Effectiveness of 2 Phase Stabilization Lime-Cement on High Plasticity Clay

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Abstract. Soil-cement has been used as an alternative of pavement materials in Indonesia since 1980. The use of local soil materials has the advantage of environmentally friendly and save the cost of transportation of pavement materials. How soil-cement reaches strength as per specification, and ease of implementation becomes a challenge of applying soil-cement stabilization as a road pavement. The addition of cement on one side will increase the soil-cement strength however it will increase the stiffness and also generate pavement crack. Several methods to improve performance and ductility of soil-cement on high plasticity clays that have been studied are: adding rice husk ash, fly ash, lime in 1 phase stabilization method and 2 phase stabilization method and adding sand to soil before cement stabilization. This paper presents the results of laboratory studies of comparison between 2 phase stabilization lime-cement method and 1 phase stabilization lime-cement method on high plasticity clay. A series of index properties and unconfined compression tests according to SNI were performed on the untreated clay, cement treated clay, and lime-cement treated clay sample that prepared using the 2 phase lime-cement stabilization method and the 1 phase lime-cement stabilization method. Lime content that was used were 2%, 6% and 10%, while the cement content was 10% of the soil dry weight. The results shows that the 2 phase stabilization lime-cement method was more effective than the 1 phase method. UCS soaked value of the clay sample treated by lime 10 % and cement 10 % prepared using 2 phase stabilization method is 9,64 time the UCS soaked value of the clay sample treated cement 10 % while the UCS soaked value of the clay sample treated by lime 10 % and cement 10 % prepared using 1 phase stabilization method is 3,66 time the UCS soaked value of the clay sample treated cement 10%.

1. Introduction

Soil-cement stabilization is a combination of chemical and mechanical stabilization. Soil-cement is a mixture of soil, cement and water compacted to form a new soil-cement material that is strong and impermeable bonds [1, 3]. The stabilization mechanism occurs due to the hydration process and pozzolanic reaction [4], soil and cement particles are mutually bound and clustered to form larger soil-cement particles [5]. Soil-cement stabilization increases shear strength and durability, reducing compressibility and soil shrinkage [3]. Soil-cement has been widely used for foundations, soil dam, slope reinforcement, embankment, soil stabilization around the tunnel, reservoir wall, pavement foundation layer, parking area, road shoulder and soil-cement column [2, 3, 6, 7, 8]. However cement stabilization was most widely used in stabilization of road subgrade or as an alternative materials for pavement [3].

The performance of soil-cement material is influenced by: soil type, cement content, degree of density, and moisture content [2, 9, 10]. Good performance of soil-cement is achieved by proper
moisture and cement content in well graded sand (A2, in AASHTO classification) and low plasticity silt (A5) [3, 9, 10]. The weaknesses of soil-cement are: 1) brittle, has a low peak strain so that it is prone to cause cracks, especially if used as a pavement materials, adding cement content on one side will increase shear strength but on the other hand will make soil cement more brittle and 2) poor performance on high plasticity clay (A7) [3, 9, 10].

Some of the benefits of using soil-cement as an alternative material for road pavement in Indonesia are: 1) the use of local soil material will reduce the use of aggregates and sand used by conventional pavement and concrete pavement, making it environmentally friendly [12]; 2) the construction of the trans-Sumatera, trans-Kalimantan, trans-Sulawesi and trans-Papua roads faced with the problem of aggregate availability and the high cost of material transportation due to the unavailability of adequate road infrastructure. The use of local soil as pavement materials will reduce the cost of transportation of the materials. The use of soil-cement as pavement in Indonesia began at 1980 with varying degrees of success [13].

The challenge of using soil-cement on high plasticity clays in Indonesia is to improve performance and increase soil-cement ductility. Several methods to improve ductility and improve the performance of soil-cement on high plasticity clays that have been studied are: 1) adding rice husk ash [14], 2) adding fly ash [15], 3) adding lime in 1 phase stabilization [4, 6, 8, 16, 17] and 2 stabilization phases [11, 18] and 4) adding sand to A7 soil before cement stabilization [19].

The 2 phase stabilization lime-cement with a 4-hour time lag at low cement content (2%, 4% and 6%) increases soil-cement unconfined compressive strength and ductility [11]. At high cement content (6%, 8% and 10%) of 2-phases stabilization lime-cement with a time lag 7 day increases the CBR value and reduces heaving [18]. However both of the above studies did not show effectiveness of the 2 phase stabilization lime-cement compared to the 1 phase stabilization lime-cement and only compared to cement stabilization.

This paper presents the results of a laboratory study of the 2 phase stabilization lime-cement on high plasticity clays with a 24 hour time lag. The objectives study to determine the effectiveness of stabilization of the 2 phase stabilization lime-cement to improve the performance of cement stabilization compared to the 1 phase stabilization lime-cement on high plasticity clay.

2. Method

This research was conducted in two stages according to Indonesian National Standar, SNI [19]. The preparation stage is to test the index properties and unconfined compression test (SNI 03-3638-2002) of clay from Tayuban Village, Panjatan District, Kulonprogo Regency, Yogyakarta Special Region. Index properties test include: specific gravity test (SNI 03-1964-1990), moisture content (SNI 03-1965-1990), grain size analysis (SNI 03-3423-1994 and SNI 03-1968-1990), liquid limit (SNI 03-1967-1990), and plastic limit (SNI 03-1966-1990). The clay is then classified based on the classification system of the American Association of State Highway and Transportation Officials, (AASHTO) and the Unified Soil Classification System, (USCS).

The main research stage includes: 1) Compaction test (SNI 03-1742-1989) of untreated clay sample and cement treated clay sample 2) Liquid limit (SNI 03-1967-1990), and plastic limit (SNI 03-1966-1990) of lime treated clay with 24 hours curring time 3) unconfined compressive test (SNI 03-6887-2002) of cement treated clay sample, lime-cement treated clay samples prepared using 1 phase stabilization method, and lime-cement treated clay samples preparing using 2 phase stabilization method. The unconfined compression test was conducted to samples in unsoaked and soaked for 4 hour conditions. The curing time for each unconfined compression test is 7 days. This research used lime content of 2%, 6% and 10% while the cement contents of 10% [1].

The 2 phase stabilization method consist of 2 phase stabilization. The first phase the clay is stabilized using lime for 24 hours curring time, aims to reduce soil plasticity and the second phase the clay is stabilized using cement while the 1 phase stabilization method clay-lime-cement is mixed at the same time.
3. Result and Discussion

3.1. Soil Classification

The index properties, grain size distribution and UCS value of untreated soil can be seen in Table 1. Soil has a fine grain content of 92.55% and sand grains 7.45% and gravel 0%. Based on the USCS classification the soil was included in the high plasticity clay, CH (Figure 1), whereas according to the AASHTO classification the soil was included in group A7-6 (Figure 2).

| Index properties                | Value       |
|---------------------------------|-------------|
| Atterberg Limits                |             |
| Liquid Limit, %                 | 69.00       |
| Plastic Limit, %                | 22.41       |
| Plasticity Index, %             | 46.59       |
| Grain Size Distribution        |             |
| Gravel, %                       | 0           |
| Sand, %                         | 7.45        |
| Fine Grained, %                 | 92.55       |
| Soil Classification             |             |
| USCS                            | CH          |
| AASHTO                          | A-7-6       |

| Mechanical Properties           |             |
|---------------------------------|-------------|
| UCS$_{unsoaked}$, kg/m$^2$      | 1.82        |
| UCS$_{soaked}$, kg/m$^2$        | Broken      |

![Figure 1](image1.png)  ![Figure 2](image2.png)

**Figure 1.** USCS soil classification.  
**Figure 2.** AASHTO soil classification.

3.2. The Effect of Cement Addition on Optimum Moisture Content and Maximum Dry Density

The results of the compaction test against the untreated clay and cement treated clay can be seen in Table 2 and Figure 3. The results show the clay treated by cement 10% had lower optimum moisture content and higher maximum dry density than the untreated clay. It describes the addition of cement effects the clay to become easier to compact.

| Treatment                          | Optimum Moisture Content (%) | Maximum Dry Density (kg/cm$^3$) |
|------------------------------------|-----------------------------|---------------------------------|
| Untreated clay                     | 24                          | 1,383                           |
| 10% cement treated clay            | 20                          | 1,462                           |
3.3. The Effect of Lime Content on UCS and MS Values

The unconfined compression test results of 7-day curing time of cement treated clay sample, lime-cement treated clay samples prepared using 1 phase stabilization method, and lime-cement treated clay samples prepared using 2 phase stabilization method can be seen in Table 3 and Table 4. Rice of lime content will increase the UCS value in unsoaked and soaked conditions. It occur in samples prepared using 1 phase stabilization method (Figure 4) and also prepared using 2 phase stabilization method (Figure 5). The highest UCS for both method were reached at lime content 10 %.

The lime content affects the sensitivity of lime-cement treated clay against water. Figure 6 show the tendency of the increasing lime content will reduce the value of MS. The smallest MS value occurs at lime content 10%. The clay sensitivity against water values (MS) is defined as the ratio between the difference of UCS values in unsoaked and soaked condition divided by the UCS value in unsoaked conditions and is expressed in units of percent (equation 1). The MS value describe reduction of unconfined compression strength in soaked condition. The lower MS value indicate better performance of soil stabilization.

\[
MS = \frac{UCS_{\text{unsoaked}} - UCS_{\text{soaked}}}{UCS_{\text{unsoaked}}} \times 100 \%
\] (1)

| Lime Content | 0 % | 2 % | 6 % | 10 % |
|--------------|-----|-----|-----|------|
| UCS unsoaked (kg/cm²) | 3,00 | 3,23 | 4,16 | 5,18 |
| UCS soaked (kg/cm²) | 0,83 | 1,21 | 1,76 | 3,04 |
| MS, % | 72 | 63 | 58 | 41 |

Table 3. UCS and MS value of the 1 phase stabilization method.

| Lime Content | 0 % | 2 % | 6 % | 10 % |
|--------------|-----|-----|-----|------|
| UCS unsoaked (kg/cm²) | - | 3,86 | 11,85 | 11,30 |
| UCS soaked (kg/cm²) | - | 3,71 | 6,46 | 8,00 |
| MS, % | - | 4 | 45 | 29 |

Table 4. UCS and MS value of the 2 phase stabilization method.
Figure 4. The effect of lime content on UCS for the 1 phase stabilization method.

|                | Untreated Clay | 10% Cement + 0% Lime | 10% Cement + 2% Lime | 10% Cement + 6% Lime | 10% Cement + 10% Lime |
|----------------|----------------|----------------------|----------------------|----------------------|------------------------|
| Unsoaked       | 1.82           | 3.00                 | 3.23                 | 4.16                 | 5.18                   |
| Soaked         | 0.83           | 1.21                 | 1.76                 | 3.04                 |                        |

Figure 5. The effect of lime content on UCS for the 2 phase stabilization method.

|                | Untreated Clay | 10% Cement + 0% Lime | 10% Cement + 2% Lime | 10% Cement + 6% Lime | 10% Cement + 10% Lime |
|----------------|----------------|----------------------|----------------------|----------------------|------------------------|
| Unsoaked       | 1.82           | 3.86                 | 11.85                | 11.30                |
| Soaked         | 3.71           | 6.46                 | 8.00                 |                      |

Figure 6. The effect of lime content on MS value.

|                | Untreated Clay | 10% Cement + 0% Lime | 10% Cement + 2% Lime | 10% Cement + 6% Lime | 10% Cement + 10% Lime |
|----------------|----------------|----------------------|----------------------|----------------------|------------------------|
| 2 Phase        |                | 4.0                  | 45.0                 | 29.0                 |
| 1 Phase        | 72.0           | 63.0                 | 58.0                 | 41.0                 |
3.4. The Effect of Stabilization Method on UCS and MS Value

Figure 7 and Figure 8 show comparison between UCS value of samples prepared using the 1 phase stabilization method and the 2 phase stabilization method. In unsoaked (Figure 7) and soaked conditions (Figure 8) the UCS value of samples prepared using 2 phase stabilization method is higher than the UCS value of samples prepared using the 1 phase stabilization method for all lime content variations.

The UCS soaked value of the clay sample treated by lime 10 % and cement 10 % prepared using 2 phase stabilization method is 9.64 time the UCS soaked value of the clay sample treated cement 10 % while the UCS soaked value of the clay sample treated by lime 10 % and cement 10 % prepared using 1 phase stabilization method is 3.66 time the UCS soaked value of the clay sample treated cement 10 %. The UCS unsoaked value of the clay sample treated by lime 10 % and cement 10 % prepared using 2 phase stabilization method is 3.77 time the UCS unsoaked value of the clay sample treated cement 10 % while the UCS unsoaked value of the clay sample treated by lime 10 % and cement 10 % prepared using 1 phase stabilization method is 1.73 time the UCS unsoaked value of the clay sample treated cement 10 %.

The 24-hour lag in the 2-stage stabilization method makes the clay and lime react first resulting in a decline in the plasticity index value (Figure 8), and flocculated clay particles into larger particles, thereby reducing the surface area of the granules [6, 8, 16]. Decline in plasticity index value and particle surface area causes cement stabilization work better so that there is a large rice in unconfined compressive strength compared to cement stabilization without the addition of lime or by adding lime in the 1 phase stabilization method.

Figure 6 show the 2 phase stabilization method produces lower MS value compare to the 1 phase stabilization method. The MS value of the clay sample treated by lime 10 % and cement 10 % prepared using 2 phase stabilization method is 29 % while the MS value of the clay sample treated by lime 10 % and cement 10 % prepared using 1 phase stabilization method is 41 %. The higher UCS value and lower MS value of sample prepared using 2 phase stabilization method indicate performance of the method is better than the 1 phase stabilization method.

![Figure 7](image_url)

**Figure 7.** The effect of stabilization method on UCS unsoaked.
Figure 8. The effect of stabilization method on UCS\textsuperscript{soaked}.

Figure 9. The effect of lime content on plasticity index.

4. Conclusion

From the comparison of 2 phase stabilization lime-cement method, 1 phase stabilization lime-
cement method and cement stabilization, it can be concluded as follows:

1. The UCS\textsuperscript{soaked} value of the clay sample treated by lime 10\% and cement 10\% prepared using 2 phase stabilization method is 9.64 time the UCS\textsuperscript{soaked} value of the clay sample treated cement 10\% while the UCS\textsuperscript{soaked} value of the clay sample treated by lime 10\% and cement 10\% prepared using 1 phase stabilization method is 3.66 time the UCS\textsuperscript{soaked} value of the clay sample treated cement 10\%.

2. The UCS\textsuperscript{unsoaked} value of the clay sample treated by lime 10\% and cement 10\% prepared using 2 phase stabilization method is 3.77 time the UCS\textsuperscript{unsoaked} value of the clay sample treated cement 10\% while the UCS\textsuperscript{unsoaked} value of the clay sample treated by lime 10\% and cement 10\% prepared using 1 phase stabilization method is 1.73 time the UCS\textsuperscript{unsoaked} value of the clay sample treated cement 10\%.

3. The MS value of the clay sample treated by lime 10\% and cement 10\% prepared using 2 phase stabilization method is 29\% while the MS value of the clay sample treated by lime 10\% and cement 10\% prepared using 1 phase stabilization method is 41\%.
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