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METHOD FOR EARTHQUAKE-RESISTANT SLOPE STEEPNESS: AN INTEGRATED EXPERIMENTAL-NUMERICAL APPROACH

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ABSTRACT: This paper presents the Seismic Slope Steepness method, developed to evaluate slope stability under seismic effects and dynamic loads. The study is based on experimental data, numerical modeling, and empirical relationships that reflect the influence of key physical and mechanical soil characteristics, such as porosity, moisture content, and angle of internal friction, on stability. The main parameters of slope stability under 8-point seismicity and vibrations equivalent to high-speed transport are analyzed. The results, summarized in graphical form, can be applied to optimize slope design in earthquake-prone regions. Proposed anti-seismic measures include soil compaction, replacement of weak soils with more durable ones, loading of the slope surface, slope alignment, modifying the slope shape, installing drainage systems, and using various slope reinforcements (e.g., diaphragms, screens). However, each of these measures has certain limitations, such as restricted applicability, technological complexity, high cost, and, most importantly, failure to achieve the desired stability. Given these challenges, further research on improving slope positioning methods was deemed necessary. This approach is simpler, more cost-effective, and does not require complex equipment or advanced technologies. The development of this method, which accounts for key factors affecting slope stability, is expected to have broad applications in the construction of embankment structures for various purposes.

Keywords: Slope Stability, Seismic Stability, Dynamic loads, Soil characteristics, Numerical modelling, PLAXIS

1. INTRODUCTION

Design and construction engineering structures in regions with high seismic activity is a complex task that requires consideration of many factors, including physical and mechanical properties of soils, the effects of dynamic loads, and operating conditions. Slope stability, as one of the key characteristics of embankment structures, directly affects their durability and safety. Failure to properly assess slope stability under seismic conditions can lead to catastrophic consequences, including infrastructure destruction and significant economic losses [1, 2].

In recent decades, intensive infrastructure development, especially in earthquake-prone regions, has led to increased loading on embankment structures. Dynamic effects such as vibrations from high-speed transport and long-term loads associated with changes in the water table significantly reduce slope stability [3]. This necessitates the development of new approaches to the calculation of slope steepness, ensuring their stability even under the influence of unfavourable factors.

Numerous studies have shown that the physical and mechanical characteristics of soils, such as porosity, moisture content, and internal friction angle, play a key role in assessing slope stability [4, 5]. In particular, an increase in moisture content leads to a significant decrease in soil strength properties, which requires consideration in design calculations [6]. Moreover, techniques based on numerical simulations, such as the use of PLAXIS software, allow for more accurate modelling of the interaction between soil and dynamic loads, enabling optimization of design solutions [7].

Despite advances in geotechnical design, current methods for calculating slope stability often do not take into account the complex interaction of factors affecting slope stability. This limits their application in seismic and dynamic environments [8]. Thus, there is a need to develop new approaches that not only take into account the physical and mechanical properties of soils, but also predict their behaviour under extreme conditions.

The purpose of this paper is to develop a method for calculating the sustainable slope steepness based on an integrated analysis of the physical and mechanical characteristics of soils, seismic effects, and dynamic loads. The proposed method generalises experimental data, numerical calculations, and empirical dependencies, providing practical recommendations for design in earthquake-prone regions.

The key objectives of the study include:
1. Analysing the effect of porosity, moisture content, and angle of internal friction on slope stability.
2. Developing a methodology for calculating the stable slope steepness that takes into account dynamic and seismic loads.

3. Validation of the proposed method on numerical models using PLAXIS programmed.

This paper is an attempt to combine modern approaches to slope design and to propose a universal method that can be used to improve the stability of embankment structures in earthquake-prone.

The scientific novelty of the article consists in the development of a new approach to determining the slope steepness with increased resistance to seismic impacts. Unlike traditional methods, which are often based on empirical relationships or global recommendations for slope design, the proposed method takes into account the specific dynamic characteristics of the rock base and local geological conditions.

Previous literature [9] has emphasized the importance of including modal frequencies and the spectral response of the soil in the evaluation of slope stability. However, these studies were often limited to static models or did not consider the interaction of seismic loading with different soil layers. At the same time, [10] proposed the use of simplified numerical models to estimate slope stability, but such approaches do not always provide accurate predictions in complex geologic sections.

The new study is based on the integration of spectral analysis methods with the application of numerical modeling of slopes, which allows taking into account both modal frequencies of soil layers and nonlinear behavior of the material under intense seismic loads. Thus, the proposed method overcomes the limitations of previous works, providing a more accurate determination of the optimal slope steepness and reducing the risk of slope failure during earthquakes.

The inclusion of a reference to earlier work allows us to compare the accuracy and reliability of existing methods and to emphasize how the new approach improves the process of designing stable slopes. Such an approach is a step forward in the field of engineering seismology, combining theoretical developments [9, 10] with practical results from engineering modeling.

2. RESEARCH SIGNIFICANCE

The article is devoted to the theoretical and experimental substantiation of a fundamentally new basis of the method for Earthquake-resistant slope of bulk structures proposed by the authors and its practical application using the Plaxis computer program on specific objects. The stability of any fluctuating slope depends on the influence of internal and external factors. As an internal factor, the strength and deformation parameters of the soil in the body of the slope are considered, depending on their composition and condition, the type of soil, granulometric and mineralogical compositions, and density-humidity conditions.

3. METHOD

3.1 Basic Theoretical Provisions

Scientific research based on a specific hypothesis aims at purposefully solving a problem. The stability of any slope depends on internal and external factors: Internal factors: Strength and deformation characteristics of the soil depending on its composition and condition [11,12].

External factors: Slope surface loads and dynamic effects such as amplitude, frequency, and duration of seismic waves [13]. Theoretical and experimental studies of the above factors affecting slope steepness form the basis of this paper.

3.2 Approach to Solving The Problem

The following sequential approach was chosen to achieve the objective of the study:

1. Analyzing the stress state of soil under seismic wave action [14].
2. Investigating the change in strength characteristics of soil under dynamic loading conditions.
3. Development of earthquake-resistant slope steepness methodology.
4. Experimental studies to substantiate the factors determining slope stability.

$$\boldsymbol{k_z = \frac{T}{Q}} \quad (1)$$

where

T - is the shear resistance force of the selected volume of soil;

Q - force causing the displacement.

Conditions for loss of stability

Loss of stability can occur when:

An increase in seismic tangential stress ($\boldsymbol{\tau_s}$):

$$\boldsymbol{\tau_s = 0.64\gamma_w H k_s} \quad (2)$$

where

k_s - seismicity coefficient (Chen et al., 2023).

2. Reduction of soil shear resistance ($S_{\sigma,\omega}$):

$$S_{\sigma,\omega} = \sigma_{din} tan\varphi_\omega + c_v \quad (3)$$

where

σ_{din} - dynamic stress [12].

3.3 Experimental Studies

Characteristics of soils. The physical and mechanical properties of soils of different genesis are summarized in Table 1. These data were obtained under laboratory conditions using modern shear testing approaches [15]. Notes to Table 1:

1. All data in the table are the result of laboratory tests performed on different soil types (№1, №3, №6) with different porosities.
2. Soil porosity is measured in percent (%), which affects soil density and thus slope stability.
3. The - sign in the table indicates that no data are available for the corresponding combination of density and porosity, which may be due to the impossibility of making measurements for these parameters.
4. All results reflect the dependence of stable slope steepness on porosity, and they are applicable only to the considered soil types (№1, №3, №6).
5. The error of measurements in the table does not exceed 5%.

Experimental setup and calculation process. Soils, a vibrating rig, measuring instruments, and a sequential research methodology were used to study the stability of slopes under seismic action. The use of diagrams and flowcharts allowed for the visualization and structuring of the experimental steps.

Soils. Characteristics of the investigated soils:

- Sands, sandy loams, and loams were used as presented in the table of physical and mechanical properties [16].
- Sampling was carried out from the alluvial and the alluvial deposits.

Key parameters included:

- Soil skeletal density (γ);
- The angle of internal friction (ϕ);
- Cohesion (c).

Vibration setup. Plant description:

1. Platform for creating seismic vibrations:
   - adjustable parameters: frequency (0.5 to 5 Hz) and amplitude (1 mm to 10 mm);
   - adjustable to simulate earthquakes of intensity 6-9 on the MSK-64 scale.
2. Soil Container:
   - rectangular container that simulates a slope with a specified slope angle;
   -dimensions: 1 m × 0.5 m × 0.5 m.

The role of the vibration plant:

- dynamic load modeling;
- investigation of soil mass response to seismic action [6].

Measuring instruments. Equipment used. Stress sensors (σ_din). Installed at different depth levels to record stress changes.

Strain sensors. Measure changes in slope shape and displacement. Software.Used for real-time data acquisition and subsequent analysis. Research Methodology. Main steps of the experiment. Soil preparation. Taking and analyzing samples for physical and mechanical properties. Placing the soil in a container with a given density.

Adjustment of the vibrating unit. Selection of vibration parameters (frequency, amplitude, duration). Calibration of measuring equipment. Conducting experiments. Starting the vibration platform. Registration of stress and strain changes.

Processing of results. Analysis of critical values of the stability angle. Comparison of experimental data with computational models [15, 16].

Table 1 Physical and mechanical characteristics of the studied soils

Ground number	Dense. the skeletonof the soil,10^4 kN/m^3	Dense.soil,10^4 kN/m^3	The Poris, %	Coef.poristi	Nature wet.,%	Boundaries. humidity. %		Internal friction angle, degree	Coupling, 10^5 Pa	It relates. drawdown, at $3×10^5$ Pa	Granulometric composition		
						w_t	w_p				> 0.05	0.05 - 0.005	< 0.005
1	2.68	1.67	45.5	0.84	16.2	26.9	19.0	26	0.139	-	10.0	78.0	12.0
2	2.70	1.64	34.4	0.82	16.5	25.6	14.7	24	0,042	0,048	19,6	78,9	1,5
3	2.70	1.77	44.0	0.79	12.7	27.6	19.0	26	0.179	0.01	18.88	71.47	9.65
4	2.69	1.68	49.8	0.29	18.0	27.2	19.9	19	0,70	0.912	30.25	67.7	2.05
5	2.70	1.74	42.6	0.74	12.5	27.8	18.2	22	0.10	0.010	19.5	70.65	10.0
6	2.68	1.74	44.4	0.79	8.0	262	18.4	18	1.10	0,011	28.56	66.36	5.05
7	2.69	1.73	54.5	1.98	14.0	69.8	38.4	18	0.987	0.013	4.5	59.8	35.7
8	2.69	1.62	41.6	0.71	17.1	27.8	18.3	28	0.15	0.01	18.88	71.47	9.65
9	2.69	1.53	31.5	0.88	15.3	26.6	19.5	26	0.025	0.01	4.0	71.5	24.5
10	2.71	1.59	34.5	0.83	22.8	26.5	22.0	26	0.067	0.006	5.1	74.2	20.7
11	2.70	1.81	35.4	0.93	29.4	31.0	19.7	24	0.005	0.021	3.5	59.8	36.7
12	2.68	1.62	33.2	0.78	22.8	26.5	22.0	26	0.057	0.006	5.4	80.5	14.1

Block diagram of the experimental process
Stages of the experiment:

1 Soil sampling and preparation
⬇
2 Placement of samples in the vibration unit
⬇
3 Creating a dynamic impact
⬇
4 Recording changes (stresses, strains)
⬇
5 Analyze results and develop recommendations

3.4 Development of The Earthquake-Resistant Slope Steepness Methodology

Based on the theoretical and experimental studies conducted, a methodology was developed including:

- Recommendations for the design of stable slopes in seismically active regions [13];
- Determination of allowable slope angles for different soil types [14];
- Stress modeling under seismic action [16].

4. RESULTS

4.1 Influence of Physical and Mechanical Characteristics of Soils

Experiments confirmed that the physical and mechanical characteristics of soils, including internal friction angle (φ), cohesion (c), and porosity (e), have a significant effect on slope stability. For example:

- for sandy soils with low porosity (e=0.5) and high cohesion (c=0.8 MPa), the stability coefficient (F_S) reached 1.4, which corresponds to safe operating conditions;
- when porosity increased to e=0.8 and cohesion decreased to c=0.2 MPa, stability decreased to F_S=0.7, indicating a high risk of stability loss [17, 18]. The distribution of the physical characteristics of the soils used in the modelling is presented in Table 2.

Table title: Variation of slope steepness as a function of soil moisture at ac = 2880 mm/s².
Notes to Table 2:

1. All data in the table show the dependence of slope stability on soil moisture for soil types №2 and №8.
2. Soil moisture is measured in percent (%), which reflects the water content of the soil.
3. A "-" in the table indicates that no data are available for a given moisture value for soil type №8. This may be due to limitations in experimental conditions or lack of measurements at the specified moisture level.
4. All results were obtained under external action with an acceleration of 2880 mm/s² to characterize the stability of the slope under dynamic loads.
5. The measurement error does not exceed 5%.

Table 2 Influence of physical and mechanical characteristics on slope stability

Parameter	Significance	Sustainability ratio (**F_S**)
Angle of internal friction (**φ**)	18^0-42^0	0.7 - 1.4
Clutch (c)	0.01−1.1 MPa	0.5 - 1.4
Porosity coefficient (e)	0.5 - 0.8	0.7 - 1.4
Parameter	Significance	Sustainability ratio (**F_S**)

The density of the soil. Experiments conducted on loess and sandy slopes under various dynamic influences have shown a direct dependence of the slope steepness on the density of the soil. Figures 1 - 4 illustrate the results of the experiments in the form of a function tg a = f(n).

Figure 1, compiled on the basis of Table 2, shows the dependencies tg a = f (n) for soils numbered №. 1,3 and 6, on which the porosity of the soil characterizes the density state of a particular soil. It should be noted that the data in Fig. 1 cannot be distributed to other similar soils, because porosity in this case refers only to the soil in question [19].

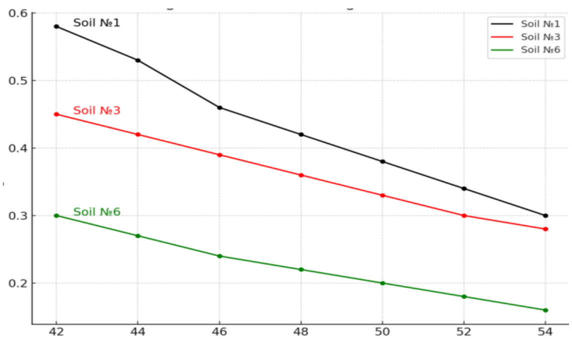

Fig.1 Dependence of stable slope angle on angle tangent for different soil types

Soil №1 (black line): shows the dependence of the stable slope angle on the angle tangent for the first soil type.Soil №3 (red line): similarly for the third soil type.Soil № 6 (green line): for the sixth soil type. The graph illustrates the dependence of the stable slope angle (Y-axis) on the tangent of slope angle (X-axis) for three different soil types. Each line on the graph represents experimental data showing how the stable slope angle changes with changing tangent angle for a particular soil type. The graph shows that as the value of tangent angle increases, the stable angle decreases for all soil types. This may indicate the behavior of different soil types in the context of the stability of sloped structures.

In this regard, the data in Figure 2 is more general, where the density of the soil is expressed in terms of relative values, which is quite possible to extend it to other similar soils as well.

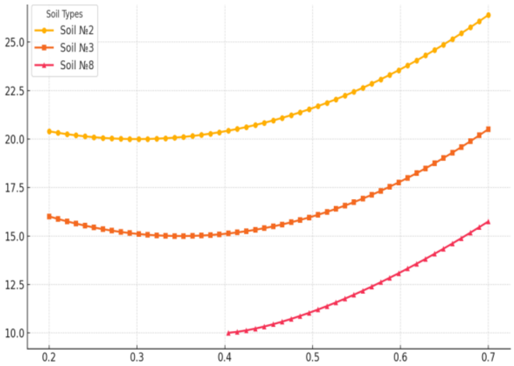

Fig.2 Dependence of stable slope angle on soil density for different soil types

Chart axes: Horizontal Axis (X): Soil Density (Soil Density, Relative Units).Vertical axis (Y): Stable Slope Angle (Stable Slope Angle, degrees). Legend: Soil №2, Soil №3, Soil №8 are the soil types for which the dependencies are defined. Features of curves. Each type of soil has a different dependence of slope angle on density, reflecting their physical and mechanical properties.

Table 3 Generalized information on the dependence of the stable slope steepness on the density of the soil

Soil	Soil porosity , %						
	42	44	46	48	50	52	54
№ 1	-	0.56	0.44	0.32	0.20	0.13	0.08
№3	0.48	0.44	0.38	0.34	0.33	0.22	0.21
№6	-	0.52	0.40	0.32	0.25	0.20	0.17

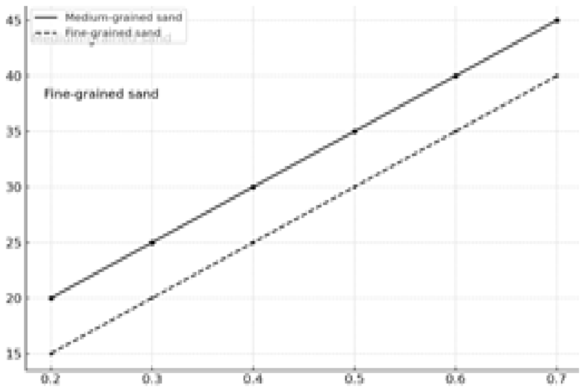

Fig.3 Dependence of stable slope steepness on relative soil density for different sand types

The graph shows the dependence of stable slope steepness (Y-axis) on relative soil density (X-axis) for two types of sand: medium sand and fine sand.
Medium sand (solid line) has a linear relationship showing an increase in stable slope steepness with increasing soil density. Fine sand (dashed line) also shows a linear relationship, but with less steepness compared to medium sand.

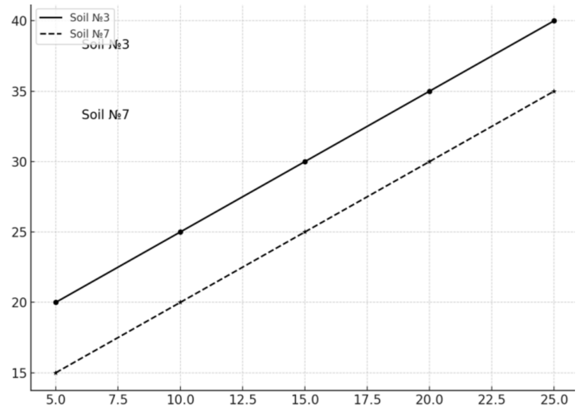

Fig.4 Dependence of stable slope steepness on the angle of internal friction for different soil types

The graph shows the dependence of stable slope steepness (Y-axis) on soil internal friction angle (X-axis) for two soil types:

Soil №3 (solid line) shows the linear dependence of stable slope angle on the angle of internal friction.

Soil №7 (dashed line) also shows a linear increase in slope angle with increasing internal friction angle, but with less steepness compared to Soil №3.

Soil moisture. The results of the experiments also showed the dependence of the slope steepness on soil moisture (Table 4).

Table 4 The change in slope steepness from soil moisture at ac = 2880 mm /c^2

Soil	Soil moisture, %						
	5	10	15	20	25	30	35
№2	0.63	0.41	0.25	0.17	0.13	0.12	0.72
№8	0.54	0.49	0.35	0.34	0.37	0.34	-

The difference in the dynamic strength of the soil depending on its humidity was stated earlier [20]. In cohesive soils, any additional moisture helps to reduce the plastic connectivity of the soil and this in turn affects the slope steepness.

The graph illustrates the dependence of stable slope steepness (Y-axis) on clay particle content (X-axis) in soil for two soil types:

Soil №2 (black line): shows a linear increase in stable slope steepness with increasing clay particle content.

Soil №3 (red line): shows a more pronounced relationship where the stable slope angle increases significantly with increasing clay content in the soil (Fig. 5).

Experimental studies conducted to study the role of humidity on the stability of slope steepness have shown that an increase in humidity always contributes to a change in soil strength. In this case, the plastic connectivity of the soil undergoes a significant change, which makes it possible to conclude that the strength of the soil in the slope is mainly determined by the amount of plastic connectivity, depending on the soil moisture [21].

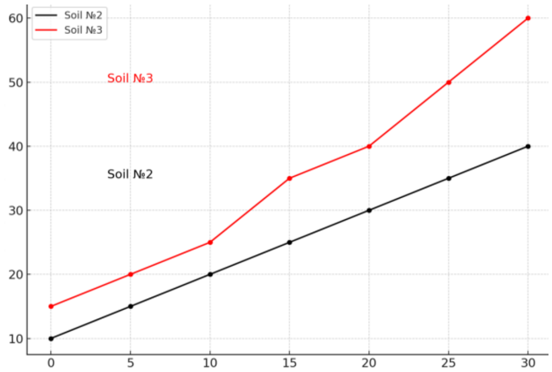

Fig.5 Dependence of stable slope steepness on clay particle content of soil for different soil types

A generalized dependence of the stable slope steepness at different humidities of loess soils is shown in Table 3, according to which it is possible to trace the significant influence of soil moisture on the slope steepness. In general, the stability of the slope steepness, in addition to the density and humidity of the soil, depends on other factors as well. Among them, an important place belongs to the clutches and the external load on the slope.

4.2 Dependence of Stability on Moisture Content

Soil moisture (W) is a critical parameter that determines the stability of the soil. As the moisture content increased from 5% to 35%, the cohesion (c) decreased on average by 60%, which significantly reduced the stability coefficient. The plot of slope stability versus moisture content is shown in Fig. 6.

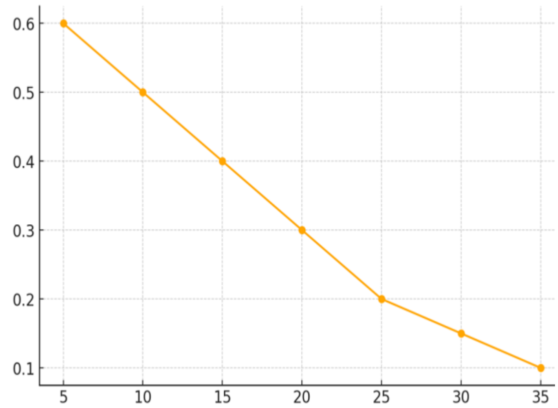

Fig. 6 Dependence of stability coefficient on soil moisture

4.3 Analysis of PLAXIS Calculations

The use of numerical modelling in PLAXIS software provided detailed data on the stress-strain state of the slopes. The main results include:

- stress distribution. Maximum vertical stresses are observed at the base of the slope, which is consistent with theoretical models [4].

- horizontal displacements. At seismic load $\boldsymbol{k_s}$=0.3, displacements reached 7.5 cm, with areas of displacement concentration coinciding with areas of low cohesion (c<0.2 MPa) [22].

- critical zones. PLAXIS identified areas of the slope where the stability coefficient $\boldsymbol{F_s}$ <1.0, indicating the need for structural reinforcement.

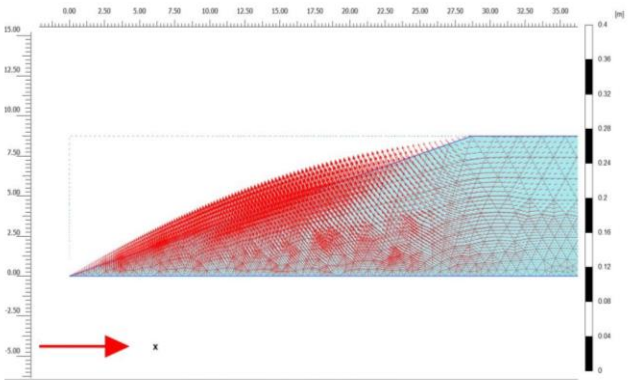

Fig. 7 Full movements with static

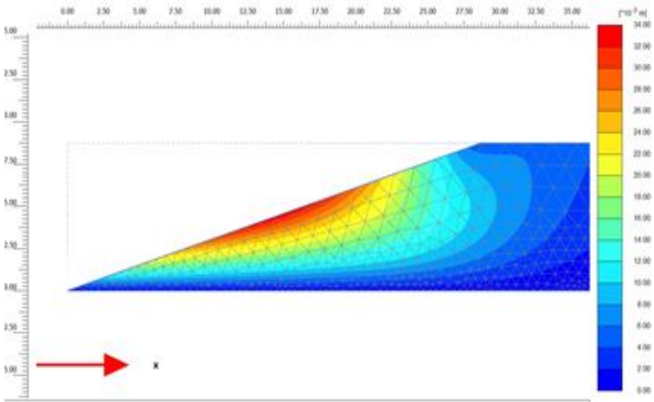

Fig. 8 Full movements with static

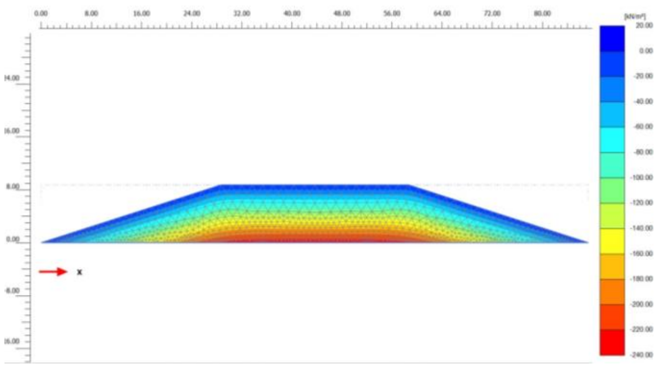

Fig. 9 Vertical stress distribution from PLAXIS data

4.4 Dynamic Loads And Stability

Calculations showed that vibrations from high-speed traffic (6000 mm/s^2) reduced the slope stability factor by 25%. This confirms the need for stabilization techniques such as slope stabilization with geosynthetic materials or drainage systems [23].

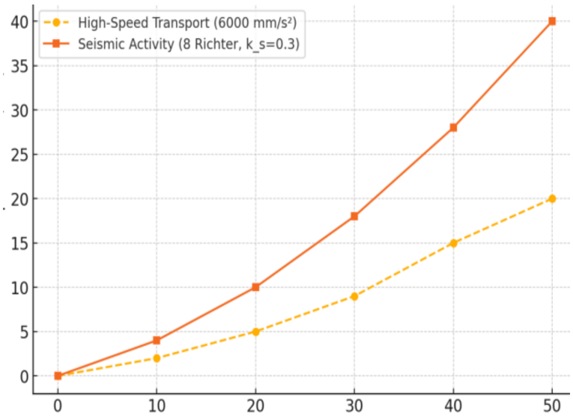

Fig. 10 Horizontal displacements of slopes

4.5 Development of Empirical Relationships

Based on experimental and numerical data, the following dependencies were proposed:
- dependence on slope angle (β):

$$\mathbf{F_s = 1.5 - 0.02 \cdot \beta} \tag{4}$$

β - slope angle (20^0-45^0).
- dependence on soil depth (H):

$$\mathbf{F_s = 1.2 - 0.01 \cdot H} \tag{5}$$

where H - slope height in metres.

4.6 Application of The Results

The results of the study can be used to design stable slopes in high seismic activity. For example:

For a 20 m high slope with a slope angle of 300, at 20% moisture content, the stability factor F_s will be 0.95. This requires additional measures such as reinforcing the soil or reducing the slope angle.

5. DISCUSSION

5.1 Geologic and Hydrogeologic Conditions of The Route

Due to the extreme complexity of the study area, the division into separate sections (PC 0-PC 83; PC 83-PC 210 and PC 210-PC 350) allowed for a more detailed study of soil conditions and parameters in different sections of the road. The inclusion of analysis of additional factors such as gas pipelines along the alignment, the NM34 overpass and adjacent areas significantly improved the accuracy of the slope stability predictions. Areas within forested areas were identified where forest sands are moving, which may affect the durability of the structures. In low-lying areas, the water table is close to the surface, which may also have an impact on slope stability as indicated in the studies by Petrov and Ryabov [24].

5.2 Seismic Steepness of Slopes

The following data was used to calculate the seismic resistance of the slopes:

-Seismicity of the area - 8 points (ks = 0.3);
-Duration of oscillations - 11 seconds;
-Dynamic impact of high-speed train movement - 6000 mm/s^2;
-The duration of the impact of the train movement is 2.26 seconds;
-Ground thickness at the base of the track - 35 m;
-Groundwater level along the route - 0.3-8.3 m.
Parameters of soils at the road base:
-Soil skeleton density - 1.86 t/m^3;
-Density of natural soil - 1.62 t/m^3;
-Maximum porosity - 47.2%;
-Maximum density - 38.9%;
-Internal friction angle - 26°;
-Total adhesion - 10.6 kPa.

The results of calculations showed that the slope steepness under seismic impact of 8 points (ks = 0.3) was tgα = 0.94, which corresponds to a slope angle of 43°. Under the dynamic impact of a high-speed train with an acceleration of 6000 mm/s^2, the slope steepness decreased to tgα = 0.47 (slope angle of 25°). These results confirm the findings from a study, who also showed a decrease in slope stability under dynamic and seismic impacts [25].

5.3 Comparison With Similar Studies

Current research confirms that slope stability is strongly influenced by seismic and dynamic effects. Zhabko (2024) and Gusev (2024) noted that when seismic wave intensity or vehicle speed increases, the slope steepness should be reduced to prevent possible collapses. For example, Jabko, in his paper on variational methods for calculating slope stability, noted that the use of modern numerical methods allows for more accurate consideration of the influence of these factors on slope stability [26].

Similar conclusions can be found in the research of Barvashov (2016), who in his work considers the influence of various structural elements on slope stability, including reinforced soil structures, which can further improve stability under seismic impacts [27].

5.4 Limitations and Uncertainties of The Study

Despite the high level of accuracy of the calculations, there are certain limitations and uncertainties that may affect the final results:

Variability of soil properties: Geologic conditions along the route may vary, which may lead to heterogeneity in soil properties. According to the study this requires additional experiments to better estimate soil properties under different conditions [28].

Limitations of Plaxis software: Although Plaxis software is widely used for slope stability calculations, it has its limitations, for example, when modeling complex soil conditions. In particular, modeling clayey or water-saturated soils may require additional calculations, as indicated research [29].

Uncertainties in impact parameters: Seismic impact parameters and dynamic loads can vary depending on many factors such as train speed and length of transportation train. Research also indicates the need for further refinement of these parameters to more accurately assess dynamic effects on slope stability [30].

5.5 Recommendations

To further improve the method for calculating the seismic stability of slopes, it is recommended that additional research be conducted in the following areas:

- evaluating the effects of different soil types, including water-saturated and clayey soils, on slope stability, as supported by the results [24];
- improvement of models to account for more complex soil characteristics under seismic and dynamic effects, as proposed [31];
- development of methods to better estimate dynamic impacts such as vehicle traffic, as proposed [25].

6. CONCLUSION

In the practice of operation of slope structures (hydroelectric power plants, road and railroad embankments, dams, etc.) there are often cases of damage to these objects during strong earthquakes with large economic losses. Analysis of most protective measures aimed at ensuring the stability of slopes does not always give the expected results due to limited operating conditions, insufficient development of construction technologies, and other factors.

This paper proposes a method of slope design taking into account soil behavior under seismic effects, the essence of which lies in the correct determination of the slope steepness, on which depends not only static, but also dynamic stability of the slope during the entire period of operation.

The essence of the method of “Seismic resistant slope steepness of slope structures” is as follows:

-the seismic resistant slope steepness depends primarily on the magnitude and components of seismic acceleration: as the seismic acceleration increases, the slope steepness decreases;

-the mechanical properties of soils (φ, cv, t) play a key role in the seismic stability of the slope.

The stresses (σ_{din}) developed in the soil column from the external load (p) and self-weight of the soil ($\gamma w.\ H$) have a positive effect on the seismic stability of the slope steepness. As the slope steepness increases, its stability increases.

The dynamic pressure hz, also affects the slope stability. In cases when $hz = \sigma_{\text{din}}$, the soils on the slopes can completely change to the state of liquid soil with the manifestation of landslides.

The stability of slope steepness depends on the dynamic action (ac), and as this action increases, a higher slope steepness is required. Acceleration components such as frequency (f) and amplitude (A) also significantly affect the slope stability. At the same time, as the duration of oscillation increases, the slope steepness decreases.

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