Comparison of the effectiveness of micromaterials and nanomaterials of lime as a stabilizing agent for expansive soils on the value of the plasticity index

Tami Silvia 1, Hendry 1*, Dewi 1, Geni 1, Muchtar 1

1 Civil Engineering Department, Bandung State Polytechnic, Jalan Gegerkalong Hilir, Ds. Ciwaruga, Bandung 40163, Indonesia

Abstract. Expansive soils are soils that have high shrinkage expansion. This condition is detrimental to buildings on it. Losses due to swelling and shrinkage in expansive soils require stabilization with quicklime with varying particle sizes of materials needed to reduce soil swelling and shrinkage. Stabilization with nano has been widely used. However, the procurement of nanomaterials is very expensive. Therefore, this paper will explain the effectiveness of micromaterials when compared to nanomaterials. The main focus that will be discussed in this paper is how the comparison of plasticity index (PI) values between micromaterials and quicklime nanomaterials on expansive soils. The research was conducted at the Bandung State Polytechnic Laboratory. This research uses a stabilization method by adding 2% lime per particle size. The procurement price of nanomaterial was Rp. 2,500,000 and micromaterial was Rp. 1,500,000. The plasticity index (PI) test results obtained are the original soil is 35.68%; mixed soil 2% micromaterial lime is 11.51%; and mixed soil 2% nanomaterial lime is 7.62%. The results of PI values < 12 both include low expansive, so the more effective result is the PI condition of adding 2% micromaterial lime with the procurement of cheaper price.

1 Introduction

One type of soil that has many problems in the construction of road construction is expansive soil. Expansive soil is composed of minerals that have very high shrinkage-development properties when there is a change in water content. This is because expansive soils contain certain types of materials that result in expansive soils having a large enough surface area and are very easy to absorb large amounts of water [1]. If construction is built on expansive soils, the type of damage that can occur is cracks in the pavement. The solution that can be used to overcome the damage caused by expansive soil is to mix the soil with lime as a stabilization material by testing the plasticity index. Plasticity index testing can be used to identify the development potential of expansive soil and determine the effective lime content to reduce the plasticity index value in expansive soil. Stabilization of expansive soils with
lime stabilizers is more advantageous when there is a longer work delay after mixing because lime is more compatible with longer hardening times [2]. In recent years, the use of nanomaterials has been shown to increase the effectiveness of stabilizers. The difference in particle size of the soil and overlapping nanomaterials can reduce the percentage of voids in the soil, sufficient to obtain significant improvements in the physical and chemical properties of the soil [3]. The use of nanomaterials (nano MgO and Nano Al₂O₃) with a percentage of 0.5% - 2% against expansive soil, with a percentage of 2% able to reduce the plasticity index value by 6.44% nano MgO and 9.14% Nano Al₂O₃ [4]. However, the procurement of these nanomaterials is quite expensive. The price of stabilizing materials such as lime is Rp. 2,500,000 and the price of stabilizing materials such as chalk is Rp. 1,500,000. As explained earlier, the disadvantage of this stabilization is the high procurement cost. The idea of using micromaterials as stabilizers emerged in this research. It is expected that with a larger material size than nanomaterials, procurement costs will be cheaper and still obtain more significant stabilization results compared to standard sizes. However, there is no research that directly compares the effectiveness of macro, micro, and nano materials. Therefore, this research will compare the effectiveness of macro, micro, and nano materials as stabilization materials on expansive soil and compare the results of stabilization of expansive soil with nano materials.

2 Materials and method

2.1 Materials

The materials used in this research are quicklime (CaO) which is the result of burning limestone at a temperature of ± 90 ° F with a composition of mostly calcium carbonate (CaCO₃) with 3 varying sizes, namely:

- Micromaterials that have a size on the micrometer scale (1 micrometer = 1 millionth of a meter). Micromaterial particles are larger than nanomaterials but still much smaller than expansive soil grains. Impact on Expansive Soils: Micromaterials, such as microfibers or microfill materials, can be used to improve expansive soil properties at a more macroscopic level than nanomaterials. For example, microfibers can be used to improve the strength and stability of expansive soils.

- Nanomaterials have a size on the nanometer scale (1 nanometer = 1 billionth of a meter). Nanomaterial particles are very small, even smaller than soil grains or expansive soil particles. Impact on Expansive Soils: Nanomaterials have the potential to modify expansive soil properties at the molecular level. Some nanoparticles, such as clay nanoparticles, can be used to change the characteristics of expansive soils, for example, by increasing the soil's ability to retain water or reducing expansion and shrinkage [5].

2.2 Method

2.2.1 Soil sampling

Expansive clay soil samples were collected in Cililin Village, Bandung City, West Java Province. The location of the soil sample is shown in Fig. 1. located at coordinates 6.98°S and 107.44°E taken from Google Earth.
2.2.2 Procurement of stabilization materials

Procurement of stabilization materials (macro material, micro material, and nanomaterial) of quicklime (CaO) was obtained from Nano Center Indonesia at Jalan Raya Serpong, Setu District, South Tangerang City, Banten, Indonesia.

2.2.3 Research location

The research was conducted at the Soil Mechanics Laboratory, Faculty of Engineering, Bandung State Polytechnic.

2.2.4 Method of the research

Physical testing of native soil (before mixing with stabilization materials), to determine the type of soil in Cililin Village, Bandung City, West Java Province. The tests conducted were Atterberg Limit, Specific Gravity (Gs), and water content. After the soil was proven to be expansive, stabilization was carried out with quicklime (CaO) with 2 grain size variations, namely 2% nanomaterial, and 2% micromaterial. Then a comparison is made with Atterberg Limit testing, to see which is more effective. Can be seen in Fig. 2.
Fig. 2. Method of the research.

3 Result and discussion

3.1 Physical properties of Cililin expansive soil

Based on visual observation, it is known that the soil of Cililin Village, Bandung City, West Java Province is expansive soil. This can be seen from the dark brown-black soil and the presence of organic remains. In the early stages of the research, physical testing of the original soil (before mixing with stabilization materials) was carried out, to determine the type of soil in Cililin Village, Bandung City, West Java Province. Table 1. shows the details of the testing.

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
<th>Value from Previous Research [6–8]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Liquid Limit (LL)</td>
<td>%</td>
<td>64,09</td>
<td>63,64</td>
</tr>
<tr>
<td>2</td>
<td>Plastic Limit (PL)</td>
<td>%</td>
<td>28,41</td>
<td>28,07</td>
</tr>
</tbody>
</table>
The results of testing the physical properties of the soil of Cililin Village, Bandung City, West Java Province against the Atterberg Limit are LL consistency limit of 64.09%, PL of 28.41%, and plasticity index (PI) of 35.68% (greater than 35%) which is categorized as a soil with a very high expansive level. According to the AASHTO system classification, the original soil tested is classified as soil class A-7-6 with a PI > LL-30 value of 35.68% > 34.09%, thus including a type of clayey soil material with a general assessment as a very poor subgrade.

The results of testing the physical properties of soil in Cililin Village, Bandung City, West Java Province on Specific Gravity (Gs) obtained a value of 2.61% which is categorized as clayey soil.

The results of testing the physical properties of soil in Cililin Village, Bandung City, West Java Province on Water Content obtained a value of 48.46%. The value of water content (w) of 48.46% based on the classification of soil types is included in the group of soft clay soil types because the value of soil moisture content that is included in the soil type group is between 30% - 50%.

The results of testing the physical properties of expansive soil in the laboratory can be seen in Table 1. From the results of physical test data, the soil of Cililin Village, Bandung City, West Java Province is classified as expansive clay. The results of testing the physical and mechanical properties of expansive soil in the laboratory can be seen in Table 1. From these data, it is known that the physical properties of the expansive soil under review are in accordance with the results of previous studies that tested the soil in West Java province, specifically the construction of the Cisumdawa Highway which includes expansive soil [6,9,10].

### 3.2 Mixed soil testing

In the final stage of research, physical testing was carried out, namely the Plasticity Index (PI) of mixed soil (native soil + 2% quicklime at each particle size). Then analyze the comparison of Specific Gravity (Gs) and Plasticity Index (PI) values of mixed soil between micro and nanomaterials of quicklime.

#### 3.2.1 Specific Gravity (Gs)

<table>
<thead>
<tr>
<th>No</th>
<th>Material Size 2% Lime (%)</th>
<th>Specific Gravity (Gs)</th>
<th>Percentage Decrease (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Native soil + 0% lime</td>
<td>2.61</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Native soil + 2% Micromaterial lime</td>
<td>2.56</td>
<td>1.728</td>
</tr>
<tr>
<td>3</td>
<td>Native soil + 2% Nanomaterial lime</td>
<td>2.55</td>
<td>2.320</td>
</tr>
</tbody>
</table>

Table 2. Result of Specific Gravity (Gs) test.
Fig. 3. Result of Specific Gravity (Gs) test.

From Table 2 and Figure 3, it can be seen that the smaller the particle size of adding 2% quicklime to expansive clay soil, the value of soil specific gravity (Gs) will decrease. The decrease in the Specific Gravity (Gs) value of expansive clay soil added with quicklime is caused by the segmentation process (clumping) in expansive clay soil. This causes the volume of grains to get bigger. Small material size greatly contributes to increasing the effectiveness of a stabilization material.

3.2.2 Plastic Limit (PL)

Table 3. Result of Plastic Limit (PL) test.

<table>
<thead>
<tr>
<th>Test Item</th>
<th>Material Size 2% Lime (%)</th>
<th>Plastic Limit/ PL (%)</th>
<th>Percentage Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Native soil + 0% lime</td>
<td>28,408</td>
<td>0,000</td>
</tr>
<tr>
<td>2</td>
<td>Native soil + 2% Micromaterial lime</td>
<td>39,323</td>
<td>38,420</td>
</tr>
<tr>
<td>3</td>
<td>Native soil + 2% Nanomaterial lime</td>
<td>42,368</td>
<td>7,490</td>
</tr>
</tbody>
</table>

Fig. 4. Result of Plastic Limit (PL) Test.

From Table 3 and Figure 4, it can be seen that the smaller the particle size of adding 2% quicklime to expansive clay soil, the plastic limit (PL) value will increase. The increasing plastic limit (PL) value is due to the fact that when expansive soil and quicklime are added
with water, the soil will dry out quickly (hydrated) and crack faster. The rapid hardening process of expansive soil is due to water absorbed by soil grains and quicklime so the attractive force of expansive soil decreases and more water is needed to bind the expansive soil to reach the soil cracks when the soil diameter is ±3 mm.

3.2.3 Plasticity Index (PI)

Table 4. Result of Plasticity Index (PI) test.

<table>
<thead>
<tr>
<th>Test Item</th>
<th>Material Size 2% Lime (%)</th>
<th>Plastic Limit/ PL (%)</th>
<th>Liquid Limit/ LL (%)</th>
<th>Indeks Plasticity/ IP (%)</th>
<th>Percentage Decrease (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Native soil + 0% lime</td>
<td>28,41</td>
<td>64,09</td>
<td>35,68</td>
<td>0,00</td>
</tr>
<tr>
<td>2</td>
<td>Native soil + 2% Micromaterial lime</td>
<td>39,32</td>
<td>50,83</td>
<td>11,51</td>
<td>67,75</td>
</tr>
<tr>
<td>3</td>
<td>Native soil + 2% Nanomaterial lime</td>
<td>42,27</td>
<td>49,89</td>
<td>7,62</td>
<td>33,76</td>
</tr>
</tbody>
</table>

Fig. 5. Result of Plasticity Index (PI) test.

From Table 4. and Figure 5. it can be seen that the smaller the particle size of adding 2% quicklime to expansive clay soil, the plasticity index (IP) value will decrease. The original soil plasticity index (IP) value shows clay soil with high plasticity. While the IP at the micromaterial particle size shows clay soil with low plasticity.

3.3 Testing results and analysis

Table 5. Testing results and analysis.

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Native Soil</th>
<th>2% Micro</th>
<th>2% Nano</th>
<th>Value from Previous Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Liquid Limit (LL) %</td>
<td>64,09%</td>
<td>50,83%</td>
<td>49,89%</td>
<td>25%</td>
</tr>
<tr>
<td>2</td>
<td>Plastic Limit (PL) %</td>
<td>28,41%</td>
<td>39,32%</td>
<td>42,27%</td>
<td>18,56%</td>
</tr>
<tr>
<td>3</td>
<td>Plasticity Index (PI) %</td>
<td>35,68%</td>
<td>11,51%</td>
<td>7,62%</td>
<td>6,44%</td>
</tr>
</tbody>
</table>
The results of the test values from previous research [11–15] are research on expansive soil with PI 38.06% stabilized with nano MgO, after stabilization the PI value has decreased, namely PI 6.44%.

The test results conducted after stabilization with quicklime decreased the PI value. The price of nanomaterials is Rp 2,500,000; and the price of micromaterials is Rp 1,500,000. so in terms of price, it is more effective to use 2% micromaterials with a PI price < 12% which already includes low expansive.

4 Conclusion

Based on Pd T-10-2005-B criteria, it shows that Cililin soil with a PI (Plasticity Index) percentage of 35.68% is classified as clay that has very high development properties. The results of the comparative analysis of the effectiveness between micro, and nanomaterials of quicklime on expansive clay soils are stabilization with quicklime micromaterials more effective with more affordable procurement costs than nanomaterials. The result obtained is PI < 12 (low expansive).

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References

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