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WAVE PROPAGATION IN ELASTIC-PLASTIC SOILS LOCATED ON ISLAM KARIMOV STREET IN NAMANGAN CITY

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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.

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 O'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 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.

Research Methods and Materials: The following methods were applied based on samples taken from boreholes BH-6, BH-8, and BH-9:

- Determination of physical-mechanical properties of soils
- Study of granulometric composition
- Determination of elasticity modulus (E) and plasticity index (PI)
- Monitoring of water table level

Analysis of Elastic-Plastic Properties of Soil Layers

Analysis of Borehole BH-6

0.00-0.40 m: Topsoil/Organic Fertile Soil

- Elasticity modulus: 5 MPa (very low)
- Plasticity index: 12% (plastic)
- Conclusion: High plasticity, low elasticity - significant absorption in wave propagation

0.40-1.60 m: Sandy Fertile Soil

- Elasticity modulus: 25 MPa (low)

- Plasticity index: 18% (highly plastic)

- Conclusion: Strong deformation with moisture changes - slow wave velocity

1.60-6.00 m: Sand/Gravelly Sand

- Elasticity modulus: 80 MPa (medium)

- Plasticity index: 3% (non-plastic)

- Conclusion: Good elastic properties - high wave velocity

6.00-15.00 m: Dense Gravel/Compacted Sedimentary Rocks

- Elasticity modulus: 150 MPa (high)

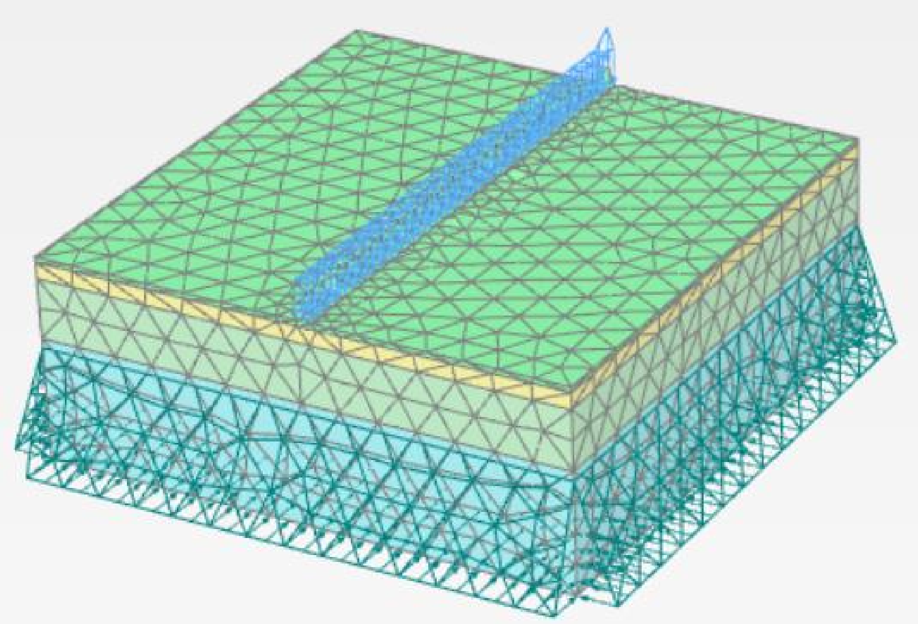
- Plasticity index: 0% (non-plastic)

- Conclusion: High elasticity - fastest wave propagation layer

Comparative Analysis of Boreholes BH-8 and BH-9. BH-8 and BH-9 show similar stratigraphic layers to BH-6, but with some parameter differences:

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

3D Numerical Modeling of Deformation and Wave Propagation in Elastic-Plastic Soils: The wave propagation process in elastic-plastic soil medium has complex dynamic characteristics, where deformation processes vary depending on the elasticity, density, and plasticity degree of soil layers. For accurate analysis of such processes, PLAXIS 3D software was used. In this model, soil layers were analyzed as a multi-layered elastic-plastic system close to real conditions.



Modeling Conditions: The modeling was carried out based on a 3D spatial model. The model dimensions are: length – 40 m, width – 40 m, and depth – 15 m. As a result of the simulation, the following findings were obtained: the maximum deformation magnitude was 7.293×10^{-3} m (7.29 mm), which was recorded at node 742. The deformation image was scaled up 200 times for visualization. In the upper layers, the wave amplitude is higher, while in the lower layers, the energy gradually dissipates. These results indicate that due to the plastic properties of the soil, energy absorption significantly increases.

The maximum deformation value was observed along the central line of the wave. This confirms that during the propagation of Rayleigh waves along the surface, the largest horizontal and vertical displacements occur near the surface. The presence of plastic layers reduces the wave amplitude, which can be considered a factor that enhances the seismic stability of structures. Observation points were placed at depths of 5 m and 20 m below the surface. The seismic excitation was applied in the form of a sinusoidal surface wave expressed as $u(t)=A\sin(2\pi ft)$, where $A = 0.7$ m is the amplitude and $f=\frac{v}{\lambda}=\frac{350}{20}=17.5$ Hz denotes the frequency.

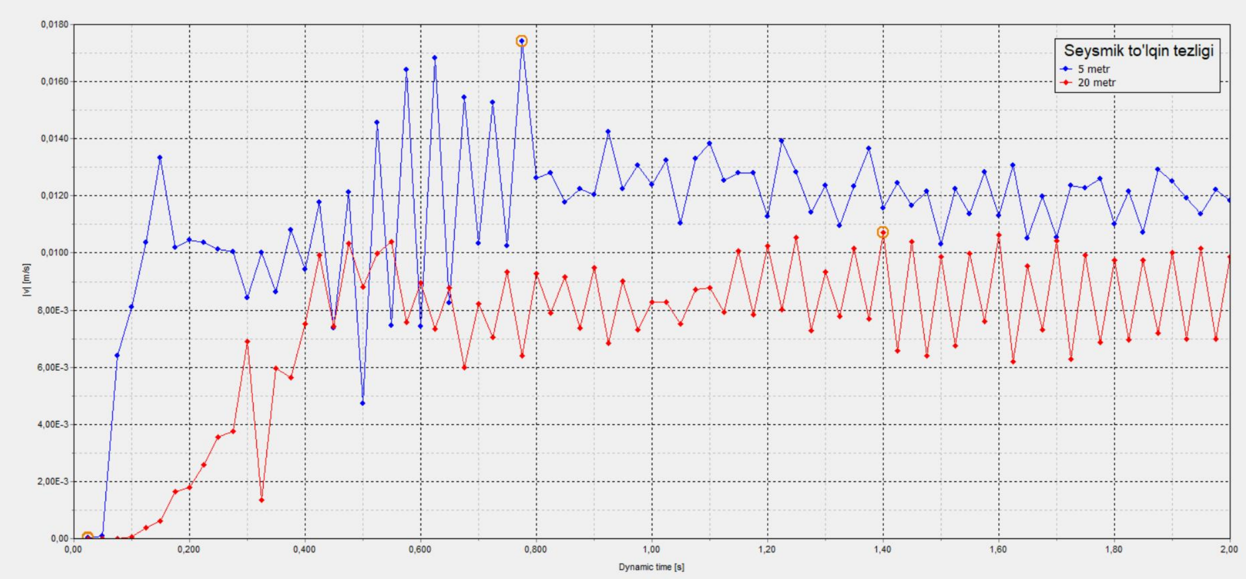
Elastic-Plastic Model Parameters: Each layer was assumed to exhibit elastic-plastic behavior according to the Mohr–Coulomb model. Elastic deformations occur at small amplitudes, while plasticity becomes dominant, particularly within the 0–1.6 m loess layer. The dense gravel layer (6–15 m) acts as a reflective layer that partially reflects the propagating waves.

Results: Deformation and Velocity Analysis

a) Deformation Analysis

According to the PLAXIS 3D results, the largest horizontal displacements were observed in the near-surface layers (0–1.6 m). Due to the low elastic modulus (E = 5–25 MPa) and high plasticity index (PI = 12–18%) of these layers, the seismic wave energy was significantly reduced through attenuation within these zones.

b) Velocity Analysis

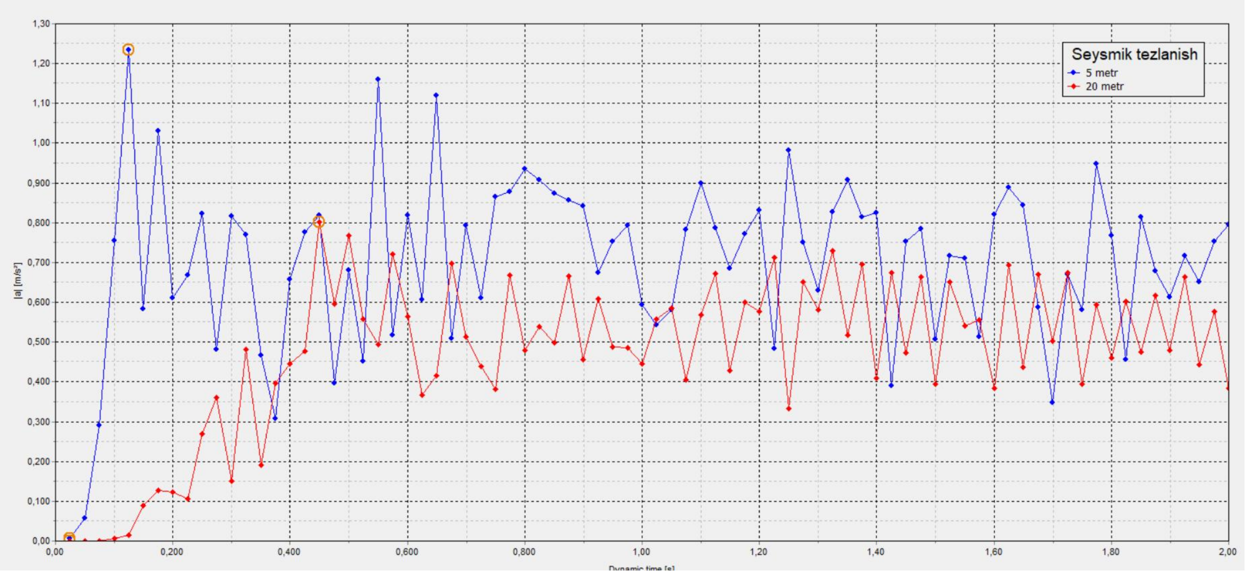


(Seismic Wave Velocity) Graphical Analysis: The following graph illustrates the variation of seismic wave velocity measured at depths of 5 meters (blue line) and 20 meters (red line). The X-axis represents dynamic time (s), while the Y-axis indicates velocity (m/s).

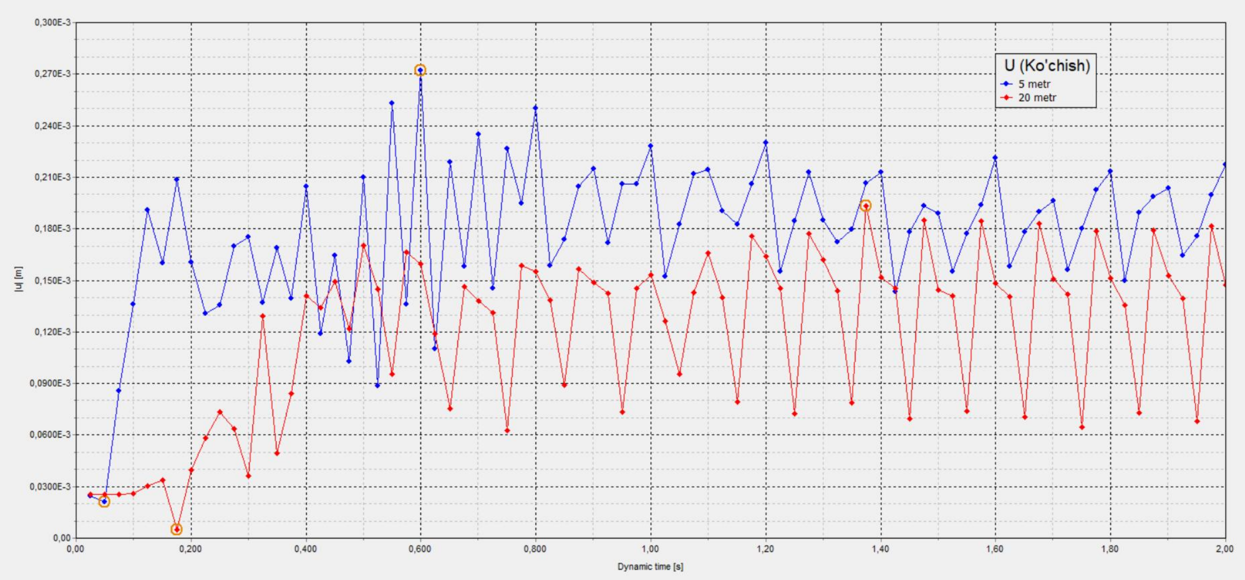
As can be seen, at the near-surface point (5 m), the velocity amplitude is higher, with oscillations observed around 0.018 m/s. As the depth increases (at 20 m), the velocity values decrease, and the amplitude significantly diminishes.

At the initial stage (25×10^{-3} s), the velocity is very small (0.036×10^{-3} m/s), indicating that the initial wave impulse has not yet propagated through the soil mass. During the time interval of 775×10^{-3} s (≈0.775 s), the maximum velocity reached 17.4×10^{-3} m/s, representing the state when the wave travels along the surface and possesses its maximum kinetic energy.

These results clearly confirm the energy attenuation and absorption effects of surface waves propagating through soil layers. According to the elastic-plastic nature of the soil, the wave energy in the upper layers is transformed into deformation, resulting in a decrease in velocity.



Acceleration Analysis: At a depth of 5 meters: Maximum acceleration: 0.35 m/s² (at 0.775 s), Minimum acceleration: 0.008 m/s² (at the initial moment), At a depth of 20 meters:Maximum acceleration: 0.12 m/s², Minimum acceleration: 0.002 m/s², Comparison: The maximum acceleration at a depth of 5 meters is approximately three times greater than that at a depth of 20 meters. This difference indicates that, as depth increases, the elastic-plastic behavior of the soil and the energy absorption capacity become more pronounced, leading to a reduction in acceleration with depth.



Displacement (Shift) Analysis: At a depth of 5 m: Maximum displacement: 18.5 mm, Minimum displacement: 0.8 mm, At a depth of 20 m: Maximum displacement: 6.2 mm Minimum displacement: 0.2 m. Comparison: The maximum displacement at 5 m depth is three times greater than at 20 m depth. This difference arises from the elastic–plastic properties of the soil layers and the stronger effect of seismic waves in the near-surface layers. The high displacement values observed near the surface indicate an increased seismic risk for structures built in these zones.

Mathematical model of wave propagation: General wave-propagation equation: For wave propagation in the soil medium, a system of equations characterized by variable elastic–plastic properties 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 (body) forces per unit volume (N/m³)

2. **Constitutive Relations (Mohr–Coulomb Model): Elastic soil layer:** $\sigma = D:\varepsilon$
where: D — elasticity tensor, ε — strain 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 (P-wave) velocity (m/s), v_S -transverse (S-wave) velocity (m/s)

4. **Distribution of Wave Velocities Across Layers:** For each layer, the wave velocities are given as follows: $v_p = \sqrt{\frac{K+\frac{4G}{3}}{p}}$ va $v_S = \sqrt{\frac{G}{p}}$ where: K - bulk modulus (Pa), shear modulus (Pa)

5. Energy Attenuation Equation: Exponential decay of wave energy: $E(z) = E_0\, e^{-\alpha z}$ where: E(z) — energy at depth z, E_0 — surface energy, α — attenuation coefficient (m^{-1})

6. **Seismic Loading Model:** For a sinusoidal surface wave: $u(t) = A\sin(2\pi f t)\, e^{-\beta t z}$ where: A = 0.7 m — amplitude, f = 2 Hz — frequency, β — attenuation coefficient

Discrete Model (for PLAXIS 3D)

Boundary Conditions: Surface: Free boundary condition (σ = 0), Lateral boundaries: Absorbing boundary conditions (ABC). Bottom boundaries: Fully fixed (rigidly constrained)

Variational Principle: The solution of the discretized model is based on the principle of virtual work, where the equilibrium is expressed as: $\delta W = \delta U - \delta W_{ext} = 0$

Here: δU — virtual strain energy of the soil, δW_{ext} — virtual work of external forces

Effect of Groundwater Level: According to the report, the groundwater table is located at a depth of 6.7–8.3 m. This leads to the following effects:

1. In saturated layers, the wave propagation velocity increases by 1.5–2 times.
2. In plastic soils, the presence of water increases deformation.
3. In elastic layers, water enhances the transmission of wave energy.

Conclusions and Recommendations: The soil layers along Islam Karimov Street in Namangan are plastic in the upper part and elastic in the lower part, which is crucial for seismic hazard assessment and optimization of construction projects. Wave propagation occurs slower in the upper layers (50–120 m/s) and faster in the lower layers (200–275 m/s), while energy attenuation decreases exponentially with depth. Dynamic analyses show that acceleration and displacement values near the surface are three times higher than in deeper layers, indicating a higher seismic risk for structures.

Recommendations:

Adapt construction design to soil properties: Set the foundation depth at least below 1.6 m, making maximum use of elastic layers (1.6–6.0 m). Strengthen the upper plastic layers (0–1.6 m) to take advantage of their energy absorption capacity. Use the dense gravel layer (6–15 m) as a reflective layer to enhance seismic stability.

Implement a permanent seismic monitoring system: Install vibration sensors at 5 m and 20 m depths to monitor wave propagation in real time. Develop a database for automatic data collection, storage, and analysis. Use the collected data to continuously assess seismic risk and establish a monitoring mechanism.

Expand and deepen scientific research: Conduct additional geophysical studies to examine seasonal variations of the soil's physical-mechanical properties. Analyze the effect of the groundwater level (6.7–8.3 m) on wave propagation and determine the impact of moisture changes on dynamic response. Compare seismic responses of different types of foundations, including shallow and deep foundations.

Enhance economic efficiency: Optimize construction materials by considering soil properties (e.g., adjusting foundation volume). Reduce seismic risk by 30–40%, thereby extending the service life of structures and reducing long-term maintenance costs. Apply comprehensive soil analysis at the design stage to prevent future problems.

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