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Design Of Building In Area Susceptible To Slide Failure

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Abstract **-** There has been a significant amount of damage and destruction caused by geotechnical failures in Ecuador. To determine the terrain's characteristics and design an adequate foundation, it is necessary to conduct a soil survey before starting a construction project. During soil exploration and characterization, standard penetration tests (SPT) were performed to identify the depth of firm soil. An unconsolidated triaxial (U-U) test was also performed to evaluate the shear strength of fine and coarse soils. In addition, the Unified Soil Classification System (USCS) was used to describe the texture and particle size in the study area.
Taking into account a building with three floors and occupational use as family housing, it was, therefore, necessary to determine the dead, live, and seismic loads in accordance with the NEC-15 SD-DS (Ecuadorian Construction Standard, Seismic Loads and Earthquake Resistant Design), the ETABS software was used, which allowed determining the moments and maximum loads, which made it possible to select an appropriate type of foundation. After considering the results of the tests, aspects of functionality and economy, it was concluded that the surface foundation is the most appropriate for this type of building and the characteristics of the study area. The objective of this applied research is to gather the necessary knowledge to provide a solution to the problem of soil instability faced by owners in the Punzara sector, Urbanization AGEUL, in the southwestern area of Loja. Providing an adequate foundation that can withstand any geotechnical challenges present in the area is key to guaranteeing the safety and stability of buildings in the region.

Keywords**:** geotechnical faults, superficial foundation, soil study.

1. Introduction

Geotechnical failures in Ecuador have caused significant damage and destruction, highlighting the importance of conducting soil studies prior to initiating any type of construction. This study analyses ground instability in the southwestern part of the city of Loja, specifically in the AGEUL Urbanization of the Punzara sector. The research included laboratory tests to determine the soil characteristics, which were found to be a mixture of silts and clays, classified as low-plasticity clay (CL) according to the Unified Soil Classification System (USCS). Parameters from the NEC-15 SD-DS regulations were applied, considering a three-story residential building. For the analysis of moments and maximum loads to which the structure would be subjected, the commercial software ETABS was used.[1]

The results of the tests and the application of the regulations demonstrated that, given the conditions and characteristics of the study area, shallow foundations are the most suitable solution for three-story residential constructions in the area. This conclusion is based on the need to address the specific characteristics of the terrain and ensure the stability of the building in the face of potential seismic and geotechnical events. The choice of this foundation is supported by NEC-15 SD-DS standards and the detailed analysis carried out using commercial software.[2]

2. Methodology

The Load and Resistance Factor Design (LRFD) method is selected for projects that require maximizing material efficiency, particularly in large-scale structures or critical infrastructure. It is also preferred when a more stringent and adaptable level of safety is needed for different types of loads, especially under extreme conditions such as earthquakes and storms. LRFD is commonly used when mandated by building codes or when an efficient and safe design is sought to account for variations in loads and resistances. The research follows a structured methodology that includes exploration and reconnaissance of the study area, a topographic survey, soil study, and building modeling with foundation design. Each of these phases is essential to ensure the safety, stability, and efficiency of the proposed construction.[3]

In the exploration and reconnaissance phase, a detailed analysis of the site and general soil conditions is conducted. This involves reviewing historical records, recent landfills, geotechnical failures, past excavations, and nearby watercourses. Understanding the type of structure to be built and its intended purpose is crucial, along with an estimation of loads and spacing requirements. Compliance with local construction codes and regulations provides a framework for defining the design parameters, ensuring that the project aligns with environmental conditions and engineering standards.[4]

During the topographic and planimetric survey, direct mapping techniques are employed to define the terrain's boundaries, adjacent buildings, and access roads. The geographical coordinates of the site are captured and transferred to Civil 3D software, where the polygon is georeferenced to create an accurate digital terrain model. This step is crucial for precise planning and engineering analysis. The geospatial representation ensures compliance with technical standards and considers potential urban development, allowing for a well-integrated and future-proofed infrastructure design.[5]

The soil study involves both field and laboratory tests to determine the geotechnical properties necessary for foundation design. This is particularly important for a three-story residential building, where soil stability and consistency must be assessed. Laboratory tests provide detailed insights into properties such as density, moisture content, compressive strength, and permeability. The equipment and testing facilities provided by the Universidad Técnica Particular de Loja ensure accuracy in data collection and analysis.

The Standard Penetration Test (SPT) is conducted to evaluate the soil's bearing capacity. This test records the number of hammer blows required to penetrate the soil, offering essential geotechnical data. The procedure involves site preparation, equipment setup, drilling, and sample extraction at a depth of three meters, reaching a stable soil layer. Laboratory tests, including quartering and wet sieving (ASTM D1556-64), Atterberg limits determination (ASTM D4318), and moisture content analysis (ASTM D2216), further characterize the soil. Classification using the Unified Soil Classification System (USCS) (ASTM D2487) identifies the soil as inorganic clay of low to medium plasticity (CL). Additionally, an unconsolidated undrained triaxial test (U-U) following NEC-SE-GM (2015) standards is conducted to evaluate shear strength, critical for structural design decisions.[6]

Building and foundation modeling is performed using ETABS, following NEC 15 regulations that govern non-seismic loads (NEC-SE-CG), seismic-resistant design (NEC-SE-DS), and geotechnical foundation requirements (NEC-SE-GC). Structural concrete design adheres to ACI 318-14 standards to ensure compliance with safety and strength regulations. The process begins with data collection, incorporating architectural plans, material specifications, and structural details. Materials used include concrete with a compressive strength of $f'c = 210$ kg/cm^2 and reinforcing steel with a yield strength of $fy = 4200$ kg/cm^2. The design accounts for dead loads, live loads, seismic loads, and wind loads, ensuring that the structural system meets all necessary performance and safety requirements. By following these standards, the building and its foundation are designed to withstand anticipated loads, ensuring structural integrity and long-term stability.[7]

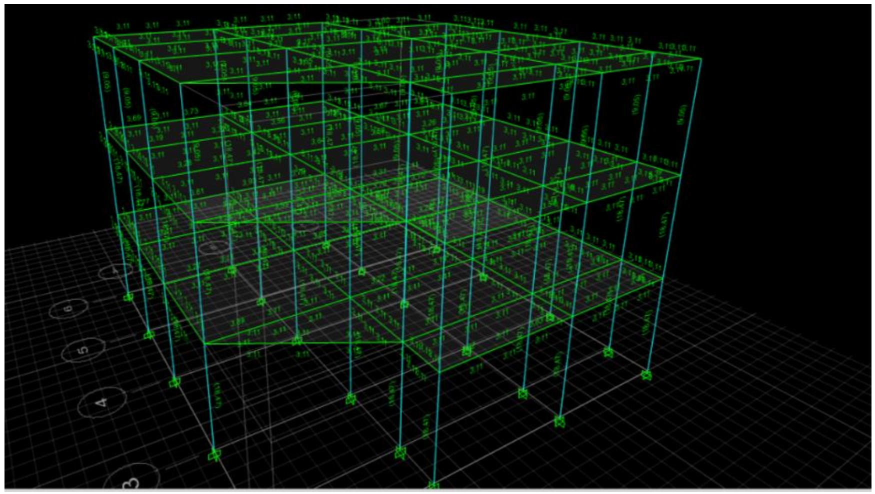

Fig 1. The **materials and dimensions** of the structural elements in this project have been carefully selected to meet both **sizing and safety** requirements, in accordance with NEC 15 regulations and ACI 318-14 standards.

The verification of the structural model in ETABS is a critical step to ensure compliance with NEC 15 regulations and ACI 318-14 standards, focusing on structural safety, efficiency, and seismic performance. Load applications, including dead, live, wind, and seismic loads, must be accurately assigned and combined to reflect real conditions. Structural integrity checks confirm that beams, columns, and slabs meet strength and serviceability requirements, particularly under lateral forces. Seismic compliance is assessed according to NEC-SE-DS, ensuring that inter-story drift and deflections remain within permissible limits to prevent excessive deformations. The foundation design plays a fundamental role in structural stability, considering geotechnical parameters such as soil classification, bearing capacity, and settlement behavior. The geotechnical study determined an allowable bearing capacity of **1.10 kg/cm²**, classifying the soil as silty clay with an **18-degree friction angle**, requiring an adequate foundation system. Initially, an **isolated footing of 1.50 x 1.50 meters** was proposed as a cost-effective solution, ensuring sufficient load distribution. However, structural analysis indicated insufficient rigidity, requiring an increase in footing thickness to comply with **rigid foundation behavior criteria**. Further analysis recommended increasing the footing size to **1.65 x 1.65 meters**, ensuring resistance to overturning and shear while optimizing reinforcement distribution and minimizing excessive material usage. This approach integrates structural analysis, geotechnical data, and footing design considerations to ensure the **building's stability under expected loads and seismic demands**, adhering to international engineering standards and best practices.

3. Results and Discussion

The vibration period of the structure, obtained from commercial structural analysis software, is **T = 0.42**, while the value calculated in Excel for the design spectrum is **0.40**. According to NEC-15 regulations, the period must fall within the range of **T to T × 1.3**, which results in an interval of **0.40 - 0.52**, confirming that the obtained value is appropriate. The base shear was determined to be **11%**, significantly below the regulatory limit of **85%**, ensuring compliance with seismic safety requirements. Additionally, an evaluation of foundation design in accordance with the **2015 Ecuadorian Construction Regulations** determined that **party wall footings are not required**, as there are no adjacent structures and the total plot area (**400 m²**) and construction area (**167.5 m²**) meet the regulatory criteria. Consequently, the use of **isolated footings** was deemed the most suitable option, ensuring structural **stability, cost efficiency, and compliance with geotechnical conditions**

Table 1: Maximum Settlements

Type of Construction	A max
(a) Buildings with walls and finishes susceptible to damage from minor settlements.	L/1000
(b) Buildings with load-bearing walls in concrete or masonry.	L/500
(c) Buildings with concrete frames, without finishes susceptible to damage from minor settlements.	L/300
(d) Buildings with a metal structure, without finishes susceptible to damage from minor settlements.	L/160

To verify this settlement control, Table 1 is employed, which is designated for the type of structure defined in subsection c, characterized by concrete frames and no finishes susceptible to damage from minor settlements; for this purpose, the value of L is taken as the maximum distance between columns, which is 4.5 meters or 450 mm (L is expressed in mm in the table), and upon performing the calculation, a maximum settlement of 1.5 mm is obtained by dividing 450 mm by 300 mm, which is below the recommended maximum value, thus maintaining the current design parameters for this structure. Additionally, the shear resistance check for the foundation shows a value of 34%, well within the maximum shear resistance value of 85% for irregular structures as established by the Ecuadorian Construction Regulations NEC-2015 in the seismic-resistant design section (NEC-SE-DS, 2015). Furthermore, the foundation satisfies another important Ecuadorian regulatory requirement that the ratio between the depth of the footing and the base or "B" should be less than or equal to 4, ensuring overall structural compliance with safety standards.[8]

$$\frac{D_f}{B} < 4\ ;\ \frac{3}{1.65} = 1.81 \quad OK \qquad \text{Ec. (1)}$$

The soil study recommends that suitable dimensions would be 1.50 x 1.50 meters, but these dimensions do not comply with force-based design. Then, a spreadsheet applying the current regulations suggested dimensions of 1.90 x 1.90 meters. However, by using the ZAPATAS software and considering functionality and economy criteria, it was determined that a foundation with dimensions of 1.65 m x 1.65 m meets the requirements.

Table 2: Minimum and maximum diameters of reinforcement bars. (NEC-15-SE-HM)

Type	Minimum bar diameter, db	Maximum bar diameter, dD
Corrugated bars	8mm	36mm
Wire for mesh	4mm	10mm
Stirrups	10mm	16mm

4. Conclusions

For any construction project, it is essential to have both a preliminary and a definitive geotechnical study, which encompasses everything from site exploration and identification to the necessary tests to characterize the physical and mechanical properties of the soil in the area in question.

In the preliminary design of a structure, in this case, a foundation, it is essential to develop a seismic-resistant design spectrum. Subsequently, modeling was performed using ETABS software, verifying the values in checks such as shear resistance, punching shear, bending, and stresses, in accordance with the Ecuadorian construction regulations, NEC 2015 – NEC-SE-DS.

In order to have a complementary method and establish a final criterion, an additional calculation was carried out using an Excel spreadsheet based on NEC 2015. Although the results were correct, they suggested high dimensions and costs for this project. Therefore, the dimensions of the footings were adjusted from 2.05 x 2.05 m to 1.65 x 1.65 m, efficiently meeting the requirements for functionality, economy, and safety.

The validation of the design through different approaches focused on the selection of the footing as the structural base, under a key criterion: functionality and safety. The design was conceived to withstand high-demand situations, considering maximum moments and loads. Increasing the allowable load value from 1.10 to 2 kg/cm² ensures an adequate response to geological or seismic events, guaranteeing the stability of the structure.

This approach, which anticipates extreme scenarios, provides a solid and reliable safety margin. The result is a resilient foundation capable of facing geotechnical challenges and changes in the terrain. In summary, this choice, in addition to meeting structural requirements, is essential for the protection and durability of the building under adverse conditions, achieving a robust and resistant foundation against various circumstances.

References

[1] Avilés-Campoverde, D., Chunga, K., Ortiz-Hernández, E., Vivas-Espinosa, E., Toulkeridis, T., Morales-Delgado, A., & Delgado-Toala, D. (2020). Seismically induced soil liquefaction and geological conditions in the city of Jama due to the M7.8 Pedernales earthquake in 2016, NW Ecuador. Applied Sciences, 10(24), 8896. https://doi.org/10.3390/app10248896 .

[2] Q. Van Nguyen, B. Fatahi, and A. S. Hokmabadi, "The effects of foundation size on the seismic performance of buildings considering the soil-foundation-structure interaction," *Structural Engineering and Mechanics*, vol. 58, no. 6, pp. 1045–1075, Jun. 2016, doi: 10.12989/sem.2016.58.6.1045.

[3] L. A. Roberts, A. Misra, and W. NeSmith, "Load and Resistance Factor Design (LRFD) Application for Auger Cast-in-Place (ACIP) and Drilled Displacement (DD) Piles," in *Contemporary Topics in In Situ Testing, Analysis, and Reliability of Foundations*, Reston, VA: American Society of Civil Engineers, Mar. 2009, pp. 434–441. doi: 10.1061/41022(336)56.

[4] "Planning Phase," in *Horizontal Auger Boring Projects*, Reston, VA: American Society of Civil Engineers, 2017, pp. 51–61. doi: 10.1061/9780784414583.ch03.

[5] J. Rada, "Progressive Methods of Topographic Site Survey," in *2019 International Conference on Military Technologies (ICMT)*, IEEE, May 2019, pp. 1–5. doi: 10.1109/MILTECHS.2019.8870058.

[6] "EFFECT OF CLIMATIC CONDITIONS ON STRENGTH OF LEAN CLAY," *International Research Journal of Modernization in Engineering Technology and Science*, Aug. 2023, doi: 10.56726/IRJMETS43975.

[7] "ANALYSIS AND DESIGN OF G+30 MULTISTOREY BUILDING BY USING ETABS," *INTERANTIONAL JOURNAL OF SCIENTIFIC RESEARCH IN ENGINEERING AND MANAGEMENT*, vol. 08, no. 06, pp. 1–5, Jun. 2024, doi: 10.55041/IJSREM35980.

[8] L. P. Viera Arroba, D. M. Quizanga Martínez, and J. L. Andino Carranco, "Análisis estático no lineal de edificios aporticados de hormigón armado aplicando normativa ecuatoriana, colombiana y peruana," *FIGEMPA: Investigación y Desarrollo*, vol. 1, no. 1, pp. 72–78, Jun. 2020, doi: 10.29166/revfig.v1i1.2186.