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The Effect of Diatomaceous Earth Addition on CBR Values of Glee Geunteng Soil in Aceh Besar, Aceh Province, Indonesia

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ABSTRACT The soil which is the platform often used for construction activities needs the strength to resist loads. However, its physical and mechanical properties are sometimes naturally limited and this implies there is a need for improvement and stabilization. Therefore, this study uses diatomaceous earth, which is a natural pozzolanic material classified as a type of Supplementary Cementing Materials (SCM), as an additive. The chemical stabilization was conducted by mixing the soil with stabilizing materials such as cement, lime, fly ash or others that have the ability to change the chemical composition and combination of soil. It is important to note that diatomaceous earth has similar properties as other pozzolanic materials such as fly ash and metakaolin powder and this is the reason it is expected to function as a soil stabilizing agent needed to improve soil properties. This study was conducted using the soil from Glee Geunteng in Peukan Bada as well as the diatomaceous earth obtained from Lambeureunut Village, Aceh Besar Regency, Aceh Province, Indonesia. The main purpose was to determine the California Bearing Ratio (CBR) value of the Glee Geunteng soil mixed with diatomaceous earth at 5, 10, 15, and 20% dry weight of the soil. The CBR test consisted of unsoaked CBR, soaked CBR testing at 4 days, and swelling properties of CBR with a variety of diatomaceous earth mixtures. Glee Geunteng soil was classified as A-6 Group Index 3 based on the AASHTO soil classification and as the SC (silty clay) soil according to the USCS classification. The results showed that the unsoaked CBR value reduced from 35.96% for the natural Glee Geunteng soil to 31.65% for the soil mixed with 20% diatomaceous earth material. A similar trend was observed for the soaked CBR value with a reduction from 15.57% to 6.98%. The decrease in CBR value was perceived to be caused by the very small silica content (SiO_2) in diatomaceous earth material with 42.09% compared to the 86% in the material obtained from another source in the previous research by Hidayati.

KEYWORDS Stabilization; Diatomaceous earth; Soaked CBR; Unsoaked CBR; Swelling

1 INTRODUCTION

Soil is a geological material composed of grains or flat slabs as well as voids filled with air and water. Moreover, the report presented by the Mining and Energy Office of Aceh Province in 2012 showed an abundant distribution of diatomaceous earth in Lambeureunuet Village, Seulimum District, Aceh Province, Indonesia. Handayani (2018) further indicated that the main chemical composition of diatomaceous earth in Aceh Besar includes SiO_2, CaO, Fe_2O_3, and Al_2O_3 with 58.87%, 12.20%, 2.25%, and 0.39%, respectively. Another study on the use of diatomaceous earth as cement substitution through the calcination treatment for normal concrete by Maulani (2016) showed that the silica content in diatomaceous earth is 86%. This material has been confirmed to be useful as an alternative choice to stabilize materials due to its high silica (SiO_2) content. Furthermore, Naifah (2020) reported that a composite cement paste produced using 20% diatomaceous earth has better resistance after two months of immersion in Na_2SO_4 solution compared to the normal cement paste.

This study was, therefore, conducted using diatomaceous earth which is a natural resource rarely used in Aceh Province, Indonesia while the soil samples were obtained from Glee Geunteng, Peukan Bada District, Aceh Besar Regency, Aceh Province, Indonesia as indicated in Figure 1. This location was selected because the material is often used as a subgrade material for the roads in Banda Aceh and Aceh Besar. It is important to

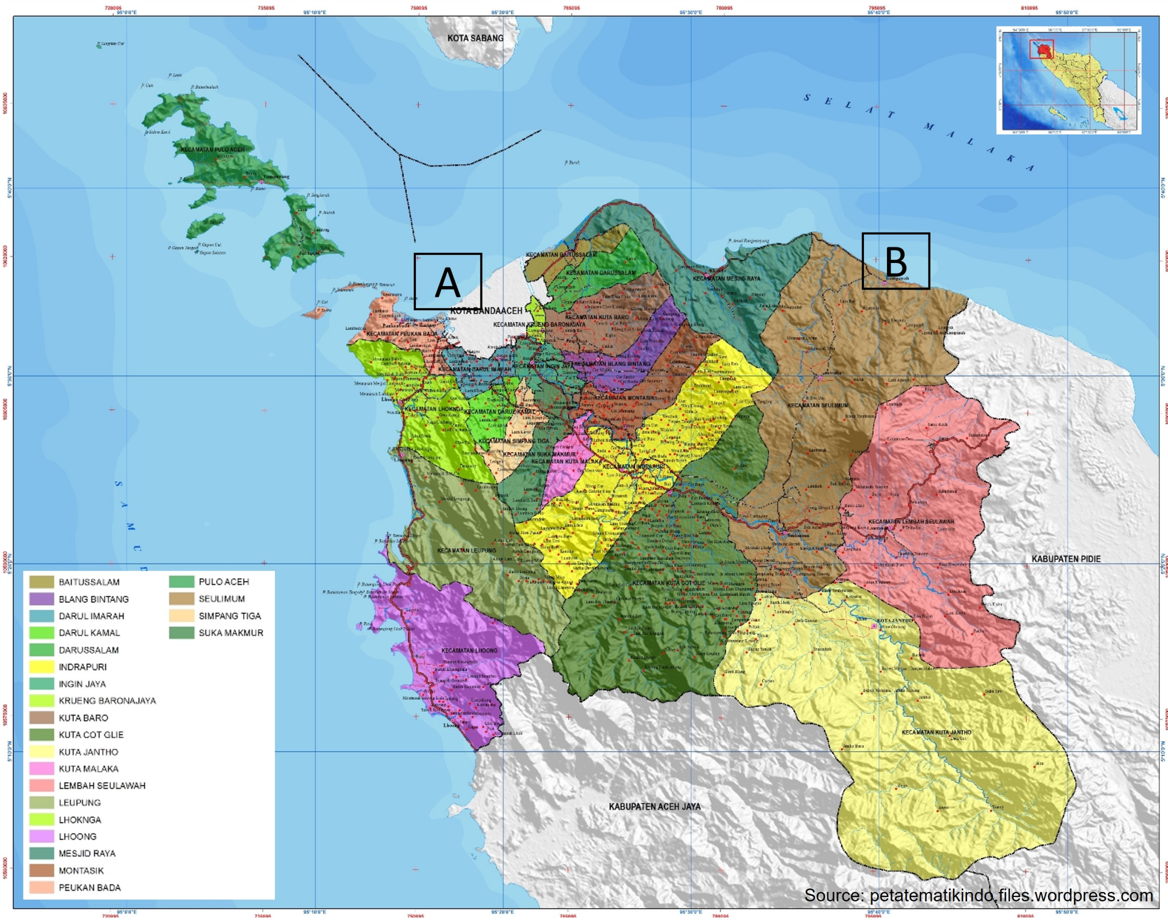

Figure 1. (A) Location map for Glee Geunteng soil and (B) Diatomaceous earth

note that this study used diatomaceous earth as an additive in Glee Geunteng soil. This is based on the observation of De Rojas et al. (1999) that diatomaceous earth is a type of SCM (Supplementary Cementing Materials) as well as the submission of Naik and Kraus (2003) that these materials such as fly ash, silica fume, natural pozzolan, slag, and several others can be used to reduce the usage of cement in construction activities. Diatomaceous earth has properties similar to other pozzolanic materials such as fly ash and this is the reason it is considered a potential stabilizing agent to improve soil properties. RockTron (2007) simply categorized pozzolans into two according to their origins and these include natural pozzolans such as volcanic ash, pumice, tuff, diatomaceous earth, and opaline shale as well as artificial pozzolans such as fly ash and those produced from coal combustion in power plants, rice husk ash, brick dust, calcined kaolin, condensed silica fume, ground granulated blast furnace slag (GGBS) and some metallurgical slag.

The purpose of this study was to determine the effect of diatomaceous earth addition on the California Bearing Ratio (CBR) values of Glee Geunteng soil. The process involved testing the un-soaked and soaked CBR at 4 days of immersion after the diatomaceous earth has been added at 5, 10, 15, and 20% dry weight of the soil. This is considered important to determine the utilization of the diatomaceous earth material in the Aceh Besar area, Aceh Province, Indonesia as well as to serve as a continuation of the previous study conducted by Naifah (2020) to determine the resistance of composite cement paste produced using diatomaceous earth mineral material to replace some quantity of cement.

2 METHODS

This section describes the research objects, reviews the literature on California Bearing Ratio (CBR), explains test methods for swelling, diatomaceous earth chemical composition, and soil physical properties, and also designs soil samples for CBR determination.

Figure 2. Glee Geunteng soil from Rima Keunereum Village, Peukan Bada District, Aceh Besar Regency, Aceh Province, Indonesia

Figure 3. Sampling of diatomaceous earth in Beureunut Village, Aceh Besar Regency, Aceh Province, Indonesia

2.1 Research Objects

The materials used in this study include Glee Geunteng soil, diatomaceous earth, and water. The soil samples were obtained from the Glee Geunteng quarry, Rima Keunereum Village, Peukan Bada District, Aceh Besar Regency, Aceh Province, Indonesia, and were disturbed as indicated in Figure 1 (A). Meanwhile, the diatomaceous earth material was collected from Beureunut Village, Lampanah District, Aceh Besar Regency as shown in Figure 1 (B). The tap water used was available at the Soil Mechanics Laboratory, Faculty of Engineering, University of Syiah Kuala (USK). It is important to note that three main tests were conducted which include the physical properties of the Glee Geunteng soil and chemical contents of the diatomaceous earth, compaction or Standard Proctor, and CBR tests.

The Glee Geunteng soil was sampled using an excavator as shown in Figure 2, transferred to the Soil Mechanics Laboratory, Faculty of Engineering, spread on a floor coated with thick plastic, and left for several days until it was air dried. The soil was later pounded using a rubber hammer to break up lumps to ensure an easy sieving process. Hasan and Saidi (2020) stated that diatomaceous earth has similar pozzolanic properties to other materials such as fly ash and metakaolin. Therefore, it was calcined in a furnace at a temperature of 600°C for five hours to determine the effect of calcination on its pozzolan reaction.

The diatomaceous earth used was obtained from Beureunut Village, Lampanah District, Aceh Besar Regency, Aceh Province, Indonesia as previously stated. The sample retrieved was examined for chemical content to determine the percentage of silica (SiO_2), lime (CaO), and alumina (Al_2O_3) which are the general constituent elements of cement. The sampling process of this material is presented in the following Figure 3.

2.2 California Bearing Ratio (CBR)

California Bearing Ratio (CBR) is an empirical method to assess soil deformation against loading. The test is normally conducted by pressing a standard piston having an area of 3 inches^2 at the end to penetrate the soil at a rate of 0.05 inches/min. The CBR values are usually calculated at 0.1 and 0.2 inches by dividing the load on penetration with the standard loads of 3,000 lbs and 4,500 lbs, respectively, and the largest CBR value is usually used. Moreover, the loads are the standard obtained from the experiments conducted on the crushed stone which is considered to have a CBR of 100%. The values were calculated using the following Equations 1 and 2.

$$CBR_{0,1} = \frac{x}{3000} \times 100 \tag{1}$$

$$CBR_{0,2} = \frac{x}{4500} \times 100 \quad (2)$$

Where, X and Y are readings of the relationship between load and penetration at 0.1 inch and 0.2 inch on the graph from the CBR test. The highest value between A and B is usually used to represent the CBR.

The equipment used in this experiment includes the Standard Proctor compaction and CBR instrument as shown in the following Figure 4.

2.3 Swelling

According to Al-Rawas and Goosen (2006), expansive soils can be predicted based on the swelling potential which is usually determined through the plasticity index (PI) or liquid limit (LL) value of the soil in line with the concept proposed by Chen (1983), Seed et al. (1962), and Daksanamurthy & Raman (1973) as shown in Table 1.

Shirley (1994) reported that the clay particles contained in soil have a very large influence on the swelling potential of the soil. Moreover, the swelling percentage can be calculated by comparing the change in height (ΔL, unit in mm) with the original height of the sample (L, unit in mm) as indicated in the following Equation 3.

$$\varepsilon = \frac{\triangle L}{L} \times 100 \quad (3)$$

2.4 Diatomaceous Earth Chemical Element Test

Diatomaceous earth (SiO_2 nH_2O) is a silica sedimentary rock consisting mainly of the remains of fossil skeletons of aquatic plants, single-celled algae, and pyroclastic rock which has a lot of SiO_2. The previous research by Hidayati (2007) showed that its chemical composition consists of 86% silica (SiO_2), 5% sodium or natrium (Na), 3% Magnesium (Mg), and 2% iron (Fe). Moreover, Khan (1980) cited by Maulani (2016) indicated that this material mainly has amorphous silica which is approximately 55%-70% of its content depending on the local environment. This indicates the silica content and structure of diatomaceous earth are very high and vary.

The chemical elements were determined using gravimetric and titrimetric methods. It is important to note that gravimetry is normally used in water content analysis but its application to a material in the solid and gas phase is usually based on the solid aspect and this is known as indirect evolutionary gravimetry. The water content can be determined by heating the compound at a temperature of 110-130^{o}C and the weight loss be-

Figure 4. Standard Proctor test equipment and the CBR instrument

Table 1. Classification of swelling potential

Degree of expansion	Chen (1983)	Seed et al (1962)	Daksanam urthy & Raman (1973)
Very high	LL >60	PI >35	LL>70
High	40 <LL ⩽ 60	20 <PI ⩽ 35	50 <LL ⩽ 70
Medium	30 ⩽ LL ⩽ 40	10 <PI <20	35 <LL ⩽ 50
Low	LL <30	PI <10	0 ⩽ LL ⩽ 35

Source: Al-Rawas and Goosen (2006)

Table 2. Total amount of soil samples

Total Amount of Samples			
Percentage of Diatomaceous Earth	LL and PL	Un-Soaked CBR	Soaked CBR
0%	2	2	2
5%	2	2	2
10%	2	2	2
15%	2	2	2
20%	2	2	2
Amount	10	10	10

Table 3. Chemical Elements in the Diatomaceous Earth from Lambeureunut Village

No.	Test Parameter	Test Method	Test Results (%)
1	SiO_2	Gravimetry	42.09
2	Al_2O_3	Gravimetry	0.49
3	CaO	Titrimetry	26.83
4	Others Element	-	30.59

fore heating is the weight of the crystalline water. Meanwhile, titrimetry which is also known as titration is a quantitative chemical analysis method commonly used to determine the concentration of a known analyte. The volume measurement plays an important role in titration and this is the reason this method is also known as volumetric analysis.

2.5 Soil Physical Properties Test

The physical properties of the soil were tested in this study using the ASTM (American Society for Testing and Materials, 1982) method. Moreover, the experiments were conducted to determine the soil classification based on the AASHTO (American Association of State Highway and Transportation Official) and USCS (Unified Soil Classification System).

According to Germaine and Germaine (2009), soil classification is the grouping of soils into different types based on certain characteristics to determine their subjective and specific description. The physical properties usually include specific gravity, liquid limit, plastic limit, and grain distribution.

2.6 Soil Sample Design

The air-dried soil samples were pounded with a hammer and sieved with 4 (4.76 mm) mesh. Diatomaceous earth materials were later added at the optimum moisture content condition (OMC) obtained based on the standard proctor compaction test for each variation at 0, 5, 10, 15, and 20% dry weight of Glee Geunteng soil. The total amount of soil sample used is presented in the following Table 2.

It is important to reiterate that the experiments conducted include the physical and the mechanical properties test for the soil using the Standard Proctor method and CBR test which consisted of the soaked and un-soaked at 4 days immersion. The swelling properties of the soil were also tested using an apparatus for the soak CBR to observe the effect of the diatomaceous earth addition. These were used to determine the effect of different percentages of the diatomaceous earth on the plasticity of the soil as well as the unsoaked and soaked CBR values accompanied by the swelling potential.

3 RESULTS AND DISCUSSION

3.1 Diatomaceous Earth Chemical Element Test

The chemical elements in the diatomaceous earth from Lambeurenut Village are presented in Table 3. It was discovered that the elements in the diatomaceous earth used are different from those in Hidayati (2007) which had 86% silica, 5% sodium or natrium, 3% magnesium, and 2% iron.

3.2 Physical Properties

The physical properties determined for the Glee Geunteng soil include the specific gravity, Atter-

Table 4. Atterberg limits

Percentage of diatomaceous earth	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity index (PI)
(%)	(%)	(%)	(%)
0	28.30	16.49	11.81
5	31.14	18.31	12.83
10	34.90	20.25	14.65
15	33.48	17.86	15.62
20	33.96	17.43	16.53

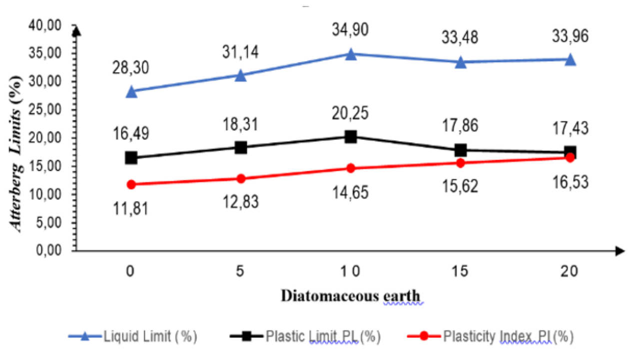

Figure 5. The relationship between the percentage of diatomaceous earth and Atterberg's limit.

berg limits, and sieve analysis. The Atterberg limits consist of the liquid limit (LL), plastic limit (PL), and plasticity index (PI) for the different variations of the diatomaceous earth added and the results are shown in Table 4 and presented graphically in Figure 5.

Table 4 shows that the highest liquid and plastic limit which are 34.90% and 20.25% respectively were found with 10% diatomaceous earth while the plasticity index was observed to have increased from 11.81% to 16.53% as the percentage of the diatomaceous earth added increased. The results of the physical properties test conducted on the Glee Geunteng soil are presented in Table 5.

3.3 Soil Compaction Test

The compaction test conducted using the Standard Proctor method showed the maximum dry volume weight (γd max) and optimum moisture content (OMC) in the Glee Geunteng soil sample, and their relationship is indicated in the graph presented in Figure 6.

It was discovered that the maximum dry density of the soil (MDD, γd max) was 2.044 grcm^{-3} and the optimum moisture content (OMC) was 11.39%.

Table 5. Physical properties of Glee Geunteng soil

No.	Testing parameters	Testing results
1	Specific Gravity	2.63
2	Liquid Limit (%)	28.76
3	Plastic Limit (%)	16.83
4	Plasticity Index (%)	11.93
5	Sieve Analysis (pass # 200, %)	42.85

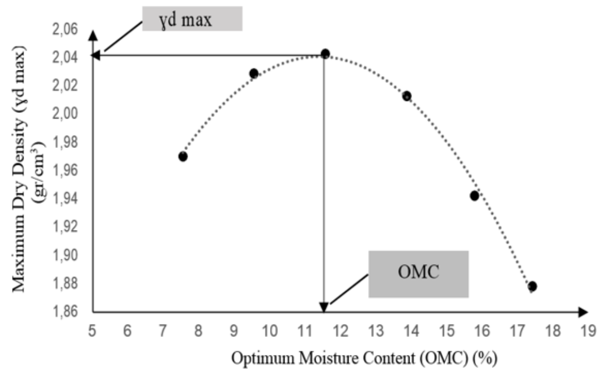

Figure 6. The relationship between dry density and moisture content of Glee Geunteng soil

3.4 CBR Test for Different Variations of Diatomaceous Earth

The sieve analysis and physical properties test showed that Glee Geunteng soil is clay soil with grains of sand and gravel (A-6) at index group 3 according to the AASHTO system. It was also classified as a poorly graded silty clay (SC) soil according to the USCS system.

The recapitulation of un-soaked and soaked CBR after 4 days of immersion is presented in Table 6 and indicated graphically in Figures 7 and 8. The results showed that the percentage of the diatomaceous earth added affects the CBR values, thereby the samples with higher content were observed to have the tendency of having a reduced CBR value. This was confirmed by the fact that the unsoaked CBR decreased from 35.96% to 31.65% and the soaked CBR from 15.57% to 6.98% in four days of immersion.

The swelling properties test conducted on the soaked CBR also showed that the expansion value increased as the percentage of the diatomaceous earth added increased as indicated by the 0.214% recorded in the original soil to 0.671% at 20% diatomaceous earth addition. This implies the in-

Table 6. Un-soaked and soaked CBR results

Percentage of Diatomaceous Earth	Un-Soaked CBR	Soaked CBR
(%)	(%)	(%)
0	35.96	16.49
5	31.56	9.47
10	30.64	7.86
15	31.46	5.65
20	31.65	6.98

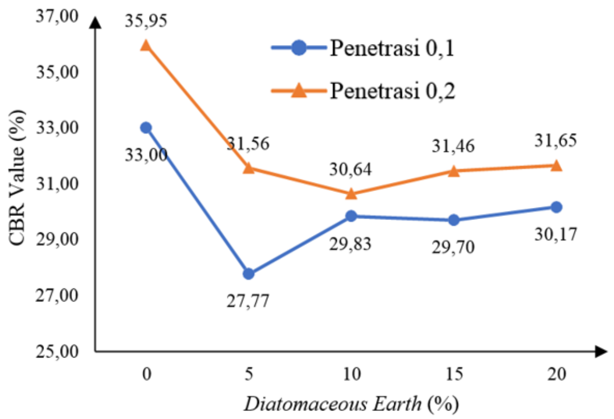

Figure 7. Graph of the relationship between un-soaked CBR values at different diatomaceous earth variations

clusion of diatomaceous earth in the Glee Geunteng soil mixture increased the plasticity index (PI), decreased the CBR value, and increased the swelling properties, thereby, indicating the material is not suitable to be used as a soil stabilizing agent.

The decrease in CBR value was observed to be due to the relatively small silica content of 42.09% in the diatomaceous earth which is less than 86% in the sample used by Hidayati from another source. Another study by Maulani (2016) focused on the compressive strength of the concrete produced using diatomaceous earth as a substitute for cement and a water-cement ratio of 0.3. It was discovered that the diatomaceous earth used contains 62.28% SiO_2, 8.28% CaO, 1.79% Fe_2O_3, and 9.52% Al_2O_3. The compressive strength was also reported to have reduced in proportion to the content of diatomaceous earth added to the cement.

It was discovered that the diatomaceous earth at Beureunut Village is not a suitable stabilizing agent for Glee Genteng soil even though its mineral content is almost similar to fly ash and metakaolin. This is due to its low silica content and ability to increase the plasticity value as well as the fact that the Glee Geunteng soil is silty clay and poorly graded. This signifies it is necessary to find alternative stabilizing materials for the soil because the addition of diatomaceous earth in both clay and cement was unable to enhance their properties and strength.

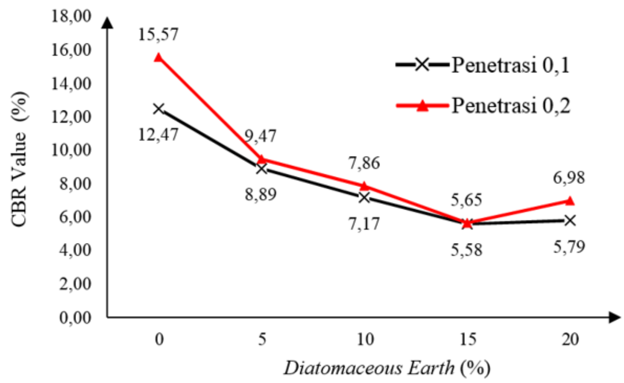

Figure 8. Graph of the relationship between soaked CBR values at different diatomaceous earth variations

4 CONCLUSION

The conclusions drawn from the results and discussion are stated as follows: 1) The addition of diatomaceous earth at a range of 5% to 20% increased the plasticity index (PI) value; 2) The original soil has the highest CBR value as indicated by the 35.96% recorded for the unsoaked and 15.57% for the soaked. It is important to note that the value decreased as the percentage of diatomaceous earth increased; 3) The addition of diatomaceous earth to Glee Geunteng soil increased the plasticity index (PI) and decreased the CBR value, therefore, it is not suitable to be used as a soil stabilizing agent.

DISCLAIMER

The authors declare no conflict of interest.

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