Development of Relationship between Liquid Limit and Clay Content for West Java Soils

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Abstract. Soil is an essential factor in implementing civil engineering construction. Each region has varying characteristics and natural properties of soils, so it needs to be tested. One of the tests to determine those properties, especially fine-grained soils, is the Atterberg limits (i.e., Liquid Limit and Plastic Limit). The fall cone penetrometer test can provide liquid-limit values similar to the other methods (i.e., Casagrande Cup test). The hydrometer test results can determine the soil classification and the amount of clay and silt content. Then, the next step is to establish the relationship between the liquid limit and clay content in a soil sample. This study uses four soil samples with direct laboratory tests and seventeen soil samples from our previous research in West Java, Indonesia. The liquid limit is in the range of 41.46% to 115.80%. Clay fraction ranges from 12.24% to 66.18%. The results show that increasing clay content is followed by increasing the liquid limit in a linear relation. Other relations, such as plastic limit and plasticity index to clay content, show the same tendencies. Then, the results are similar to the other research using soils from England and Kenya.

1. Introduction
Soil is a material that is difficult to identify accurately. In some cases, soil can sometimes be a sensitive material by changing conditions. Clay is a fine-grained soil that has diverse characteristics. One can observe the changing of water content to find out a clay behavior. Clay can form various states (i.e., viscous liquid, plastic, a semi-solid, or a solid-state) depends on water content; Atterberg limits can show the existence behaviors. Hence, clay content and water content have a relationship.

In this research, the location of soil samples is from West Java soils, Indonesia. The sites are unique because the soils influenced by volcanic activity. For this reason, the soils may have different behavior than other locations. Then, determining the relationship between clay content and liquid limit in West Java soils becomes the focus of this paper.

2. Literature Review
Clays are soil particles smaller than 2 μm. Clay soil may be soft, plastic, or hard depending on its water content. Clay soil composed of various minerals, most commonly found is montmorillonite, kaolinite, and illite. Fall Cone Penetration Test can determine Atterberg limits (i.e., liquid limit and plastic limit). Table 1 shows the absorption water content by clay minerals.

The distributions of fine-grained soils are useful to determine the amount of clay content in the soil using a hydrometer test. Uplift water pressure will affect the weight of soils' solid parts in the suspension. Another principle applied is the Stokes principle, where the speed of a falling ball depends on the grain size diameter and density of suspensions.
There is some research focusing on observing the correlation between clay content and liquid limit. For example, Sheeler and Davidson (1957) in [1] used 223 samples of Iowa Loess soil in various depth and districts. The result indicated that increasing clay content is followed by increasing the liquid limit. Dumbleton and West (1966) in [2] used two types of soil samples. There was a mixture of montmorillonite and sand-silt mixture (called Surrey Finest) and a mixture of kaolinite and sand-silt mixtures (Supreme Kaolin). As a comparison, this paper also uses soil samples from Kenya, Jamaica, Borneo, Tanganyika, and Melbourne. However, the result shows a linear relationship between clay content, liquid limit, and plastic limit.

Table 1. Typical values of liquid limit, plastic limit, and activity of some clays [3]

| Mineral                  | Liquid Limit, LL | Plastic Limit, PL | Activity, A |
|--------------------------|------------------|-------------------|-------------|
| Kaolinite                | 35-100           | 20-40             | 0.3-0.5     |
| Illite                   | 60-120           | 35-60             | 0.5-1.2     |
| Montmorillonite          | 100-900          | 50-100            | 1.5-7.0     |
| Halloysite (hydrated)    | 50-70            | 40-60             | 0.1-0.2     |
| Halloysite (dehydrated)  | 40-55            | 30-45             | 0.4-0.6     |
| Attapulgite              | 150-250          | 100-125           | 0.4-1.3     |
| Allophane                | 200-250          | 120-150           | 0.4-1.3     |

3. Method
This study uses West Java soils, which consisted of 4 soil samples with direct laboratory tests and 17 samples from previous studies. Soil samples were tested for index properties to determine the physical properties of the soils. To obtain Atterberg Limits, the authors use a Fall Cone Penetrometer Test [4]. The liquid limit is a certain soil water content when cone penetration reaches 20 mm. If the penetration reaches 2 mm, the water content is the plastic limit.

Then, the next step compares the result from the laboratory test and other relevant research studies (4 locations). As the final step, the authors propose the characteristics of West Java soils using the relationship between clay content and liquid limit.

4. Result and Discussion
Table 2 shows that sample data were used in this study. Most soil samples are classified as silt with high plasticity (MH) based on USCS Classification (Figure 1). Figure 2 shows the correlations between clay content (CC) and liquid limit (LL). Clay content increasing is followed by increasing in LL. Table 3 presents the equation of this relationship.

Based on the result, West Java soils have water content relatively higher than in other locations. This result shows that these soils can absorb water to a relatively high level. The correlation is almost similar to the Kenya Black Clays (Figure 2). The difference values of LL between West Java soil and other locations range from 2.64% to 65.6% (Table 4).

Clay content (CC) also plays a role in increasing the plastic limit (PL). However, increasing of PL is not as significant as increasing of LL. Compared with previous studies, the increasing PL due to clay content also occurred in most locations of this study except for Iowa Loess soil (Figure 3). The increasing plastic limit of West Java soils is higher than in other places, but the result is lower than Kenya Black Clay. Figure 3 also shows that the correlation from West Java soils has a similar gradient to the Surrey Finest soils. The deviation of PL is from 0.45% to 29.39%, comparing the plastic limit of all soils different to West Java soils (Table 5).
Table 2. Index properties of soils

| Sample Code | w (%) | PL | LL | PI | USCS Class. | CC (%) | A | References |
|-------------|-------|----|----|----|-------------|--------|---|------------|
| P-1         | 53.27 | 32.45 | 67.64 | 35.19 | CH | 25.61 | 1.37 |            |
| P-2         | 40.96 | 38.55 | 62.91 | 24.36 | MH | 25.73 | 0.95 |            |
| P-3         | 44.82 | 54.08 | 98.2  | 44.12 | MH | 63.36 | 0.7  |            |
| P-4         | 51.06 | 48.16 | 89.59 | 41.43 | MH | 43.69 | 0.95 |            |
| S-1         | 44.14 | 40.5  | 101   | 60.5  | CH | 51.94 | 1.28 | [5]        |
| S-2         | 26.2  | 37.97 | 70.5  | 32.53 | MH | 52.8  | 0.62 | [6]        |
| S-3         | N/A   | 31.08 | 83.68 | 52.6  | CH | 47.04 | 1.12 | [7]        |
| S-4         | 33.4  | 34.6  | 69.4  | 34.8  | MH | 34.8  | 1    | [8]        |
| S-5         | 57.7  | 59.9  | 104.7 | 44.7  | MH | 60.6  | 0.7  | [8]        |
| S-6         | 48.5  | 44.4  | 91.6  | 47.2  | MH | 66.2  | 0.7  | [8]        |
| S-7         | 43    | 43.9  | 83.9  | 40    | MH | 33.6  | 1.2  | [8]        |
| S-8         | 30    | 34.85 | 89.7  | 54.9  | MH | 39.7  | 1.4  | [8]        |
| S-9         | 28.9  | 32.3  | 80.9  | 48.7  | MH | 43.5  | 1.1  | [8]        |
| S-10        | 32.6  | 28.7  | 64    | 35.3  | MH | 36.7  | 1    | [8]        |
| S-11        | 34.6  | 19.94 | 41.46 | 21.52 | CL | 12.24 | 1.76 | [9]        |
| S-12        | 17.36 | 25.63 | 59.49 | 33.86 | CH | 17.96 | 1.89 | [9]        |
| S-13        | 11.6  | 24.02 | 43.81 | 9.37  | CL | 27.8  | 0.71 | [9]        |
| S-14        | 47.78 | 34.34 | 43.71 | 9.37  | ML | 18.93 | 0.49 | [9]        |
| S-15        | 55.35 | 48.99 | 77.3  | 28.31 | MH | 29.69 | 0.95 | [9]        |
| S-16        | 70.4  | 77.11 | 115.8 | 38.69 | MH | 43.63 | 0.89 | [9]        |
| S-17        | 0.36  | 28.3  | 53.6  | 25.3  | CH | 38.01 | 0.67 | [9]        |

Laboratory test results

![Figure 1. USCS Classification soils](image)

The plasticity index also increases with increasing clay content (Figure 4). Compared to the correlation of clay content to liquid limit and plastic limit, the plasticity index becomes the second influential parameter. The increasing plasticity index in West Java soils is higher than in the United States.
States and Kenya, as seen in Figure 4. Surrey Finest soils have a higher plasticity index than the current study. The result shows the steepest gradient line is Iowa Loess soils.

**Table 3.** Correlations between Atterberg limits equations

| Sample Name         | Liquid Limit | Plastic Limit | Plasticity Index |
|---------------------|--------------|---------------|------------------|
|                     | Slope (m)    | Constant (b)  | Slope (m)        | Constant (b) |
| West Java           | 1.15         | 32.78         | 0.51             | 19.57        | 0.64 | 13.21 |
| Surrey Finest       | 1.29         | 16.47         | 0.53             | 2.86         | 0.76 | 13.61 |
| Supreme Kaolin      | 0.78         | 4.49          | 0.36             | 2.81         | 0.39 | 1.68  |
| Kenya Black Clays   | 1.20         | 8.15          | 0.78             | -3.04        | 0.41 | 11.19 |
| Kenya Red Clays     | 0.62         | 32.40         | 0.37             | 10.12        | 0.25 | 22.27 |
| Iowa Loess          | 0.91         | 10.90         | -0.04            | 24.70        | 0.95 | -13.80 |

**Figure 2.** Correlation between clay content and liquid limit

**Table 4.** Liquid limit deviation between West Java soils and other sites

| Locations            | LL Low | % Dev. | LL High | % Dev. | Range |
|----------------------|--------|--------|---------|--------|-------|
| West Java            | 46.87  | -      | 148.37  | -      | -     |
| Surrey Finest        | 32.23  | 14.64  | 145.73  | 2.64   | 14.64 |
| Kenya Black Clays    | 22.78  | 24.09  | 128.11  | 20.26  | 24.09 |
| Kenya Red Clays      | 40.05  | 6.82   | 95.19   | 53.18  | 53.18 |
| Supreme Kaolin       | 14.03  | 32.84  | 82.77   | 65.6   | 65.6  |
| Iowa Loess           | 22.04  | 24.83  | 102.26  | 46.11  | 46.11 |
Figure 3. Correlations between clay content and plastic limit

Table 5. Plastic limit deviations between West Java soils and other sites

| Locations            | PL Low | % Dev. | PL High | % Dev. | Range |
|----------------------|--------|--------|---------|--------|-------|
| West Java            | 25.80  | -      | 70.64   | -      | -     |
| Surrey Finest        | 9.32   | 16.47  | 55.85   | 14.79  | 14.79 |
| Kenya Black Clays    | 12.60  | 13.20  | 81.51   | 10.86  | 10.86 |
| Kenya Red Clays      | 14.71  | 11.09  | 47.71   | 22.93  | 22.93 |
| Supreme Kaolin       | 7.53   | 18.26  | 41.52   | 29.12  | 29.12 |
| Iowa Loess           | 24.21  | 1.59   | 20.68   | 49.96  | 1.59  |

Figure 4. Correlations between clay content and plasticity index
### Table 6. Index plasticity deviation between West Java soils and other locations

| Locations          | PI Low  | % Dev. | PI High | % Dev. | Range |
|--------------------|---------|--------|---------|--------|-------|
| West Java          | 21.08   | -      | 77.73   | -      | -     |
| Surrey Finest      | 22.91   | 2.89   | 89.87   | 19.23  | 19.23 |
| Kenya Black Clays  | 16.25   | 9.55   | 52.67   | 17.97  | 17.97 |
| Kenya Red Clays    | 25.35   | 0.45   | 47.48   | 23.16  | 23.16 |
| Supreme Kaoline    | 6.50    | 19.30  | 41.25   | 29.39  | 29.39 |
| Iowa Loess         | -2.17   | 27.97  | 81.58   | 10.94  | 10.94 |

**Figure 5.** Expansion potential of West Java soils

### 5. Conclusions

From this study, the majority of soils from West Java soil samples are silt with high plasticity based on USCS Classification. The liquid limit values of West Java soils range from 41.46 – 115.80, the plastic limit ranges from 19.94 – 77.11, and the plasticity index ranges from 12.24 – 66.18.

Atterberg limits (LL and PL) values influence the clay content. The liquid limit has a significant factor comparing to plastic limits. The values of the liquid limit and plastic limit in West Java soils are higher than in England, the United States, and Kenya. But, the plasticity index of the data is lower than England (Surrey Finest soils). Soil composition, type of clay minerals, and environmental conditions cause different correlation results among all soils. One reason is that soil from West Java soils is residual soils due to near active volcanoes. Activities values in West Java range from 0.49 – 1.89. Most of this soil has normal swelling potential. The contribution of this research is to get the influence of Atterberg limits to clay content.

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