NAMANGAN SHAHRI ISLOM KARIMOV KO'CHASIDA JOYLASHGAN ELASTIK-PLASTIK GRUNTLARDA TO'LQIN TARQALISHI.

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Annotatsiya: Ushbu maqolada Namangan shahri Islom Karimov ko‘chasida joylashgan grunt qatlamlarining elastik-plastik xususiyatlari va seysmik to‘lqinlarning u orqali tarqalish mexanizmlari 3D raqamli modellashtirish yordamida o‘rganildi. Tadqiqot “Namangan Premium Investments” obyekti uchun O‘ZGASHKLITI tomonidan 2019-yilda tayyorlangan geotexnik ma’lumotlar asosida olib borildi. Grunt qatlamlari 15 metr chuqurlikkacha bo‘lib, ular topraq (E=5 MPa), loess (E=25 MPa), qum-shag‘al (E=80 MPa) va zich shag‘al (E=150 MPa) qatlamlaridan tashkil topgan. PLAXIS 3D dasturi yordamida elastik-plastik modellashtirish amalga oshirilib, to‘lqin tarqalishi, deformatsiya, tezlik va tezlanish tahlil qilindi. Natijalarga ko‘ra, maksimal deformatsiya qiymati 7.29 mm ni tashkil etdi, bu sirtga yaqin qatlamlarda (0–1.6 m) kuzatildi. 5 m chuqurlikdagi tezlik qiymati 17.4×10^{-3} m/s bo‘lsa, 20 m chuqurlikda bu qiymat 0.036×10^{-3} m/s gacha kamaydi. Shuningdek, tezlanish 5 m da 0.35 m/s², 20 m da esa 0.12 m/s² ga teng bo‘lib, grunt chuqurligi ortgani sari energiya so‘nishining eksponent tarzda kamayishini ko‘rsatdi. Model natijalari sirt qatlamlarining yuqori plastiklik indeksi (PI=12–18%) va past elastiklik moduli (E=5–25 MPa) tufayli to‘lqin energiyasi kuchli yutilishini, pastki zich qatlamlar esa reflektiv xususiyatga ega ekanligini tasdiqlaydi. Ushbu tadqiqot seysmik xavfni baholash, poydevor loyihalarini optimallashtirish hamda gruntlarning dinamik barqarorligini oshirish uchun muhim ilmiy asos yaratadi.

Kalit so‘zlar*:* Elastik-plastik grunt, 3D modellashtirish, PLAXIS 3D, seysmik to‘lqin, deformatsiya, tezlik, tezlanish, energiya so‘nishi, Rayleigh to‘lqini, Mohr–Coulomb modeli, Namangan, seysmik barqarorlik.

Аннотация:В данной статье исследуются упругопластические свойства грунтовых слоёв и механизмы распространения сейсмических волн в условиях города Наманган (ул. Ислама Каримова) с использованием 3D численного моделирования. Исследование выполнено на основе геотехнических данных, подготовленных О’ЗГАШКЛИТИ в 2019 году для объекта «Namangan Premium Investments». Грунтовый разрез до глубины 15 м представлен слоями: растительный слой (E=5 МПа), лёсс (E=25 МПа), песчано-гравийный слой (E=80 МПа) и плотный гравий (E=150 МПа). С помощью программы **PLAXIS 3D** было проведено упругопластическое моделирование, в результате которого проанализированы деформации, скорости и ускорения колебаний. Максимальная деформация составила **7.29**

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мм в приповерхностных слоях (0–1.6 м). Скорость волны на глубине 5 м составила **17.4×10^{-3} м/с**, а на глубине 20 м снизилась до **0.036×10^{-3} м/с**. Ускорение изменялось от **0.35 м/с²** (5 м) до **0.12 м/с²** (20 м), что указывает на экспоненциальное затухание энергии с увеличением глубины. Результаты моделирования показали, что верхние слои с высоким индексом пластичности (PI=12–18%) и низким модулем упругости (E=5–25 МПа) обладают значительным демпфированием волновой энергии, тогда как нижние плотные слои проявляют отражательные свойства. Исследование имеет важное значение для оценки сейсмического риска, оптимизации проектирования фундаментов и повышения динамической устойчивости грунтов.

Ключевые слова: упругопластический грунт, 3D моделирование, PLAXIS 3D, сейсмическая волна, деформация, скорость, ускорение, затухание энергии, волна Рэлея, модель Мора–Кулона, Наманган, сейсмостойкость.

Abstract: This paper investigates the elasto-plastic properties of soil layers and the propagation mechanisms of seismic waves in Namangan City (Islom Karimov Street) using 3D numerical modeling. The study is based on geotechnical data prepared by O‘ZGASHKLITI (2019) for the “Namangan Premium Investments” project. The 15-meter soil profile consists of **topsoil (E=5 MPa)**, **loess (E=25 MPa)**, **sandy-gravel layer (E=80 MPa)**, and **dense gravel (E=150 MPa)**. Using the **PLAXIS 3D** software, elasto-plastic modeling was carried out to analyze the deformation, velocity, and acceleration fields. The maximum deformation was **7.29 mm** and occurred in the near-surface layers (0–1.6 m). Wave velocity decreased from **17.4×10^{-3} m/s** at a depth of 5 m to **0.036×10^{-3} m/s** at 20 m. Acceleration decreased from **0.35 m/s²** to **0.12 m/s²**, indicating exponential energy attenuation with depth. The results show that upper layers with higher plasticity index (PI=12–18%) and lower elasticity modulus (E=5–25 MPa) strongly absorb wave energy, while the lower dense layers exhibit reflective behavior. The study provides valuable insights for **seismic risk assessment**, **foundation design optimization**, and **enhancing the dynamic stability of soils**.

Keywords: elasto-plastic soil, 3D modeling, PLAXIS 3D, seismic wave, deformation, velocity, acceleration, energy attenuation, Rayleigh wave, Mohr–Coulomb model, Namangan, seismic stability.

Kirish

Tadqiqot usullari va materiallar: Tadqiqot uchun BH-6, BH-8 va BH-9 burg'ilash nuqtalarida olingan namunalar asosida quyidagi usullar qo'llanildi:

- Gruntning fizik-mexanik xususiyatlarini aniqlash
- Granulometrik tarkibni o'rganish
- Elastiklik moduli (E) va plastiklik indeksi (PI) ni aniqlash

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- Suv darajasini kuzatish

Grunt qatlamlarining elastik-plastik xususiyatlari tahlili: BH-6 burg'ilash nuqtasi bo'yicha tahlil

0.00-0.40 m: Yer usti qatlami / organik unumdor grunt
- Elastiklik moduli: 5 MPa (juda past)
- Plastiklik indeksi: 12% (plastik)
- Xulosa: Yuqori plastiklik, past elastiklik - to'lqin tarqalishida sezilarli yutilish

0.40-1.60 m: Qumli unumdor grunt
- Elastiklik moduli: 25 MPa (past)
- Plastiklik indeksi: 18% (yuqori plastik)
- Xulosa: Namlik o'zgarganda kuchli deformatsiya - to'lqin tezligi sekin

1.60-6.00 m: Qum / shagalli qum
- Elastiklik moduli: 80 MPa (o'rta)
- Plastiklik indeksi: 3% (plastik emas)
- Xulosa: Yaxshi elastik xususiyatlar - to'lqin tezligi yuqori

6.00-15.00 m: Zich shagal / siqilgan cho'kindi jinslar
- Elastiklik moduli: 150 MPa (yuqori)
- Plastiklik indeksi: 0% (plastik emas)
- Xulosa: Yuqori elastiklik - to'lqin eng tez tarqaladigan qatlam

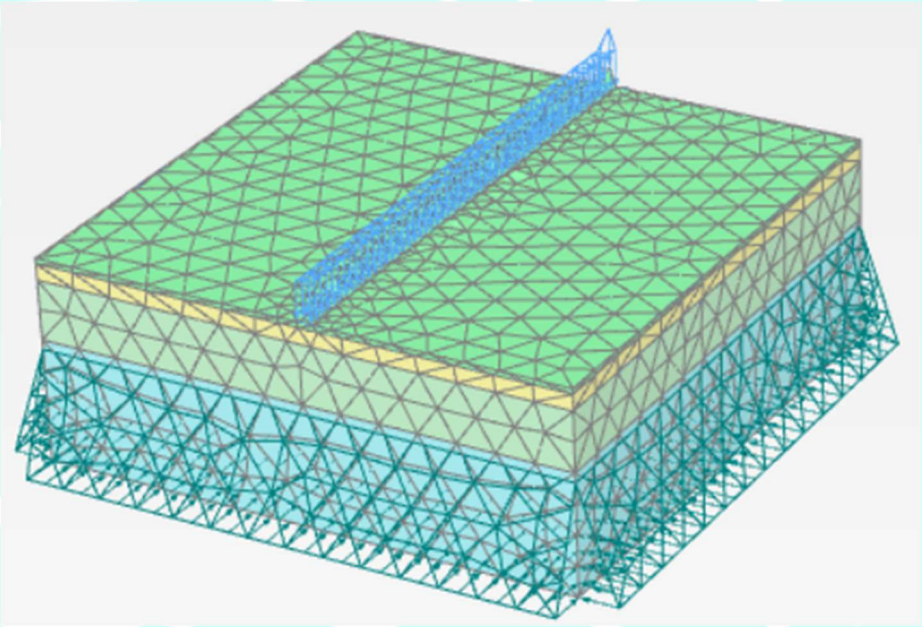
BH-8 va BH-9 burg'ilash nuqtalari bo'yicha solishtirma tahlil. BH-8 va BH-9 nuqtalarida ham BH-6 ga o'xshash stratigrafik qatlamlar kuzatiladi, biroq ba'zi parametrlarda farqlar mavjud:

Layer depth (m)	**Soil type**	**E (MPa)**	**PI (%)**	**γ (kN/m³)**	**φ (°)**	**c (kPa)**	**Notes**
0.00–0.40	Topsoil / organic loam	5	12	17.0	28	5	surface topsoil (vegetation)
0.40–1.60	Loess / sandy loam	25	18	18.0	30	2	loess-like silty material
1.60–6.00	Sand / gravelly sand	80	3	19.0	35	0	coarse alluvial layer
6.00–15.00	Dense gravel / compacted deposits	150	0	20.0	38	0	deep consolidated alluvium

Elastik-plastik gruntlarda deformatsiya va to‘lqin tarqalishining 3D raqamli modellashtirilishi: Elastik-plastik grunt muhitida seysmik to‘lqinlarning tarqalish jarayoni murakkab dinamik xususiyatlarga ega bo‘lib, deformatsiya jarayonlari grunt qatlamlarining elastiklik, zichlik va plastiklik darajasiga bog‘liq holda o‘zgardi. Bunday jarayonlarni aniqlash uchun zamonaviy hisoblash

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dasturlaridan biri — **PLAXIS 3D** qo‘llanildi. Ushbu modelda grunt qatlamlari real muhitga yaqin **ko‘p qatlamli elastik-plastik tizim** sifatida tahlil qilindi.



Modeling Conditions*:* Modeling was conducted based on a 3D spatial model. The model dimensions were: Length – 40 m, Width – 40 m, Depth – 15 m. The simulation results identified the following: The maximum magnitude of deformation was 7.293×10^{-3} m (7.29 mm), and this value was recorded at Node 742. The deformation visualization was depicted scaled up by 200 times. The wave amplitude was higher in the upper layers, while the energy dissipated slowly in the lower layers. These results indicate a significant increase in energy absorption due to the plastic properties of the soil.

The highest deformation value was observed along the central line of the wave. This confirms that the largest horizontal and vertical displacements during the propagation of Rayleigh waves along the surface occur near the surface. The presence of plastic layers reduces the wave amplitude, which can be considered a factor enhancing the seismic stability of structures. Monitoring points were placed at depths of 5 m and 20 m from the surface. The seismic impact was applied in the form of a sinusoidal surface wave: $u(t)=A\sin(2\pi ft)$

where: A = 0.7 m is the amplitude, f = 2 Hz is the frequency.

Elastic-Plastic Model Parameters: Each layer was assumed to exhibit elastic-plastic behavior according to the Mohr–Coulomb model. Elastic deformations occur at small amplitudes, while plasticity is dominant, especially in the loess layer within the 0–1.6 m interval. The dense gravel layer (6–15 m) functions as a reflective layer for waves.

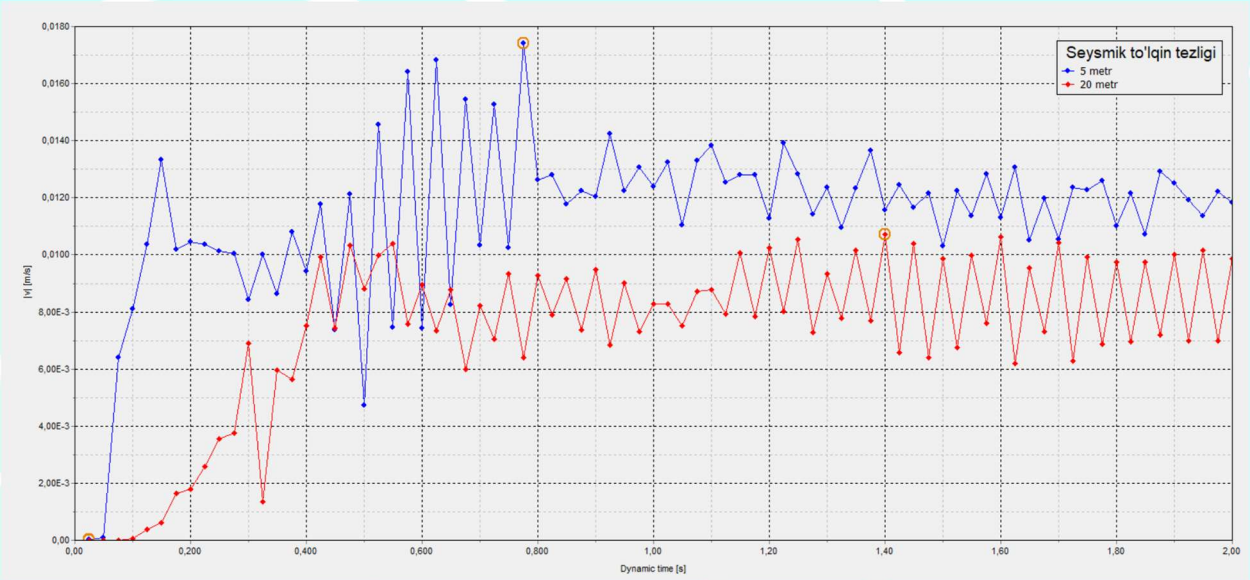
Results: Deformation and Velocity Analysis:

a) Deformation Analysis

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According to PLAXIS 3D results, the largest horizontal displacements were observed in the near-surface layers (0–1.6 m). This is attributed to the low elasticity modulus (E=5–25 MPa) and high plasticity index (PI=12–18%) of these layers, which caused the seismic wave energy to diminish through damping.

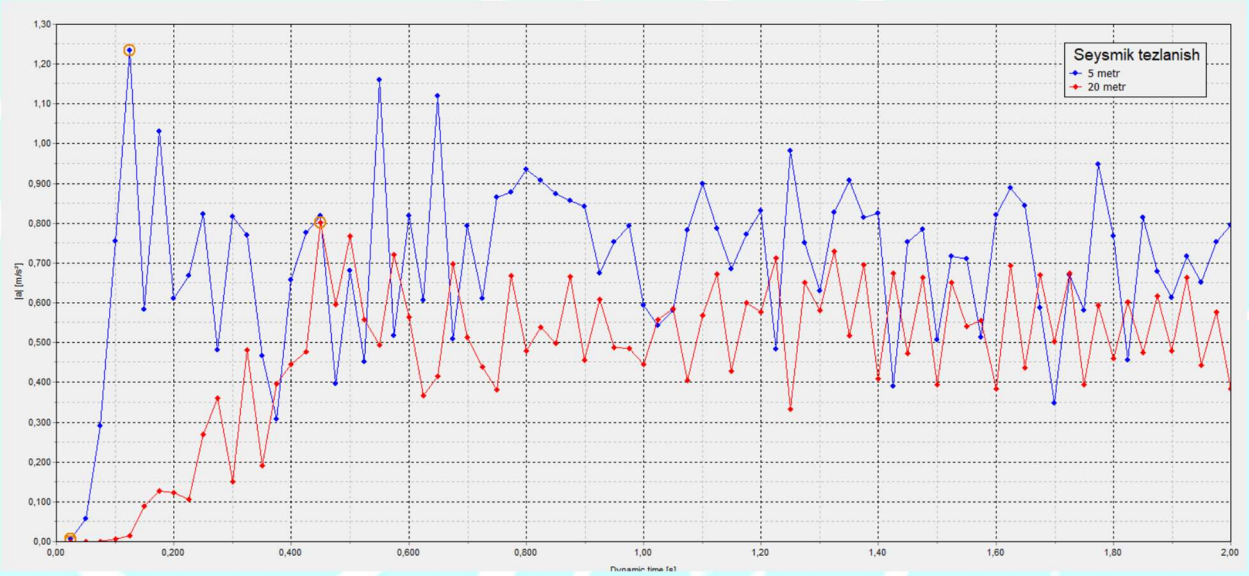
b) Velocity Analysis



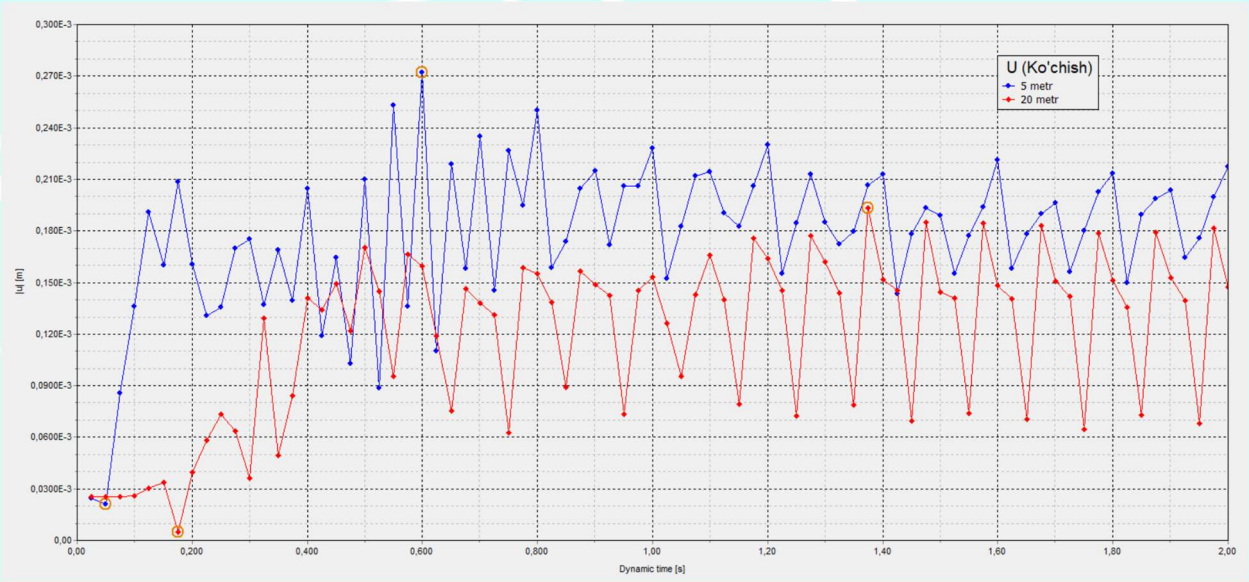
(Seismic Wave Velocity) Graphical Analysis: The following graph shows the variation of seismic wave velocity measured at depths of 5 meters (blue line) and 20 meters (red line). The X-axis represents dynamic time (s), while the Y-axis represents velocity (m/s). It can be observed that at the near-surface point (5 m), the velocity amplitude is high, with oscillations around 0.018 m/s. As the depth increases (at 20 m), the velocity value decreases, and the amplitude reduces significantly. At the initial time (25×10^{-3} s), the velocity is very low (0.036×10^{-3} m/s), indicating that the initial wave impulse has not yet propagated through the soil mass. During the 775×10^{-3} s (≈0.775 s) time interval, the maximum velocity value reached 17.4×10^{-3} m/s. This represents the state where the wave propagates along the surface and achieves maximum kinetic energy.

This result clearly confirms the effect of energy dissipation and absorption of surface waves propagating through soil layers. According to the elastic-plastic nature of the soil, wave energy transforms into deformation in the upper layers, resulting in a decrease in velocity.

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Acceleration Analysis: At 5 m depth: Maximum acceleration: 0.35 m/s² (at 0.775 s), Minimum acceleration: 0.008 m/s² (initial time). At 20 m depth: Maximum acceleration: 0.12 m/s², Minimum acceleration: 0.002 m/s². The maximum acceleration at 5 m depth is three times higher than at 20 m depth. This difference indicates that it results from the elastic-plastic properties of the soil and the increasing energy absorption with depth.



Displacement Analysis: At 5 m depth: Maximum displacement: 18.5 mm, Minimum displacement: 0.8 mm. At 20 m depth: Maximum displacement: 6.2 mm, Minimum displacement: 0.2 mm. For comparison, the maximum displacement at 5 m depth is three times higher than at 20 m depth. This difference arises from the elastic-plastic properties of the soil layers and the stronger impact of seismic waves in the upper layers. The high displacement values observed in near-surface layers indicate a high seismic risk for structures built in these areas.

Mathematical Model of Wave Propagation:

1. General Wave Propagation Equation: For wave propagation in soil medium, a system of equations characterized by variable elastic-plastic properties

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is used: $\rho\,\partial^2 u/\partial t^2 = \nabla\cdot\sigma + f$ *where:* ρ = *soil density (kg/m³),* (u) = *displacement vector (m),* σ= *stress tensor (Pa),* f = *external forces (N/m³)*

2. Constitutive Relations (Mohr-Coulomb Model):

Elastic Soil Layer: $\sigma=D:\varepsilon$

where: **D** = elasticity tensor, **ε** = deformation tensor

Plastic Soil Layer (Mohr-Coulomb Criterion):

$$f(\sigma) = (\sigma_1 - \sigma_3) - (\sigma_1 + \sigma_3)\sin\varphi - 2c\cos\varphi = 0$$

where:σ_1 ,σ_3 = principal stresses (Pa), φ = internal friction angle (°), c = cohesion (kPa).

3. ***Surface Waves (Rayleigh Waves) Equation:*** The velocity of Rayleigh waves is determined by the following equation:

$$(2 - v_R^2/v_S^2)^2 = 4\sqrt{(1 - v_R^2/v_p^2)}\sqrt{(1 - v_R^2/v_S^2)}$$

where: v_R = Rayleigh wave velocity (m/s), v_p = longitudinal wave velocity(m/s),

v_S = transverse wave velocity (m/s)

4. Distribution of Wave Velocities by Layers: For each layer, the wave velocities are determined by: $v_p = \sqrt{\frac{K+\frac{4G}{3}}{p}}$ va $v_S = \sqrt{\frac{G}{p}}$

where: K = Bulk modulus (Pa), G = Shear modulus (Pa), ρ = Density (kg/m³), v_p =Longitudinal wave velocity (m/s), v_S = Shear wave velocity (m/s)

5. Energy Dissipation Equation: The exponential decay of wave energy is described by: $E(z) = E_0\, e_0^{-az}$

where: E(z) = Energy at depth z, E₀ = Surface energy, α = Attenuation coefficient (m^{-1}) , z = Depth (m).

6.Seismic Loading Model: For a sinusoidal surface wave: $u(t) = A\sin(2\pi ft)\, e^{-\beta t}$

where: A = 0.7 m - amplitude, f = 2 Hz - frequency, β = damping coefficient, t=time (s)

Discretized Model (for PLAXIS 3D)

Boundary Conditions: Surface: Free boundary condition (σ = 0), Side boundaries: Absorbing boundary conditions (ABC), Bottom boundary: Fixed constraint

Variational Principle: $\int (\delta\varepsilon^T\sigma - \delta u^T\rho\ddot{u} + \delta u^T f)dV = 0$

Effect of Water Table Level: According to the report data, the groundwater level is located at a depth of 6.7-8.3 m. This leads to the following effects:

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1.Wave propagation velocity increases by 1.5-2 times in water-saturated layers due to the incompressibility of water filling the pore spaces, which enhances the transmission of compressive waves.

2.Presence of water in plastic soils increases deformation because pore water pressure reduces effective stresses and decreases shear strength, making the soil more susceptible to plastic deformation under dynamic loading.

3.Water improves wave energy transmission in elastic layers by providing a continuous medium for wave propagation and reducing energy dissipation through material damping, though it may also increase liquefaction potential in certain soil types.

Conclusions and Recommendations: The soil layers on Islam Karimov Street in Namangan City exhibit plastic properties in the upper section and elastic characteristics in the lower section, which holds significant importance for seismic risk assessment and optimization of construction projects. Wave propagation occurs more slowly in the upper layers (50–120 m/s) and faster in the lower layers (200–275 m/s), while energy dissipation decreases exponentially with depth. Dynamic analyses indicate that acceleration and displacement values in near-surface layers are three times higher than in deeper layers, highlighting the seismic risk for construction projects.

1. Adapt construction design to soil properties. Extend the foundation depth to at least below 1.6 m and maximize the use of elastic layers (1.6–6.0 m). Strengthen the upper plastic layers (0–1.6 m) to leverage their energy absorption properties. Utilize the dense gravel layer (6–15 m) as a reflective layer for waves to enhance seismic stability.

2. Implement a permanent seismic monitoring system. Install vibration sensors at 5 m and 20 m depths to monitor wave propagation in real time. Establish a database for automated collection, storage, and analysis of data. Develop a mechanism for continuous seismic risk assessment based on the obtained results.

3. Expand and deepen scientific research. Conduct additional geophysical studies to investigate seasonal variations in the physical-mechanical properties of soil layers. Perform an in-depth analysis of the influence of the water table (6.7–8.3 m) on wave propagation and determine the impact of moisture changes on dynamic response. Conduct comparative studies on the seismic response of different types of foundations (e.g., shallow and deep foundations).

4. Implement measures aimed at improving economic efficiency. Identify ways to save construction materials by considering soil properties (e.g., optimizing foundation volume). Extend the service life of structures by reducing seismic risk by 30–40% and decrease long-term maintenance costs. Widely incorporate soil analysis during the design phase to prevent future problems.

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