

The effect of lime and phosphoric acid on the CBR value of soft soil based on curing time

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Abstract. Road construction, both for flexible and rigid pavements, needs to pay attention to the bearing capacity of the subgrade. Especially on soft clay soils. The method to determine the bearing capacity value is through CBR testing in the laboratory. Soft soil has a low bearing capacity, so it cannot accept the load acting on it, such as the soil in the Gedebage area of Bandung. Because the carrying capacity value is decreasing, it is necessary to improve the soil with soil stabilization methods. In this research, stabilization materials will be used in the form of lime with a percentage of 10% and phosphoric acid 5%. Aiming to increase the bearing capacity value of the soil based on the results of laboratory CBR tests with 3, 7, and 14 days of curing, as well as to determine the optimum curing period of the test. Based on the test results, very positive results were obtained because it can increase the soaked CBR of 0.8% and 3% unsoaked for the native soil to 5.6% for soaked and 15.23% for unsoaked CBR in soil that has been stabilized with a 14-day curing period. Thus, these stabilization results meet the minimum requirements for pavement subgrade.

1 Introduction

In a highway construction project, particularly for flexible pavement, it is crucial to consider the bearing capacity of the subgrade soil, especially when dealing with soft soils. Soft soils pose a significant challenge due to their extremely low subgrade soil bearing capacity, leading to numerous issues in highway construction. One of the methods to assess the bearing capacity is through laboratory CBR testing. For subgrade soil intended for flexible pavement, if the CBR value is less than 6%, it falls below the standards set by Bina Marga and is categorized as unsuitable for supporting the loads placed upon it [1]. Soft soils can be classified as fine-grained soils with very low bearing capacity, often having CBR values less than 5% [2]. States that a crucial factor influencing the increase in CBR value in the stabilization of soft clay soil with lime is the curing period [3]. The positive outcomes have been observed in soil stabilization using a chemical solution of phosphoric acid at a 7.5% concentration, leading to enhanced CBR values [4]. The stabilization of soft clay soil using phosphoric acid also reduces its plasticity index [5]. The soil in the Gedebage area of Bandung is classified as soft soil with the symbol CH [6]. This calls for soil improvement

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measures, specifically soil stabilization, involving the use of lime at an 11% concentration and a 5% chemical solution of phosphoric acid mixed with the soft soil from the area. The objective is to determine the optimum CBR value based on the curing period.

2 Material

As discussed in the introduction, concerning soil stabilization materials in the Gedebage area, lime and a chemical solution of phosphoric acid will be mixed. The following provides an explanation regarding the materials for testing the CBR value.

2.1 Soft soil

In the field of Civil Engineering, soft soil is often referred to as problematic due to its CBR value being less than 6%, high moisture content, and a Plasticity Index (PI) greater than 17% [7]. Consequently, any structure built on such soil always experiences issues, including significant settling and shifting.

2.2 Lime

Lime, as a stabilization material, is commonly used [8] which can reduce the soil plasticity index and increase the soil bearing capacity [9]. Mixing lime with soil will result in alumina and silica reactions, and will gain higher strength when mixed with soil; this phenomenon is called pozzolanic. For this research, lime obtained from the store DEKI.ID was used, and the chemical composition values can be seen in the following Table.

Table 1. Chemical composition of quicklime.

| Element | Unit | Lime DEKI.ID |
|-------------------------------------|------|--------------|
| CaO | % | 61.68 |
| TiO ₂ | % | 0.07 |
| K ₂ O | % | <0.01 |
| Fe ₂ O ₃ /FeO | % | 0.10 |
| MgO | % | 2.10 |
| Al ₂ O ₃ | % | 0.42 |
| P ₂ O ₅ /P | % | 0.00 |
| SiO ₂ | % | 0.25 |

Source: DEKI.ID store (2023)

2.3 Phosphoric acid

Phosphoric acid, as one of the chemical solutions, can be used as a material for stabilization in both soft and expansive soils. The reaction of phosphoric acid with soft soil can enhance the soil's bearing capacity against water seepage [4]. The introduction of phosphoric acid

chemicals triggers a reaction in the soil that reduces water content and increases soil strength [10]. For the mineral composition of phosphoric acid, refer to Table 3.

Table 2. Composition of phosphoric acid minerals.

| Chemical composition | Maximum quantity (ppm) |
|-----------------------------|------------------------|
| Nitrates (NO ₃) | 3.0 |
| Fluoride (F) | 1.0 |
| Chloride (cl) | 2.0 |
| Copper (Cu) | 0.50 |
| Calcium (Ca) | 0.20 |
| Lead (Pb) | 0.50 |
| Sodium (Na) | 200 |
| Sulfates (SO ₄) | 20 |
| Magnesium (Mg) | 5 |
| Zinc (Zn) | 2 |

2.4 California Bearing Ratio (CBR)

Laboratory CBR testing is divided into two parts: both soaked and unsoaked conditions [11]. To determine the CBR value, it is based on the comparison between the required penetration loads for soil specimens, such as at 0.1" and 0.2", with the same standard load [12]. The relationship between soil bearing capacity characteristics and CBR values is described in accordance with [13].

Table 3. The relationship between soil bearing capacity characteristic and CBR value.

| No | Bearing capacity | CBR value |
|----|------------------|-----------|
| 1 | Low | 2%-5% |
| 2 | Medium | 6%-9% |
| 3 | Good | >9% |

2.5 Soil stabilization

Stabilization is one of the efforts to improve the strength of weak soil so that it can bear the load applied on the soil [14], with the process of selecting stabilization materials based on Raharmadi as in [15], as shown in the following Table.

Table 4. The process of selecting soil stabilization materials.

| Material passed the sieve 0.075 mm | > 25% passed the sieve No. 0.075 mm | | | < 25% passed the sieve 0.075 mm | | |
|------------------------------------|-------------------------------------|-------|------|---|------|------|
| | ≤ 10 | 10-20 | ≥ 20 | ≤ 6 (PI x percent passed the sieve 0.075 mm ≤ 6 | ≤ 10 | ≥ 10 |
| Plasticity index PI (%) | | | | | | |
| Stabilization method | | | | | | |

| | | | | | | |
|-----------------------|-------|-------|-----|-----|-------|-------|
| Cement and mix binder | Yes | Doubt | No | Yes | Yes | Yes |
| Lime | Doubt | Yes | Yes | No | Doubt | Yes |
| Asphalt (bitument) | Yes | Doubt | No | Yes | Yes | Doubt |
| Asphalt/Cement mixed | Yes | Doubt | No | Yes | Yes | Doubt |
| Granular | Yes | No | No | No | Yes | Doubt |
| Ect mixtured | No | Yes | Yes | No | Doubt | Yes |

3 Research methodology

In this research, we will perform stabilization on soft soil obtained from the Gedebage area in Bandung. Then, various tests will be conducted to determine the physical and mechanical properties based on several standards as follows.

Table 5. Standard of soil testing.

| No | Testing type | Standard |
|-----|------------------|---------------|
| 1 | Water content | ASTM 2216-71 |
| 2 | Specific gravity | ASTM D854-58 |
| 3 | Sieve analysis | ASTM D2487-69 |
| 4 | Atterberg limit | ASTM D4318 |
| 4.1 | Liquid limit | ASTM D423-59 |
| 4.2 | Plastic limit | ASTM D424-59 |
| 5 | Compaction | ASTM D698 |
| 6 | CBR | ASTM D1883-87 |

After obtaining the testing values for the native soil, next, it will be mixed with a stabilizing material, which is 11% lime and a 5% Phosphoric Acid chemical solution. The lime material is sourced from DEKI.ID store, and the Phosphoric Acid solution is obtained from the Kimia Farma Pharmacy in the city of Bandung. After mixing the soil with these materials, it will be cured for 3, 7, and 14 days, in order to determine the optimum value of this curing period. This research itself is conducted at the Soil Mechanics Laboratory of Politeknik Negeri Bandung. For a clearer understanding, please refer to the following flow diagram.

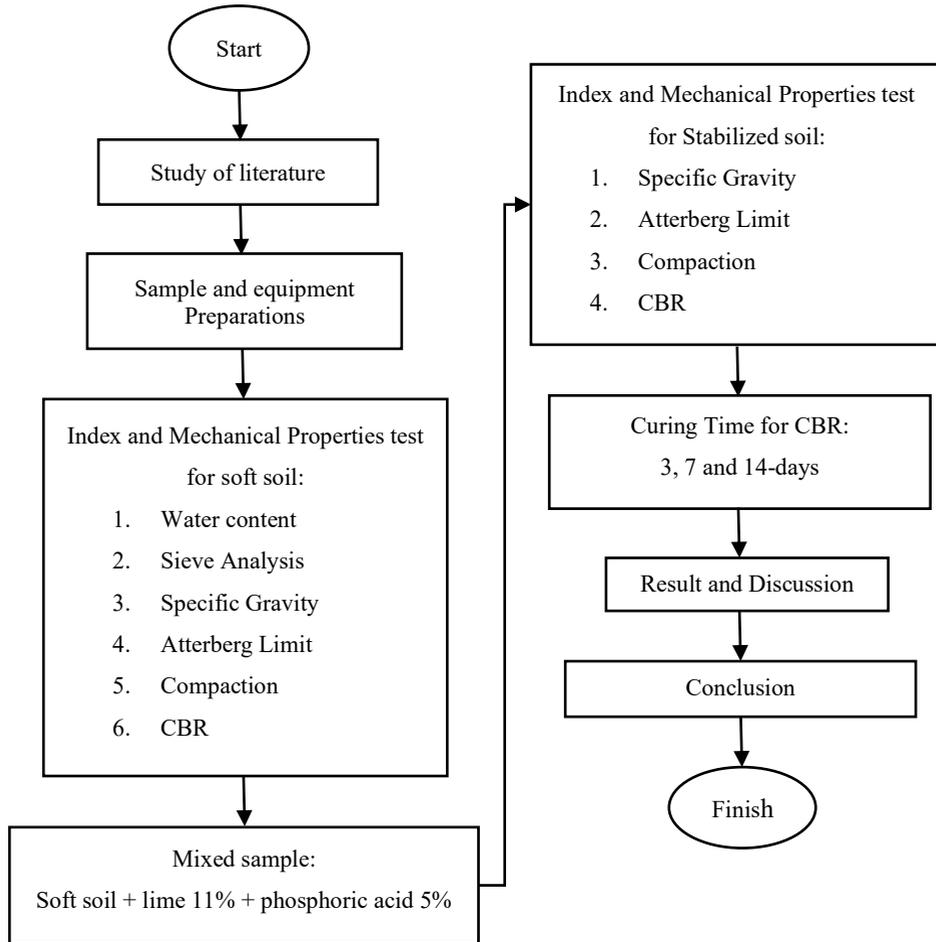


Fig. 1. Research flow charts.

4 Result and discussion

4.1 Index properties test

Here are the results of research related to the index properties of both native soil and stabilized soil, including specific gravity, Atterberg limits, grain analysis, and soil activity levels. This research follows ASTM standards. Following in the table 6 demonstrated result of index properties test that carried out in this research.

Table 6. Summary of index properties values.

| No | Types of index properties test | Symbol | Unit | Native soil | Stabilized soil |
|-----|--------------------------------|--------|------|-------------|-----------------|
| 1 | Grain size | | | | |
| 1.1 | Gravel | G | % | 0 | |
| 1.2 | Sand | S | % | 14.48 | |
| 1.3 | Silt | M | % | 29.2 | |

| | | | | | |
|-----|------------------|----|---|-------|------|
| 1.4 | Clay | C | % | 56.32 | |
| 2 | Specific gravity | Gs | - | 2.45 | 2.71 |
| 3 | Atterberg limit | | | | |
| 3.1 | Liquid limit | LL | % | 75 | 60 |
| 3.2 | Plastic limit | PL | % | 38 | 44 |
| 3.3 | Plasticity index | PI | % | 37 | 16 |
| 4 | Activity level | AC | % | 0.8 | 0.34 |

Based on the obtained results, the soil in the Gedebage area is initially classified as soft soil, with a plasticity index (PI) value of 37%, it can be determined from table 4 that lime stabilization material can be used because the native soil PI value is more than 20%. After stabilization, positive outcomes are achieved, as indicated by a 21% reduction in the Plasticity Index value and a soil activity level of 0.46%. These values fulfil the criteria for subgrade material in flexible pavement.

4.2 Mechanical properties result

For soil compaction testing using standard compaction where each mold requires a sample of 2.5kg passing a 4.25mm sieve for native soil while for stabilized soil the percentage of lime is 11% of 2.5kg which is mixed until evenly distributed and then pounded 25 times per layer, based on ASTM standards. The compaction graph for native soil and stabilized soil can be seen in figure 2 and 3. For samples tested on CBR that are soaked and unsoaked, approximately ± 4.5 kg that passes through the number 4 sieve (4.25 mm) is used for native soil. For stabilized soil, the amount of sample used is around ± 4.5 kg + 11% lime. Then let it cures for 3, 7 and 14 days. Then, table 7 and figures 2, 3 and 4 are demonstrated detailed data and results.

Table 7. Summary of mechanical properties values.

| No | Types of mechanical properties test | Unit | Native soil | Stabilized soil |
|-----|-------------------------------------|--------------------|-------------|-----------------|
| 1 | Compaction | | | |
| 1.1 | Dry density | gr/cm ³ | 1.173 | 1.27 |
| 1.2 | Moisture content | % | 32.75 | 23.46 |
| 2 | CBR soaked | % | 0.80 | - |
| 2.1 | Curing 3 days | % | - | 1.33 |
| 2.2 | Curing 7 days | % | - | 5.34 |
| 2.3 | Curing 14 days | % | - | 5.6 |
| 3 | CBR unsoaked | % | 3 | - |
| 3.1 | Curing 3 days | % | - | 3.07 |
| 3.2 | Curing 7 days | % | - | 5.45 |
| 3.3 | Curing 4 days | % | - | 15.23 |

4.3 Graphs of soil mechanical properties

Figure 2 and Figure 3 are shown the results of the mechanical properties of native and stabilized soil. It was found that the native soil compaction resulted in a moisture content value of 32.75% with a dry unit weight of 1.173. However, after stabilization, these values decreased to 23.46% for moisture content and 1.27 for dry unit weight.

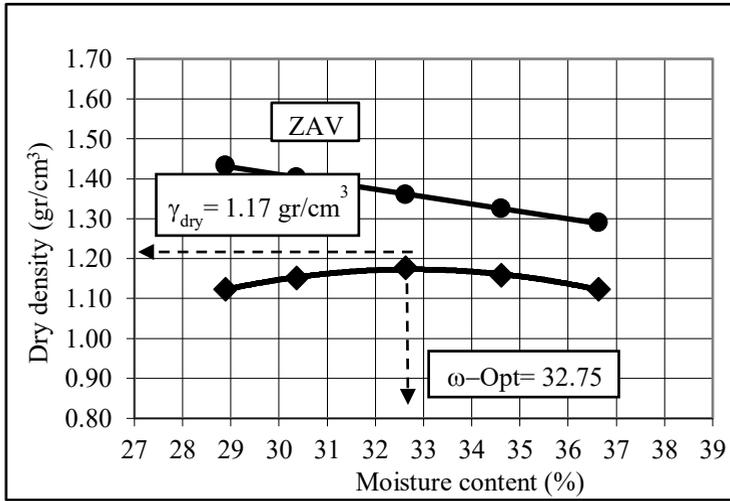


Fig. 2. Native soil compaction graph, the relationship between dry density and moisture content.

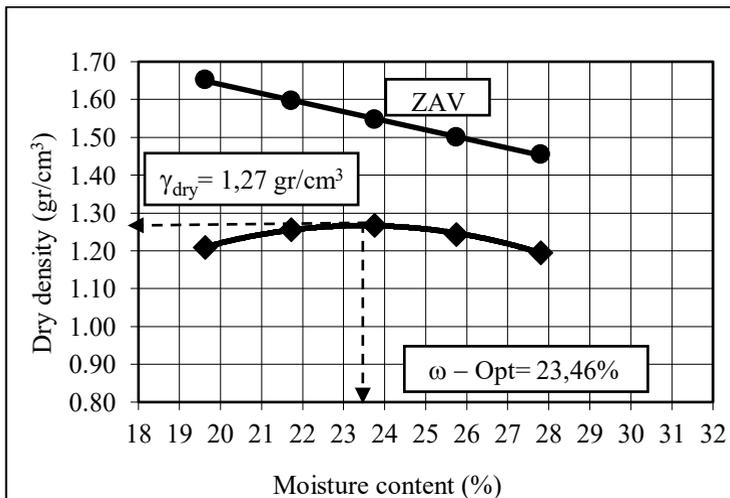


Fig. 3. Stabilized soil compaction graph, the relationship between dry density and moisture content.

Based on Figures 4 and 5, it can be seen that the longer the curing time, the more the CBR value tends to increase, both in the soaked and in the unsoaked condition. Curing times were varied from 3 days, 7 days and 14 days. CBR of native soil without chemical admixtures was 0.8 %, CBR of soil mixed with limes and phosphates was 1.33 %, CBR of soil mixed with limes and phosphates was 3.56 % and CBR of soil mixed with limes and phosphates was 5.6 %. In addition, the unsoaked CBR for the native soil is 3%, the 3-day CBR is 3.74%, the 7-

day CBR is 5.45%, and the 14-day CBR is 15.23%, as shown in Figure 4. The reaction of chemicals such as lime and phosphoric acid with soft soil can compensate the void of the native soil itself, lower the plasticity index, and improve the bearing capacity of soil, the longer the curing time, the better for soft soil to bear heavy load and more stable for road construction.

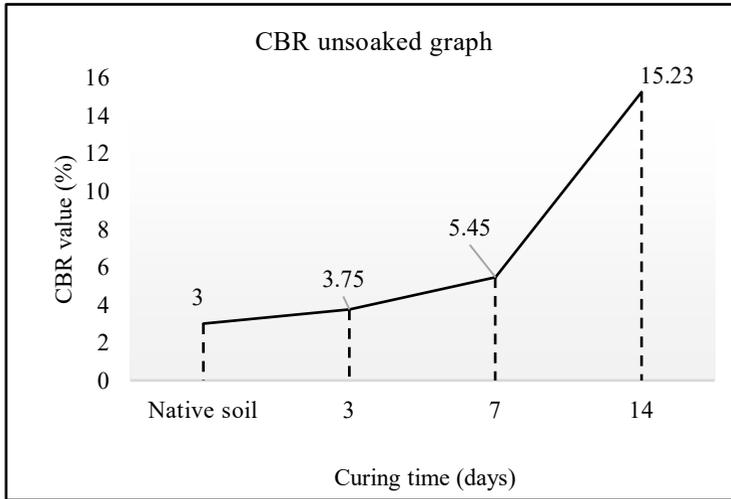


Fig. 4. CBR unsoaked chart, the relationship between CBR value and curing time.

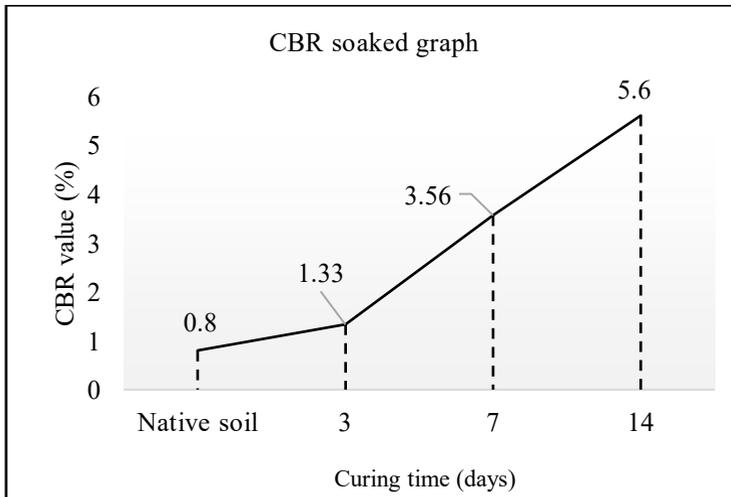


Fig. 5. CBR soaked chart, the relationship between CBR value and curing time.

5 Conclusion

Based on the result, it can be concluded that the stabilization of soft soil using a mixture of lime and phosphoric acid can decrease the soil plasticity index and increase the CBR values for both soaked and unsoaked conditions. The plasticity index of the native soil which was 37% reduced to 16%. Meanwhile, the CBR value of the native soil as 0.8% for soaked and 3% for unsoaked conditions, which increased to 5.6% for soaked and 15.23% for unsoaked conditions after a curing time of 14 days. Therefore, as demonstrated in table 3, the optimum

curing period in this study was found to be 14 days, and the results meet the minimum requirements for subgrade material in road pavement construction.

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