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Geotechnical Evaluation of Subgrade Soil on the Frans Kasaipo Road in Tosa Urban Village

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ABSTRACT

Soil is a vital natural resource that plays a crucial role in sustaining life. In addition to serving as a medium for plant growth, a provider of essential resources, and a physical foundation, soil also functions as an integral component of ecosystems. Degradation of soil functions may lead to ecosystem disturbances. The road section in Tosa Urban Village, East Tidore District, frequently experiences landslides during the rainy season. This road serves as a critical transportation route for the local community, supporting daily activities such as education, economic transactions, social interactions, and cultural events. Several segments of the road are characterized by steep slopes, which increase the potential for landslides, particularly during periods of high rainfall. Laboratory testing of soil samples from the Tosa area indicated a California Bearing Ratio (CBR) value of 5.77%, a maximum moisture content of 20.5%, and a maximum dry density of 1.73 g/cm³, reflecting very low bearing capacity. Grain size analysis showed that the natural soil consists predominantly of silt–clay materials, with more than 35% passing the No. 200 sieve, classifying it as A-7 soil according to the AASHTO system. The percentage passing the No. 200 sieve reached 108.77% for samples 1–3, exceeding the minimum classification requirement. The plasticity index was recorded at 14.91%. Atterberg limits testing further classified the soil as A-7-6, with a liquid limit exceeding 41% and a plasticity index greater than 11%. Specific gravity tests revealed that soil samples 1 and 2 are classified as humus soils, while sample 3 is identified as organic silt. Based on these findings, appropriate landslide mitigation measures for locations 1–3 include slope cutting, soil anchoring, and drainage system installation.

Keywords: Soil testing; road section; landslide potential; Tosa Urban Village

INTRODUCTION

Rapid globalization has significantly transformed human activities, particularly through advancements in transportation technology. Motorized vehicles play a fundamental role in facilitating mobility and supporting economic growth, social interaction, and cultural exchange. As traffic volume and vehicle usage continue to increase, the demand for safe, reliable, and sustainable road infrastructure becomes increasingly critical (Huang, 2014; Papagiannakis & Masad, 2008). Roads serve as essential links between regions, enabling the efficient movement of people and goods. However, road performance and safety are often compromised by structural damage caused by various factors, among which subsoil conditions and geological characteristics are particularly influential (Das, 2016; Yoder & Witczak, 1975).

Soil is a vital natural resource that plays an essential role in both ecological systems and civil engineering applications. In addition to supporting vegetation growth and serving as a reservoir of natural resources, soil functions as a key structural element in infrastructure development, particularly as subgrade material for roads and slopes (Braja & Sobhan, 2018). Degradation of soil properties may disrupt ecosystem balance and reduce its mechanical performance, resulting in instability and failure of engineered structures (Lambe & Whitman, 1969; Mitchell & Soga, 2005). In geotechnical engineering, soil characteristics such as grain size distribution, plasticity, moisture content, and bearing capacity are critical parameters that determine the stability and durability of road infrastructure (Coduto et al., 2011). In mountainous and hilly regions, road construction is frequently associated with slope instability problems, particularly during periods of intense rainfall. Landslides are among the most common natural hazards affecting transportation networks worldwide and are strongly influenced by steep slopes, weak soil conditions, and high water infiltration (Cruden & Varnes, 1996; Highland & Bobrowsky, 2008). Rainfall-induced landslides often occur when increased pore water pressure reduces effective stress and shear strength within soil masses, leading to slope failure (Fredlund & Rahardjo, 1993; Iverson, 2000). These phenomena pose serious risks to road safety, serviceability, and long-term infrastructure performance.

The road section in Tosa Urban Village, East Tidore District, represents a crucial transportation corridor for the local community, supporting daily activities such as education, economic exchange, social interaction, and cultural events. However, several segments of this road traverse steep terrain with unfavorable soil conditions, making them highly susceptible to landslides during the rainy season. Similar conditions have been reported in many developing regions, where limited geotechnical investigation and inadequate slope protection measures exacerbate landslide hazards along road corridors (Dai et al., 2002; Turner & Schuster, 2007). Poor subgrade conditions not only disrupt traffic flow but also increase maintenance costs and negatively impact regional economic development. Given the importance of transportation infrastructure in sustaining socioeconomic activities, systematic evaluation of soil characteristics and bearing capacity is essential for effective road planning and maintenance. Therefore, this study aims to assess the engineering properties and bearing capacity of soils along the road section in Tosa Urban Village. Furthermore, appropriate landslide mitigation measures are proposed to reduce slope failure risks and ensure road stability. The results of this study are expected to contribute to improved understanding of local soil behavior and provide technical guidance for landslide mitigation and sustainable road infrastructure management in landslide-prone areas.

LITERATURE REVIEW

Road infrastructure stability is strongly influenced by the engineering properties of subsoil materials, particularly in regions characterized by steep terrain and high rainfall intensity. Numerous studies have emphasized that inadequate understanding of soil characteristics often leads to premature road deterioration and slope failure, especially in developing regions where geotechnical investigations are limited (Papagiannakis & Masad, 2008; Yoder & Witczak, 1975). Soil behavior under loading conditions determines the bearing capacity of road subgrades and directly affects pavement performance, serviceability, and safety. Soil classification systems, such as the Unified Soil Classification System (USCS) and the AASHTO classification, are widely used to evaluate soil suitability for road construction. According to Das (2016), soils with high fines content and plasticity generally exhibit low bearing capacity and poor drainage characteristics, making them vulnerable to deformation and failure. Grain size distribution and Atterberg limits are essential parameters for identifying problematic soils, particularly clayey and silty soils that are susceptible to volumetric changes due to moisture variation (Lambe & Whitman, 1969). Previous studies have shown that A-7 soils under the AASHTO classification are often associated with low strength and poor subgrade performance, requiring stabilization or special treatment before being used in road construction (Coduto et al., 2011).

The California Bearing Ratio (CBR) test remains one of the most widely adopted methods for evaluating the strength and bearing capacity of subgrade soils in pavement design. Low CBR values are commonly linked to weak soils with high plasticity and moisture sensitivity, which can significantly reduce pavement life (Katte et al., 2019; Leung et al., 2013; Mukherjee & Ghosh, 2021). Research by Mitchell & Soga (2005) highlighted that moisture content plays a critical role in controlling soil strength, as an increase in water content leads to reduced effective stress and shear strength. Consequently, road sections constructed on soils with low CBR values are more prone to rutting, cracking, and structural failure, particularly under repeated traffic loading. Slope instability and landslides represent major challenges for road infrastructure in hilly and mountainous areas. Landslides are complex phenomena influenced by geological conditions, slope geometry, soil properties, hydrological factors, and external triggers such as rainfall and seismic activity (Jaafari, 2024; McColl, 2022). Rainfall-induced landslides are especially common in tropical regions, where prolonged or intense precipitation increases pore water pressure and reduces soil shear strength, leading to slope failure (Iverson, 2000; Fredlund & Rahardjo, 1993). Several studies have demonstrated that soils with high fines content and poor drainage are particularly susceptible to rainfall-triggered landslides (Dai et al., 2002).

Transportation corridors are among the infrastructures most frequently affected by landslides, resulting in traffic disruption, economic losses, and safety hazards. Turner and Schuster (2007) emphasized that inadequate slope design and lack of drainage systems significantly increase landslide risk along road alignments. Furthermore, Highland and Bobrowsky (2008) noted that slope failures along roads are often exacerbated by excavation activities that alter natural slope geometry and disturb soil equilibrium. These findings underline the importance of integrating geotechnical investigations into road planning and maintenance practices.

Various landslide mitigation techniques have been proposed to enhance slope stability and protect road infrastructure. Common structural measures include slope cutting, retaining structures, soil nailing, anchoring systems, and surface and subsurface drainage (Duncan et al., 2014). Drainage systems are particularly effective in reducing pore water pressure and improving slope stability by controlling groundwater flow (Fredlund & Rahardjo, 1993). Non-structural approaches, such as land-use planning and routine monitoring, also play a complementary role in landslide risk management (Dai et al., 2002). The selection of appropriate mitigation measures should be based on site-specific soil characteristics, slope geometry, and environmental conditions. Overall, existing literature highlights the critical role of soil characterization and bearing capacity assessment in ensuring road stability and mitigating landslide hazards. However, site-specific studies remain essential, as soil behavior and landslide mechanisms can vary significantly depending on local geological and climatic conditions. Therefore, detailed evaluation of soil properties and appropriate mitigation strategies is necessary to support sustainable road infrastructure development in landslide-prone areas such as Tosa Tosa Urban Village.

METHOD

This study was conducted in Tosa Urban Village, North Maluku Province, Indonesia. Laboratory testing was carried out at the Soil Mechanics Laboratory of Khairun University, located in Gambesi Urban Village, South Ternate District. The research was undertaken over a two-month period, from August to September 2022. The study area was selected due to its frequent occurrence of landslides during the rainy season and its importance as a primary transportation corridor for the local community.

(a) (b)

Figure 1. Locations of sample collection at site 1 (a) and site 2 (b)

Soil sampling was performed at three representative locations along the road section in Tosa Urban Village. These locations were selected based on field observations of slope geometry, signs of soil instability, and accessibility. Sampling Point 1 was located in RT 01 RW 01, Sampling Point 2 was also situated in RT 01 RW 01 at a different segment of the road, and Sampling Point 3 was located in RT 04 RW 02. The spatial distribution

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of these sampling points was intended to capture variations in soil conditions along the road alignment.

Figure 2. Location of the third sample collection

Disturbed soil samples were collected using a hand boring tool (hand auger), which is commonly employed for shallow geotechnical investigations. At each sampling point, soil samples were obtained at a depth of 1.0 m below the ground surface. This depth was selected to represent the typical subgrade layer influencing road performance and slope stability. The collected samples were carefully sealed and labeled to preserve their natural moisture content and to prevent contamination during transportation to the laboratory. Laboratory testing was conducted to determine the physical and engineering properties of the soil samples. The tests included natural moisture content, specific gravity, grain size distribution (sieve analysis), Atterberg limits (liquid limit and plastic limit), and California Bearing Ratio (CBR). These tests were carried out in accordance with relevant ASTM and AASHTO standards to ensure consistency and reliability of the results. The obtained data were used to classify the soil based on the AASHTO soil classification system and to evaluate its bearing capacity and suitability as road subgrade material.

The results of laboratory testing were analyzed to identify soil characteristics that contribute to slope instability and low bearing capacity along the studied road section. Based on these findings, appropriate landslide mitigation measures were proposed, considering local soil properties, slope conditions, and practical implementation constraints. The methodological framework adopted in this study provides a systematic approach for assessing soil behavior and supporting effective decision-making for road stability and landslide risk mitigation.

RESULTS AND DISCUSSION

Site Description and Laboratory Testing Overview

This study investigates the geotechnical characteristics of subgrade soil collected from Tosa Urban Village, North Maluku Province, Indonesia. Field sampling was conducted at a depth of 100 cm to represent the subgrade layer influencing road performance. Laboratory testing was performed at the Soil Mechanics Laboratory, Faculty of Engineering, Universitas Khairun Ternate, focusing on physical properties, consistency limits, compaction characteristics, and bearing capacity. The results provide an empirical basis for evaluating soil suitability and determining appropriate slope stabilization and road improvement measures.

Particle Size Distribution

Sieve analysis was carried out to determine soil gradation and classify the material based on particle size distribution. Each sample weighed 500 g and was tested following standard procedures.

Table 1. Particle Size Distribution of Soil Samples

No.	Diameter (mm)	Retained Weight (g)	Cumulative Weight (g)	Retained (%)	Passing (%)
4	4.75	0.1	0.1	0.02	99.98
8	2.36	4.7	4.8	0.96	99.04
16	1.18	53.8	58.6	11.72	88.28
30	0.6	75.6	134.2	26.84	73.16
40	0.425	38.9	173.1	34.62	65.38
50	0.3	26	199.1	39.82	60.18
60	0.25	4.8	203.9	40.78	59.22
100	0.15	54.9	258.8	51.76	48.24
200	0.075	61	319.8	63.96	36.04
Pan	–	180.2	500	100	0

The results indicate that approximately 36.77% of the soil consists of fine particles (passing sieve No. 200), while the remaining fraction is dominated by sand-sized particles. This gradation suggests a soil with moderate fines content, which significantly influences plasticity, permeability, and bearing capacity. The dominance of sandy fractions combined with fine material indicates susceptibility to moisture variation and reduced shear strength under saturated conditions.

Natural Water Content

Natural water content was measured to assess in-situ moisture conditions, which strongly affect soil strength and compressibility.

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Table 2. Natural Water Content of Soil Samples

Sample	Sampling Depth (cm)	Average Water Content (%)
1	100	172.7
2	100	20.6
3	100	123

The results reveal extremely high water content, particularly in Samples 1 and 3. Such conditions are characteristic of organic soils and indicate poor drainage, high compressibility, and low bearing capacity. These properties explain the vulnerability of the study area to slope instability and pavement deformation.

Specific Gravity and Soil Classification

Specific gravity (Gs) testing was conducted to identify mineral composition and organic content.

Table 3. Specific Gravity and Soil Type

Sample	Specific Gravity (Gs)	Soil Type
1	1.37	Humus
2	1.37	Humus
3	2.67	Organic Silt

The very low specific gravity values for Samples 1 and 2 confirm the dominance of organic matter, consistent with humus soil. In contrast, Sample 3 exhibits characteristics of organic silt. Compared with standard reference values (Table 4), the soil is classified as weak and unsuitable for direct load-bearing applications without improvement.

Table 4. Typical Specific Gravity Values for Soils

Soil Type	Specific Gravity (Gs)
Gravel	2.65–2.68
Sand	2.65
Organic Silt	2.62–2.68
Organic Clay	2.58–2.65
Inorganic Clay	2.68–2.75
Humus	~1.37
Peat	1.25–1.28

Atterberg Limits

Liquid limit (LL) and plastic limit (PL) tests were performed to evaluate soil consistency.

Table 5. Atterberg Limits Test Results

Sample	Depth (cm)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
1	100	43.86	31.88	11.98
2	100	44.96	26	18.96
Average	–	43.86	28.94	14.91

The plasticity index of 14.91% indicates medium plasticity soil. Combined with high moisture content, this condition increases the likelihood of deformation and loss of shear strength, particularly under traffic loads and rainfall.

Compaction Characteristics

Standard Proctor compaction tests were conducted to determine optimum moisture content (OMC) and maximum dry density (MDD).

Table 6. Compaction Test Results

Parameter	Value
Optimum Moisture Content (OMC)	20.21%
Maximum Dry Density (MDD)	1.44 g/cm³

Table 6 presents the results of the standard compaction test, which indicate an optimum moisture content (OMC) of 20.21% and a maximum dry density (MDD) of 1.44 g/cm³. The relatively high OMC suggests that a substantial amount of water is required to achieve maximum compaction, reflecting the soil's fine-grained and organic characteristics. Such soils typically exhibit high water affinity, causing the soil structure to become adequately rearranged only at elevated moisture levels. Meanwhile, the low MDD value indicates limited compactability and a loose soil matrix, which is commonly associated with organic or silty soils. This condition implies that even under optimum compaction conditions, the soil attains a relatively low dry unit weight, resulting in reduced stiffness and bearing capacity. From an engineering perspective, these characteristics signal that compaction alone may not be sufficient to significantly enhance subgrade performance. Therefore, additional ground improvement measures, such as soil stabilization, replacement, or improved drainage, are necessary to ensure adequate strength and long-term stability for pavement and slope applications.

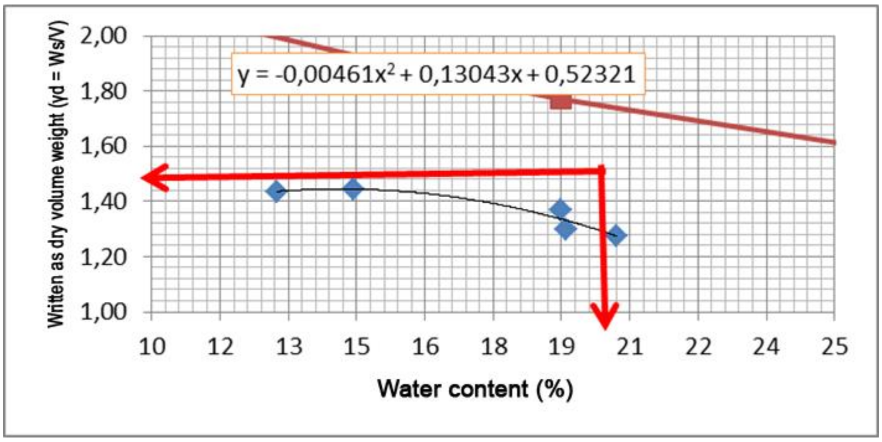

Figure 1. Compaction curve and the relationship of dry density to moisture content

Figure 1 illustrates the relationship between water content and dry density. The relatively low MDD reflects the high organic content, confirming that compaction alone may not significantly improve bearing capacity without soil replacement or stabilization.

California Bearing Ratio (CBR)

CBR testing was conducted under unsoaked conditions to evaluate subgrade strength.

Table 7. CBR Test Summary (Unsoaked Condition)

Penetration	CBR (%)
0.1 inch	5.77
0.2 inch	5.77
Adopted CBR Value	5.77

A CBR value below 6% indicates very weak subgrade conditions, unsuitable for direct pavement support. This finding strongly justifies the need for structural reinforcement and drainage improvement.

Engineering Implications and Slope Stabilization Measures

Based on the laboratory investigation, the soil conditions at Tosa Urban Village are characterized by a high organic content, elevated natural moisture, low dry density, and limited bearing capacity. These unfavorable geotechnical properties indicate that the soil is inherently weak and highly vulnerable to instability, particularly under external loading and during periods of intense rainfall. As a result, the subgrade is prone to slope failure, surface deformation, and premature pavement distress, which may compromise both structural safety and serviceability if left unaddressed.

To mitigate these risks, several engineering measures are proposed. First, slope cutting and terracing are recommended to reduce the overall slope angle and, consequently, the driving forces that contribute to landslide occurrence. By reshaping the slope into stepped or benched profiles, stress distribution within the soil mass can be improved, enhancing overall slope stability. Second, the construction of a retaining wall with a height of 3 m and a foundation depth of 1 m is suggested to provide effective lateral support and restrain soil movement. This structure is particularly important in areas with limited space where slope flattening alone is insufficient. Finally, the installation of an adequate drainage system, utilizing horizontal and radial drainage techniques, is essential to facilitate rapid dissipation of pore water pressure. Improved drainage reduces soil saturation, increases shear strength, and enhances the long-term performance of both slopes and pavement structures. Collectively, these mitigation strategies align with established geotechnical engineering practices for managing organic and weak subgrade soils and are expected to significantly improve stability and durability in the study area.

Discussion

The findings of this study clearly indicate that the soil conditions in Tosa Urban Village are predominantly composed of humus and organic silt, both of which are well known for their unfavorable engineering characteristics. Organic soils typically contain a high proportion of decomposed plant material, which significantly reduces interparticle bonding and load-bearing capacity. As a result, such soils exhibit low strength, high compressibility, and poor resistance to deformation, making them unsuitable as natural subgrade materials for road infrastructure without adequate treatment or reinforcement.
One of the most critical factors contributing to instability in the study area is the exceptionally high natural water content. Elevated moisture levels reduce effective stress within the soil mass, weaken particle interaction, and increase pore water pressure, particularly during prolonged rainfall events. In organic soils, water is easily retained within the soil structure due to the presence of organic matter and fine particles, which further exacerbates softening and loss of shear strength. This condition explains why slopes in Tosa Urban Village are highly susceptible to landslides, especially under seasonal climatic conditions typical of tropical regions.
The low specific gravity values observed in the soil samples further confirm the dominance of organic constituents. Compared to mineral soils such as sand or gravel, organic soils possess significantly lighter particles, which translate into lower dry density even after compaction. This characteristic limits the effectiveness of conventional compaction methods, as achieving a dense and stable soil structure becomes inherently difficult. Consequently, the subgrade remains weak and prone to excessive settlement under traffic loads, leading to pavement cracking, rutting, and eventual structural failure.
In addition, the soil exhibits medium plasticity, as reflected by the plasticity index values. While medium plasticity soils are not always problematic, their behavior becomes critical when combined with high moisture content and organic composition. Under fluctuating moisture conditions, such soils tend to undergo volume changes, including swelling and shrinkage, which can induce differential settlement and accelerate pavement deterioration. These volumetric changes also contribute to the formation of tension cracks on slopes, creating preferential pathways for water infiltration and further reducing slope stability.
The low California Bearing Ratio (CBR) value obtained from the laboratory tests provides quantitative evidence of the soil's poor load-bearing capacity. A CBR value in this range categorizes the soil as a very weak subgrade, incapable of supporting pavement structures without significant improvement. This finding aligns with field observations of frequent road damage and slope failures in the study area. The low CBR

value reflects the combined influence of high moisture content, organic matter, and loose soil structure, all of which limit resistance to penetration and applied loads.

The results of this study are consistent with previous research on organic and tropical soils, which consistently highlights drainage control and structural reinforcement as key factors in achieving long-term stability. Studies conducted in similar climatic and geological settings have demonstrated that without effective drainage systems, organic soils remain saturated for extended periods, leading to progressive strength degradation. Structural measures, such as retaining walls and slope terracing, are therefore essential to counteract lateral earth pressures and reduce driving forces acting on unstable slopes. Overall, the result underscores that the geotechnical problems encountered in Tosa Urban Village are not isolated but rather characteristic of organic soil environments in tropical regions. Addressing these challenges requires an integrated approach that combines geometric slope modification, structural support, and efficient drainage systems. Without such comprehensive measures, infrastructure development on organic soils is likely to experience recurrent failures, increased maintenance costs, and reduced service life.

CONCLUSION

This study has evaluated the geotechnical characteristics and bearing capacity of subgrade soils in Kelurahan Tosa, Tidore Timur District, with the aim of understanding the factors contributing to slope instability and pavement distress. Based on the laboratory testing results, several important conclusions can be drawn. First, the soil exhibits a very low bearing capacity, as indicated by an unsoaked California Bearing Ratio (CBR) value of 5.77%. This value, together with an optimum moisture content of approximately 20.5% and a maximum dry density of 1.73 g/cm^3, confirms that the soil is categorized as a weak subgrade material. Such conditions imply limited resistance to traffic loading and a high susceptibility to deformation, rendering the soil unsuitable for direct use as a pavement foundation without prior improvement. Second, the particle size distribution and consistency limit tests reveal that the soil is dominated by fine-grained materials. More than 35% of the soil passes sieve No. 200, classifying it as a silty–clayey soil. According to the AASHTO soil classification system, the soil falls within the A-7 group, with Atterberg limits indicating a plasticity index of 14.91% and a liquid limit exceeding 41%, corresponding specifically to the A-7-6 subgroup. This classification reflects soils with poor engineering performance, particularly in terms of strength and volume stability under varying moisture conditions. Finally, the occurrence of slope failures in the study area is strongly influenced by both geotechnical and environmental factors. The upper slope adjacent to the road is predominantly used for plantation activities, while the lower slope directly borders a coastal area. The combination of steep slope geometry, significant elevation differences, and inadequate drainage capacity has intensified the adverse effects of high rainfall, leading to soil saturation and reduced shear strength. Consequently, effective slope stabilization and drainage improvement are essential to mitigate landslide risk and ensure the long-term performance of road infrastructure in Kelurahan Tosa.

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