The use of bottom ash and limestone as soil stabilization material based on unconfined compression test

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Abstract. Unconfined Compression Test (UCT) is a test for cohesive soil strength, and this could be tested both for existing soil and remolded. UCT is aimed to determining the soil strength rapidly and quickly and economically. This research uses chemical stabilizers, i.e., limestone and bottom ash. This research is meant to determine the value of maximum compression strength using UCT with additional stabilizing materials and to determine the optimum water content of additional limestone and bottom ash. Based on the result, it is known that the existing soil has water content 24.35%, unit weight 2.673, liquid limit (LL) 38.15%, and plasticity index (PI) 21.54%. Based on AASHTO, that soil is categorized as Clay Low (CL), whereas based on USCS it is categorized as A-6. Value of UCT of existing soil is 1.320 kg/cm². After the soil is mixed with variation of limestone and bottom ash determined, it is obtained that the most optimum UCT value is at variation of 4% limestone + 8% bottom ash with value 2.585 kg/cm², optimum water content (W_{opt}) 21.80 % and dry weight maximum (\gamma_{d \text{ max}}) 1.427 gr/cm³.

1. Introduction

With all the limited lands for facility development by humans can cause a development of building on top of soft soil. Clay is soil in a form of microcronical until sub microcronical size originated from sedimentation of chemical elements of the rock. Clay is very hard in drought and has plastic characteristic with medium water content. In a higher water content, clay tends to be more cohesive and soft [1][2]. Generally, soft soil is a cohesive soil that has a non benefit characteristics in a civil construction such as low shear strength and high compressibility. A specific characteristic from soft soil is when in drought it will be hard while in a wet condition it will be soft and becomes plastic and cohesive, and will experience swelling and shrinking quickly until the volume gets bigger caused by mixed water. This characteristic that dangers the construction. One of the ways to prevent this is to increase the bearing capacity. Therefore, it needs a stabilization in this soil [3].

The development of industry in Indonesia is getting higher and makes waste from factories becomes much more produced, such as coal waste stick on the bottom or walls of the combustion which is called bottom ash. This waste can be found in few factories using coal as basic material for burning, both from industrial or steam power plant [4].

Bottom ash set to a dangerous and poisonous waste category that has big potential to be an issue. Therefore, it needs a research on the use of bottom ash as a material that can be used for soil stabilization. The use of bottom ash in this research is to increase the cohesion of the soil [5]. Tohor (CaO) is a
burning product from natural stone that has a composition of mostly carbonated calcium. The use of limestone on this research is to help the drying process of wet soil, to decrease the plasticity index caused by the decrease of liquid limit and increase of plastic limit from the reaction of clayey mineral with limestone [6][7].

2. Method
Method that can be done in this research is laboratorium experiment. Laboratorium used is Soil Mechanics Laboratory, Civil Engineering Department, Universitas Sumatera Utara. Sample used is clay soil from Limau Manis, Tanjung Morawa, Sumatera Utara. Stabilization material of limestone is from chemical store Inti Jaya Kimia, Medan and the bottom ash is from Labuhanangin Steam Power Plant. The process of sampling is divided into two, disturbed sample using hand bore and undisturbed sample using a cylinder with a size of ±50 cm. Sampling must not contains plant roots. Limestone used is the one passed the sieve No. 200. On UCT test, the sample is taken from undisturbed sample using an extruder and put it into a mould for UCT test.

2.1. Sampling
The total sample tested includes 1 existing soil for index properties, 14 sample Atterberg Limit test, 105 sample compaction test and 16 sample of Unconfined Compression Test. Soil used in Atterberg Limit is soil that has been sieved with siever No. 40. For compaction test and UCT test using sieve no. 4. Then, the sample is mixed with bottom ash and limestone to go through curing for 7 days. Curing time is done in order to make the stabilized material can react on the mixed soil. Disturbed sampling is done on repeat with trial error to make the water content of mixed soil, bottom ash and limestone be equal with the existing.

2.2. Sample testing
The test done including physical characteristics of soil and bottom ash and limestone. It consists of Water content test, Specific Gravity Test, Volume Weight Test, Atterberg Limit and Sieve Analysis. Engineering properties consists of Proctor Standard Test (Standard Compaction Test).

3. Results and discussions
The results will be discussed in 6 subsections, they are the index properties test of existing soil, bottom ash and limestone, engineering properties of stabilization material, Proctor Standard Test (Standard Compaction Test) and UCT test.

3.1. Index properties of existing soil, bottom ash and limestone

| No | Testing          | Original soil | Limestone (L) | Bottom ash (BA) |
|----|------------------|---------------|---------------|-----------------|
| 1  | Water Content    | 24.35%        | -             | -               |
| 2  | Specific Gravity | 2.67          | 2.52          | 2.60            |
| 3  | Liquid Limit     | 38.15%        | Non plastic   | Non plastic     |
| 4  | Plastic Limit    | 16.61%        | Non plastic   | Non plastic     |
| 5  | Plasticity Index | 21.54%        | Non plastic   | Non plastic     |
| 6  | Sieve Analysis   | 50.19%        | 43.01 %       | 1.48 %          |
|    | passing No. 200  |               |               |                 |

According to soil classification system AASHTO, soil passed the siever no. 200 is 50.19%, with biggest LL of 38.15% and PI of 21.54%. Therefore that particular soil has met the criteria > 35% passing no. 200, has LL 40 and PI ≥ 11. This makes the soil tested is classified into a class of A-6. Based on soil
classification USCS, soil passed the siever no. 200 is 50.19%, so that he soil is classified into fine grained soil. With LL 38.15% and PI 21.54%, these values will be plotted to a graph to determine the soil classification shown in Figure 1. Based on the result, it is shown that the soil is classified into CL, an anorganic clay with low to medium lasticity.[2][1]

![Graph of soil classification USCS.](image)

**Figure 1.** Graph of soil classification USCS.

3.2. **Atterberg limit sample mixed with stabilized material**

![Correlation of liquid limit and variation of mixture of limestone with bottom ash.](image)

**Figure 2.** Correlation of liquid limit and variation of mixture of limestone with bottom ash.

![Correlation of plastic limit with variation of mixture of limestone with bottom ash.](image)

**Figure 3.** Correlation of plastic limit with variation of mixture of limestone with bottom ash.

Figure 2 shows the Atterberg Limit gives liquid limit of 38.15%. With th increase of stabilizer, liquid limit will be decreased. The bigger the stabilizer content added to the soil, the bigger the decrease of liquid limit. This decrease can reach 33.73% at variation of 2% K + 14% BA and 32.31% at variation of 4% K + 14% BA. This proves that the additional stabilizer on the soil will give cementation process.
on the soil grains that makes the soil mixture will be water resistant that has an effect towards the liquid limit.

Figure 3 shows that the Atterberg Limit gives liquid limit of 16.61%. After few additional variations of stabilizer content, plastic limit will increase with the increase of stabilizer content. This can be concluded that the bigger the stabilizer content in soil mixture, the plastic limit of that soil mixture can increase as well. Plastic limit can increase until 21.27% at variation of 2% K + 14% BA of 22.07% at variation of 4% K + 14% BA. The increase of plastic limit is caused by the hydration process that can strenghten the binding within particles to make the soil becomes harder and more stable.

Figure 4 shows that the Atterberg Limit on the existing soil is obtained from plasticity index of 21.54%. With an additional stabilizer on the soil mixture, plasticity index is decreasing with the increase of variation of stabilizer content. The lowest plasticity index is at 12.46% at variation of 2% K + 14% BA and 10.24% at variation of 4% K + 14% BA. This is caused by the additional stabilizer filling the
pores on soil mixture and makes the soil becomes harder and more stable, that can decrease the seepage that makes it less to shrink. Based on the formula, plasticity index is the difference between liquid limit with plastic limit. When the liquid limit decreases and plastic limit increases, the plasticity index will decrease.

3.3. Engineering properties (compaction test)
On the experiment of this compaction, the correlation of maximum dry weight and optimum water content will be determined. The soil used is the existing soil from Limau Manis, Tanjung Morawa. The compaction uses Standard Proctor Test. The result is shown in Figure 5.

Based on the compaction, it is determined that the maximum dry weight is 1.427 gr/cm³. From this experiment with stabilizer mixture, maximum dry weight will increase to 1.498 gr/cm³ for 2% K + 2% BA and 1.490 gr/cm³ for 4% K + 2% BA. This proves that the additional stabilizer can increase the maximum dry weight as the stabilizer can fill the void with water and air previously. This stabilizer is a solid particle that can increase that causes the maximum dry weight increases as well, compared to the existing soil. The increase of maximum dry weight will continue until the peak, that is 1.640 gr/cm³ for 2% K + 10% BA, and 1.591 gr/cm³ for 4% K + 8% BA. Then, it will decrease with the increase of variation of bottom ash for each limestone. This decrease occurs as it has met the effective content of stabilizer. The weight of stabilizer increases, while the soil will stay still, this will decrease the binding within soil particles that makes the soil easily cracking.

Based on the experiment above Figure 7, it is shown that the optimum water content for existing soil is 21.80%. Then, with additional stabilizer, optimum water content will be less. This is because the stabilizer will fill up the void until the water cannot absorb anything to fill up the voids and causes the water percentage becomes less. The decrease of water content will continue until the mixture has met its effective content, then the water content will increase. This is because the additional stabilizer can cause the binder becomes weak. This can cause the water to get into the soil and water content can increase. Soil with limestone of 4% has higher water content optimum than soil with 2% limestone. This is because the limestone makes the soil heats up, so that the soil with more limestone will need more water to bind to each other.

3.4. Results of unconfined compression test (UCT)
In this experiment, it will show the effect of additional stabilizer towards unconfined compression test (qu). Sample that will be tested is undisturbed sample, remoulded and sample with additional stabilizer.
Then from this value, cohesion will be determined which is half of the unconfined compression test that will be tested.

**Figure 8.** Correlation of unconfined compression test with variation of limestone and bottom ash mixture.

Using soil mixture with stabilizer, the unconfined compression test will increase until 1.594 kg/cm² for 2% K + 2% BA and 1.727 kg/cm² for 4% K + 2% BA. This proves that the additional stabilizer in the soil mixture can increase the soil compression strength as the stabilizer is solid particle that can fill up the voids that makes it becomes stronger after given vertical load. The value of compression soil strength will increase with the increase of bottom ash for each variation of limestone, and it will reach its effective peak, 2.037 kg/cm² for 2% K + 10% BA and 2.585 kg/cm² for 4% K + 8% BA. After it passes the effective content of stabilizer, the soil compression strength will decrease with the increase of bottom ash for each variation of limestone as the stabilizer increases but the unit weight of soil stays. This can make the binder within particles becomes less that makes the soil can easily crack.

### 4. Conclusions

Base on the analysis, the points of conclusion can be stated as follows:

1. The soil is categorized as CL (*Clay with Low Plasticity*) based on soil classification USCS, and A-6 based on soil classification AASHTO.
2. Existing soil has water content 24.35% and unit weight 2.6732.
3. Based on Atterberg Limit, existing soil has liquid limit (LL) 38.15%, plastic limit (PL) 16.61%, and plasticity index (PI) 21.54%.
4. Stabilizer material, limestone and bottom ash, has unit weight 2.5246 and 2.6037.
5. Based on the standard compaction, it is obtained that :
   a) Existing soil has max dry weight (γ_d max) 1.427 gr/cm³ and optimum water content (w_opt) 21.80%.
   b) For variation 2% limestone, at variation of 2% K + 10% BA, has the highest maximum dry weight 1.640 gr/cm³ and optimum water content 20.12%.
   c) For variation 4% limestone, at variation 4% K + 8% BA, has the highest maximum dry weight 1.591 gr/cm³ and optimum water content 20.62%.
6. Based on Unconfined Compression Test (UCT), it is obtained that :
   a) Undisturbed sample has compression strength of 1.320 kg/cm² and the remoulded one has 0.537 kg/cm².
   b) Existing soil is categorized as soil with medium sensitivity
   c) For variation 2% limestone, at variation 2% K + 10% BA, has highest compression strength 2.037 kg/cm².
d) For variation 4% limestone, at variation 4% K + 8% BA, has highest compression strength 2.585 kg/cm².

7. Limestone and bottom ash can stabilize the existing soil tested.

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