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OPTIMIZATION OF A MIXTURE OF LIME AND PORTLAND COMPOSITE CEMENT (PCC) FOR STABILIZING PEAT SOIL IN ROAD CONSTRUCTION

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ABSTRACT

Peat soil presents significant challenges in construction due to its low bearing capacity and high compression. Several soil improvement methods are available to address these issues. One viable approach to enhancing soil quality is through lime and cement stabilization. This research aims to investigate the impact of a lime and cement mixture on the physical and mechanical properties of the soil at the research location. The research results reveal that the CBR (California Bearing Ratio) value for the original soil is 5.60%. CBR values increased in specific mixture variations, with the CBR value for the original soil + 3% lime + 5% cement mixture reaching 11.56%. This mixture can be employed in the subgrade, meeting the CBR requirement for road construction subgrade, which is 6%. In the case of the mixture involving the original soil + 10% lime + 10% cement, a CBR value of 26.50% was achieved. The CBR value for subgrade with outstanding criteria for road construction is 20% to 30%. The addition of a lime and cement mixture for peat soil stabilization can significantly enhance the soil's bearing capacity, and increasing the percentage of lime and cement in the mixture leads to higher CBR values.

Keywords: peat soil, lime, cement, soil stabilization, CBR.

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INTRODUCTION

Roads play a crucial role in connecting regions, particularly in developing areas, facilitating the connection between different areas. In road construction, the subgrade is vital as it must withstand traffic loads and support the layers above it. The growing demand for space for new buildings and infrastructure has led to increased use of soft soils like peatlands. However, peat soils have insufficient bearing capacity, making them unsuitable for constructing embankments, roads, buildings, or other load-bearing engineering structures [1].

In Masarang, Tondano, North Sulawesi, Lake Tondano is being revitalized, and road projects can support its development as a tourism area in Tondano. In areas where road construction is planned, there are situations where the subgrade consists of peat soil, making it necessary to give it special treatment.

The main issues with peat soils are their high moisture content, high compressibility, and low shear strength [1,2,3]. Due to their high water and organic matter content, peat deposits need to be stabilized to support construction, such as buildings or roads [4,5,6]. When building on peat soil, problems can arise, such as excessive settlement, horizontal movement, and differential settling [7].

To improve the properties of the original soil and make it suitable for use as a subgrade in road construction, several efforts must be made. The subgrade's inability to carry the load can lead to damage to the layers above it. Given these soil conditions, one method for soil stabilization is to use lime and cement. The choice of lime and cement as mixing materials in the study area is based on the availability of materials and the cost-effectiveness of on-site application.

The success of road construction on soft soils depends on several crucial factors, including planning and construction [8]. Additionally, the availability and practicality of logistics for equipment and materials play a significant role [9]. The project's technical and financial requirements guide engineers in selecting the appropriate type of stabilization method to use [10]. There are several methods available for improving peat soil. One practical approach is preloading, which involves using backfill material to expedite compression and enhance the bearing capacity of the peat [11]. Another method is the partial replacement of peat soil through preloading, where the compressible peat soil is excavated and replaced with a sand-filling material, providing a more robust and less compressible foundation [9]. The use of a combination of bamboo grids and concrete piles for reinforcement can increase the CBR (California Bearing Ratio) value of soil embankments on peat soil [12].

The geotechnical properties of peat soil can be effectively stabilized by using Ordinary Portland Cement (OPC) and by modifying the hardening period. The addition of OPC to peat soils brings about modifications in the characteristics of the techniques studied [13]. When peat soils are treated with OPC, there is a decrease in liquid limit and permeability values due to pozzolanic activity [1]. Various techniques have been employed to enhance the physical and engineering properties of peat soil, including stabilization with $CaCO3$ lime and fly ash [14]. Shallow peat, which contains a mixture of clay, silt, and fine-grained sand, serves as a natural filler or stiffener, leading to an improved estimation of UCS (Unconfined Compressive Strength) for cement-peat stabilization [15]. Mass stabilization is an effective method for improving the properties of peat base soil, involving the creation of a hardened soil mass through the addition of a binder to the soil and controlled in situ mixing [3].

The utilization of a mixture of lime and rice husk ash (RHA) as a novel material for stabilizing fibrous peat soils has been explored [16]. The addition of clay with calcium carbide residue (CCR) and clay with rice husk ash (RHA) enhances soil bearing capacity, owing to the pozzolanic properties of silica and lime, which can bind soil particles [17]. Fly ash, being one of the primary sources of geopolymer binders and widely available worldwide, has proven effective in stabilizing peat soils when combined with bottom ash and Ordinary Portland Cement (OPC), improving the engineering properties of peat soils and enhancing their strength [18]. A mixture of geopolymers known as Geopolymer Flexible Activator (GeoFlexA) and fly ash serves as an alternative solution for addressing ground settlement issues associated with soft soils [5]. The addition of Envirotac polymer as a liquid soil stabilizer to peat soil can increase the strength of peat soil samples. However, it is important to mix Envirotac with other materials, such as High-Density Polyethylene (HDPE), to control peat soil shrinkage [19].

Scrap tire debris and sand supplemented with a pozzolanic binder (gypsum, lime, or cement) are stabilizers for peat soils. Established with ordinary Portland cement exhibited the most significant improvement in UCS and the direct shear parameters [4]. Using fly ash and palm shell activated carbon as additives and substitutes for ordinary Portland cement (OPC) in soil stabilization improves the overall characteristics of peat soils, and it increases the possibility of construction on peatlands [20]. Do stabilize peat soil using ordinary Portland cement (OPC) and magnesium oxide (MgO) as a binder, garnet and sand are used as fillers; the UCS test results showed that peat soil stabilization using MgO and spent garnet improved the strength of stabilized peat [21]. The compaction of peat treated with various compositions of pond ash (PA) and hydrated lime (HL) is doing, and the maximum dry density (MDD) increased with increasing PA and HL; at the same time, optimum moisture content (OMC) decreased with PA and HL [6].

Mixing quick lime and cement with peat soil is an effective method, especially for stabilizing peat soils that experience high moisture content [22]. Additionally, using a lime-cement mixture for peat soil stabilization helps prevent peat fires by slowing down the combustion process, rendering the stabilized peat soil non-flammable [23]. In another study, local admixtures such as diatomite clay have been utilized in peat soil stabilization. The first mixture comprises diatomite clay, calcium carbonate, lime, and water, while the second mixture replaces diatomite clay with cement. The diatomite clay mix is more cost-effective than the cement mix, but the cement mix outperforms the diatomite clay mix in terms of overall performance [10].

RESEARCH METHOD

The research was conducted in Masarang Village, West Tondano District, Minahasa Regency, and North Sulawesi. Figure-1 illustrates the location of the peat soil sampling.

Figure-1. Study area.

Given the conditions at this site, this study's focus was on evaluating lime and cement mixtures for soil stabilization in Masarang Village. The objective of this study was to assess the impact of various lime and cement mixtures on the physical and mechanical properties of the soil at the research location. The following ratios of lime to cement were used in the study: 3% lime: 5% cement, 10% lime: 10% cement, 5% lime: 15% cement, 10% lime: 15% cement, 15% lime: 15% cement, 17.5% lime: 17.5% cement, 15% lime: 20% cement, 20% lime: 20% cement, and 20% lime: 25% cement.

Before conducting the California Bearing Ratio (CBR) test, a compaction process is conducted for each sample variation to determine the maximum dry weight (γdry maximum) and optimum water content (Woptimum). Subsequently, these compaction results are employed to prepare CBR test samples. The CBR test is carried out under soaked conditions. The CBR values are then calculated at penetrations of 0.1 inches and 0.2 inches using the following formulas:

$$CBR_{0.1} = \frac{A}{3000} x100\% \quad (1)$$

$$CBR_{0.2} = \frac{A}{4500} x100\% \quad (2)$$

RESULTS AND DISCUSSIONS

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Table-1. Recapitulation of original peat soil test results.

Testing	Result
Water content	292.51%
Sieve analysis passing sieve no. 200	73.43%
Hydrometer analysis passing sieve no. 200	99.33%
Liquid limit (LL) Plastic limit (PL) Plasticity index (PI)	96.79% 91.07% 5.72%
Specific gravity (Gs)	1.86
Soil compaction Optimum moisture content Maximum dry density (γ max)	58.50% 0.84 gr/cm^3
CBR design	5.60%

In the Masarang West Tondano Subdistrict area, peat soil typically has a thickness of 1 meter, classifying it as shallow peat soil. Table 1 shows the results of the physical and mechanical properties test of peat soil. The test results indicate that peat soil exhibits high water content and organic content, with a water content value of 292.51%, highlighting the soil's exceptional water retention capacity. The specific gravity value shows a value of 1.86; this corresponds to the specific gravity category of peat soil: 1.25 - 1.80 [24]. The specific gravity value of peat soil, which exceeds 2.0, indicates that the peat soil has been contaminated by minerals [16]. The CBR design value of the peat soil in this study area is 5.60%. In Indonesia, the bearing capacity of subgrade for a road pavement design is determined by CBR testing with a minimum CBR value of 6% by the specifications of the Highways [25]. Therefore, it is still necessary to stabilize the soil by increasing the CBR value to meet the standard CBR value for subgrade in road construction.

Soil Compaction

The purpose of the compaction test is to enhance the shear strength of the soil, reduce its compressibility, lower its permeability, and minimize volume changes caused by variations in water content. The results of the compaction test provide the maximum dry density (γdry maximum) and optimum moisture content (W optimum), which serve as the basis for preparing CBR test samples.

Table-2. Compaction test results.

Compaction Test Results		
Sample	Wopt (%)	γ max (gr/cm^3)
Peat soil	58.50	0.840
Peat + 3% lime +5% cement	40.50	0.969
Peat + 10% lime +10% cement	54.50	0.881
Peat + 5% lime +15% cement	51.30	0.917
Peat + 10% lime +15% cement	48.00	0.922
Peat + 15% lime +15% cement	48.20	0.928
Peat + 17.5% lime +17.5% cement	48.80	0.929
Peat + 15% lime +20% cement	38.00	1.020
Peat + 20% lime +20% cement	38.50	1.022
Peat + 20% lime +25% cement	35.50	1.045

The findings presented in Table-2 indicate that as the percentage of lime and cement added increases, the value of the optimum water content decreases. This trend can be attributed to the property of lime and cement to bind soil particles, resulting in soil hardening through the absorption of soil water content. This action reduces soil plasticity and diminishes soil shrinkage and expansion, which is particularly advantageous for highway foundations.

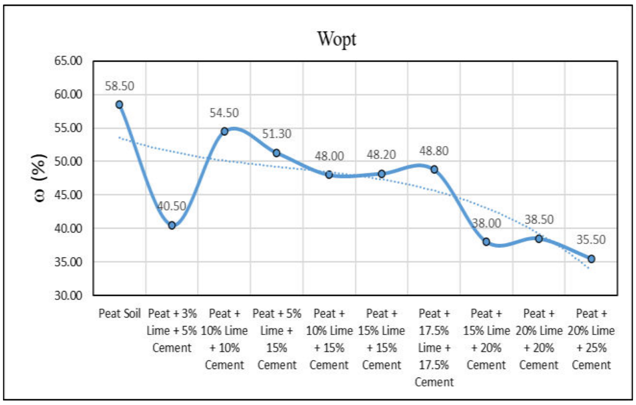

Figure-2. Optimum moisture content for each variation.

Furthermore, the maximum dry density values demonstrate that with a higher percentage of added lime and cement, the soil becomes denser or exhibits higher compaction variation. This observation suggests that the incorporation of lime and cement aids in achieving greater soil compaction, which is essential for improving the mechanical properties of the soil and enhancing its suitability for construction purposes.

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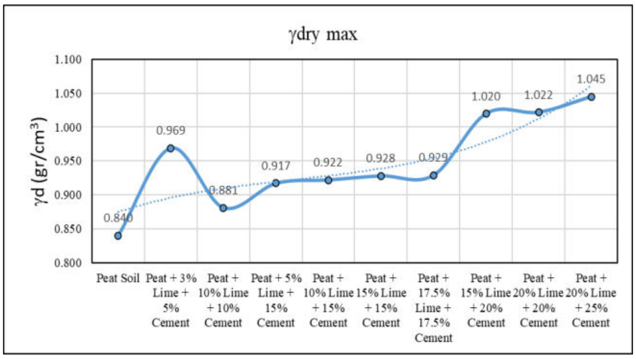

Figure-3. Maximum dry density of each variation.

Specific Gravity

The specific gravity test for each variation was conducted using a dry soil sample that had passed through sieve No. 40 during the compaction test for each variation.

Table-3. Specific gravity test results.

Specific Gravity	
Sample	**Value**
Peat soil	1.860
Peat + 3% lime +5% cement	1.895
Peat + 10% lime +10% cement	1.924
Peat + 5% lime +15% cement	1.952
Peat + 10% lime +15% cement	2.010
Peat + 15% lime +15% cement	2.072
Peat + 17.5% lime +17.5% cement	2.090
Peat + 15% lime +20% cement	2.178
Peat + 20% lime +20% cement	2.200
Peat + 20% lime +25% cement	2.252

The objective of the test was to determine the specific gravity values for each variation of the soil sample. This information is crucial for analyzing the characteristics and quality of each variation intended for use in road construction. The specific gravity test results for each variation are documented in Table-3, providing a comprehensive account of the specific gravity values obtained from the compaction process for each soil sample across various variations. There is an increase in specific gravity after adding various lime and cement mixtures, with a more significant percentage of addition resulting in a greater increase.

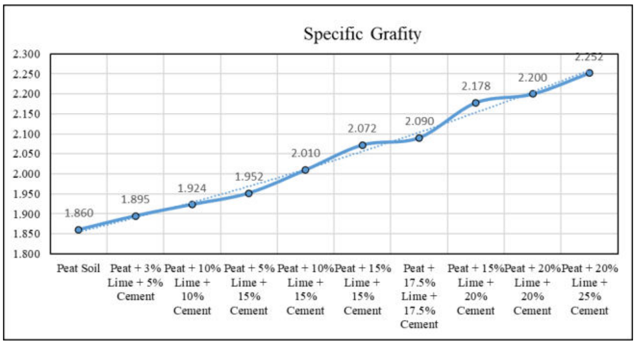

Figure-4. Peat soil specific gravity for each variation.

CBR Test Results

To assess the bearing capacity of the soil, the CBR test values were determined for each soil variation. The CBR test was conducted using the immersion method with a soaking duration of 4 x 24 hours. Before testing, compaction was carried out. The impact variations, with 15x, 35x, and 56x blows used in the CBR test. Three samples were prepared for each variation of the mixture to ensure reliable test results.

Table-4. CBR test results.

California Bearing Ratio (CBR)							
No. of Blows	**15**		**35**		**56**		**CBR Design (%)**
Sample	**0.1 (inch)**	**0.2 (inch)**	**0.1 (inch)**	**0.2 (inch)**	**0.1 (inch)**	**0.2 (inch)**	
Peat Soil	3.11	3.73	3.73	4.15	4.98	5.81	5.60
Peat + 3% Lime + 5% Cement	3.73	3.32	6.31	6.31	7.70	9.84	11.56
Peat + 10% Lime + 10% Cement	11.82	10.78	21.45	22.71	26.50	26.95	26.50
Peat + 5% Lime + 15% Cement	13.06	12.44	22.08	21.87	28.39	27.76	28.00
Peat + 10% Lime + 15% Cement	16.17	15.98	23.34	23.13	29.65	29.52	29.00
Peat + 15% Lime + 15% Cement	16.17	16.40	24.60	25.23	31.54	30.37	30.50
Peat + 17.5% Lime + 17.5% Cement	11.82	10.78	25.23	24.81	28.39	29.94	31.60
Peat + 15% Lime + 20% Cement	11.82	10.78	25.23	24.81	27.13	28.23	39.00
Peat + 20% Lime + 20% Cement	12.44	10.78	27.13	27.38	36.59	36.36	41.00
Peat + 20% Lime + 25% Cement	9.33	7.46	25.23	21.03	29.02	29.09	47.90

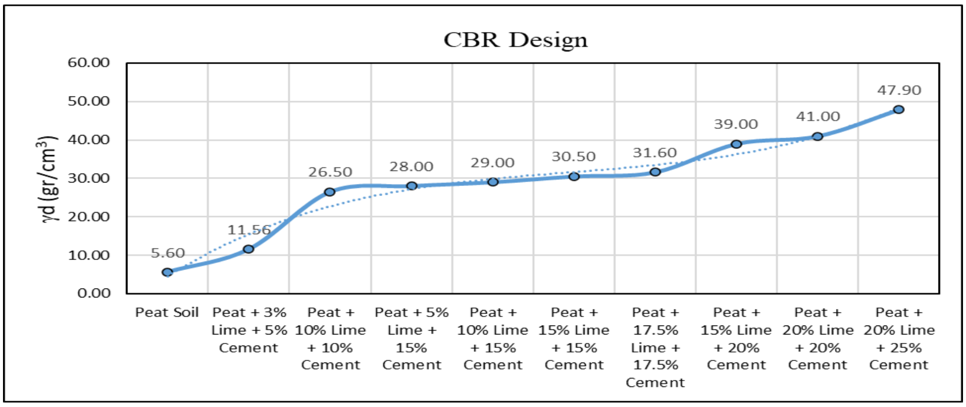

Figure-5. CBR design value.

The CBR value is determined by dividing the penetration load by the standard load and then multiplying it by 100%. Table 4 clearly illustrates that as the percentage of added lime and cement increases, there is a corresponding increase in the CBR value. This substantial increase in the CBR value is primarily attributed to the addition of lime and cement to the soil, which enhances the composition of the mixture. Figure-5 shows that the CBR design result for the original soil was 5.60%. The mixture with the addition of 3% lime + 5% cement yielded a CBR of 11.56%, while the variation with the addition of 10% lime + 10% cement resulted in a CBR of 26.50%. The variation with 20% lime + 25% cement reached a maximum value of 47.90%.

CONCLUSIONS

a) The mixture of lime and cement significantly improves soil quality in Masarang Village, West Tondano for subgrade The test results indicate that this mixture effectively improves the physical and mechanical characteristics of the soil.
b) Various mixtures were tested, and the combination of soil + 3% lime + 5% cement yielded the most effective result, with a CBR value of 11.56%. This exceeds the standard subgrade CBR value of 6%, indicating that the mixture meets the requirements for improving subgrade strength and stability.
c) Mixtures with a composition of soil + 10% lime + 10% cement exhibited a CBR value of 26.50%, meeting the criteria for a very good CBR value for subgrade in road construction, which typically falls in the range of 20% to 30%.
d) After stabilizing the soil with lime and cement, a noticeable increase in bearing capacity, as indicated by the CBR results, was observed. The CBR value increased with higher percentages of lime and cement in the mixture. Additionally, changes in characteristics were observed, including reduced water content and increased specific gravity after stabilization.

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