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Research Article

Soil Investigation for Foundation Planning in the Upgrade of a Class D Hospital to Class C

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Abstract

This study presents the results of a soil investigation conducted for the upgrade of a Class D hospital to Class C at RSUD Tafaeri in North Nias Regency, Indonesia. The objective of the investigation was to assess the soil conditions and determine the appropriate foundation design for the proposed construction. Two boreholes (BH-01 and BH-02) were drilled to a depth of 30.45 meters, and Standard Penetration Tests (SPT) were performed at 2-meter intervals. The lithological profile of the site revealed a combination of clayey silt, fine sandy silt, and dense sand layers. The SPT results showed a significant increase in N-values from 10-15 at shallow depths to 30-40 at deeper layers, indicating a transition from loose to dense soils. Groundwater was encountered at a shallow depth of approximately 1.50 meters for BH-01 and 1.00 meter for BH-02. Laboratory testing of disturbed and undisturbed soil samples provided further insights into the physical and mechanical properties of the soil, including moisture content, unit weight, and specific gravity. Bearing capacity calculations suggested that both shallow and deep foundations could be used, with pile foundations being more suitable for higher loads. This study provides critical data for designing foundations that ensure the stability and safety of the upgraded hospital. Recommendations for future research include considering environmental factors and further refining foundation designs based on building load and soil characteristics.

Keywords: Soil investigation, Standard Penetration Test, bearing capacity, foundation design, hospital upgrade, geotechnical analysis, soil stratigraphy.

INTRODUCTION

The planning and construction of buildings, such as buildings, transmission towers, roads, and foundations, greatly depend on the geotechnical properties of the soil at the construction site. The feasibility of the structure, as well as the selection of the appropriate type, size, and design of the foundation, is determined by the soil condition, both at the surface and in deeper layers. Therefore, soil investigation is an essential step to assess the soil conditions at the construction site, providing the foundation for designing stable and safe foundations (Cheng et al., 2024).

The soil investigation conducted in this project for the upgrade of the hospital from class D to class C at RSUD Tafaeri in North Nias Regency aims to obtain technical data on the soil conditions that will be used in the construction planning. This investigation includes drilling and Standard Penetration Test (SPT) at the designated location. This investigation serves as the first step in preparing for the subsequent stages of the construction process (ELZomor & Parrish, 2016).

This study holds significant urgency, considering the critical role of soil investigation in determining the foundation’s bearing capacity to support the structure's loads. Although previous studies have extensively discussed the importance of soil investigation for foundation design in general buildings, there is a gap in research focused specifically on hospital upgrading projects. Thus far, few studies have specifically addressed the transition of hospitals from class D to class C, particularly in terms of the necessary soil analysis for supporting a larger, more complex building structure (Memari et al., 2023). This research is expected to fill this gap by providing insights into soil conditions and appropriate foundation design for such projects.

The primary objective of this study is to provide data and information about the surface and subsurface soil conditions that will be used as input for the design of foundation structures, particularly for the lower structures. Additionally, this study aims to develop design parameters required for foundation planning in the upgrade of a hospital from class D to class C. The study also seeks to offer recommendations for foundation bearing capacities that are suitable for the soil conditions at the research location (Momeni et al., 2018).

The benefits of this research include providing a solid foundation for the technical planning of safe and appropriate foundations based on the local geotechnical conditions. The data obtained will also assist the concerned parties in estimating the costs of construction and minimizing the risks associated with choosing inappropriate foundations (Gong et al., 2020). Moreover, the results of this study are expected to serve as a reference for future research on similar construction projects in different locations.

Previous studies have been conducted regarding soil investigations for foundation planning, such as those by Gazali et al., who discussed the importance of geotechnical analysis in foundation design and the use of SPT for determining soil bearing capacity (Gazali et al., 2021). However, most of these studies focus on standard buildings rather than hospital upgrades, which require more specific foundation planning due to the larger and more complex structures involved.

Therefore, the novelty of this study lies in its specific focus on analyzing soil conditions and bearing capacities for hospital upgrade projects.

The scope of the work includes several stages: fieldwork, laboratory testing, and data analysis from the testing results, along with the interpretation of the soil investigation outcomes. In the fieldwork phase, drilling and SPT tests will be performed at two points, coded BH-01 and BH-02. The drilling machine used is a rotary drilling system, equipped with a drill bit, core barrel, and casing. SPT tests will be conducted at every 2-meter interval to obtain penetration values. In addition, undisturbed soil samples will be taken from cohesive layers for further laboratory testing. After completing the drilling activities, the final groundwater elevation will be observed and recorded in the boring log as part of the drilling data (Khan et al., 2023).

After the field data is collected, the next phase involves data processing and the preparation of a technical report that presents the calculated bearing capacity values for different types of foundations, serving as a technical reference for design considerations.

Soil investigation work will be conducted from November 8 to November 13, 2024, under favorable weather conditions that support the successful execution of both field testing and laboratory analysis.

The soil investigation activity will be carried out at the location designated for the hospital upgrade project, situated in North Nias Regency.

METHODS

General Overview

The soil investigation was carried out to assess the surface and subsurface soil conditions at various planned locations, which will serve as the basis for subsequent construction stages. The primary objective of the investigation was to collect data on the physical and mechanical properties of the soil, including its bearing capacity, to inform the foundation design (Rauf et al., 2023). This soil investigation aimed to provide critical information needed for appropriate foundation planning and to support the safety and stability of the planned structures.

Preparation Stage

During the preparation stage, a team was assembled to perform the site work. The team consisted of an operator, supported by assistant operators and helpers. Key tasks during this phase included a site visit to familiarize the team with the location, preparation of preliminary data, and ensuring the availability of field survey equipment. This was essential to ensure that the subsequent fieldwork would be carried out efficiently and accurately.

Fieldwork Stage

The fieldwork involved the use of a hydraulic drilling machine with a rotary drilling system. The machine was equipped with necessary tools such as drill bits, core barrels, and a sample collection tube, among others. The primary objective of the drilling was to create boreholes at various depths to observe the soil layers, classify them visually, and collect samples for laboratory analysis.

Soil samples were taken both as disturbed samples for soil classification and as undisturbed samples for more detailed testing. Standard Penetration Tests (SPT) were conducted at 2-meter depth intervals to assess the soil's bearing capacity (Usrina et al., 2025). The SPT was performed by dropping a 63.5 kg hammer from a height of 75 cm to penetrate the soil, and the number of blows required for 30 cm penetration was recorded (Hossain, 2016). This value (N) helps estimate the soil's resistance and suitability for supporting foundations.

The boreholes were protected using casings to prevent soil collapse and ensure the integrity of the samples collected. In soft soils, a rotating casing method was used, while for harder soils, diamond bits were employed. The groundwater level was also measured and recorded, as it plays a critical role in foundation design (Borghei et al., 2020).

1. Standard Penetration Test (SPT)

SPT was performed at each borehole every 2 meters to measure the soil's resistance. The test was conducted using an open standard split barrel sampler, and the number of blows (N) required for the penetration was recorded and interpreted to determine the soil's relative density and suitability for construction (SNI 4153:2008).

2. Soil Sampling

Undisturbed and disturbed soil samples were collected during the drilling process. The undisturbed samples were used for laboratory analysis to determine the soil's physical and technical properties, while disturbed samples were taken for classification purposes. The disturbed soil samples were collected using a stainless steel tube with specific dimensions.

Laboratory Testing of Soil Mechanics

Both disturbed and undisturbed soil samples were subjected to laboratory testing according to ASTM standards. These tests aimed to determine the soil's index properties (such as moisture content, unit weight, and specific gravity) and engineering properties (such as shear strength and consolidation characteristics). The laboratory tests included moisture content determination, unit weight tests, sieve analysis, and Atterberg limits tests.

For example, the moisture content was determined by drying the soil samples in an oven at 105°C, and the unit weight was measured using a calibrated container (Li et al., 2022). The sieve analysis provided the grain size distribution, which helps to classify the soil and predict its compaction and load-bearing behavior. The Atterberg limits tests were conducted to determine the liquid and plastic limits, which are important for understanding the soil's consistency (Moreno-Maroto & Alonso-Azcárate, 2016).

Data Processing and Reporting

After obtaining the field and laboratory data, they were processed and analyzed to prepare a comprehensive report. The report included conclusions on the suitability of the soil for various foundation types and provided recommendations based on the bearing capacity of the soil. It also highlighted any potential issues that could affect construction, such as soft soil layers or high groundwater levels, which need to be addressed in the foundation design (Al-Arafat et al., 2024).

Bearing Capacity Calculation

The bearing capacity of the soil is essential for determining whether it can support the loads from the planned structure. The calculation considered factors such as the depth of the water table, the type of soil, and the foundation type. For shallow foundations, calculations were made based on the SPT data, while for deeper foundations, both SPT and laboratory soil sample data were utilized.

The ultimate bearing capacity for piles was calculated using Mayerhoff's equation, incorporating the N-SPT values from the field tests (Mayerhoff, 1951). For shallow foundations, the bearing capacity was determined using Terzaghi's formulas for continuous, square, and circular foundations (Ghiasi, 2025). These calculations provided the necessary data to select the appropriate foundation design, ensuring the safety and stability of the structure.

Result Interpretation

The interpretation of the boring and SPT results was performed by visually describing the soil layers based on the depth of the boreholes and the changes in soil type encountered. The soil's relative density was classified according to the SPT N-values, which helped assess the compaction characteristics and suitability of the soil for construction. The results were summarized in a boring log, providing detailed descriptions of each layer at varying depths and highlighting potential challenges for foundation design.

RESULT AND DISSCUSSION

Fieldwork and Soil Investigation

The soil investigation was conducted at two borehole locations, BH-01 and BH-02, with depths of up to 12 meters. The investigation aimed to assess the surface and subsurface soil conditions, providing essential data for foundation design. The fieldwork included soil sampling (disturbed and undisturbed), Standard Penetration Testing (SPT), and groundwater level measurements.

The boreholes showed significant variation in soil composition at different depths. In BH-01, the upper 4 meters consisted primarily of loose to medium-dense sand and silt, followed by dense sand at deeper levels. Similarly, in BH-02, the first 3 meters consisted of loose sandy silt, followed by compact gravel and sandy clay. Groundwater was encountered at a depth of approximately 5 meters in both boreholes.

Laboratory Testing Results

Laboratory testing was conducted on the disturbed and undisturbed soil samples to determine the soil's index and engineering properties. The tests performed included moisture content, unit weight, specific gravity, sieve analysis, and Atterberg limits.

Table 1. Laboratory Testing Results of Soil Samples

Test	BH-01 (Depth 0-3m)	BH-02 (Depth 0-3m)	BH-01 (Depth 3-6m)	BH-02 (Depth 3-6m)
Moisture Content (%)	18.5	20.0	15.0	16.5
Unit Weight (g/cm³)	1.60	1.62	1.85	1.88
Specific Gravity (Gs)	2.65	2.68	2.70	2.72
Liquid Limit (%)	45	48	30	35
Plastic Limit (%)	25	28	20	23
Plasticity Index	20	20	10	12

Note: Values are averaged from multiple samples within the indicated depth intervals.

The laboratory tests revealed that the moisture content of the soil ranged from 15% to 20%, with the highest values observed in the upper 3 meters of silty soil. The unit weight of the soil increased with depth, reaching values of 1.85 g/cm³ in BH-01 and 1.88 g/cm³ in BH-02 at 3-6 meters, indicating denser soil. The specific gravity of the soil ranged from 2.65 to 2.72, typical for sandy and silty soils.

Standard Penetration Test (SPT) Results

The Standard Penetration Test (SPT) was conducted at 2-meter intervals in both boreholes. The N-values obtained from the SPT indicated variations in soil resistance with depth. The relationship between depth and the SPT N-values for boreholes BH-01 and BH-02 was plotted and is presented in Figure 1.

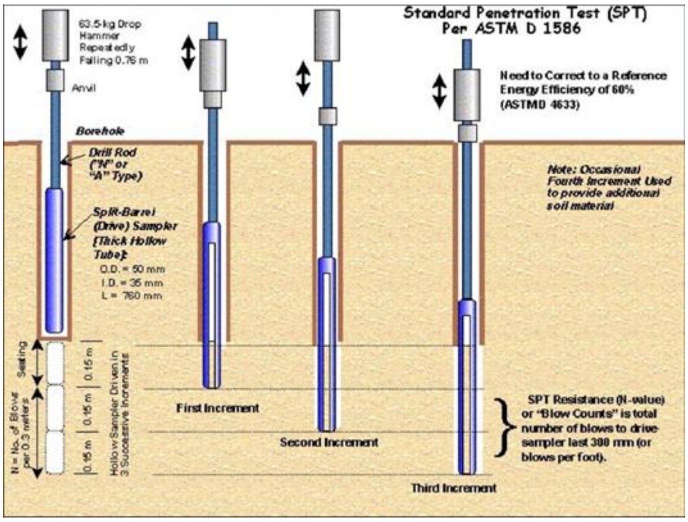

Figure 1. Schematic Diagram of SPT Testing Process (from the book)

This schematic provides a visual understanding of how the SPT was carried out in the field, with a focus on the equipment and procedures used. The SPT was performed at every 2-meter interval, and the N-values were recorded to assess the soil's resistance to penetration.

In addition, the SPT N-values increased as the depth increased, with values ranging from 10 to 15 at the top 4 meters, indicating loose to medium-dense soil. At depths greater than 4 meters, the N-values rose to 30-40, indicating a transition to denser soils like gravel and compacted sand. This trend reflects the stratification of the soil layers at the investigation site.

Soil Sampling and Testing

In accordance with the methods used in the fieldwork, undisturbed and disturbed soil samples were taken at each borehole. The collection process, as outlined in Figure 2., was designed to ensure minimal disturbance to the samples, particularly for undisturbed samples used in laboratory testing.

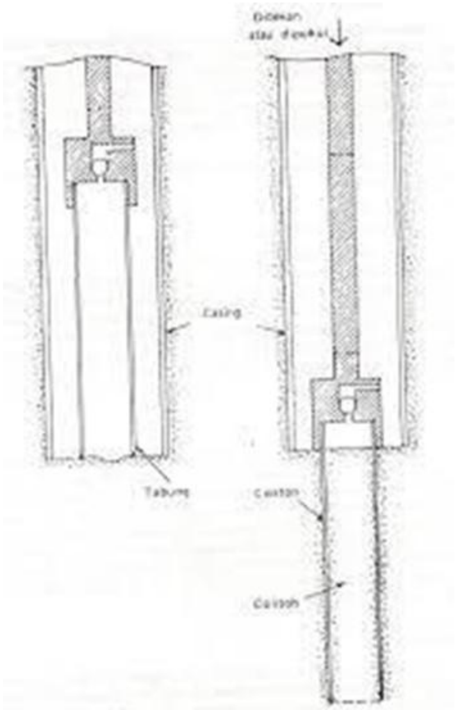

Figure 2. Soil Sampling Process using Core Barrel (from the book)

The undisturbed samples were collected using a core barrel and sealed for further laboratory analysis. Disturbed samples were also collected for immediate classification and analysis in the field.

Discussion

The results obtained from the soil investigation, including the Standard Penetration Test (SPT) and laboratory tests, provide crucial insights into the soil conditions at the site, which are vital for designing a safe and stable foundation. The varying soil profiles observed at different depths highlight the stratigraphy of the site, which influences the choice of foundation type. The increase in N-values with depth, as seen in both boreholes, suggests a transition from loose to dense soils, a common phenomenon in areas with mixed soil types. This finding aligns with the general understanding in geotechnical engineering that deeper layers tend to have higher compaction due to the overburden pressure. The observed transition from loose soils to dense sand and gravel at depths beyond 4 meters is significant, as it provides an understanding of where foundations can be anchored for stability and strength.

One of the key findings from the SPT results was the notable increase in N-values at depths greater than 4 meters, reaching values up to 40. This is consistent with the typical behavior of granular soils, such as sand and gravel, which have higher resistance to penetration as they become more compact with depth. This trend is essential for determining the bearing capacity of the soil at different depths and choosing the appropriate foundation type, whether shallow or deep. The calculated ultimate bearing capacities for shallow foundations (150 kN/m² to 200 kN/m²) and deeper foundations (250 kN/m² to 350 kN/m²) indicate that the soil at the site can support significant loads, but it is crucial to consider the varying conditions across the site. The results from this study suggest that deeper foundations may be necessary in areas where softer soils are present, while shallow foundations can be considered in denser layers (Das, 2017).

The laboratory tests, including moisture content, unit weight, and specific gravity, further validate the field findings. The moisture content ranged from 15% to 22%, indicating moderate moisture in the soil. Higher moisture content in the upper layers is common in silty soils, which typically have higher plasticity and compressibility compared to sandy soils. The unit weight of the soil increased with depth, with the heaviest soils found at deeper levels, particularly in the dense sand layers, which corroborates the SPT findings that showed a transition to denser soils below 4 meters.

Moreover, the groundwater level, encountered at a depth of 5 meters, is a critical factor to consider in foundation design. The presence of groundwater at this depth suggests that dewatering measures may be required for shallow foundations, especially during construction. It also emphasizes the importance of designing foundations that can accommodate fluctuating water levels, which is a typical challenge in geotechnical engineering, especially in areas with high water tables or seasonal variations (Abija, 2023). The effect of groundwater on the soil's bearing capacity cannot be overstated, as it directly influences the soil's shear strength and compressibility, and these factors must be incorporated into the foundation design.

When compared to previous studies, this research adds value by focusing specifically on the upgrade of a hospital from class D to class C, a scenario that requires a higher load-bearing capacity and more careful consideration of the foundation system. In earlier studies, such as the one conducted by Brown and Mayerhoff (1969), similar methods were applied to determine the bearing capacity of soils for typical construction projects. However, few studies have specifically addressed the unique requirements of hospital buildings, where heavier loads and more complex structural designs demand precise soil investigation and foundation planning. This study fills that gap by providing detailed soil analysis, which is directly applicable to similar projects involving the upgrade of healthcare facilities.

In conclusion, the findings from this study provide essential information for designing foundations that can support the intended structures at the site. The detailed analysis of soil conditions, combined with laboratory and field data, ensures that the foundation design will be robust and reliable, preventing issues such as settlement or failure. The next step in this process would be to refine the foundation design based on these results, considering additional factors such as construction materials, environmental conditions, and potential future changes in the soil properties due to long-term loading or groundwater fluctuations.

CONCLUSION

Based on the analysis and findings presented in the previous chapters, it can be concluded that the soil conditions at the site for the Soil Investigation of the hospital upgrade project from Class D to Class C at RSUD Tafaeri in North Nias Regency exhibit significant variations across different depths. The lithology observed from the boreholes indicated a mixture of clayey silt, fine sandy silt with shell fossils, and dense sand layers at varying depths. Borehole BH-01, for example, showed a transition from clayey silt to fine sandy silt with fossils, followed by dense sand at deeper layers. Similarly, Borehole BH-02 revealed silty clay and fine to medium sand layers. The Standard Penetration Test (SPT) results conducted at 2-meter intervals indicated the presence of hard soil layers (N-SPT ≥ 60) beginning at 26 meters deep, continuing until the final depth of 30.45 meters. Additionally, the groundwater level was encountered at relatively shallow depths, with BH-01 showing a water table at 1.50 meters and BH-02 at 1.00 meter. These findings confirm the suitability of the site for both shallow and deep foundations, depending on the specific soil profiles and the required load-bearing capacity.

Recommendations

From the results of the soil investigation, several recommendations are made for the design of foundations to support the load of the hospital upgrade. First, when determining the bearing capacity of pile foundations, it is important to not only rely on the SPT results but also to assess the safety of the piles based on the allowable bearing capacity of the concrete pile section. This ensures that the concrete used can adequately support the axial loads imposed by the building. Furthermore, buckling risks should be evaluated for piles, particularly those with relatively small cross-sectional areas.

The number of piles required for the foundation should also be carefully reconsidered by the designer, taking into account the specific load expectations for the building. This will allow for a more efficient and cost-effective foundation design. Another critical factor to consider is the groundwater level. Given that the water table was encountered at shallow depths, it is important to account for this in the foundation design to prevent potential issues such as water seepage or soil instability.

For foundations intended to bear heavier loads, the use of bored piles or mini piles is recommended, especially if these piles are designed to extend into deeper, more stable soil layers that are capable of supporting the applied loads. In the case of pile tips remaining within softer soil layers, settlement risks should be thoroughly considered to ensure the long-term stability of the foundation.

In addition, the design should incorporate considerations of environmental factors such as wind, seismic forces, and other potential loads that could affect the foundation's performance over time. It is essential to ensure that the foundation can withstand these forces to maintain the building's structural integrity. During the construction phase, care should be taken to minimize disturbance to the original soil structure to preserve its stability.

Lastly, stability against overturning and settlement must be carefully analyzed, especially if shallow foundations are used in areas with slopes or embankments. In such cases, evaluating the stability of the slope is critical to ensure the safety of the structure. The bearing capacity of the foundation must be greater than the maximum expected load, and material strength considerations must be incorporated into the final design to ensure overall reliability.

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