The Effect of Water-Binder Ratio on The Unconfined Compression Strength of Lime Treated Expansive Soils

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Abstract. This paper discusses unconfined compression strength in expansive soils using lime added as an ingredient. Soil samples were taken from one location in Manado City and tested in the laboratory to obtain soil properties values such as liquid limit, plastic limit, plasticity index, activity, and unconfined compression strength. For the water-binder ratio, three variations are used, namely 1.0, 1.2, and 1.5. From the test results obtained, expansive clay characteristics are very plastic with an enormous PI value. The addition of 200 kg of lime in 1 cubic meter of soil increased the unconfined compression strength by 95.4% to 510.3%. The highest unconfined compression test was for water binder ratio 1.2 for curing time of 14 days, 28 days, and 90 days.

1. Introduction

The Expansive soil in the North Sulawesi area is found in several locations, including Manado City, East Bolaang Mongondow Regency, and the other regions scattered in several districts and cities. Expansive soil in several areas caused damage to roads and houses. The expansive soil has high expansion and shrinkage properties with montmorillonite clay's mineral content [1].

Expansive soils, which are also called swell shrink soil, tend to shrink and swell with moisture content variation, which leads to taking in the ground. Significant distress occurs in the soil, which is subsequently followed by damage to the overlying structures. During periods of more significant moisture, like monsoons, these soils imbibe the water and swell. afterward, they become soft, and their water holding capacity diminishes, and in summer seasons, these soils lose the moisture contained in them due to evaporation, resulting in their becoming harder. [2]. Expansive soil has a high plasticity index and activity values.

researched the influence of the amount of lime, the porosity, and the moisture content on the strength of a lime-treated sandy lean clay soil, as well as to evaluate the use of a water/lime ratio and a voids/lime ratio to assess its unconfined compression strength [3].

Some researchers also analyzed soil solidified with both lime and fibers to investigate the soil's mechanical properties [4]. Wheat straw, rice straw, jute, and polypropylene fiber were added to the soil and lime-soil, respectively. An unconfined compressive test of the fiber-soil was conducted to confirm the optimal fiber content and optimal fiber length.

In recent years, cement and soil improvement techniques have been well studied in geotechnical engineering. Lime has been utilized as a cementing agent for several decades. Due to the pozzolanic
reactions induced by the lime in the soil in the presence of water, the mechanical resistance developed by soil-lime blends can take from several weeks to months [5]. It is CaO (calcium oxide or quicklime), Ca(OH)2 (hydrated lime), and CaCO3 (calcium carbonate), and for stabilization, both CaO and Ca(OH)2 are widely used. As research conducted by [6], limestone as a stabilizing agent contains a compound content of CaO 95.03%. The purpose of this study was to discuss the value of unconfined compression strength in expansive soils with lime added.

2. Material and Methods

2.1. Soil Samples
Soil samples used in the study were taken from one location in Manado City, North Sulawesi Province, with the coordinates of sampling N.1°.29'.32.88"E.124°.54'.0.71" (see Figure 1).

Figure 1. Soil Sample Location

Soil samples were taken at a depth of 1 meter by hoeing (disturbed samples) and undisturbed samples (undisturbed samples) using a thin tube covered with a plastic bag. The soil sample is then dried in the sun to air dry. The clods of soil are broken down with a rubber hammer and then filtered with a sieve No.4.

2.2. Mixture Composition and Curing Time
The lime used in the mixture comes from the people's mining in Lobong, Kotamobagu, and 200 kg in 1 cubic meter of soil. The water ratio to lime used three variations: 1.0, 1.2, and 1.5 (Table 1). Curing time was observed at 14 days, 28 days, and 30 days.

| Water Binder Ratio (%) | Curing Period (days) |
|------------------------|----------------------|
| 1.0                    | 14, 28, 90           |
| 1.2                    | 14, 28, 90           |
| 1.5                    | 14, 28, 90           |
2.3. Testing Procedure
The tests carried out included moisture content, specific gravity, linear bar shrinkage, atterberg limits, unconfined compression strength, and USCS classification using ASTM and BS standards (see Table 2). The unconfined compression strength test is shown in Figure 2.

| Type of Testing                | Standard used       |
|-------------------------------|---------------------|
| Water content                 | ASTM-D-2216-92      |
| Specific gravity              | ASTM-D-854-92       |
| Bar linear shrinkage          | BS 1377:1975        |
| Atterberg limits              | ASTM-D-4318-95      |
| Unconfined compression strength| ASTM-D-2166-05      |
| USCS Classification           | ASTM-D2487-00       |

Figure 2. The unconfined compression strength test

3. Results and Discussion

3.1. Soil Index Test Results
The results of soil index testing are presented in Table 3. The test results obtained for the plasticity index (PI) value are 62.39%, linear shrinkage (LS) is 20.8%, and activity is 1.39%. The value in the test results is then compared with previous research (see Table 4). The soil identification test results can be concluded that the soil is categorized as a very plastic expansive clay with a very high development rate. It is indicated by a PI value that far exceeds previous studies' limits with Montmorillonite's alleged mineral content.
Table 3. Soil Index Test Results

| Soil Parameters          | Unit | Results |
|-------------------------|------|---------|
| Unit Weight (γ)         | gr/cm³ | 1.59    |
| Water content (w)       | %    | 56.43   |
| Specific Gravity (Gs)   |       | 2.59    |
| Liquid Limit (LL)       | %    | 105.28  |
| Plastic Limit (PL)      | %    | 42.82   |
| Plasticity Index (PI)   | %    | 62.39   |
| Linear Shrinkage (LS)   | %    | 20.8    |
| Pass the filter No.#200 | %    | 98.04   |
| Clays Fraction (C)      | %    | 55      |
| Activity                | %    | 1.39    |
| USCS classification     |      | CH/OH   |

Table 4. Comparison of test results with previous research

| No | Theory/Research | Limitation | Test Result | Conclusion                  |
|----|-----------------|------------|-------------|-----------------------------|
| 1  | Hols and Gibbs  | PI > 35 %  | PI = 62.39 %| Very high level of development|
|    |                 | PI > 55 %  | PI = 62.39 %|                             |
|    |                 | % passing ≥ 200 > 95 % | % passing # 200 = 98.04 % | The potential for development is very high |
|    |                 | LL > 60 %  | LL = 105.28 %|                             |
|    |                 | Swelling > 10 % | LL = 105.28 %|                             |
| 2  | Chen            | AC > 1.25  | AC = 1.39   | The potential for development is very high |
|    |                 | PI > 17 %  | PI = 62.39 %| Clay is very plastic        |
| 3  | Skempton        | PI > 17 %  | PI = 62.39 %| Clay is very plastic        |
| 4  | Atterberg limits| LL > 50 %  | LL = 105.28 %| CH classification (high plasticity clays) |
|    |                 | PI > 42 %  | PI = 62.39 %|                             |
|    |                 | PI = 0.73 (LL-20) | PI = 62.25 %|                             |

3.2. Stress-Strain Behavior
The stress-strain relationship curves for untreated soil and treated soil are shown in Figures 3, 4, and 5. For natural soils, the unconfined strength value was 0.87 kg/cm². The addition of 200 kg of lime in 1 cubic meter of soil increased the unconfined compression strength by 1.70 kg/cm² to 5.31 kg/cm² or an increase of 95.4 % to 510.3 %. It is because of a force-increasing pozzolanic reaction involving ion exchange between calcium ions from lime and cations on the clay soil surface.
Figure 3. Stress-Strain Curve of Soil with Water/Binder 1.0

Figure 4. Stress-Strain Curve of Soil with Water/Binder 1.2
The strain on the untreated soil was 5%, while the treated soil's pressure was 3%. This shows that the addition of lime causes the soil to behave more rigidly than the untreated soil.

3.3. **Effect of Water-Binder (W/B) Ratio on Unconfined Compressive Strength**

The effect of water binder ratio and curing time on the unconfined compression test is presented in Table 5 and Figure 6.

**Table 5. Unconfined Compression Strength**

| Water Binder ratio (%) | Curing period in days | Unconfined Compression Strength (kg/cm²) |
|-----------------------|----------------------|------------------------------------------|
| Untreated soil        | 14                   | 0.87                                     |
| 1.0                   | 28                   | 1.70                                     |
|                       | 90                   | 1.85                                     |
| 1.2                   | 14                   | 4.13                                     |
|                       | 28                   | 4.41                                     |
|                       | 90                   | 5.31                                     |
| 1.5                   | 14                   | 3.61                                     |
|                       | 28                   | 4.21                                     |
|                       | 90                   | 5.19                                     |
The highest unconfined compression test was for water binder ratio 1.2 for curing time of 14 days, 28 days, and 90 days. For example, for 28 days, the unconfined compression test values for water binder ratios 1.0, 1.2 and 1.5 were 1.85 kg/cm\(^2\), 4.41 kg/cm\(^2\) and 4.21 kg/cm\(^2\), respectively.

![Figure 6](image-url)  
**Figure 6.** Effect of Water-Binder (W/B) Ratio on Unconfined Compression Strength

The increase in unconfined compression strength with curing time under normal conditions with a temperature of 23 ± 1°C with a humidity of 95% was due to cementation bonds compared to suction stress development.

4. Conclusion
   1. The soil identification test results can be categorized as very plastic expansive clay with a very high level of development, which is indicated by an enormous PI value.
   2. The addition of 200 kg of lime in 1 cubic meter of soil increased the unconfined compression strength by 95.4% to 510.3% due to the pozzolanic reaction.
   3. The highest unconfined compression test was for water binder ratio 1.2 for curing time of 14 days, 28 days, and 90 days. The increase in unconfined compression strength with fixing time under normal conditions was due to cementation bonds.

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