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ANALYSIS OF THE EFFECT OF MOISTURE CONTENT AND *SWELL PRESSURE* ON THE SHEAR STRENGTH OF BOBONARO CLAY IN THE KUPANG REGION, EAST NUSA TENGGARA PROVINCE

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ABSTRACT

The Bobonaro Formation, which is widely distributed in the Kupang region, East Nusa Tenggara Province, is known to have a dominant expansive clay lithology. This formation forms the basis for several very important infrastructure projects, including the Manikin Dam, where expansive clay soil can pose challenges to stability and deformation control. This study aims to analyze the relationship between moisture content, *swell pressure*, and shear strength in Bobonaro Clay taken from several locations in Kupang Regency and Kupang City, which have the same geological formation as the Manikin Dam area. Laboratory tests included natural moisture content, Atterberg limits, specific gravity, standard proctor compaction, direct shear test, and *swell pressure* test. Linear regression analysis was used to determine the relationship between parameters. The results of this study indicate that an increase in moisture content causes a decrease in shear strength and an increase in swelling pressure simultaneously. These findings confirm the expansive nature of Bobonaro Clay and provide important geotechnical insights for the planning and implementation of construction in areas with this formation.

KEYWORDS: Bobonaro Formation, Expansive Clay, Moisture Content, Swelling Pressure, Shear Strength, Kupang Region.

1. INTRODUCTION

The Bobonaro Formation is one of the main geological units in the West Timor region of Indonesia, with a dominant composition of claystone, marl, and calcareous breccia (Titu-Eki and Dethan, 2023). This formation is spread across several areas of Kupang Regency and Kupang City, including around the Manikin Dam area. The clay component in this formation, which mainly contains montmorillonite minerals, exhibits expansive properties that have the potential to cause problems in geotechnical work.

Expansive clay soils are highly sensitive to changes in moisture content. When moisture content increases, clay minerals absorb water and expand, causing an increase in *swell pressure* and a decrease in shear strength (Huang et al., 2019; Ongen and Erguler, 2021). This behavior can result in ground heave, cracks, and damage to structures such as foundations and tunnels (Stephen, 2022).

Previous studies have shown a significant correlation between moisture content and the mechanical behavior of clay soils. Dian and Elfrida (2019) stated that variations in moisture content outside the optimum range cause a significant decrease in shear strength. Meanwhile, Karunarathne et al. (2020) found a strong statistical relationship between initial water content and swelling pressure in expansive soils. However, specific studies on Bobonaro Formation clay in the Kupang region are still very limited.

This study was conducted by taking samples of Bobonaro clay from several locations in Kupang Regency that have similar lithology to the Manikin Dam area. The aim was to analyze the effect of water content and swelling pressure on the shear strength of the expansive clay and to provide a basis for understanding the application of geotechnical design in local infrastructure.

Geological and Geotechnical Background

The Bobonaro Formation (Miocene-Pliocene age) is widely distributed in the Timor region and consists of claystone, siltstone, and limestone fragments that are often found in the form of scaly clay (Vong, 2016). These deposits were formed under complex tectonic conditions and exhibit high plasticity and compressibility. In the Kupang region, this formation forms the basis of various engineering structures such as tunnels, road embankments, and civil buildings.

Previous geotechnical studies have shown that Bobonaro clay has moderate to high expansion potential, low permeability, and is highly sensitive to changes in water content (Titu-Eki and Dethan, 2023). These characteristics make this soil important to study in the context of infrastructure safety and resilience in the region.

2. METHOD

Sample Collection Locations

Soil samples were taken from several locations in Kupang Regency that were selected based on their geological similarity to the Bobonaro Formation, which was confirmed through regional geological maps and field observations, including.

- Baumata Village, Taebenu District, Kupang Regency (Location 1)
- Baumata Timur Village, Kupang Regency (Location 2)
- Manulai 2 Village, Alak Subdistrict, Kupang Regency (Location 3)
- Manulai 1 Village, Alak Subdistrict, Kupang Regency (Location 4)

Sampling points can be seen in **Figure 1** and **Figure 2**

Laboratory Testing

Testing was conducted in a soil mechanics laboratory in accordance with ASTM standards, including.

- Moisture content (ASTM D421-72)
- Sieve analysis (ASTM D422-72)
- Atterberg limits (ASTM D4318)
- Specific gravity (ASTM D854)
- Standar Proctor Test (ASTM D698)
- Direct Shear Test (ASTM D3080)
- Swelling Pressure Test (ASTM D4546)

Each test was conducted on natural samples and compacted samples with controlled moisture content variations.

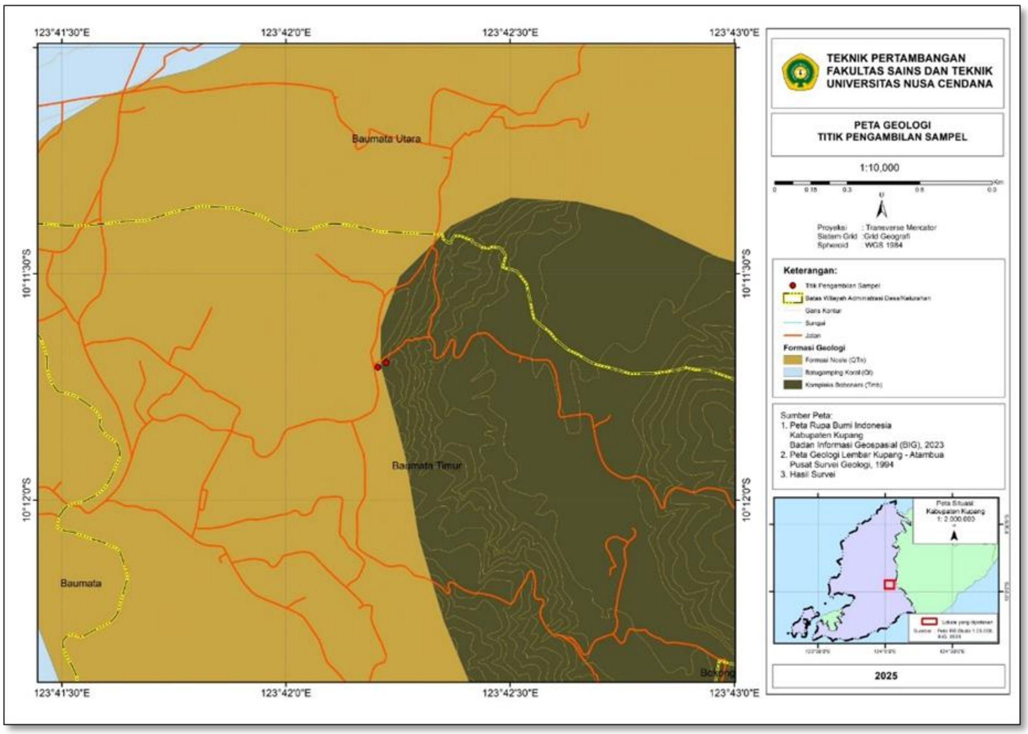

Figure 1: Sample Collection Points 1 and 2.

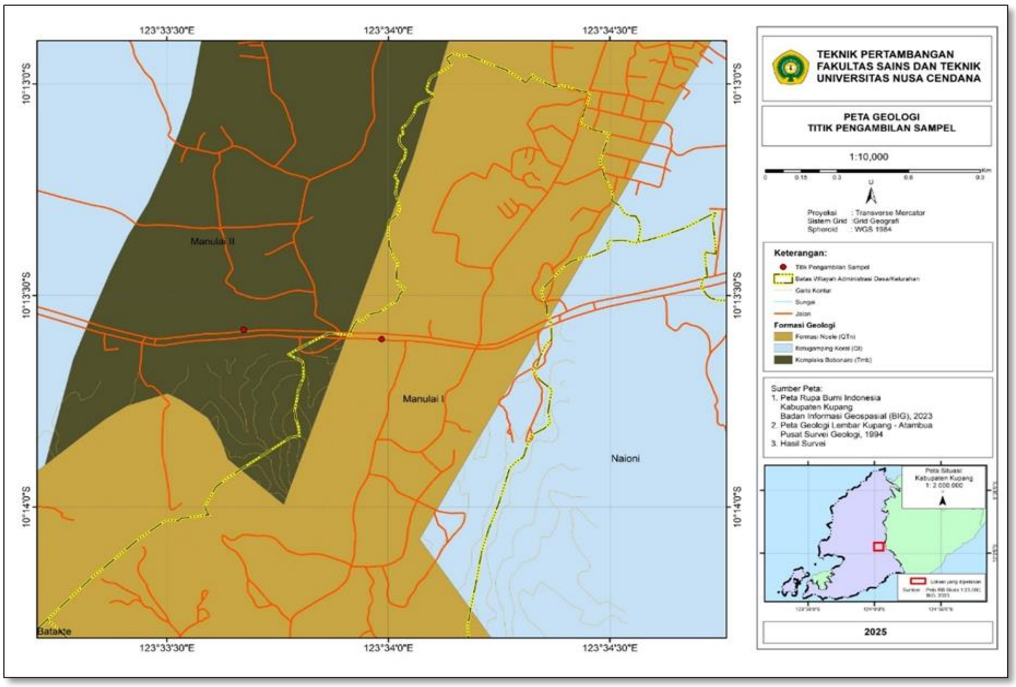

Figure 2: Sample Collection Points 3and 4.

Data Analysis

The relationship between water content, shear strength, and swelling pressure was analyzed using simple linear regression and correlation analysis with the following basic equation:

$\tau = c + \sigma \tan(\emptyset)$

Where:

τ : shear strength

c : cohesion

σ : normal stress

Ø : internal friction angle

In addition, the statistical relationship between moisture content and swelling pressure was analyzed to identify the behavior patterns of expansive clay.

RESULTS AND DISCUSSION

The discussion of the research results focused on analyzing the relationship between water content, development potential (swell pressure), and shear strength of Bobonaro Clay using a physical and mechanical soil properties approach. The analysis was conducted to explain the relationship between geotechnical parameters that control the deformation behavior and failure of plastic clay soil on a regional scale. Soil samples were taken from four locations in the district that are regionally located in the same geological unit as the Manikin Dam area, so the results of this study are relevant as a representation of regional geotechnical conditions.

Table 1: Results of Soil Physical Property Testing.

Parameter	Location			
	1	2	3	4
Water Content (%)	32.38	22.09	23.74	21.45
Specific gravity	2.72	2.61	2.67	2.69
Soil bulk density (g/cm^3)	2.62	2.09	2.06	2.04

The results of physical property testing from 4 sampling locations are shown in **Table 1**, indicating that the natural moisture content of Bobonaro clay soil ranges from 21.45% to 32.38%. This value describes the condition of the soil as relatively moist to partially saturated, which is a common characteristic of Bobonaro clay in the East Nusa Tenggara region. The highest moisture content was found at Location 1, indicating poor drainage conditions or the influence of active clay minerals.

The specific gravity of the soil ranges from 2.61 to 2.71, indicating a predominance of inorganic silicate minerals with low organic content. This range is consistent with the characteristics of clay soil resulting from the weathering of deformed sedimentary material.

The bulk density of the soil ranges from 2.04 to 2.62 g/cm³ with variations that describe the differences in the degree of compaction and soil structure of each location.

Table 2: Results of Soil Index Property Testing.

Soil Index Properties	Location			
	1	2	3	4
Liquid limit (LL)	58.94	34.02	42.38	34.16
Plastic limit (PL)	31.25	29.6	22.2	22.77
Plasticity Index (PI)	27.69	4.42	20.16	11.39

Atterberg limit testing showed a liquid limit (LL) value between 34.02-58.94% and a plasticity index (PI) between 4.42-27.69%. The relatively high LL and PI values at several locations indicate the presence of active clay minerals with a large specific surface area, resulting in high water adsorption capacity. This condition is directly correlated with the potential for volumetric expansion (*swelling*) and increased *swelling pressure* when the water content increases, especially under confined conditions. Locations 1 and 3 have relatively high PI values, indicating that the soil is moderately to highly plastic and sensitive to changes in moisture content. This condition has the potential to cause an increase in *swelling pressure* and a significant decrease in shear strength when the soil is wet or saturated.

Table 3: Soil Mechanical Parameters.

Soil Mechanical Parameters	Location			
	1	2	3	4
Cohesion (c)	0.93	1.3	0.001	2.06
Internal friction angle	0.72	0.51	3.54	2.36

Based on the LL and PI values, soil classification according to *the Unified Soil Classification System* (USCS) can be determined using the Casagrande plasticity chart. Interpretation of the results shows that.

- Location 1 : high plasticity clay (CH)
- Location 2 : low plasticity clay (CL)
- Location 3 : medium to high plasticity clay (CL-CH)
- Location 4 : low to medium plasticity clay (CL)

This classification confirms that Bobonaro clay is dominated by fine-grained soil with plastic to highly plastic properties. Geotechnically, soils classified as CL-CH to CH have low permeability, high *swelling* potential, and significant shear strength degradation due to changes in moisture content, making them problematic materials in geotechnical construction without special treatment. Soils with a CH classification generally have high *swelling* potential and low shear strength under saturated conditions.

Relationship between Moisture Content, *Swell Pressure*, and Shear Strength

The shear strength test results show cohesion (c) values ranging from 0.001 to 2.06 and internal friction angle (φ) values ranging from 0.51 to 3.54°. These values indicate clay soil conditions with low shear strength that are greatly influenced by moisture content and changes in soil microstructure due to expansion processes. An increase in moisture content causes water molecules to enter the intermineral layers of clay, increasing swelling pressure and decreasing the electrostatic attraction between particles, which ultimately reduces effective cohesion and internal friction angle. The very small angle of internal friction value indicates that the mechanical behavior of the soil is dominated by cohesion, with minimal contribution from inter-particle friction. This condition is commonly found in soft to very soft clay soils.

Low cohesion values were found at Location 3, indicating weak bonds between soil particles. In plastic clay soils, an increase in water content will increase the distance between particles, increase expansion pressure, and simultaneously decrease the effective cohesion of the soil. Under saturated conditions, the effective cohesion of clay soils tends to decrease, making the soil highly susceptible to shear strength.

Slope Stability Analysis and the Role of *Swell Pressure*

To assess the geotechnical implications for slope stability, a simple slope stability analysis was performed using *the infinite slope* approach with the Mohr-Coulomb criterion. The safety factor (SF) can generally be expressed as.

$$SF = (c + (\sigma - u) \tan \varphi) / \tau$$

Considering the low values of c and φ, as well as the potential increase in pore water pressure (u) and expansion pressure due to the *swelling* process during the rainy season, the FK value of the Bobonaro clay slope is estimated to be close to or less than 1.5, especially in natural slopes with moderate to steep inclines. This condition indicates that the slope is in a critical to unstable state, especially in zones that experience seasonal fluctuations. *Swell pressure* acts as an additional mechanism that accelerates the decline in safety factors through increased lateral stress and weakening of the soil structure.

Qualitatively, locations with high PI and low cohesion (at Location 1 and Location 3) have a greater potential for slope failure than other locations. Therefore, surface and subsurface water control is a key factor in maintaining slope stability in areas dominated by Bobonaro clay.

Geotechnical Engineering Implications

Based on testing and analysis results, Bobonaro clay has unfavorable geotechnical characteristics, especially for slope construction, mining roads, and shallow foundations. Recommended mitigation measures include improving the drainage system, reducing slope angles, and stabilizing the soil using additives such as lime or cement to increase soil shear strength.

Implications for Engineering Design

Based on the results obtained, Bobonaro clay in the Kupang region is categorized as moderately to highly expansive soil. Therefore, infrastructure projects such as tunnels, roads, and foundations in this area need to implement mitigation measures, including.

- Surface water control and drainage
- Use of moisture barrier layers or stabilizing materials
- Design of flexible support structures (hanif and Wasin, 2023)

The results of this study are consistent with the geotechnical conditions in the Manikin Dam area and reinforce the importance of managing expansive soil in areas with Bobonaro formations.

CONCLUSION

1. Bobonaro formation clay spread across Kupang Regency and Kupang City exhibits high plasticity and moderate to high swelling potential
2. Increased water content causes a decrease in shear strength and an increase in swelling pressure, with an inversely proportional functional relationship
3. These research results provide an important basis for geotechnical design, particularly in water content control, soil stabilization, and support structure design on expansive soils of the Bobonaro Formation.

Further research is recommended to analyze the mineralogy and microstructure of the soil in order to understand the expansion mechanism in more detail.

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