A study of calcium hydroxide as a stabilizing agent in clay soil toward California bearing ratio and unconfined compression value

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Abstract. Soil is one of the most important materials in construction. Soil stabilization is an attempt to increase condition of soil that have poor engineering properties. Soil stabilization is also a mixture of soil with certain stabilizing agents to increase the engineering properties of the soil to attain technical requirements. This research used calcium hydroxide as a stabilizing material. The study purposes were to improve the engineering properties of clay due to the addition of 3% - 30% calcium hydroxide, Ca(OH)₂. The clay soil was classified as A-7-6 (9) based on the AASHTO classification system and was classified as CL (Clay – Low Plasticity) based on USCS. The unsoaked California Bearing Ratio (CBR) of original soil was 6.29%. Meanwhile, the Unconfined Compression Test (UCT) of original soil was 1.42 kg/cm². The study showed that the addition of calcium hydroxide increased the engineering properties of clay soil. The unsoaked CBR reached the maximum value of 11.46% at a variation of 12% calcium carbonate. The UCT also gained the maximum value of 3.12kg/cm² at a variation of 12% calcium hydroxide.

1. Introduction
Soil stabilization is a mixture of soil with chemical materials to improve the engineering of soil [1]. The usual soil stabilization is by mixing chemical materials to the soil. The most common additives are Portland cement, lime, bitumen, and tar [2]. The clay stabilization research was carried out by adding calcium hydroxide, Ca(OH)₂. For engineering soil modification, lime is used in the form of quicklime, CaO and calcium hydroxide, Ca(OH)₂. Calcium hydroxide called slacked lime is used in the form of a fine powder with a density of 0.45 to 0.6 t/m³ [3]. Subgrade may be identified by the CBR laboratory test. The California Bearing Ratio (CBR) number is used to rate the performance of soils for use as bases and subgrades beneath pavements of roads and airfields [4]. Unconfined Compression Test (UCT) is commonly used for clay specimens. In this test, the confining pressure, σ₁ is 0. At failure the minor principal stress is 0 and the major principal stress is σ₁ = σ₁/2 = q/2 = c_u and q is referred to as the unconfined compression strength. [5]. Clay stabilization by using gypsum and volcanic ash was explored and it was deduced that the addition of gypsum and volcanic ash increased the engineering properties of original clay soil [6]. Clay stabilization by using gypsum and paddy husk ash was investigated and it was concluded that the addition of paddy husk ash degraded the engineering properties of original clay soil [7]. This study analyzed the stabilization of clay which was mixed with calcium hydroxide, Ca(OH)₂ as stabilizing agents which were expected to increase the engineering properties of the clay specimens.

2. Method
The study was conducted using experimental methods in the Soil Mechanics Laboratory, Department of Civil Engineering University of Sumatra Utara. The specimens were original clay which had been stabilized with calcium hydroxide, Ca(OH)₂.
2.1. Preliminary work
The preliminary work made in this study were as follows:
1. Determining the location of clay soil sampling. The clay soil was taken from PTPN II, Patumbak, Deli Serdang.
2. Providing Calcium Hydroxide, Ca(OH)\textsubscript{2} as a stabilizing agent.

2.2. Specimen fabrication
There were 8 soil specimens for determining index properties. Then 12 samples were employed for the Atterberg test. Next, 55 samples were used for standard proctor test, and afterward 33 samples were utilized for CBR tests and 12 specimens for UCT tests

2.3. Testing implementation
Standard proctor test was done to get the optimum water content and the maximum unit weight. Then the CBR test and UCT test were carried out. The curing time of each sample was three days. All results were analyzed and were presented in the form of tables, figures, and descriptions. The schematic flow of the study was shown in Figure 1.

![Figure 1. The schematic flow of the study.](image-url)
3. Result

3.1. Clay soil
Index properties of clay soil were shown in Table 1 below:

| No. | Test                  | Results   |
|-----|-----------------------|-----------|
| 1   | Water content         | 34.43%    |
| 2   | Specific gravity      | 2.65      |
| 3   | Liquid Limit          | 47.33%    |
| 4   | Plastic Limit         | 17.45%    |
| 5   | Plasticity Index      | 29.88%    |
| 6   | Sieve analysis        | 48.81%    |
| 7   | Optimum moisture content | 21.12% |
| 8   | Maximum dry density   | 1.340 gr/cm³ |
| 9   | CBR                   | 6.29%     |

3.2. Stabilizing agent
The index properties of calcium hydroxide, Ca(OH)₂, were presented in Table 2.

| No. | Test                  | Calcium hydroxide |
|-----|-----------------------|-------------------|
| 1   | Specific gravity      | 2.36              |
| 2   | Liquid limit          | Non-Plastic       |
| 3   | Plastic limit         |                   |
| 4   | Plasticity Index      |                   |
| 5   | Sieve analysis        | 7.25%             |

3.3. Plasticity of the stabilized soil
The correlation of Liquid-limit, Plastic-limit, and Plasticity Index toward calcium hydroxide with a variation of 3% - 30% of stabilized soil were displayed in Figure 2 until Figure 4 respectively.

![Figure 2. Correlation between liquid-limit (LL) and calcium hydroxide of stabilized soil with a variation of 3% - 30% calcium hydroxide.](image)
It was shown in Figure 2 that the liquid limit due to the addition of calcium hydroxide of stabilized material decreased. The greater the percentage of calcium hydroxide, the smaller the liquid limit of stabilized soil. In original clay soil, the liquid limit value reached 47.33%, while the lowest liquid limit value was in the variation of 30% calcium carbonate mixture with three days curing time was 25.89%. This was caused by undergoing cementation process by calcium hydroxide.

**Figure 3.** Correlation between plastic-limit (PL) and calcium hydroxide of stabilized soil with a variation of 3% - 30% calcium hydroxide.

Figure 3 showed an increase in the plastic limit value due to the addition of calcium hydroxide. The initial clay soil had a plastic limit of 17.45% and continued to increase until the highest plastic limit value of 20.65% in a variation of 30% calcium hydroxide of stabilized soil.

**Figure 4.** Correlation between Plasticity Index (PI) and calcium carbonate of stabilized soil with a variation of 3% - 30% calcium hydroxide.

Figure 4 showed a decrease in the value of the plasticity index due to the addition of calcium hydroxide in stabilized soil. The decline in the value of the plasticity index can reduce the potential for the development and depreciation of the soil. In this study, the decline in the value of the plasticity index of the original clay soil was 29.88%. The plasticity index decreased with increasing calcium hydroxide in stabilized soil and reached the lowest plasticity index at 5.24% in the variation of 30% calcium hydroxide mixture with 3-days curing time. The correlation of maximum dry unit weight with calcium hydroxide of stabilized soil with a variation of 3% - 30% calcium hydroxide based on the Standard Proctor was presented in Figure 5.
It was seen in Figure 5 that the original clay soil had 1.34 gr/cm³ maximum dry unit weights. Figure 5 explained that the addition of calcium hydroxide in stabilized soil increased the maximum dry unit weight and reached the maximum value of 1.76 gr/cm³ of a variation of 12% calcium hydroxide. The correlation of $w_{opt}$ with a variation of 3% - 30% calcium hydroxide of stabilized soil was displayed in Figure 6.

Figure 5. Correlation of dry unit weight with a variation of 3% - 30% calcium hydroxide of stabilized soil.

It was seen in Figure 6 that the original clay soil had 21.12% optimum water content. A variation of 12% calcium hydroxide of stabilized soil gave 21.62% optimum water content. The correlation of the CBR value with a variation of 3% - 30% calcium hydroxide of stabilized soil was shown in Figure 7.

Figure 6. Correlation of $w_{opt}$ with a variation of 3% - 30% calcium hydroxide of stabilized soil.

Figure 7. Correlation of the CBR value with a variation of 3% - 30% calcium hydroxide of stabilized soil.
It was seen in Figure 7 that the original clay soil had a 6.29% CBR value. The addition of calcium hydroxide in stabilized soil increased the maximum CBR value and reached the maximum value of 11.46% at a variation of 12% calcium hydroxide. The correlation of compressive strength with a variation of 3% - 30% calcium hydroxide of stabilized soil was shown in Figure 8.

![Figure 8. Correlation of compressive strength with a variation of 3% - 30% calcium hydroxide of stabilized soil.](image)

It was observed in Figure 8 that the original clay soil had 1.42 kg/cm$^2$ unconfined compressive strength. The addition of calcium hydroxide in stabilized soil increased the unconfined compressive strength and reached the maximum value of 3.12 kg/cm$^2$ at a variation of 12% calcium hydroxide.

4. Conclusion
From the study results, it could be concluded that:
1. Based on the USCS classification, the clay soil specimen was classified as CL (Clay-Low Plasticity) type, which inorganic clay with low to moderate plasticity.
2. Based on the AASHTO classification, the clay soil samples were classified as A-7-6 (9). The stabilized soil with a 12% calcium carbonate was classified as A-7-6 (6).
3. The specific gravity of clay soil was 2.65 and the specific gravity of calcium hydroxide was 2.36.
4. The clay soil had a liquid limit (LL) of 47.33% and the plasticity index of 29.88%. The addition of 30% calcium hydroxide, the liquid limit value is 25.89% and the lowest plasticity index (IP) value is 5.24%.
5. From the standard Proctor test, the optimum water content was 21.12% and the maximum dry unit weight was 1.34 gr/cm$^3$. While the stabilized soil at 12% calcium hydroxide had 21.62% optimum moisture content and 1.76 gr/cm$^3$.
6. The CBR value of clay soil was 6.29%. The largest CBR value of 11.46% was obtained from a 12% calcium hydroxide mixture.
7. The unconfined compressive strength value of clay soil was 1.42 kg/cm$^2$, while the remoulded clay soil was 0.71 kg/cm$^2$. The largest unconfined compressive strength value of 3.12 kg/cm$^2$ was obtained from a 12% calcium hydroxide mixture.

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