Soil Improvement for clay with limestone and glass slag based on CBR value

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Abstract. Trash is one of the biggest problems for the cities in Indonesia, especially the city that has a relatively big number of citizens. One of them is glass, where glass is a material that is not decomposed by soil biologically. The negative impact from glass waste is it harms the environment. The objective of this research is to determine whether glass can be useful as the material for clay stabilization and to determine the bearing capacity using limestone and glass slag and also to determine bearing capacity using only the limestone. The mixture used in this research is 2% limestone and 4% limestone with additional glass slag of 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9% and 10%. Based on the research, it is determined that the biggest CBR value at a mixture of 2% limestone and 10% glass slag is 8.86%, and at variation of mixture of 4% limestone and 10% glass slag with CBR of 10.5%.

1. Introduction
Soil has a role as support of a building and used as a land development facility. The obstacle that is often met in the field is several locations have inadequate soil characteristics, hence it needs an improvement for the soil capacity in order to meet the soil stabilization. Soil is identified as a material that contains aggregate, cemented solid minerals (tied chemically) and from organic materials that has been weathered with liquid and air that fills up the void in between those solid particles. Soil in geotechnical engineering is meant to cover all materials from clay to rocks. Clay consists of clay particle and mixture of silts and sand and organic materials. The characteristics of clay is the grain size is less than 0.002, low permeability, high capillary, cohesive and high swelling and very slow consolidation process. Clay characteristics can change and increase in volume from the water underlying clay needs an improvement to increase the bearing capacity and to improve the soil characteristics [1][2].

Soil classification for fine grained soil is called consistency. The limitations of soil consistency is the liquid limit, plastic limit and shrinkage limit. Plasticity index is the difference between liquid limit and plastic limit. [3] Soil is classified using a very simple index test to determine that soil characteristics. That particular characteristic is used to determine the group classifications. Generally, soil classification based on particle size obtained from sieve analysis and its plasticity. Now day, there are two classification systems used, they are USCS and AASTHO. USCS stands for Unified Soil Classification System where soil is classified into coarse-grained soil such as gravel and sand where 50% of total weight passed sample from sieve analysis no. 200, using group symbol starting from letter G (gravel) or S (sand). Fine-grained soil is where more than 50% of total weight passed sample from sieve analysis no. 200, with group symbol started with letter M (silt) an organic, C (clay) an organic and O (silt). Symbol PT used for peat, muck. Coarse grained soil is assigned with group symbol such as GW, GP,
GM, GC, SW, SP, SM and SC. AASHTO (American Association of State Highway Transportation Official) is useful to determine the soil quality for subbase and subgrade road fill. AASHTO divides the soil into 7 groups, A-1 until A-7. The determination of this classification needs more data such as sieve analysis and liquid limit, plastic limit and plasticity index from Atterberg limit. [4][2][3]

| Soil Group in AASHTO System | Most Probable | Possible | Possible but Improbable |
|-----------------------------|---------------|----------|-------------------------|
| A-1-a                       | GW, GP        | SW, SP   | GM, SM                  |
| A-1-b                       | SW, SP, GM, SM| GP       | -                       |
| A-3                         | SP            | -        | SW, GP                  |
| A-2-4                       | GM, SM        | GC, SC   | GW, GP, SW, SP          |
| A-2-5                       | GM, SM        | -        | GW, GP, SW, SP          |
| A-2-6                       | GC, SC        | GM, SM   | GW, GP, SW, SP          |
| A-2-7                       | GM, GC, SM, SC| -        | GW, GP, SW, SP          |
| A-4                         | ML, OL        | CL, SM, SC| GM, GC                  |
| A-5                         | OH, MH, ML, OL| -        | SM, GM                  |
| A-6                         | CL            | ML, OL, SC| GC, GM, SM              |
| A-7-5                       | OH, MH        | ML, OL, CH| GM, SM, GC, SC          |
| A-7-6                       | CH, CL        | ML, OL, SC| OH, MH, GC, GM, SM      |

Table 1. Comparison of the USCS and AASHTO [5].

Glass is a matter that often seen and used daily. Therefore, often seen glass waste in our daily life. Glass waste is also often recycled for commercial necessity such as food products, drinks and others. However, if glass often seen is not in a whole lot of good condition, as an example a fraction from glass bottle, window, a cup, car window, aquarium, etc, it makes the recycling process more difficult and these fractions can be such a waste.

2. Literature review

2.1. Chemical stabilization
Chemical stabilization is to increase the strength and improve the bearing capacity by reducing or losing the engineering properties of soil that is not useful by mixing the soil with chemical materials. A lot of materials used as stabilization material, such as cement, limestone, etc. Alaska Department of Transportation and Public Facilities Research & Technology Transfer recommends the way to pick the stabilization material as shown in Table 2 In this method, the grained size distribution Atterberg limit used as basic judgement. Guidance in Table 1 is just for an early consideration and it can be used soil modification, such as stabilization with limestone to make a drier material and reduce the plasticity.

Table 2. Guidance to options of stabilization methods [6].

| Material passed sieve no. 200 | <25% passed sieve no. 200 | <25% passed sieve no. 200 | ≤ 6 (PI x % pass sieve no. 200) |
|-------------------------------|---------------------------|---------------------------|-------------------------------|
| Index Plasticity Stabilization Method Cement and binding material | | | |
| Limestone | | | |
| Appropriate | Maybe | Inappropriate | Appropriate | Appropriate | Appropriate |
| Maybe | Appropriate | Inappropriate | Maybe | Appropriate | Appropriate |

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2.2. Clay sensitivity
Sensitivity is reducing soil strength as there is damage in soil structure. The sensitivity level can be determined as a comparison of natural soil strength with same soil strength after remoulded, if the strength tested with unconfined compression. There are several types of clay that can change into liquid because of that damage. Those kinds of soil is partly seen in northern America and Scandinavia that used to be covered by ice. Clayey soil like this is usually known as quick-clays [7]. As some of the clayey soil like this has sensitivity towards different disturbance, then it needs a classification that is related to its sensitivity characteristics. In general, the classification can be seen in the following Table 3.

Table 3. Classification of soil base on sensitivity characteristic [1].

| Characteristics | Sensitivity  |
|-----------------|--------------|
| < 2             | Insensitive  |
| 2 – 4           | Moderately sensitive |
| 4 – 8           | Sensitive    |
| 8 – 16          | Very sensitive |
| 16 – 32         | Slightly quick |
| 32 – 64         | Medium quick |
| > 64            | Quick        |

2.3. Stabilization with limestone
Limestone that is generally used for stability is: Calcium Oxyde CaO and Calcium Hydroxide Ca(OH)2. Hydrated limestone is used in the lab and component Ca(OH)2 is the determinant of reaction with sub-base soil stability. The conversion is very important for the amount to spread as there are differences from the factory. Briefly, hydrated limestone (Ca(OH)2 is not pure and the variations of function in the field varies [8][9].

3. Methodology
The methodology used in the research is the experimental method done in the Soil Mechanics Lab, Civil Engineering Department, covering all the preparation for material used, such as clay, limestone and glass that has been grained to pass the sieve no. 200. The chemical composition of those materials can be seen in Table 4.

Table 4. Chemical limestone, glass slag composition.

| Parameter | Limestone (L) | Glass Slag |
|-----------|---------------|------------|
| SiO2      | 3.03%         | 73.4%      |
| Al2O3     | 1.53%         | 1.80%      |
| Fe2O3     | 0.54%         | 0.25%      |
| CaO       | 51.58%        | 10.8%      |
| MgO       | 0.81%         | 0.15%      |
4. Results

Laboratory test is conducted for the existing soil in the research consisting of Index Properties (water content, gamma, Atterberg limit and sieve analysis test). After clay is mixed with stabilized material for testing, Compaction Test and CBR test are the next steps to do.

4.1. Physical characteristics test

Index properties can be seen in the following Table 5.

| No | Test                      | Existing soil | Limestone (L) | Glass slag |
|----|---------------------------|---------------|---------------|------------|
| 1  | Water Content             | 34.43%        | -             | -          |
| 2  | Specific Gravity          | 2.65          | 2.59          | 2.60       |
| 3  | Liquid Limit              | 47.33%        | Non plastic   | Non plastic|
| 4  | Plastic Limit             | 17.45%        | Non plastic   | Non plastic|
| 5  | Plasticity Index          | 29.88%        | Non plastic   | Non plastic|
| 6  | Sieve Analysis passing No. 200 | 51.38%    | 30.05%        | 15.06%     |

Based on the data on Table 4, the sample that is used as the material research and classified as A-7-6. Based on USCS, sample used is classified into CL, an organic clay with low-medium plasticity.

4.2. Physical characteristics test for stabilizer material

The result of soil mixed with limestone and glass slag can be seen in this following table that is done through Atterberg Limit Test.

| No | Sample      | Liquid Limit (LL) | Plastic Limit (PL) | Plasticity Index |
|----|-------------|-------------------|--------------------|------------------|
| 1  | Original Soil | 47.33             | 17.45              | 29.88            |
| 2  | 2%L + 2%G   | 45.45             | 20.16              | 25.29            |
| 3  | 2%L + 3%G   | 44.76             | 20.32              | 24.44            |
| 4  | 2%L + 4%G   | 43.55             | 20.65              | 22.90            |
| 5  | 2%L + 5%G   | 42.38             | 20.91              | 21.47            |
| 6  | 2%L + 6%G   | 41.24             | 21.30              | 19.94            |
| 7  | 2%L + 7%G   | 40.53             | 21.76              | 18.77            |
| 8  | 2%L + 8%G   | 39.06             | 22.01              | 17.05            |
| 9  | 2%L + 9%G   | 38.33             | 22.42              | 15.91            |
| 10 | 2%L + 10%G  | 36.51             | 22.87              | 13.64            |
| 11 | 4%L + 2%G   | 45.05             | 20.56              | 24.49            |
| 12 | 4%L + 3%G   | 44.14             | 20.88              | 23.26            |
| 13 | 4%L + 4%G   | 43.14             | 21.12              | 22.02            |
| 14 | 4%L + 5%G   | 41.84             | 21.56              | 20.28            |
| 15 | 4%L + 6%G   | 40.52             | 21.81              | 18.71            |
**Figure 1.** Liquid limit (%) from mixture of limestone and glass slag.

| Glass Slag (%) | 4%L + 7%G | 4%L + 8%G | 4%L + 9%G | 4%L + 10%G |
|----------------|-----------|-----------|-----------|------------|
| 16             | 39.66     | 38.32     | 37.02     | 35.15      |
| 17             | 22.13     | 22.59     | 22.78     | 23.17      |
| 18             | 17.53     | 15.73     | 14.24     | 11.98      |
| 19             | 36.51     | 35.15     | 36.51     | 35.15      |

**Figure 2.** Plastic limit (%) from mixture of limestone and glass slag.
There is a decrease in plasticity index caused by the additional limestone and glass slag, this is affected by the cementation by limestone and glass slag as the CaO content is big so that the soil becomes bigger grains. The decrease can reduce the swelling potential. Added with a stabilizer such as glass slag, silica and alumina from glass slag with water can form a paste that binds the clay particle and covering the pores in the soil. The voids are surrounded by cemented material that is difficult to be passed by water that will make the soil-glass slag mixture is more resistant to water and it can reduce the plasticity. It is shown that the reduce in plasticity index (from 29.88 %), is reducing as the glass slag mixture is added until its lowest plasticity index at variations of 4% mixture + 10% glass slag ripening for 7 days, it is 11.98%.

4.3. Compaction test
The test is conducted using the Proctor Standard and the result can be seen in this following table.

| Tests             | Results   |
|-------------------|-----------|
| Optimum water content | 21.12%    |
| Maximum dry density | 1.34 gr/cm³ |

4.4. Compaction test with stabilizer material
From the compaction test conducted, it is determined that the dry weight is 1.34 gr/cm³. Figure 4 is shown that the dry weight keeps increasing as limestone is added until 2% and 4%, also as the glass slag is added from 2% to 10%. The mixture variation that has biggest dry weight is at 2% L + 10% G which is 1.613 gr/cm³. For mixture variation of 4% limestone + 10% % glass slag has dry weight of 1.591 gr/cm³. In this case, the glass slag has more impact to increase the dry weight than the limestone.
Figure 4. Correlation between soil maximum dry weight ($\gamma_{d_{\text{Maks}}}$) and mixture variation of limestone and glass slag.

The result of optimum water content from the experiment is that the optimum water content is 21.12% and then it decreases. In Figure 5 The graph shows that the optimum water content when it reaches its maximum dry weight, and increases when it has passed the maximum dry weight soil. Figure 4 Shows the changes of optimum water content with mixture variation; from the graph it shows that the 4 % limestone is more affecting to increase the water content than 2 % limestone for the same amount of glass slag. This occurs as the stabilizer material for limestone causes the soil to heat up so that the mixture needs more water content to bind to each other. However, as the percentage of glass slag is added, the water content keeps decreasing. The decrease in water content is caused by the stabilizer keeps pushing the water out from the pores and voids and replaced by the stabilizer until the water cannot go back into the soil micropore. This causes the water percentage inside the soil will be less. In the variation of 2% limestone + 10% glass slag results the lowest water content, 20.10% and variation of 4% limestone + 2 % glass slag results the biggest water content 21.33 %.

Figure 5. Correlation between Optimum water content (W_{\text{opt}}) with mixture variation of limestone and glass slag.
4.5. CBR test

Graph of CBR can be shown in Figure 6.

![Graph of CBR](image)

Figure 6. Correlation between CBR value and variations of percentage in additional limestone and glass slag mixture.

The binding in between the grains is the capability to lock grains, and there is a glue to stick the surface of those grains. The stronger the binder is, it will give higher value of CBR and vice versa. CBR Test conducted in this research is meant to give an impact towards the CBR value.

Figure 6. Shows the impact towards the additional limestone and glass slag mixture for CBR, where it shows that the CBR value keeps increasing by adding the percentage of limestone of 2% and 4% also with the additional percentage of glass slag starting from 2% to 10%. This occurs as the mineral in the limestone is sued as a binder added in the glass mineral and solid that cooperates to form a new stronger and more stable binder. The additional limestone of 4% is more affecting to increase the CBR value compared to the limestone with 2%. The biggest CBR value determined is at variation of 2% limestone + 10% glass slag that is 8.86%, and 4% limestone + 10% glass slag 10.5%.

5. Conclusion

Based on the research on the impact of stabilizer material for limestone and glass slag towards clayey soil with water content pointed out and curing time for 7 days, it is concluded that:

1. Based on the USC classification, soil sample is classified into CL (Clay-Low Plasticity) an organic clay with low – medium plasticity and based on AASHTO, soil sample is classified into A-7-6.
2. From the test, it shows that the biggest water content is 34.33%.
3. From the specific gravity test, shows that the specific gravity of the soil is 2.65. Specific gravity of limestone is 2.59 and specific gravity of glass slag is 2.60.
4. From the Atterberg limit, it is determined the Liquid Limit (LL) is 47.33% and Plasticity Index is 29.88%. The effect of additional 2% limestone + 10% glass slag, is to get the lowest plasticity index (IP) that is 13.64%. With a liquid limit of 36.51% and additional 4% limestone + 10% glass slag it gives the lowest plasticity index (IP) that is 11.98%, with biggest liquid limit (LL) 35.15%.
5. From the Proctor Standard test, it gives optimum water content of 21.12%, and maximum dry weight 1.34 gr/cm
6. From CBR, the existing soil is 6.29%, and at mixture of 2% limestone + 10% glass slag, the maximum CBR value is 8.86% and mixture of 4% limestone + 10% glass slag determined by biggest CBR of 10.50%.
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