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Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

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Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

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ASSESSMENT OF SOIL LIQUEFACTION HAZARD UNDER STRONG SEISMIC LOADING BASED ON SPT TESTS AND PEAK GROUND ACCELERATION

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Abstract. *Relevance.* Soil liquefaction is one of the most critical geotechnical hazards in seismically active regions. During strong ground shaking, saturated loose granular soils may experience a significant reduction in strength and stiffness, potentially causing ground deformation and damage to foundations and engineering structures. Therefore, reliable identification of liquefaction-prone soil layers is essential for seismic hazard assessment, seismic microzonation, and earthquake-resistant design. *Objective*. This study aims to assess the liquefaction hazard of foundation soils under strong seismic loading by integrating Standard Penetration Test (SPT) data with peak ground acceleration (PGA) parameters and to identify potentially liquefiable soil layers within the investigated geological profiles. *Methods*. Liquefaction potential was evaluated using the factor of safety (FS) approach based on the relationship between the cyclic stress ratio (CSR) induced by earthquake loading and the cyclic resistance ratio (CRR) estimated from corrected SPT blow counts. Field investigations and laboratory analyses were used to characterize the lithological composition and engineering properties of the soils. Groundwater conditions and PGA values representing expected seismic loading were incorporated into the calculations. Soil layers with FS≤1 were classified as potentially susceptible to liquefaction. *Results*. The analysis revealed a clear dependence of liquefaction resistance on soil composition, density, saturation conditions, and seismic loading. Loose, poorly graded, water-saturated granular soils showed the lowest FS values and the highest liquefaction susceptibility. Potentially liquefiable intervals characterized by FS≤1 were identified within the investigated profiles. Their spatial distribution was represented on lithological cross-sections, allowing hazardous layers and their depth intervals to be clearly distinguished. *Conclusions*. The integrated use of corrected SPT parameters and PGA provides a practical framework for evaluating soil liquefaction hazard under strong seismic loading. The proposed approach enables the identification and spatial characterization of liquefaction-prone layers and can support seismic microzonation, foundation design, and engineering measures aimed at reducing liquefaction-related seismic risk.

Keywords: Soil liquefaction, engineering geology, cyclic stress ratio (CSR), peak ground acceleration (PGA), standard penetration test (SPT), factor of safety (FS)

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ҚАТТЫ СЕЙСМИКАЛЫҚ ӘСЕР КЕЗІНДЕ ТОПЫРАҚТЫҢ СҰЙЫҚТАНУ ҚАУПІН SPT СЫНАҚТАРЫ МЕН МАКСИМАЛДЫ ТОПЫРАҚ ҮДЕУІ НЕГІЗІНДЕ БАҒАЛАУ

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Аннотация. *Өзектілігі*. Топырақтың сұйылуы сейсмикалық белсенді аймақтардағы аса маңызды геотехникалық қауіптердің бірі болып табылады. Күшті сейсмикалық тербелістер кезінде суға қаныққан борпылдақ түйіршікті топырақтардың беріктігі мен қаттылығы едәуір төмендеуі мүмкін, бұл жер бетінің деформациясына, іргетастар мен инженерлік құрылыстардың зақымдануына әкелуі ықтимал. Сондықтан сұйылуға бейім топырақ қабаттарын сенімді анықтау сейсмикалық қауіпті бағалау, сейсмикалық микроаудандастыру және сейсмикаға төзімді жобалау үшін маңызды. *Мақсаты*. Зерттеудің мақсаты стандартты пенетрациялық сынақ (SPT) деректері мен топырақ үдеуінің ең жоғары мәні (PGA) параметрлерін кешенді пайдалану арқылы күшті сейсмикалық әсер жағдайында негіз топырақтарының сұйылу қаупін бағалау және зерттелген геологиялық қималардағы сұйылуға бейім топырақ қабаттарын анықтау. *Әдістері*. Топырақтың сұйылу ықтималдығы қауіпсіздік коэффициенті (FS) негізінде бағаланды. Бұл тәсілде жер сілкінісі әсерінен туындайтын циклдік кернеулер қатынасы (CSR) түзетілген SPT соққы саны бойынша анықталған циклдік кедергі қатынасымен (CRR) салыстырылды. Далалық және зертханалық зерттеулер арқылы топырақтардың литологиялық құрамы мен инженерлік қасиеттері анықталды. Есептеулерде жерасты суларының жағдайы және күтілетін сейсмикалық әсерді сипаттайтын PGA мәндері ескерілді. $FS \leq 1$

болған топырақ қабаттары сұйылуға ықтимал қабаттар ретінде жіктелді. *Нәтижелері*. Талдау нәтижелері топырақтың сұйылуға төзімділігі оның құрамы, тығыздығы, суға қаныгу жағдайлары және сейсмикалық әсер деңгейімен тығыз байланысты екенін көрсетті. Борпылдақ, нашар сұрыпталған және суға қаныққан түйіршікті топырақтарда FS мәндері ең төмен болып, олардың сұйылуға бейімділігі жоғары екені анықталды. Зерттелген қималарда FS≤1 мәнімен сипатталатын сұйылуға ықтимал аралықтар анықталды. Олардың кеңістіктік таралуы литологиялық қималарда көрсетіліп, қауіпті қабаттар мен олардың орналасу тереңдігін нақты ажыратуға мүмкіндік берді. *Қорытынды*. Түзетілген SPT параметрлері мен PGA мәндерін кешенді пайдалану күшті сейсмикалық әсер кезінде топырақтың сұйылу қаупін бағалаудың практикалық тәсілі болып табылады. Ұсынылған әдіс сұйылуға бейім қабаттарды анықтауға және олардың кеңістіктік таралуын сипаттауға мүмкіндік береді, сондай-ақ сейсмикалық микроаудандастыру, іргетастарды жобалау және сұйылумен байланысты сейсмикалық қауіпті төмендетуге бағытталған инженерлік шараларды негіздеу үшін қолданылуы мүмкін.

Түйін сөздер: топырақтың сұйықтануы; инженерлік геология; циклдық кернеу қатынасы (CSR); максималды топырақ үдеуі (PGA); стандартты өткізу сынағы (SPT); қауіпсіздік коэффициенті (FS)

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ОЦЕНКА РИСКА РАЗЖИЖЕНИЯ ГРУНТОВ ПОД ВОЗДЕЙСТВИЕМ СИЛЬНЫХ СЕЙСМИЧЕСКИХ НАГРУЗОК НА ОСНОВЕ ДАННЫХ SPT И МАКСИМАЛЬНОГО УСКОРЕНИЯ ГРУНТА

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Аннотация. *Актуальность.* Разжижение грунтов является одной из наиболее значимых геотехнических опасностей в сейсмически активных районах. При сильных сейсмических колебаниях водонасыщенные рыхлые дисперсные грунты могут существенно терять прочность и жёсткость, что способно приводить к деформациям грунтового основания, повреждению фундаментов и разрушению инженерных сооружений. Поэтому достоверное выявление грунтовых слоёв, склонных к разжижению, имеет важное значение для оценки сейсмической опасности, сейсмического микрорайонирования и сейсмостойкого проектирования. *Цель.* Оценить опасность разжижения грунтов основания при сильных сейсмических воздействиях на основе комплексного использования данных стандартного пенетрационного испытания (SPT) и значений пикового ускорения грунта (PGA), а также выявить потенциально разжижаемые слои в исследуемых геологических разрезах. *Методы.* Потенциал разжижения оценивался с использованием коэффициента безопасности (FS), определяемого как отношение циклического сопротивления грунта (CRR) к отношению циклических напряжений (CSR), возникающих при сейсмическом воздействии. Значение CRR рассчитывалось на основе скорректированного числа ударов SPT. Полевые и лабораторные исследования проводились для определения литологического состава и инженерно-геологических свойств грунтов. При расчётах учитывались условия залегания подземных вод и значения PGA, характеризующие ожидаемый уровень сейсмического воздействия. Слои грунта со значением FS $\leq$ 1 классифицировались как потенциально подверженные разжижению. *Результаты.* Анализ показал чёткую зависимость сопротивляемости грунтов разжижению от их состава, плотности, степени водонасыщения и уровня сейсмического воздействия. Рыхлые, плохо отсортированные и водонасыщенные дисперсные грунты характеризовались наиболее низкими значениями FS и повышенной склонностью к разжижению. В исследованных разрезах выявлены потенциально разжижаемые интервалы со значением FS $\leq$ 1. Их пространственное распределение представлено на литологических разрезах, что позволило наглядно определить опасные слои и глубины их залегания. *Выводы.* Комплексное использование скорректированных параметров SPT и значений PGA представляет собой практический подход к оценке опасности разжижения грунтов при сильных сейсмических воздействиях. Предлагаемый подход позволяет выявлять и пространственно характеризовать слои, склонные к разжижению, и может применяться при сейсмическом микрорайонировании, проектировании фундаментов и разработке инженерных мероприятий, направленных на снижение сейсмического риска, обусловленного разжижением грунтов.

Ключевые слова: разжижение грунтов, инженерная геология, циклическое отношение напряжений (CSR), максимальное ускорение грунта (PGA), стандартное пенетрационное испытание SPT, коэффициент запаса устойчивости (FS)

Introduction. At present, particular attention is being paid in our country to the construction of high-quality and safe buildings and structures. Especially in regions characterized by high seismic activity, the issue of earthquake-resistant construction is of critical importance not only for ensuring public safety but also for preventing potential economic and social losses (Ismailov et al., 2025-a). Ensuring the seismic stability of buildings and structures requires a comprehensive consideration of regional seismic hazard factors as well as the engineering-geological characteristics of foundation soils (Ismailov et al., 2025-b: Andrus et al., 2000).

Historical sources and modern observations indicate that the damage caused by strong earthquakes manifests not only in engineering structures but also in various forms of deformation of the ground surface (Avazov et al., 2026). Among these adverse processes, one of the most hazardous is soil liquefaction induced by seismic loading. Soil liquefaction primarily occurs in water-saturated, fine-grained sandy layers and is characterized by a sharp reduction in effective stress and a loss of soil strength properties. As a result, the stability of building and structure foundations is placed under serious threat (Moss et al., 2006).

In regions experiencing rapid urbanization and high levels of seismic hazard, the assessment of soil liquefaction potential is of particular scientific and practical significance. Therefore, evaluating the response of foundation soils to seismic loading in specific areas, as well as conducting a detailed analysis of their physical-mechanical and hydrogeological properties, constitutes a pressing scientific task (Ishihara, 1993; Cetin et al., 2004).

The main objective of this study is to assess the susceptibility of foundation soils to liquefaction under strong seismic loading for a residential building planned for construction in the city of Termez. To achieve this objective, the following key tasks were defined: investigation of the engineering-geological and hydrogeological conditions of the study area; determination of the lithological composition and physical-mechanical properties of the soils; evaluation of the seismic resistance of soils based on the results of in situ Standard Penetration Tests (SPT); and identification of liquefaction hazard under strong earthquake conditions.

The methodological framework of the study is based on the soil liquefaction assessment approach proposed by Seed and Idriss (Seed et al., 1971). In this method, liquefaction potential is determined based on the ratio between the cyclic stress ratio (CSR) and the cyclic resistance ratio (CRR) representing the soil's resistance to external loading (Boulanger et al., 2014). In addition, a magnitude scaling factor (MSF) accounting for earthquake magnitude was applied, allowing empirical adjustment of the assessment results for different seismic conditions. The results of in situ SPT tests were adopted as the primary source of input data for the calculations.

The conducted investigations revealed that water-saturated sandy layers exhibit a high susceptibility to liquefaction under strong seismic loading. This condition may lead to hazardous engineering-geological consequences, such as foundation settlement, differential deformations, and a reduction in the structural stability of buildings and structures. The results of the study scientifically substantiate the necessity of considering seismic hazard factors in the justification of construction projects within the territory of Termez city and are of significant scientific and practical importance for improving seismic microzonation efforts.

Materials and research methods. The susceptibility of soils to liquefaction under seismic loading is based on an integrated analysis of regional engineering-geological conditions, hydrogeological factors, and seismological parameters (Youd et al., 2001). The study utilized engineering-geological materials for the area, including previously conducted field observations, drilling works, Standard Penetration Test (SPT) results, and laboratory test data. Below, the engineering-geological conditions of the area, the structure of the geological cross-section, and the properties of soil layers are described in detail.

Engineering-Geological Conditions. The engineering-geological conditions of the study area were investigated based on data from exploratory boreholes. The boreholes were drilled to a depth of 50 m to determine the lithological composition of soils, their physical-mechanical properties, and the groundwater table. According to the obtained data, the geological profile of the site exhibits a complex layered structure. The upper part of the cross-section comprises a fill layer extending from 0 to 1.3 m depth. This layer contains construction and domestic waste, characterized by disturbed structure and heterogeneous density. Between 1 and 4 m depth, light brown loess and loam soils occur. These layers exhibit stiff-plastic strength and are located above the groundwater table. At depths of 3-7.5 m, loess, loam, and fine-grained sands alternate with some silt layers. As these layers are situated within the saturated zone, they are partially moist and exhibit variability in their physical-mechanical properties. Between 7.3 and 50 m depth, sand soils of various grain sizes (fine to medium) are present. The sands are grayish-brown, water-saturated, and have medium density. Thin silt layers occur in some intervals within the sand strata.

In water-saturated sandy soils, seismic shaking induces cyclic loading that leads to a sharp increase in pore water pressure. This phenomenon reduces the effective stress of the soil skeleton and significantly decreases shear resistance and strength parameters. As a result, soil layer stability is compromised, increasing the likelihood of engineering-geological hazards such as foundation settlement, differential deformations, tilting, or leaning of structures (Marcuson, 1978).

Hydrogeological Conditions. Groundwater in the study area is located in Quaternary deposits and is widespread across the region. Aquifers consist primarily of fine- to medium-grained light gray sands, containing gravel and compacted silts. Seasonal fluctuations of the groundwater table are observed. During summer and autumn, the water level rises, while the minimum level is typically recorded in February (sometimes in December or March), and the maximum rise occurs between July and September. The long-term average amplitude of water table fluctuations is 1.0-1.5 m. During field observations conducted in March 2025, the groundwater table was found at a depth of 4-4.8 m. During the period of maximum rise, the water table is expected to increase by 1.5 m, reaching 2.5-3.3 m below the surface.

Seismic Conditions and Design Seismic Parameters. The seismicity of the area is closely associated with tectonically active zones in southern Uzbekistan and neighboring Afghanistan. In this study, the seismic activity and potential hazard of the major seismogenic zones near the construction site were analyzed. The Gissaro-Kokshal seismogenic zone in the northern part of the region exhibits high seismicity, with historical Karategin earthquakes (1907, M=7.3-7.4) producing ground shaking of up to 7 points on the MSK-64 scale in the project area. For the Baysun-Kuhitang and Surkhontog-Sherobod-Kelif seismically active zones in the northwest direction, a maximum magnitude of M_{max}=6.5 is estimated, generating seismic effects of up to 5 points in the project area. For the Bobotog-Kuhitang seismogenic zone in the eastern part of the site, M_{max} values of 6.0-6.5 were determined. On November 3, 2025, an earthquake of M_{max}=6.9 occurred approximately 90 km southwest of Termez city, in Afghanistan. This seismic event significantly affected local settlements, including residential buildings and ordinary structures, with observed shaking. The earthquake-induced ground motion was assessed at 6 points on the MSK-64 scale, indicating a potential hazard level for foundations and low-rise residential buildings. These data serve as a basis for assessing the seismic hazard of the project area and for defining earthquake-resistant construction measures (Yodgorov et al., 2025).

According to the MSK-64 scale, the Termez city area belongs to a seismic zone with I = 7 points and corresponds to Category II soil conditions. Based on these seismic conditions, the maximum peak ground acceleration (PGA) for the study area was adopted in the range of 0.20-0.25g (Chen et al., 2009). These PGA values were used as the main seismic parameter for assessing the susceptibility of soils to liquefaction under seismic loading. In particular, the seismic stability of soils was evaluated in conjunction with Standard Penetration Test (SPT) data, and the factor of safety (FS) was determined. Corresponding to the adopted PGA values, synthetic accelerograms representing the temporal variation of seismic effects are presented below (Kayen et al., 2013; Khayriddinov et al., 2026) (Figures 1 and 2).

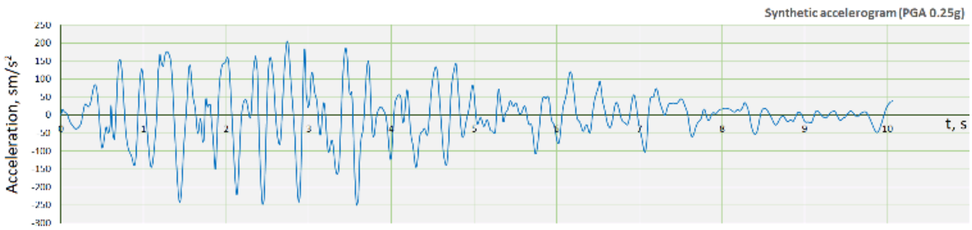

Figure 1. Synthetic accelerogram (PGA=0.20g).

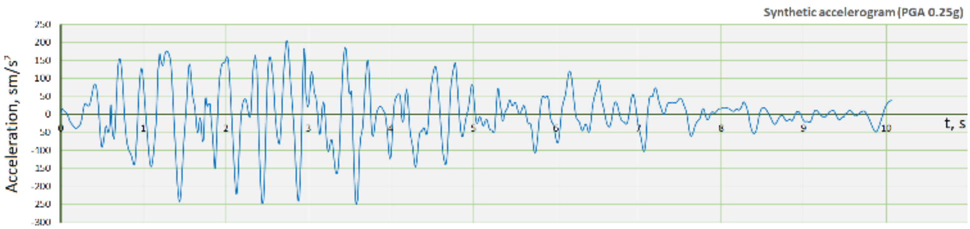

Figure 2. Synthetic accelerogram (PGA=0.25g).

At the same time, synthetic accelerograms play a crucial role in evaluating the response of building structures to seismic loading, performing dynamic calculations, and ensuring the seismic stability of constructions. They allow the expected seismic loads on the designed buildings and structures to be approximated as closely as possible to real conditions. In the design of residential and socially significant facilities planned in Termez city, the use of seismic hazard parameters based on synthetic accelerograms is of considerable scientific and practical importance, enabling the justification of effective seismic safety measures.

Standard Penetration Test (SPT). Based on the results of engineering-geological investigations, the boundaries, lithological composition, and physical-mechanical properties of potentially liquefiable soil layers were evaluated. In this assessment, in situ Standard Penetration Test (SPT) results served as the primary data source (Figure 3). These test results provide essential information for determining the density, strength, and stability of soils under seismic shaking.

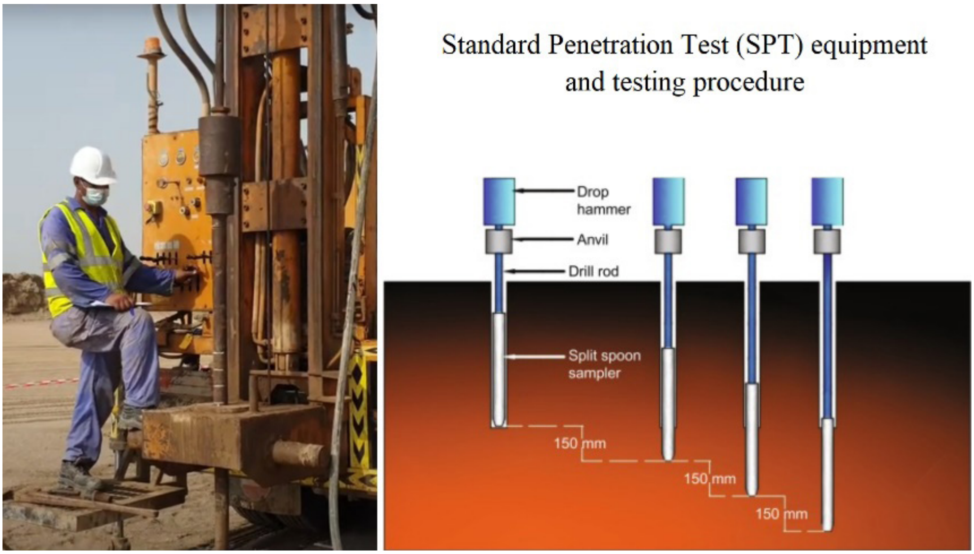

Figure 3. Standard penetration test (SPT) field investigations.

The results of in situ Standard Penetration Tests (SPT) conducted in exploratory boreholes serve as the primary parameter for assessing the stiffness of soil layers and their resistance to cyclic loading within the study area (Table 1).

Table 1. Table of In Situ Standard Penetration Test (SPT) Results from Exploratory Boreholes.

№	Penetration interval, m	SPT-test (S_1, T_1, T_2)			Number of blows	Conditional dynamic resistance, P_d	Vertical stress	
		S_1	T_1	T_2				
		150 mm					σ_v, kPa	$\sigma_{v(eff)}$, kPa
1	1.5-1.95	3	4	5	9	0.9	29	29
2	3.0-3.45	4	6	8	14	1.4	57	45
3	4.5-4.95	2	3	4	7	0.7	85	59
4	6.0-6.45	4	5	6	11	1.1	114	73
5	7.5-7.95	6	7	9	16	1.6	143	87
6	9.0-9.45	5	4	6	10	1.0	171	100
7	10.5-10.95	4	5	7	12	1.2	200	114
8	12.0-12.45	7	8	9	17	1.7	228	128
9	13.5-13.95	10	11	13	24	2.4	256	142
10	15.0-15.45	12	13	14	27	2.7	285	156
11	16.5-16.95	13	15	17	32	3.2	313	169
12	18.0-18.45	15	17	19	36	3.6	342	183
13	19.5-19.95	11	13	16	29	2.9	370	197
14	21.0-21.45	14	15	18	32	3.2	399	211
15	22.5-22.95	13	16	19	35	3.5	428	224
16	24.0-24.45	16	18	20	38	3.8	456	238
17	25.5-25.95	19	20	22	42	4.2	485	252
18	27.0-27.45	20	21	24	44	4.4	513	266
19	28.5-28.95	17	19	21	40	4.0	542	280
20	30.0-30.45	21	22	24	46	4.6	570	293
21	31.5-31.95	23	24	26	50	5.0	599	307
22	33.0-33.45	21	22	23	45	4.5	627	321
23	34.5-34.95	22	24	25	49	4.9	656	335
24	36.0-36.45	24	26	28	54	5.4	684	349
25	37.5-37.95	21	23	25	48	4.8	713	362
26	39.0-39.45	22	24	27	51	5.1	741	376
27	40.5-40.95	25	27	29	56	5.6	770	390
28	42.0-42.45	26	28	30	58	5.8	798	404
29	43.5-43.95	25	29	31	60	6.0	827	417
30	45.0-45.45	27	31	32	63	6.3	855	431
31	46.5-46.95	29	33	34	67	6.7	884	445
32	48.0-48.45	28	30	32	62	6.2	912	459
33	49.5-49.95	31	33	35	68	6.8	941	473

For each sounding interval (depth range, m), the penetrator is driven to a depth of 150 mm, and the number of blows in three series is recorded (S_1 - result of the first series of blows; T_1, T_2 - results of the subsequent two series). Based on the number of blows, the conditional dynamic resistance of the layers (P_d) is determined, which represents the soil's resistance to cyclic loading and seismic effects. The Pd value serves as a primary parameter for evaluating the stiffness and stability of soil layers, as well as for calculating the factor of safety (FS) under seismic loading.

Liquefaction Analysis Methodology

The liquefaction analysis was performed using the approach proposed by Seed and Idriss (Seed et al., 1971). The methodology included the following steps:

* Determination of the maximum shear stress (τ_{max}) and the stress reduction coefficient (r_d).

$$\tau_{\max} = \sigma_v \cdot \frac{a_{\max}}{g}; \qquad r_d = \frac{(\tau_{\max})_d}{(\tau_{\max})_r}$$

* Calculation of the cyclic stress ratio (CSR).

$$CSR = 0.65 \cdot \frac{\sigma_v}{\sigma_v^{'}} \cdot \frac{a_{\max}}{g} \cdot r_d$$

* Application of the magnitude scaling factor (MSF) to adjust the soil's cyclic resistance (CRR) to the conditions of the study area.

$$CRR_M = CRR_{M=7.5} \cdot MSF$$

* Calculation of the factor of safety against liquefaction (FS_{liq}) and assessment of the liquefaction hazard based on the results.

$$FS_{liq} = \frac{CRR}{CSR}$$

FS_{liq} is an engineering parameter that directly reflects the liquefaction hazard. It is determined based on the cyclic resistance ratio (CRR) obtained from SPT tests and the cyclic stress ratio (CSR) calculated from seismic loading. In the assessment of liquefaction potential, in situ SPT data serve as the primary source of information. The number of blows recorded during the SPT ($N=T_1+T_2$ values) provides information on soil density and strength, and allows determination of whether liquefaction is likely to occur under seismic loading (Robertson et al., 1998).

From a practical perspective, an $FS_{liq} \geq 1$ indicates relative stability of the soil; however, for engineering safety, values of 1.2-1.5 or higher are typically required. Considering the historical earthquake data, the moderate seismic regime, and the flat terrain of the Termez city area, the liquefaction hazard in the study site was assessed based on soil layers with $FS_{liq} \leq 1$ under seismic loading.

Results and analysis. The liquefaction hazard of soils at the study site under seismic loading was assessed based on the results of field and laboratory investigations, as well as regional seismic parameters. Standard Penetration Test (SPT) results obtained from exploratory boreholes were systematically compiled, and key parameters including the number of blows (N), conditional cyclic resistance (P_d), vertical stresses (σ_v, $\sigma_{v(eff)}$), normalized SPT values (N_{60cs}), cyclic resistance ratio (CRR), stress reduction coefficient (r_d), and cyclic stress ratio (CSR) were calculated for peak ground accelerations of 0.20g and 0.25g. Based on these parameters, the factor of safety against liquefaction was determined for each soil layer under seismic loading, allowing the stability of the soils to be evaluated (Table 2).

Table 2. SPT-based parameters calculated for liquefaction potential analysis under seismic loading (PGA=0.20g and 0.25g).

№	Penetration interval, m	N	P_d	σ_v, kPa	$\sigma_{v(eff)}$, kPa	C_N	N_{60cs}	CRR_M	r_d	CSR 0.20g	FS 0.20g	CSR 0.25g	FS 0.25g
1	1.5-1.95	9	0.9	29.325	29.325	1.700	15.300	0.163	0.987	0.128	1.271	0.160	1.017
2	3.0-3.45	14	1.4	57.275	45.258	1.486	20.810	0.226	0.975	0.160	1.407	0.201	1.126
3	4.5-4.95	7	0.7	85.775	59.043	1.301	9.110	0.105	0.964	0.182	0.579	0.228	0.463
4	6.0-6.45	11	1.1	114.275	72.828	1.172	12.890	0.140	0.952	0.194	0.718	0.243	0.574
5	7.5-7.95	16	1.6	142.775	86.613	1.075	17.192	0.183	0.941	0.202	0.907	0.252	0.726
6	9.0-9.45	10	1.0	171.275	100.398	0.998	9.980	0.113	0.928	0.206	0.549	0.257	0.439
7	10.5-10.95	12	1.2	199.775	114.183	0.936	11.230	0.124	0.888	0.202	0.615	0.252	0.492
8	12.0-12.45	17	1.7	228.275	127.968	0.884	15.028	0.160	0.848	0.197	0.816	0.246	0.653
9	13.5-13.95	24	2.4	256.775	141.753	0.840	20.158	0.217	0.808	0.190	1.143	0.238	0.915
10	15.0-15.45	27	2.7	285.275	155.538	0.802	21.649	0.237	0.767	0.183	1.295	0.229	1.036
11	16.5-16.95	32	3.2	313.775	169.323	0.768	24.592	0.284	0.727	0.175	1.621	0.219	1.297
12	18.0-18.45	36	3.6	342.275	183.108	0.739	26.604	0.328	0.687	0.167	1.962	0.209	1.570
13	19.5-19.95	29	2.9	370.775	196.893	0.713	20.667	0.224	0.647	0.158	1.413	0.198	1.130
14	21.0-21.45	33	3.2	399.275	210.678	0.689	22.736	0.253	0.607	0.150	1.690	0.187	1.352

15	22.5-22.95	35	3.5	427.775	224.463	0.667	23.361	0.263	0.567	0.141	1.869	0.176	1.495
16	24.0-24.45	38	3.8	456.275	238.248	0.648	24.619	0.285	0.200	0.050	5.715	0.062	4.572
17	25.5-25.95	42	4.2	484.775	252.033	0.630	26.456	0.324	0.200	0.050	6.480	0.063	5.184
18	27.0-27.45	45	4.4	513.275	265.818	0.613	27.601	0.356	0.200	0.050	7.095	0.063	5.676
19	28.5-28.95	40	4.0	541.775	279.603	0.598	23.922	0.272	0.200	0.050	5.400	0.063	4.320
20	30.0-30.45	46	4.6	570.275	293.388	0.584	26.856	0.334	0.200	0.051	6.617	0.063	5.294
21	31.5-31.95	50	5.0	598.775	307.173	0.571	28.528	0.390	0.200	0.051	7.686	0.063	6.149
22	33.0-33.45	45	4.5	627.275	320.958	0.558	25.118	0.294	0.200	0.051	5.790	0.064	4.632
23	34.5-34.95	49	4.9	655.775	334.743	0.547	26.782	0.332	0.200	0.051	6.527	0.064	5.221
24	36.0-36.45	54	5.4	684.275	348.528	0.536	28.925	0.407	0.200	0.051	7.968	0.064	6.375
25	37.5-37.95	48	4.8	712.775	362.313	0.525	25.217	0.296	0.200	0.051	5.791	0.064	4.633
26	39.0-39.45	51	5.1	741.275	376.098	0.516	26.298	0.320	0.200	0.051	6.248	0.064	4.998
27	40.5-40.95	56	5.6	769.775	389.883	0.506	28.361	0.383	0.200	0.051	7.459	0.064	5.967
28	42.0-42.45	58	5.8	798.275	403.668	0.498	28.868	0.404	0.200	0.051	7.860	0.064	6.288
29	43.5-43.95	60	6.0	826.775	417.453	0.489	29.366	0.429	0.200	0.051	8.327	0.064	6.661
30	45.0-45.45	63	6.3	855.275	431.238	0.482	30.338	0.800	0.200	0.052	15.514	0.064	12.411
31	46.5-46.95	67	6.7	883.775	445.023	0.474	31.760	0.800	0.200	0.052	15.494	0.065	12.395
32	48.0-48.45	62	6.2	912.275	458.808	0.467	28.945	0.408	0.200	0.052	7.886	0.065	6.309
33	49.5-49.95	68	6.8	940.775	472.593	0.460	31.280	0.800	0.200	0.052	15.457	0.065	12.365

The obtained FS values were compared under peak ground accelerations (PGA) of 0.20g and 0.25g. This comparison is of critical importance for defining precautionary measures for surface layers, designing structures based on dynamic calculations, and ensuring seismic stability.

In the next step, the FS (factor of safety) values determined from the calculations were schematically illustrated in relation to the soil's lithological profile. This diagram clearly shows the lithological composition of each layer, the groundwater table, and its seasonal fluctuation levels. Additionally, intervals where FS≤1 were specifically highlighted, indicating soil layers that are susceptible to liquefaction (Figure 4).

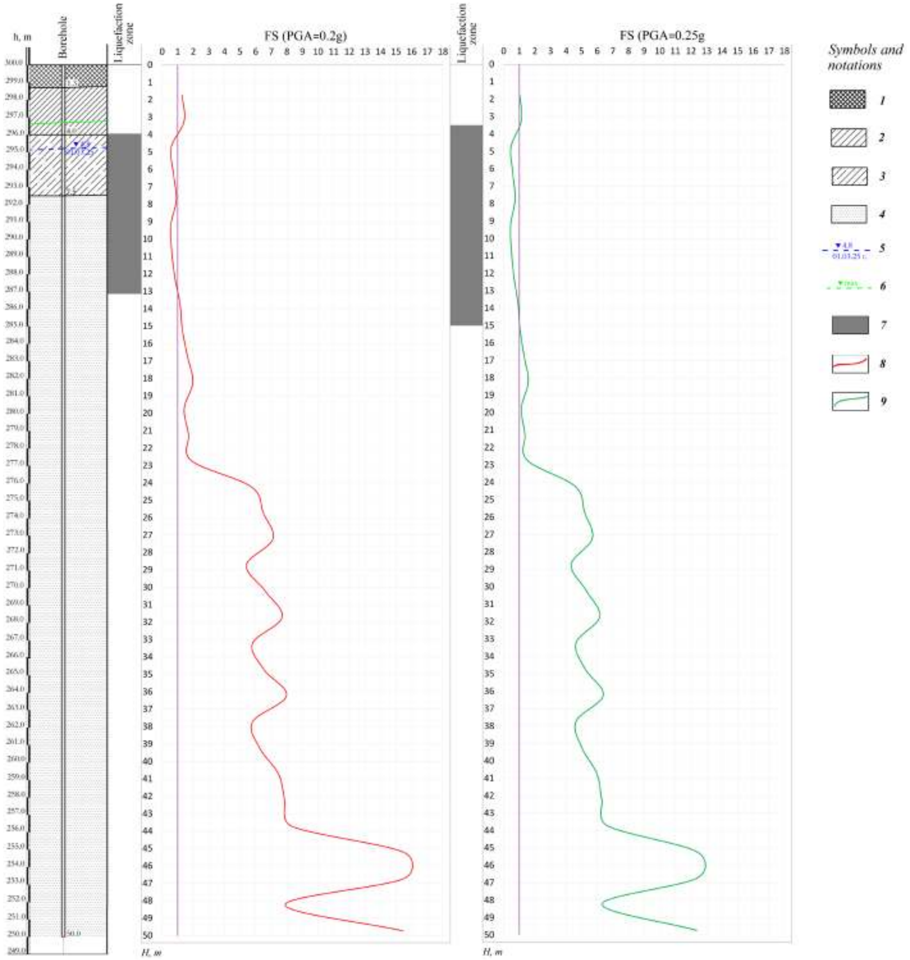

Figure 4. Liquefaction zones of soils and variation of safety factor (FS) along the lithological profile (PGA 0.20g and 0.25g).
Scale: Horizontal - 1:500, Vertical - 1:100.

Legend: 1) Fill soil - loam with disturbed structure containing construction and domestic debris; 2) Loess-like loam, light brown in color, with consistency ranging from hard to stiff-plastic, collapsible, occurring above the groundwater table (GWT); 3) Loess-like loam with interlayers of sandy loam, light brown in color, with consistency from semi-hard to soft-plastic, non-collapsible, occurring below the GWT and within the capillary rise zone; 4) Heterogeneous sand, from fine to medium-grained, grayish-brown in color, water-saturated, of medium density, with thin interlayers of loam; 5) Groundwater level as of March 2025; 6) Groundwater level at the calculated maximum; 7) Soil liquefaction zone; 8) Safety factor (FS) at PGA 0.20g; 9) Safety factor (FS) at PGA 0.25g

This approach allows for a visual analysis of the stability of soil layers under seismic loading. As a result, fine- to medium-grained saturated sand layers were identified as the primary hazard source, being the most sensitive zones to liquefaction under cyclic seismic loading. In contrast, compacted loess and silty layers, as well as deeper dense sand layers, constitute relatively stable zones.

The combined analysis of the lithological-structural profile and FS values is of significant practical importance for seismic hazard assessment, providing a basis for identifying precise depth ranges of liquefaction-prone soils and guiding the design of foundation structures.

Based on the engineering-geological data and calculated FS values, the susceptibility of soils to liquefaction was divided into the following depth zones:

0-1.5 m and 1.5-3.5 m depth - stable zone: FS(0.20g) = 1.27-1.40, FS(0.25g) = 1.02-1.12. These layers consist of dense loess and stiff-plastic silty soils, showing no significant liquefaction risk under seismic loading.

4.5-6.5 m depth - highly hazardous zone: FS(0.20g) = 0.57-0.72, FS(0.25g) = 0.46-0.57. This zone primarily comprises fine sand and partially saturated silty soils, with a sharp decrease in resistance to seismic shaking.

7.5-12.0 m depth - moderately hazardous zone: FS(0.20g) = 0.61-0.91, FS(0.25g) = 0.49-0.72. Sand layers are saturated, and some intervals may exhibit reduced resistance.

Below 13.5 m depth - conditionally stable zone: FS(0.20g) ≈ 1.14, FS(0.25g) ≈ 0.91. Due to compaction, sand layers in this zone show minimal liquefaction potential.

Seasonal fluctuations of the groundwater table may reduce FS values in the upper layers. The most hazardous interval was identified at 4.5-6.5 m depth, considered the primary zone negatively affecting foundation stability.

Conclusions. In this study, the susceptibility of foundation soils of a residential building in Termez city to liquefaction under seismic loading was comprehensively assessed. The results indicated that the stability of soil layers under seismic influence is not uniform with depth and is strongly dependent on engineering-geological conditions. In particular, fine- to medium-grained saturated sand layers exhibited the most unfavorable engineering-geological conditions under seismic shaking and were identified as the zones most sensitive to liquefaction. In contrast, high-density loess and silty layers, as well as deeper dense sand layers, demonstrated relatively stable behavior under seismic loading. Alongside the lithological composition of the soils, seasonal fluctuations of the groundwater table were found to significantly affect seismic stability, with rising groundwater levels potentially increasing the risk of liquefaction in certain layers. The findings highlight the importance of integrating engineering-geological data with seismic calculations for reliable assessment of foundation soil stability. The study conclusions provide a scientific basis for selecting engineering measures aimed at soil improvement, reducing seismic risk, and accounting for seasonal variations in groundwater during foundation design. Furthermore, the results can serve as a scientific and practical foundation for developing seismic safety measures for residential and infrastructure facilities in Termez city and surrounding areas, as well as contribute to the advancement of regional studies on soil liquefaction susceptibility.

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