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Generation of a Susceptibility Map with Geomechanical Soil Data in the Southwestern Zone of Loja Ecuador

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Abstract **-** This study's objective is to develop a susceptibility map based on the geomechanical characterization of soils in the southwestern region of Loja, with a special focus on assessing their bearing capacity. This project is critical for the planning and designing of infrastructure, particularly in areas with complex geological conditions.

Geomechanical characterization involves identifying and analyzing various physical and mechanical properties of the soil, such as texture, structure, density, and strength, through a combination of field studies and laboratory tests. The methodology begins with the collection of geological and geotechnical information, followed by specific geotechnical studies. For this investigation, Dynamic Cone Penetrometer (DCP) and Standard Penetration Test (SPT) were employed, alongside lithological and geological surveys to identify different formations and lithologies in the area.

The results will allow the creation of a geomechanical characterization map, which will serve as an essential tool for engineers, architects, and urban planners. This map optimizes structural design and minimizes risks associated with geotechnical failures. In summary, the bearing capacity map, complemented by laboratory and field studies, demonstrates that the area's lithology is suitable and offers favorable conditions for expanding the urban cadastral boundaries in Loja.

Keywords**:** Bearing capacity, geomechanical, infrastructure, planning.

1. Introduction

Geomechanical soil characterization is a critical component in civil engineering, providing essential data on the physical and mechanical properties of soils, such as texture, structure, density, and strength. This information is crucial for the planning and design of infrastructure, particularly in areas with complex geological conditions [1]. The assessment of soil bearing capacity is vital for determining its ability to support loads and resist deformations, which is key for informed decision-making in land use and foundation design.

This study aims to develop a susceptibility map that evaluates the bearing capacity of soils in the southwestern region of Loja, utilizing Dynamic Cone Penetration (DCP) tests and Standard Penetration Tests (SPT). Data on the California Bearing Ratio (CBR) and bearing capacity will be obtained from these tests, allowing the creation of a detailed geomechanical model for the area. The methodology includes the collection of existing geological and geotechnical data, as well as field surveys and laboratory analysis of the collected soil samples [2].

The results of this research will not only contribute to advancing the geotechnical understanding of the region but will also provide a solid foundation for future infrastructure projects. The generated maps will serve as valuable tools for engineers, architects, and urban planners, enabling the optimization of foundation design and minimizing geotechnical risks[3]. In conclusion, this study has the potential to significantly contribute to the development of safe and sustainable infrastructure, fostering responsible and resilient urban growth.

2. Generation de information geology y geomechanics

Subsurface characterization is an essential process in civil and geotechnical engineering, as it provides critical information about the composition, structure, and properties of the ground, which are fundamental for the design of foundations, slopes, and other infrastructures. The proper generation of lithological and geological information allows for an understanding of soil conditions and their behavior under loads and other structural demands [4]. This process is based on a combination of field studies, laboratory analyses, and geological modeling, ensuring the acquisition of accurate and relevant data for decision-making in engineering projects. This article presents a systematic methodology that encompasses everything from research planning to sample collection and subsequent analysis, thus contributing to a precise characterization of the subsurface [5].

2.1. Lithological survey

To carry out a systematic and detailed lithological survey, a rigorous process was implemented that included comprehensive data collection, intensive fieldwork, and thorough analysis of the gathered information. This approach is crucial for the study of soil mechanics and for gaining a deep understanding of the geological characteristics of the area of interest.

The survey began with the acquisition of the Digital Terrain Model (DTM) of the city of Loja, which served as a key tool for work planning. In the initial phase, previous geological studies and lithological maps of the region were reviewed, providing a comprehensive view of both regional and local geology. This preliminary information was essential for organizing field expeditions, during which direct observations of outcrops and surface soils were made. During these visits, geological contacts were recorded, and representative samples of the various lithologies present in the study area were collected [6].

This approach ensured that the information obtained was accurate and representative, thereby facilitating a detailed understanding of the geomechanical behavior of the soils and the geological conditions of the site.

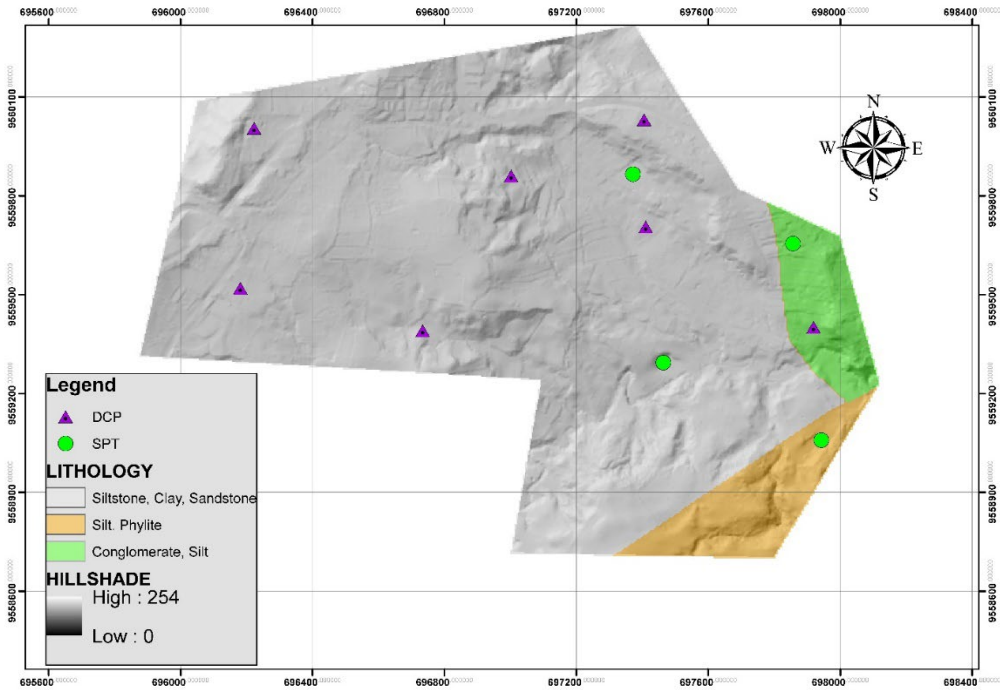

Fig 1: Lithological map

2.2. Generation of a slope map

A slope map is an essential tool in geotechnical studies and land use planning, as it allows for the precise identification identification and representation of terrain inclination. This analysis is key for assessing landslide risks, planning infrastructure works such as roads, bridges, buildings, and drainage systems, as well as for defining safe and suitable areas for construction. Furthermore, it facilitates land use management by identifying zones with restrictions for urban or industrial development due to their slope. Slope maps are also crucial in evaluating the stability of slopes and in designing cuts and fills in civil engineering projects [7].

In this context, ArcGIS was utilized for the creation of the map, providing an advanced platform that enables the processing of data from the Digital Elevation Model (DEM), generating slopes with precision, and applying symbologies that facilitate data interpretation. Thus, the slope map becomes an indispensable tool for engineering project planning, ensuring a safer and more efficient development.

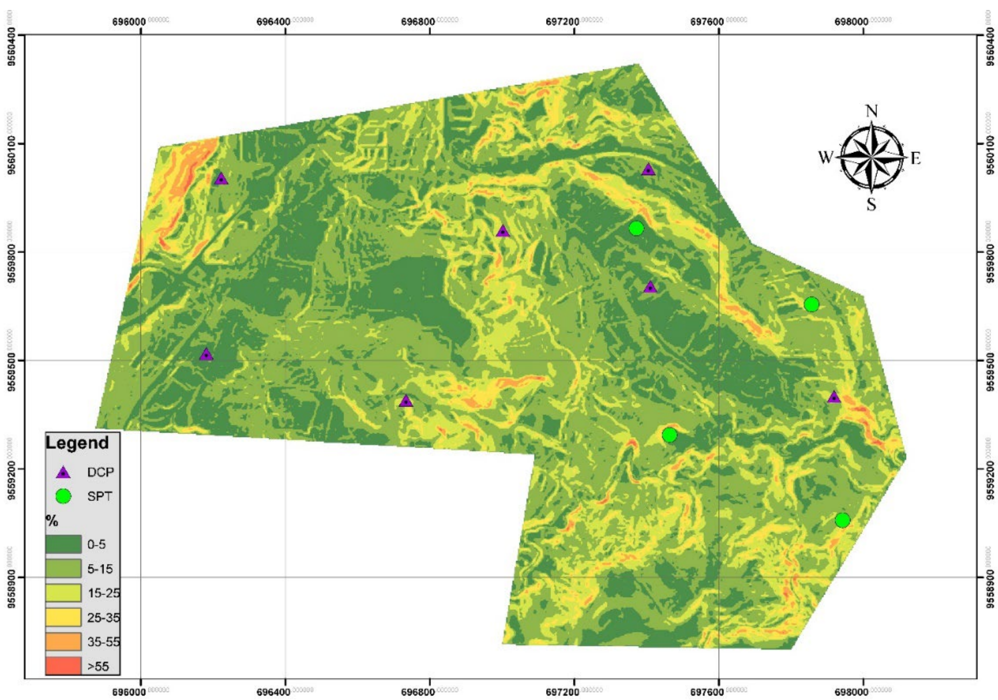

Fig 2: Slope map

2.3. Generation of geomorphological unit’s map

A map of geomorphological units is a key tool in geological and environmental studies, as it allows for a clear and visual representation of the different landforms and the processes that have shaped them. This type of analysis is fundamental for understanding landscape dynamics, identifying areas prone to erosion, landslides, or flooding, and planning land use sustainably. Furthermore, geomorphological unit maps are essential for assessing natural hazards and making decisions in infrastructure projects, environmental conservation, and water resource management[8].

In this context, ArcGIS was used for the creation of the map, leveraging its capability to integrate geospatial data, perform topographic analysis, and apply effective symbologies that facilitate the interpretation of geomorphological units. This enhances the process of territorial planning and management.

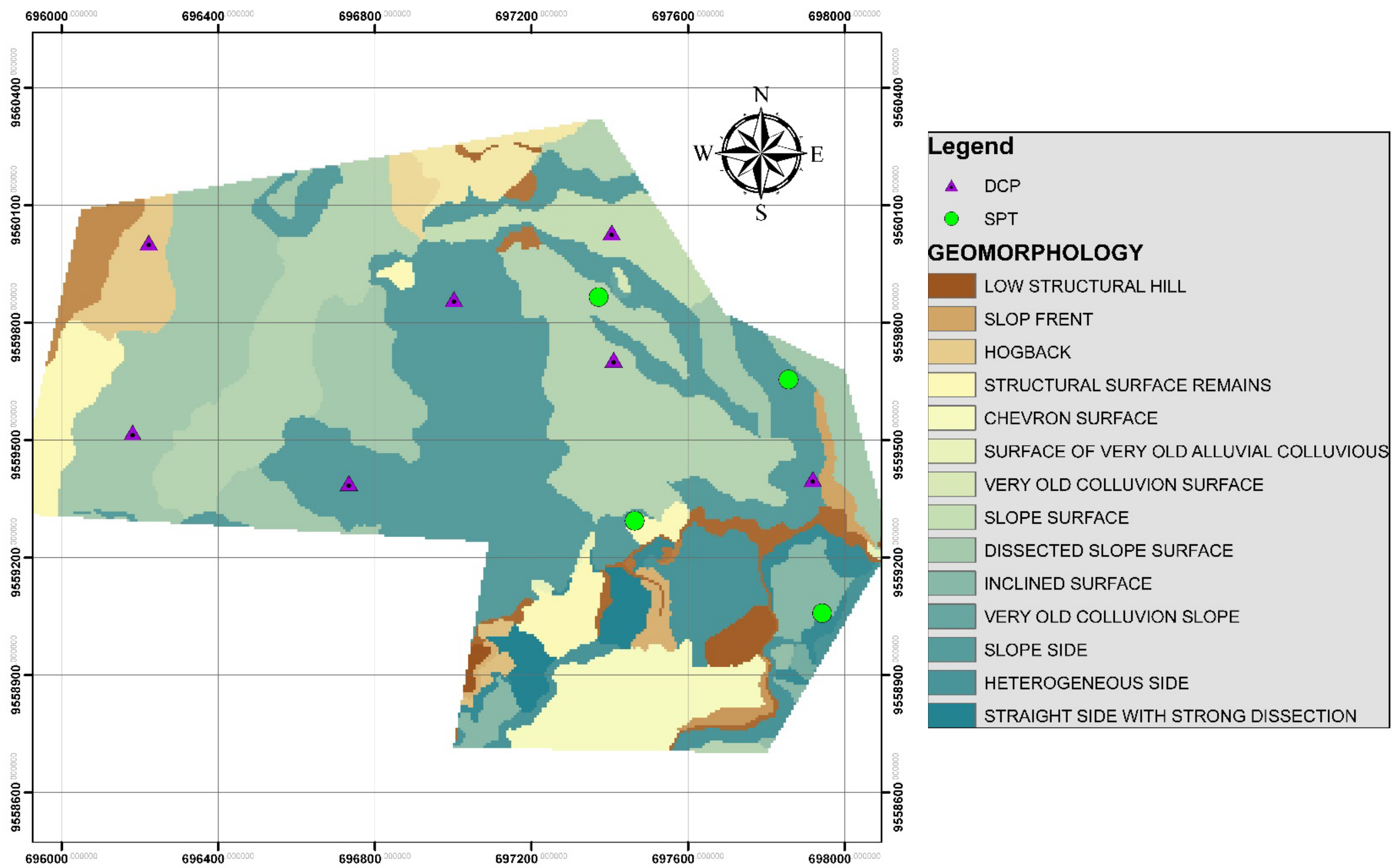

Fig. 3: Geomorphological map

2.4. Analysis of geomechanical characteristics

2.4.1. SPT test

Standard Penetration Tests (SPT) were conducted at four predefined locations, selecting specific areas of interest for each test. The first test (SPT 1) was performed in a sector with nearby buildings within the reference area, aiming to assess the existing structural integrity of the site. Similarly, the second test (SPT 2) was executed in the Borja neighborhood, providing relevant data on the mechanical properties of the soil, with potential applications in engineering [9]. The remaining SPTs (SPT 3 and SPT 4) were conducted in areas without existing constructions, yielding valuable information for future civil engineering projects.

SPT tests are fundamental for identifying various geotechnical parameters of the soil, including soil type, stratigraphy, relative density, and compressibility at different depths. However, their greatest utility lies in determining the bearing capacity of the ground, which is assessed by measuring the number of blows, the internal friction angle, and cohesion. This information is essential for ensuring the proper design and execution of the proposed structures, as well as for maintaining the stability of the ground on which they are founded [10].

Fig. 4: SPT Test

2.4.1. The Dynamic Cone Penetrometer (DCP)

The Dynamic Cone Penetrometer (DCP) test provides valuable information that complements conventional compaction control methods, allowing for a reduction in the time dedicated to construction monitoring in soil compaction projects [11]

Fig. 5: DCP Test

The geotechnical exploration of the soil was conducted in the subgrade through open-pit excavations, reaching a depth of -1.00 m relative to the current ground surface. At each of these locations, the subsoil structure was determined by sampling the present materials.

At each site, field California Bearing Ratio (CBR) values were determined using the Dynamic Cone Penetrometer (DCP) following ASTM D6951-03. During the field phase, the DCP test was executed at each sampling point, achieving a maximum of 40 blows at various depths. The available excavations were used to extract samples for laboratory testing, which was carried out to a depth of 100 cm[11].

2.. Generation of a susceptibility map

Slope instability, landslides, and other adverse geological phenomena are significant concerns in geotechnical engineering. This type of map provides a comprehensive overview of the terrain's susceptibility, based on factors such as geology, slope, land use, and climatic conditions. By incorporating geomechanical data derived from field tests such as the Dynamic Cone Penetrometer (DCP) and the Standard Penetration Test (SPT), the accuracy of the map is significantly enhanced, allowing for a detailed characterization of the subsurface.

These tests provide critical information regarding the strength and compaction of the soil, facilitating the identification identification of areas with lower bearing capacity or greater vulnerability. Together, this approach offers an essential tool tool for decision-making in the planning and design of infrastructure projects, as well as for mitigating geotechnical risks risks [12].

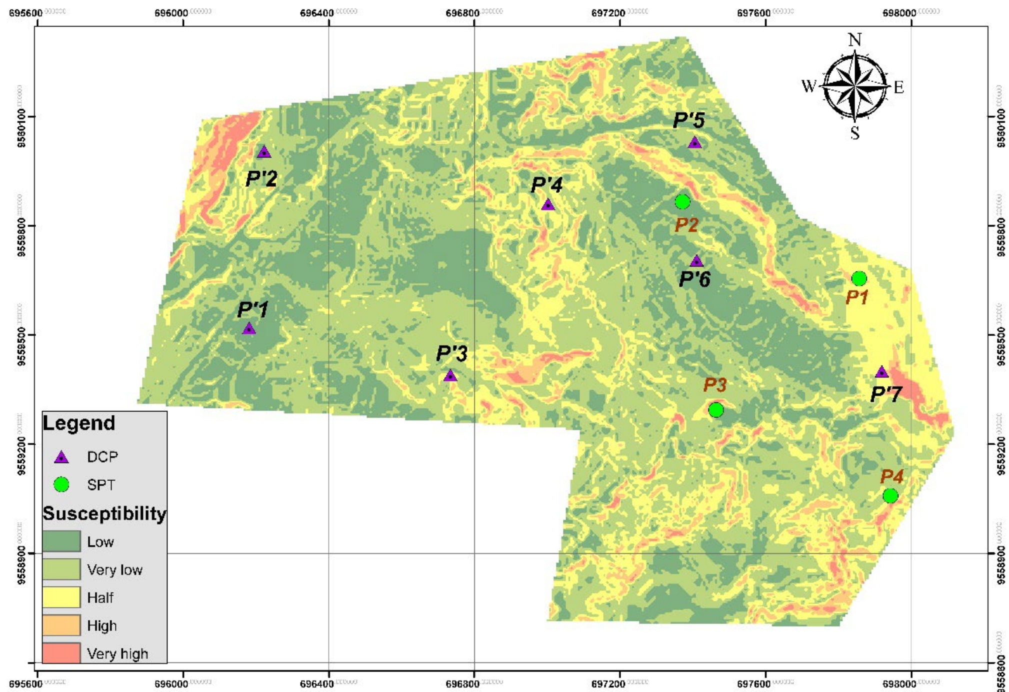

Fig. 6: Susceptibility map

Tables 1 and 2 present the laboratory results obtained from the various tests, including both the Dynamic Cone Penetrometer (DCP) and the Standard Penetration Test (SPT). Additionally, it shows the degree of vulnerability to mass movement at the different sampling points where the tests were conducted.

Table 1: SPT test results

Samples	Qad	Lithology	Vulnerability
P1	12,40 Tn/m²	Low plasticity slime type ML	Half
P2	11,70 Tn/m²	High plasticity slime type ML	Very low
P3	11,76 Tn/m²	High plasticity silt with sand-type	Low
P4	11,62 Tn/m²	High plasticity slime type ML and MH	Half

Table 2: DCP test results

P'1	7.4	Low plasticity silt with ML sand	Low
P'2	3.4	Low plasticity silt with ML sand	Low
P'3	5.4	Low plasticity silt with ML sand	Half
P'4	8.2	Low plasticity silt with ML sand	Half
P'5	8.5	Low plasticity silt with ML sand	Low
P'6	8.9	Low plasticity silt with ML sand	Low
P'7	9.2	Low plasticity silt with ML sand	Half

3. Discussion

When comparing the results of the Dynamic Cone Penetrometer (DCP) and Standard Penetration Test (SPT), it is observed that both provide similar estimates of the soil's bearing capacity. A study conducted in Mexico reported CBR values ranging from 3% to 9%, while the standard penetration resistance obtained with SPT varied between 1.8 and 6.2 tons/m². This evidence demonstrates that both DCP and SPT are effective and complementary tools for assessing soil strength, providing reliable data for geotechnical design and planning.

According to the Ecuadorian Construction Code, a live load of 200 kg/m² is established for residential buildings. In a reinforced concrete system, the permanent load is 622 kg/m², and when applying the corresponding load combinations, the maximum combination (1.2CD + 1.6CV) results in a total load of 11.1 tons/m². This value will be used as a reference to compare the load capacities obtained in the research. The results indicate that the construction of single-family homes is feasible, provided that the number of stories recommended by the municipality is adhered to and necessary soil improvements are implemented.

In the city of Loja, a study evaluated the load-bearing capacity of lime-stabilized soils through CBR tests. The results showed a notable increase in CBR values after stabilization, which aligns with the findings of the present investigation. This increase indicates an improvement in soil-bearing capacity, which is essential for the viability of construction projects.

In the study, soil characteristics were considered according to the consistency table. Standard Penetration Tests (SPT) were conducted to identify and classify the types of soil found in different boreholes:

- **SPT No. 1**: Identified as low plasticity silt with sand (type "ML").
- **SPT No. 2**: Found to be high plasticity silt (type "MH").
- **SPT No. 3**: Observed two strata: high plasticity silt with sand (type "MH") in the first 2 meters, and low plasticity silt (type "ML") from 2 to 6 meters.
- **SPT No. 4**: Similar to SPT No. 3, with two strata of high plasticity silt (type "MH"), but with sand in the first 2 meters.

4. Conclusions

The results obtained from the DCP tests indicate that the soils in the study area exhibit bearing capacities ranging from acceptable to good, with CBR values between 3.4% and 9.2%, and an average of 6.9%. These values are adequate for the construction of single-family homes, provided that appropriate soil improvements are made in areas with lower CBR values. The overall feasibility of residential development in the area is high, contingent upon the implementation of the recommended geotechnical improvements.

The analysis of the susceptibility map and geomechanical characterization shows that the allowable bearing capacity of the soil ranges from 1,240 to 1,620 kg/cm², which is in line with the requirements for low to medium-complexity residential construction. The low susceptibility to mass movements observed in the area further enhances the stability of the ground and significantly reduces the risk of geotechnical failures that could compromise the safety of the proposed structures.

For projects involving more complex or larger structures, the geotechnical conditions of the area may not be sufficient. In these cases, additional soil improvement techniques, such as cement grouting or the installation of piles, will be necessary to ensure the stability and strength of the infrastructure. Implementing these techniques not only optimizes the bearing capacity but also mitigates potential risks related to settlement or differential subsidence, which are critical for the safety and durability of the construction.

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