.bozorov1968@gmail.com, https://orcid.org/0009-0008-5676-0144;
Хусомиддинов Ахрор — доктор философии геолого–минералогических наук (PhD), Институт сейсмологии АН РУз, Ташкент, Узбекистан, E-mail: ahrorhs1980@gmail.com, https://orcid.org/0000–0001–6970–3482;
Ядигаров Элдор — доктор философии геолого–минералогических наук (PhD), Институт сейсмологии АН РУз, Ташкент, Узбекистан, E-mail: eldoradigarov@gmail.com, https://orcid.org/0000–0002–2305–279X;
Мансуров Азизжон — Институт сейсмологии АН РУз, Ташкент, Узбекистан, E-mail: mazizjon876@gmail.com, https://orcid.org/0009-0007-9807-6925.

Аннотация. Настоящее исследование направлено на детальную оценку эффективности инженерной подготовки строительной площадки «Labzak Park City», расположенной в городе Ташкент – регионе с выраженной сейсмической активностью. Территория объекта характеризуется сложными инженерно-геологическими и сейсмотектоническими условиями: зона расположена в пределах активных разломов и исторически подвержена землетрясениям интенсивностью 7–8 баллов по шкале MSK-64. Основной задачей исследования стало количественное сравнение динамической реакции грунтового массива до и после применения армированных буронабивных свай. Для численного анализа использовалась современная программа геотехнического моделирования Plaxis 3D, основанная на методе конечных элементов (МКЭ). В расчетной модели было задействовано 10 468 конечных элементов и 24 231 узел, что обеспечило высокую степень детализации и достоверности результатов. В качестве входного сейсмического воздействия использовалась акселерограмма реального землетрясения магнитудой M = 5,2 зарегистрированного вблизи исследуемой площадки в 2020 году. Результаты моделирования показали значительное снижение параметров сейсмического воздействия после инженерной подготовки основания. Так, максимальное ускорение в ключевом расчетном узле уменьшилось на 41,53%, скорость – на 16,91%, а перемещения – на 11,29%. Это указывает на высокую эффективность демпфирования сейсмических волн с помощью армированных буронабивных свай, особенно в условиях лессовидных, склонных к просадке грунтов. Полученные данные подтверждают целесообразность применения данной технологии при проектировании зданий и сооружений в районах с высокой сейсмической опасностью, так как она существенно повышает надежность и устойчивость оснований в процессе землетрясения.

Ключевые слова: сейсмическое воздействие, сейсмичность, сейсмическая интенсивность, ускорение, скорость, перемещения, пиковое ускорение грунта

Introduction.

Significant efforts are being undertaken worldwide to mitigate the consequences of major earthquakes and to ensure seismic safety (Ismailov, et al, 2023, 2024-a; Khusomiddinov, et al., 2022; Sadykov, et al., 2023; Atabekov, et al., 2022; Artikov, et al., 2022; Artikov, et al., 2020a-b; Ibragimov, et al., 2022). In seismically active regions, particular attention is given to enhancing the seismic resilience of soil covers for buildings and structures and to reducing the intensity of seismic impact, which, in turn, is transmitted to buildings and structures. Currently, in developed foreign countries, research is being conducted to reduce seismic intensity at construction sites where collapsible loess soils are widespread (Ismailov, et al., 2024-b). One of the priority tasks is also to determine the engineering preparation methods depending on the type of collapsible loess soils, to create an optimal methodology for assessing seismic impact on buildings and structures using selected one-dimensional models, and to develop methods for evaluating changes in seismic intensity using various technologies.

Materials and methods

The primary advantage of bored piles is the relative simplicity of their manufacturing and installation technology. Since these piles are produced by pouring concrete into a pre-prepared hole, several beneficial qualities can be highlighted, including the ability to manufacture bored pile shafts of any length. Moreover, during installation, bored piles, unlike driven piles, are almost not subjected to dynamic impacts, which positively affects their strength. Another significant advantage of bored piles is their applicability in reconstruction projects, including the densification (reinforcement) of existing pile foundations (Kolosov, et al., 2018).

“Labzak Park City,” site hereinafter referred to as the “Object” is located in the Shayhontohur district of Tashkent. Structurally, this area belongs to the transitional region from the Tien Shan epi-platformal orogen to the Turan platform. The seismicity of the area is directly related to the tectonics of this region and is manifested along seismogenic faults that have been activated in the current stage of geological development (Ibragimov, 1978). Local seismic manifestations are associated with the modern seismic activity of the Karjantau fault system, which trends northeast, and the Pretashkent flexure-fault zone. Alongside local earthquakes, the area is also affected by transit earthquakes occurring within the Nurek fault system, the North-Angren and South-Angren faults, the eastern end of the North-Fergana seismically active zone, the South-Fergana seismogenic zone, as well as strong earthquakes occurring within the Chatkal Ridge. The dynamic influence zones of the aforementioned faults have been delineated by Ibragimov (1978) into corresponding seismogenic zones.

Figure 1 presents a map of the epicentres of significant and strong earthquakes recorded in the vicinity of the site over the past 150 years, indicating the seismically active zones within which they occurred. Table 1 provides the parameters of these earthquakes and their distances from the site. The greatest seismic effects on the site were noted from the historical earthquakes of 1868 and 1886, with magnitudes of M=6.5 and M=6.7, respectively, which occurred at a distance of approximately 20-30 km from the site. Among the strong earthquakes of the early instrumental period, special attention should be given to the 1946 Chatkal earthquake with a magnitude of M=7.6, which occurred at a distance of approximately 200 km from the site. According to macroseismic data, the intensity of seismic impacts from this earthquake at the construction site reached 7 according to the MSK-64 scale. Several strong earthquakes occurred in the vicinity of the construction site during the instrumental observation period. During the 1966 Tashkent earthquake with M=5.2, whose epicentre was almost directly at the construction site, the macroseismic effect was 7-8 according to the MSK-64 scale. Strong tremors (I=7) were felt at the construction site during the 1977 Tavaksay earthquake with M=5.2, which occurred approximately 40 km from the site; the 1980 Nazarbek earthquake with M=5.3, which occurred 20 km from the construction site (I=7); and the 1987 Altyn-Tyube earthquake with M=5.1, at a distance of approximately 60-70 km from the site (I=6).

In the last 10-15 years, several moderate-strength earthquakes have occurred within a 50 km radius of the construction site: within the city of Tashkent in August 2008, January 2010, and March 2018. The earthquake with a magnitude of M=5.6 that occurred in the Tuyabuguz area on May 25, 2013, at a distance of 30 km from the site, caused tremors at the construction site with an intensity of 5-6 on the MSK-64 scale.

Thus, the maximum macroseismic effect from all known seismic events at the construction site has not exceeded 7-8 according to the MSK-64 scale.

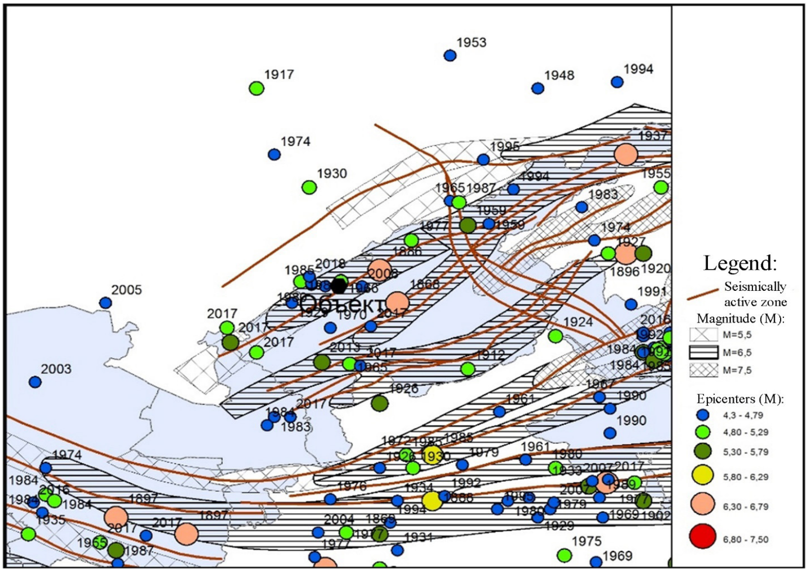


Fig. 1. Map of epicentres of strong earthquakes in the vicinity of the site from historical times to the present day

Results.

The construction site "Labzak Park City" (Fig. 1) is the subject of this research. An assessment of seismic impact and changes in seismic effect will be conducted using the Finite Element Method (FEM) by spatially reinforced bored piles at construction sites where loess-like soils are prevalent. Direct support for numerical methods in addressing the propagation of seismic waves in an infinite half-space is not feasible. To accomplish this, the area of interest within the infinite space is substituted into a finite parallelepiped. Boundary conditions are applied to the extended sides of the parallelepiped to represent the effect of the discarded portion, allowing waves incident on the boundary to be transmitted without reflection.

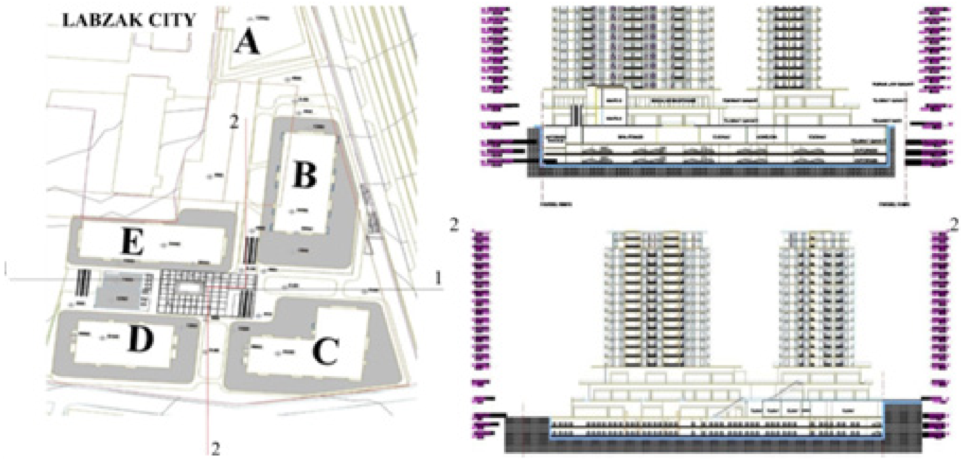


Fig. 2. Schematic map of "Labzak Park City" buildings

The displacements and velocities of the obtained nodes in the soils will be determined, taking into account the physical and mechanical properties of the material. In this task, the infinite half-space will be replaced with a finite parallelepiped (Ilyichev, et al., 1999; Yuldashev, et al., 2018; Lysmer, et al., 1969). Boundary conditions will be applied to the sides of the parallelepiped where the continuation of the medium has been discarded.

$$\left.\begin{aligned}\sigma_x &= a\rho V_p \dot{u}\\ \tau_{yz} &= b\rho V_s \dot{u}\\ \tau_{zy} &= b\rho V_s \dot{w}\end{aligned}\right\} \qquad \left.\begin{aligned}\sigma_y &= a\rho V_p \dot{v}\\ \tau_{xz} &= b\rho V_s \dot{w}\\ \tau_{zx} &= b\rho V_s \dot{u}\end{aligned}\right\} \qquad \left.\begin{aligned}\sigma_z &= a\rho V_p \dot{w}\\ \tau_{xy} &= b\rho V_s \dot{u}\\ \tau_{yx} &= b\rho V_s \dot{v}\end{aligned}\right\} \tag{1}$$

The kinematic relation can be formulated as follows:

$$\varepsilon = Lu \tag{2}$$

L^T – is the transpose of the differential operator, defined as

$$L^T = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial z} \\ 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial x} & \frac{\partial}{\partial z} & 0 \\ 0 & 0 & \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial y} & \frac{\partial}{\partial x} \end{bmatrix}. \tag{3}$$

To solve the problem we will use the finite element method. The dynamic model of the problem solution field is presented in Fig. 2.

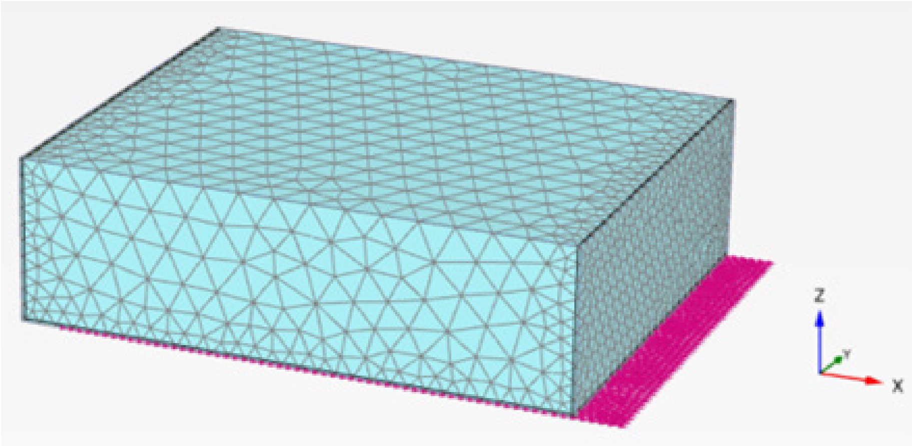


Fig. 3. A model in which the domain is partitioned into finite elements

As a result of applying the Finite Element Method (FEM), the continuous mechanical system is transformed into a discrete one. The studied area is divided into 10 468 finite elements with 24 231 nodes. The finite elements are shaped as irregular tetrahedrons. The primary equation, which depends on the time of motion of the volume under dynamic loading, is expressed as follows:

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F\} \quad (4)$$

The order of the system of differential equations is 72 693, where
M - the mass matrix;
C - the damping matrix, which also accounts for boundary conditions;
K - the stiffness matrix;
F - the load vector;
u - the displacement vector;
u' - velocity;
u" - acceleration.

The theory is described here within the framework of linear elasticity. However, all models can, in principle, be used for dynamic analysis. Groundwater levels may be present in the studied areas to obtain data.

For the numerical implementation of the given task, the Plaxis 3D software package (Lysmer, et al., 1969) will be used, which includes various options for physical material equations. The matrix M accounts for the mass of the materials (soil + any structure).

When performing integration with respect to time in the numerical representation of dynamics, stability and accuracy of the computational process are important factors. The Newmark numerical integration scheme is used. The properties of the soil are provided in Table 1.

Table 1. Physical and mechanical properties of materials

Soil parameters	Before stabilization	After stabilization
Bulk density (ρ), g/cm^3	1.40-1.74 1.55	1.96-2.30 2.2
Dry density (ρ_d), g/cm^3	1.25-1.50 1.40	1.79-1.95 1.85
Moisture content (W), %	10-20.5 13.5	8.2-12.5 11.5
Porosity (n), %	46.4-55.0 48.2	30.5-34.3 32.5
Shear wave velocity (V_s), m/s	220-298 245	750-1250 950
Longitudinal wave velocity (Vp), m/s	450-560 500	2000-2210 2100
Young modulus, E (MPa)	229	4420
Poisson's ratio, μ	0.34	0.30
Internal friction angle, φ	24	31
Cohesion C, (kPa)	6	20
Groundwater level, h	12.5	12.5
Dimensions of the site	80 × 100 × 30 m	80 × 100 × 30 m

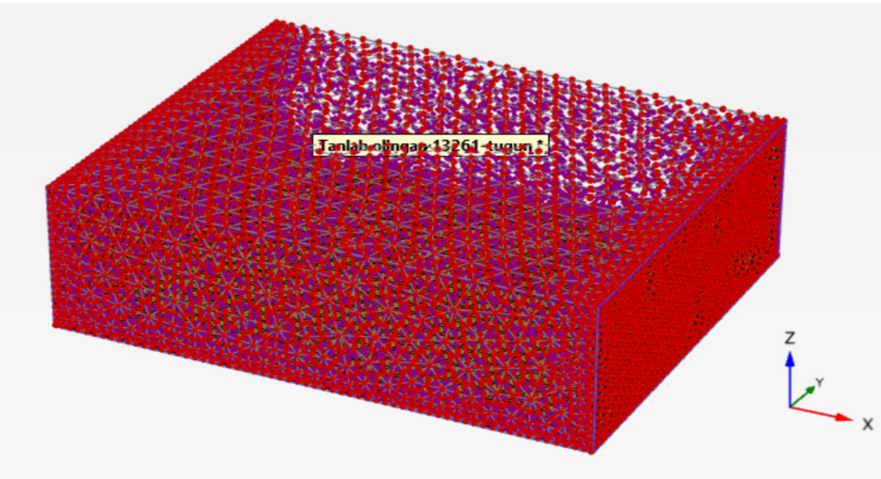


Fig. 4. Representation of 13261 nodes used in our model

As a result of applying the Finite Element Method, the continuous mechanical system is replaced by a discrete one. The studied area with 24 231 nodes is divided into 10 468 finite elements. The number of resulting second-order linear differential equations is 72 693. The finite element shapes are chosen as irregular tetrahedrons.

For both models of equal size, selected after inputting the soil parameters, a real accelerogram recorded after an earthquake in the same area is introduced as the seismic impact. The accelerogram is shown in Figure 5. It was recorded as a result of an earthquake with a magnitude of M = 5.2, which occurred at 7:38 AM local time on 06.11.2020, with the accelerometer coordinates (X = 40.16; Y = 71.72) and a focal depth of H = 10 km.

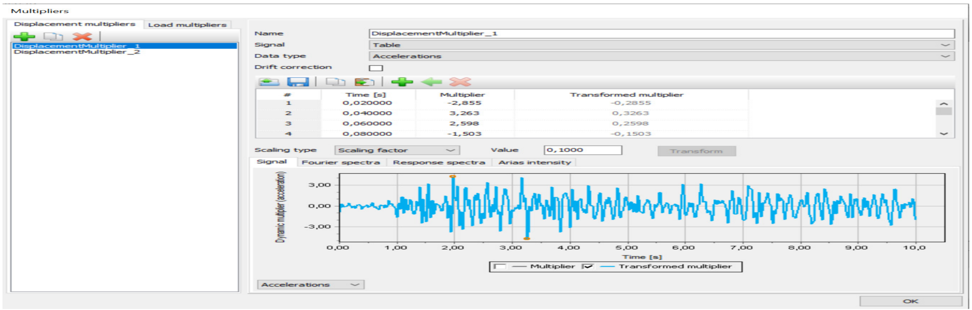
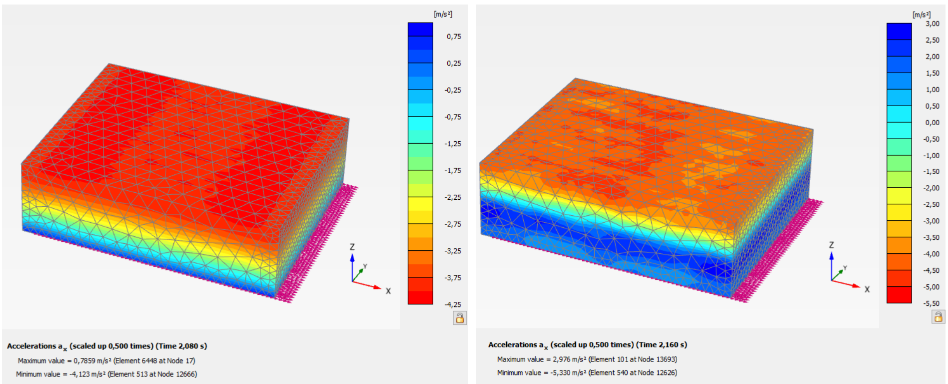


Fig. 5. Accelerogram used in our model to simulate dynamic impact

The selected model consists of 24 231 nodes, with the irregular tetrahedron divided into 10 468 finite elements. Plaxis 3D was used for calculation of velocity, acceleration and displacement during the application of seismic impact. Figure 6 shows the comparison of accelerations at the maximum seismic impact in the nodes before and after soil stabilization (Fig. 6).



(a) (b)

Fig. 6. Accelerations in all nodes along the X-axis in the natural state (a) and after soil stabilization (b) at t = 2 s

The difference in maximum accelerations at node 13 261 at t = 2.6 seconds along the X-axis for both cases will be considered. In the natural state, the highest acceleration achieved by this seismic impact is a_{x1} = 376.3 cm/s^2, while after soil stabilization (engineering preparation), it reaches a_{x2} = 220 cm/s^2. This means that after the engineering preparation of the construction pit using the reinforced pile method, the acceleration at the node decreased by $\Delta a_x = 156.3$ cm/s^2 (Fig. 7). Overall, it can be stated that the acceleration decreased by 41.53%.

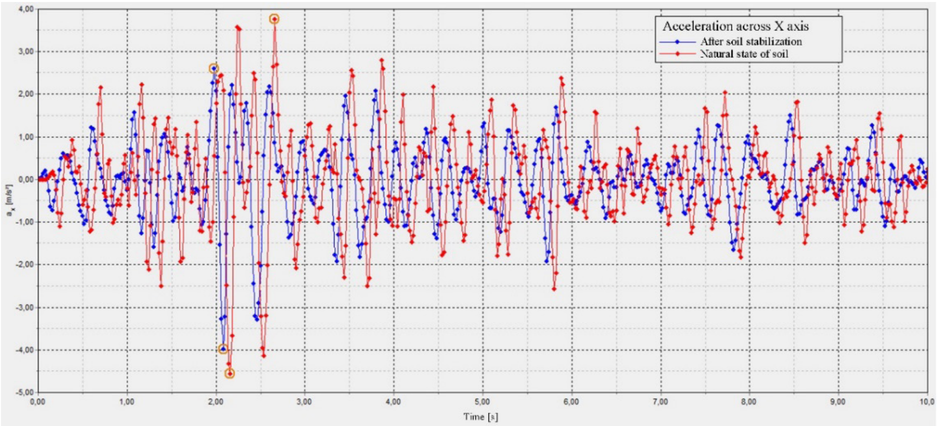
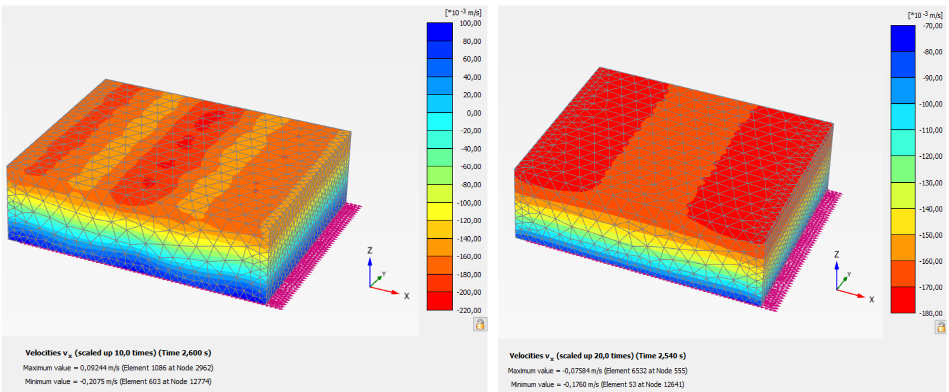


Fig. 7. Acceleration of the 13261[st] node (x = 50, y = 40, z = 0) at time t = 10 sec along the X-axis

Figure 7 shows the acceleration of a selected node over 10 second period. It can be seen that the time during which the accelerogram reaches its maximum and minimum values, corresponds to the acceleration values from a seismic impact. It can be assumed that the application of dynamic impact (represented by accelerogram) was appropriate and correct.



(a) (b)

Fig. 8. Velocities at all nodes along the X-axis in the natural state (a) and after soil stabilization (b) at t = 2.6 s

For both cases, the change in acceleration values at node 13 261 at t = 2.6 s along the X-axis was considered (Fig. 8). In the natural state, the maximum velocity reached $v_{x1} = 20.1$ cm/s, while after engineering preparation, the maximum velocity was v_{x2} = 16.7 cm/s. This indicates that after the engineering preparation, the velocity at the node decreased by Δv_x = 3.4 cm/s, which corresponds to a reduction of 16.91% in percentage terms (Fig. 9).

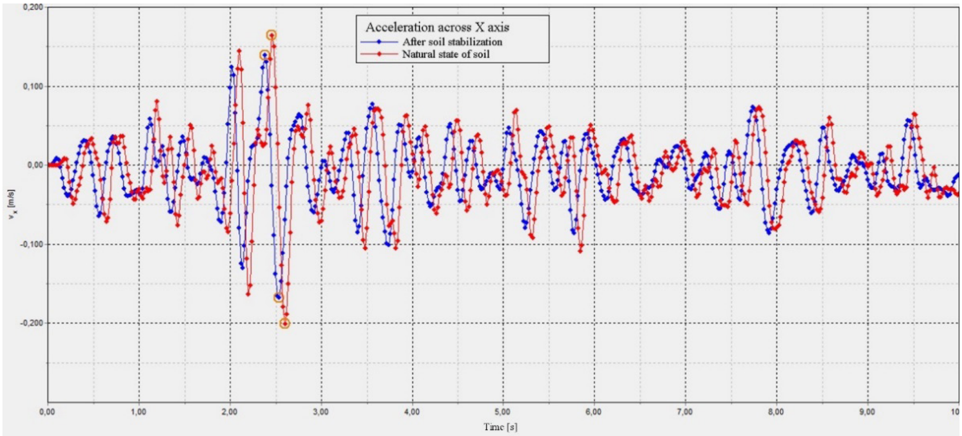
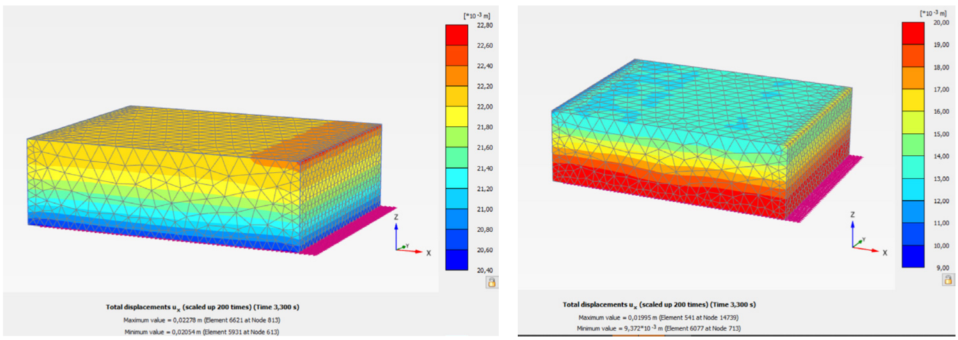


Fig. 9. Velocity characteristics of the 13261st node (x = 50, y = 40, z = 0) at time t = 10 sec along the X axis



(a) (б)

Fig. 10. Displacements in all nodes along the X-axis in the natural state (a) and after soil stabilization (b) at *t* = 3.3 sec

Changes in the maximum displacement values at node 13261 along the X-axis over t = 3.3 seconds were analyzed in the natural state and after engineering preparation (Fig. 10). In the natural state, the maximum displacement was u_{x1} = 3.92 cm, while in the model after soil stabilization, it reached u_{x2} = 3.59 cm. This indicates that displacement at the nodes decreased by Δu_x = 0.33 cm, after engineering preparation, representing a difference of 11.29%. Values of velocity, acceleration, and displacement at the node along the X-axis before and after soil stabilization are provided in Table 2.

Table 2. Displacement, velocity and acceleration along the X-axis before and after soil stabilization

	Before	After	Differ.	Before	After	Differ.	Before	After	Differ.
Value	Acceleration, a_x (cm/s^2)			Velocity, v_x (cm/s)			Displacement, u_x (cm)		
Method of st.	a_{x1}	a_{x2}	Δa_x	v_{x1}	v_{x2}	Δv_x	u_{x1}	u_{x2}	Δu_x
Reinforcement of piles	*376.3*	*220*	*156.3*	*20.1*	*16.7*	*3.4*	*3.92*	*3.59*	*0.33*

Discussion

A comparative assessment was conducted at a single node for two models with coordinates X = 100 m, Y = 80 m, Z = 30 m, selected for the state before and after engineering preparation. This comparison was carried out for two cases, i.e., the results for velocity, acceleration, and displacement of the soil in the natural state and after engineering preparation were compared. For both models, it was determined that the difference in maximum acceleration values at t = 2.6 s along the X-axis at node 7011, with coordinates (X = 50, Y = 40, Z = 0), decreased by Δa_x = 156,3 cm/s^2. Additionally, for both models at t = 2,6 s, the difference in velocity along the X-axis was Δv_x = 3,4 cm/s. For these models, the difference in maximum displacements along this coordinate decreases by Δu_x = 0,33 см, which corresponds to the decrease by 11.29% in percentage.

Conclusion

The article is devoted to investigate the effect of soil stabilization to the change in mechanical response of soil. The site where construction of multi-storey buildings in now taking place is well-known for its subsidence-prone soils. The site was simulated using Plaxis 3D software, and an accelelogram was used to simulate the dynamic effect of such soils. It was found that soil stabilization had a considerable effect on improvement of soil strata and increased it’s seismic resistance.

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