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Geotechnical Assessment and Stabilization of a Rocky Slope for Residential Construction in Tbilisi, Georgia

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ABSTRACT
Constructing stable residential structures on natural slopes with complex geological and hydrological conditions presents significant challenges, especially in seismically active regions like Georgia. This study focuses on a planned construction project in Tbilisi, between Lake Lisi and Vashlijvari, where multiple buildings are planned on a rocky slope. The site's stability is influenced by unfavorable stratification of sandstone and argillite, which are subject to surface erosion and groundwater infiltration in bedding joints.

The primary objective is to assess the stability of the rock slope qualitatively and quantitatively. Key factors analyzed include rock orientation, geological fractures, groundwater influence, and potential landslide planes. The investigation involved engineering-geological mapping, borehole drilling, and laboratory testing of rock and soil properties. Stability calculations considered stress changes due to excavation, groundwater effects, and seismic forces.

Based on the analysis, engineering solutions were proposed, including rock anchoring, retaining walls, protective nets, and drainage systems. These measures aim to mitigate slope instability and ensure the structural safety of the project. The study provides a framework for addressing geotechnical challenges in complex terrains, contributing to sustainable urban development.

Keywords: Slope Stability, Geotechnical Investigation, Rock Mass Stabilization, Structural Safety Measures

Introduction

Constructing stable residential structures on natural slopes with complex geological and hydrological conditions presents significant challenges, particularly in seismically active regions such as Tbilisi, Georgia. The planned construction site, located between Lisi Lake and Vashlijvari, consists of multiple residential buildings positioned on naturally rocky slopes. This terrain presents stability risks due to varied soil composition, geological fractures, groundwater infiltration, and seismic vulnerability, raising concerns about long-term structural integrity and occupant safety [1].

The primary focus of this study is the stability and strength of the rocky slopes supporting the construction pits. The site's complex engineering-geological conditions—fractured rock masses, variable soil layers, and groundwater presence—pose significant risks to slope stability. Critical factors such as the dip and orientation of rock layers, groundwater influence, and potential sliding planes increase the likelihood of slope failure.

To address these concerns, this study involves a comprehensive geotechnical investigation, including borehole drilling, rock and soil sampling, and site mapping to classify rock formations and assess subsurface conditions. The results inform engineering decisions on the site's bearing capacity, moisture content, and

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mechanical properties of soil and rock layers, which are essential for designing stable structures.

The research aims to develop effective engineering solutions to mitigate slope instability while minimizing environmental impact. Proposed stabilization techniques include retaining walls, soil anchors, drainage systems, and waterproofing measures to enhance structural resilience. By addressing these geotechnical challenges, this study supports safe and sustainable construction practices in complex terrains, ensuring long-term stability while preserving the surrounding environment [2].

The study aims to evaluate the stability and strength of rocky slopes supporting construction pits at the site. Key research objectives include:

- Investigating engineering-geological conditions such as fractured rock masses, variable soil layers, and groundwater influence.
- Assessing slope stability risks based on rock orientation, slope gradient, and groundwater presence.
- Developing geotechnical recommendations to ensure construction safety.

Figure 1: Study area map

Literature Review

Overview of Geotechnical Studies on Natural Slopes The Stability assessment of natural slopes has been widely studied using various geotechnical methodologies, including limit equilibrium methods and finite element modeling. Research has highlighted the importance of geological structures, hydrogeological conditions, and material strength in determining slope stability [3].

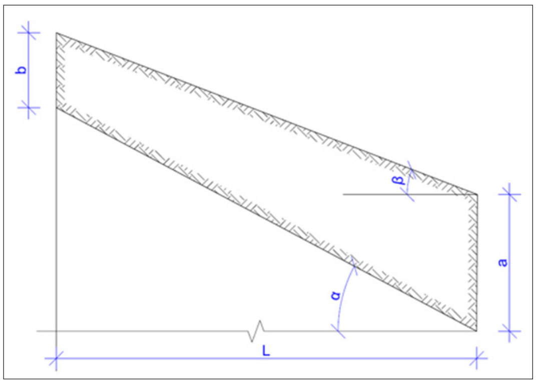

Figure 2: Slope stability model

$$Q.\cos\alpha tg\varphi + c\frac{L}{\cos\alpha} = Q\sin\alpha$$

Where:
Q - weight of the slid rock mass;
α - angle of the sliding plane to the horizon;
φ - Internal friction angle on the sliding surface;
c - specific cohesion

Studies on pile foundations in rocky formations emphasize the influence of rock mass fracturing, bedding plane orientation, and groundwater presence. Various stabilization techniques, such as reinforced concrete piles and deep foundation anchoring, have been proposed to counteract instability.

Several approaches exist for stability assessment, including the Rock Mass Rating (RMR) system, Geological Strength Index (GSI), and kinematic stability analysis. Past research has demonstrated that stability conditions can be effectively modeled using a combination of these methods [4].

Methodology

The site is characterized by alternating layers of Middle and Upper Oligocene sedimentary rocks, primarily composed of sandstones and mudstones. The area has a complex tectonic setting with dip azimuths ranging between 110° and 170° and dip angles varying from 10° to 65°.

Geotechnical investigations include:

- Borehole drilling (31 boreholes, 8-19m depth)
- Engineering-geological mapping
- Laboratory testing for soil and rock mechanical properties

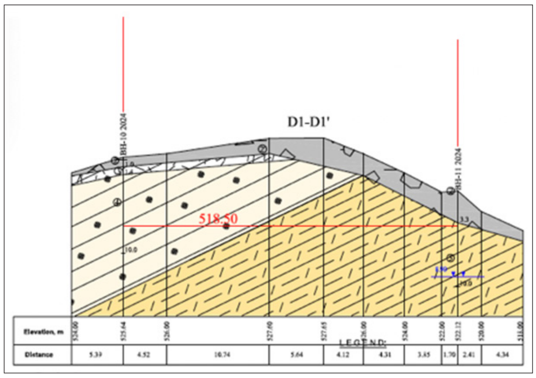

Figure 4: Geological cross-section of the study area

For Example: The cross-section displays a sandstone and mudstone combination with a slope angle of 51.8°, which may impact slope stability.

Results and Discussion

Analysis of Geotechnical Data

Internal friction angles range from 17.8° to 18.7°.
Cohesion values range from 0.046 MPa to 0.065 MPa.
Groundwater levels range from 1.75m to 13m across boreholes.

Stability of Construction Piles in Rocky Slopes

Borehole data indicate variability in soil stiffness and density.
Lower-density areas require additional foundation reinforcement.
Stability reliability coefficient K ranges from 0.96 (unstable) to 1.4(stable).

Table 1: Borehole data

Building (block)	Borehole No.	Coordinates		Final depth, m	Total depth, m each block
		X	Y		
A-G	1	479483.492	4620302.939	14	47
A-B	2	479515.850	4620275.160	12	
A	3	479470.373	4620279.175	10	
A-B	4	479527.731	4620259.805	11	
B	5	479556.029	4620267.711	11	20
	6	479553.557	4620249.798	9	
C	7	479561.224	4620225.241	9	19
	9	479599.203	4620215.773	10	
C-D	10	479603.209	4620233.779	10	40
D	11	479617.984	4620263.255	10	
	12	479618.990	4620225.725	10	
	13	479634.751	4620256.876	10	
E	14	479585.600	4620309.973	12	30
	15	479593.185	4620271.359	8	
	16	479602.672	4620305.203	10	
F	17	479522.373	4620359.110	19	79
	18	479565.816	4620323.077	13	
	19	479511.735	4620342.865	17	
	20	479554.131	4620308.015	12	
	21	479538.579	4620333.437	18	
G	22	479462.820	4620340.031	16	39
	23	479495.558	4620327.350	14	
	24	479458.025	4620324.034	9	
H	25	479472.161	4620368.447	13	59
	26	479517.261	4620400.937	14	
	27	479483.435	4620353.107	8	
	28	479525.867	4620386.898	10	
	29	479500.239	4620377.468	14	
Courtyard	30	479630.938	4620296.203	11	20
	31	479542.165	4620213.386	9	
	Final depth, m			353	353

Table 1: provides detailed data on boreholes drilled across various building blocks (A-G, Courtyard) for geotechnical analysis. Each borehole is identified by its unique number, with specific coordinates (X, Y) and final depth in meters

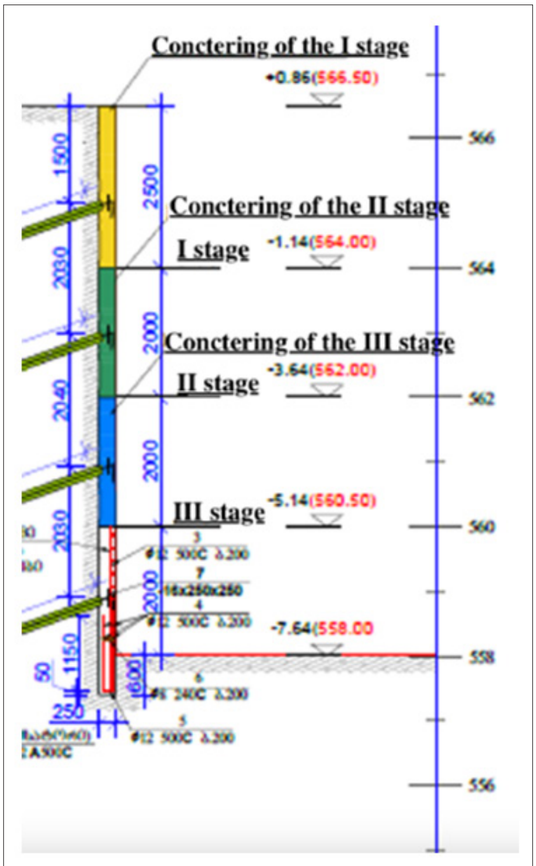

Figure 5: Structural reinforcement details multi-level construction

Concreting Stages: The diagram is divided into three distinct concreting stages, each representing a separate level:

I Stage (Uppermost Section): Concreting is conducted at the highest elevation, forming the first structural layer.

II Stage (middle section): Concreting takes place in the section immediately below the I Stage, effectively anchoring the first stage while preparing the foundation for the next layer.

III Stage (Lowest Section): Concreting is completed at the lowest elevation, which provides the base support for the structure above.

Structural Reinforcement

The diagram highlights the arrangement and specifications of reinforcement bars (rebar) used at various levels:

Rebar types are labeled with notations such as Φ12 50^0C and Φ16 24^0C, indicating the diameter and grade of reinforcement used at each stage.

Both horizontal and vertical reinforcement positioning is detailed, showing how reinforcement density and orientation vary with depth to address load distribution and structural requirements.

The placement of rebar in strategic positions ensures that each stage can bear the weight of subsequent layers and withstand external forces, providing both stability and durability to the structure.

Based on field investigations, laboratory analysis, and literature review, the construction site is classified as Category III (Complex) due to the influence of geomorphological and geological-structural factors. The area, located on the southeastern hillside of Lisi Ridge, consists of alternating layers of Middle and Upper Oligocene sandstones and mudstones. The dip of these rock layers generally aligns with the natural slope, and the site is characterized by three well-defined joint systems, which impact overall stability [5].

Groundwater was detected at varying depths across multiple boreholes, indicating that many building foundations will be located in an aqueous rock environment. In addition to natural factors, artificial sources such as leaks from utility lines and irrigation may contribute to water encroachment. To mitigate these risks, appropriate drainage systems must be implemented under building foundations, along with waterproofing measures for substructures in contact with water-bearing soils and rocks.

Surface water runoff, particularly during heavy rainfall, poses an additional challenge, requiring the design and installation of an effective collection and drainage system to prevent infrastructure damage. The site's groundwater chemistry shows moderate sulfate aggressiveness (XA2) to concrete, with isolated cases of high aggressiveness (XA3), necessitating the use of sulfate-resistant concrete in certain areas [6].

Seismic assessment indicates an intensity of 8 on the MSK64 scale, requiring adherence to earthquake-resistant construction standards. While the natural slope remains stable, excavation of construction pits may disturb equilibrium, increasing the risk of landslide-gravitational processes, particularly in buildings C, D, E, F, G, and H. To ensure stability, excavation slopes should be reinforced with anchors, shotcrete, and wire mesh where necessary [7,8].

Stability calculations reveal that some construction pit slopes are unstable (K<1), making reinforcement essential. Strengthening measures, including anchored retaining walls and reinforced concrete structures, must be implemented in accordance with site-specific engineering-geological conditions. Additionally, careful planning of access roads and internal development roads should account for slope stability to ensure long-term safety and sustainability of the development.

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