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Behavior of Clay Soil Mixed with Bentonite Viewed Through CBR Values

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A B S T R A C T

Expansive clay is a soil that is very easily affected by air. This causes expansive clay to have several adverse properties such as large swelling and shrinkage properties and has a high plasticity index value which results in the soil under certain air conditions can experience changes in volume. With the change in soil volume due to low water content can cause subsidence in the building above it (Settlements). In addition to subsidence, the high water content in the soil also causes the soil to expand so that it can cause the building to lift (Uplift). This study aims to investigate the bearing capacity of clay soil expansion, in this case the CBR value of the soil tested in two conditions: unsoaked and soaked. In addition, the amount of expansion can also be known from the soaked CBR test. To support the main research, a property index study was conducted to explain the expansion behavior of clay soil. In this study, bentonite was used to obtain the required expansive soil characteristics with a composition of 25%, 50%, 75% and 100% bentonite. Bentonite is known to have a large swelling capacity, easily absorbs air, and has a high plasticity index because it contains the mineral montmorillonite. The results of the study showed that the CBR value of the embankment soil sample, bentonite, and the bentonite mixture were categorized as good for use as a base soil. Meanwhile, from the results of the soaked CBR test, the CBR value of the embankment soil sample, bentonite, and the bentonite mixture were categorized as poor for use as a subgrade because they had a low CBR value and large swelling

INTRODUCTION

Soil plays a crucial role in civil engineering, such as in buildings, highways, bridges, dams, and other structures. Therefore, it requires soil with adequate technical properties. The stability of road pavement construction is directly influenced by the road's base's ability to absorb and transmit loads. However, not all subgrade layers can support the loads above them; only well-classified soils can exert their bearing capacity. Knowledge of soil mechanics is essential to understand soil properties, analyze these properties, and determine the methods used to calculate these properties in construction planning. Expansive clay is a soil that is highly susceptible to water. This causes it to have several adverse properties, such as high swelling and shrinkage and a high plasticity index, which can cause volume changes under certain water conditions. Expansive soil can pose problems in construction projects, particularly for embankment work on the subgrade of a building. Changes in soil volume due to low water content can lead to settlement of the building above, especially if the settlement is non-uniform. This subsidence can occur during construction or during the building's operation. In addition to subsidence, high water content in the soil can also cause the soil to expand, causing the building to lift (uplift).

The subgrade is the foundation soil that directly supports the load, including the weight of the pavement layer and the weight of vehicles traveling on the road surface. The characteristics of the original subgrade soil significantly determine the strength of the road construction, ensuring stability and driving safety. The pavement and road surface layers, acting as protectors for the subgrade, distribute the load from vehicle wheels to the subgrade. Without adequate subgrade support, the pavement is susceptible to damage. The bearing capacity of the subgrade for road pavement is influenced by its characteristics. The selected subgrade should have adequate characteristics and meet requirements and requirements. However, many subgrade soils still have characteristics that are less than optimal for use as subgrade.

LITERATURE REVIEW

A characteristic that needs to be known about road subgrade is the CBR value. A common problem encountered with road subgrade is low soil bearing capacity, characterized by a low California Bearing Ratio (CBR). The minimum CBR value for subgrade soil is 6% to prevent the pavement from cracking and collapsing due to road subsidence (Soedarsono, 1985). According to Bowles (1992), soil with a CBR value <3% is classified as having a low CBR, 3-7% as having a low to moderate CBR, 7-20% as having a moderate CBR, and >20% as having a good CBR. The CBR value of the subgrade serves as a reference in highway pavement planning; therefore, the subgrade CBR value should meet certain requirements, in addition to other requirements.

"Expansive soil" is a term used for soil with a high potential for expansion or shrinkage due to the influence of water content. Expansive soil shrinks when its water content decreases and expands when its water content increases. In nature, soils that have the potential for expansion also have the potential to shrink due to changes in water content.

The terms expansive soil and swelling potential are generally used to describe soils prone to this swelling and shrinkage. Soils that readily change volume are those with a high clay content, particularly those containing the mineral montmorillonite (Hardiyatmo, 2017).

According to Snethen et al. (1975), clay minerals originate from the weathering or diagenetic alteration of pre-existing minerals, resulting in very small grain sizes but large surface areas. Physical heating over long periods and chemical changes in the material resulting from changes in overburden pressure or groundwater conditions are termed diagenetic factors. Diagenetic factors are generally described as interparticle bonding phenomena resulting from re-crystallization from contact between clay minerals under high overburden pressure, or by particle cementation resulting from the precipitation of intermediary materials from groundwater.

According to Chen (1975), clay particles are sheet-like with distinct surfaces. Clay minerals are formed through a complex process from various parent materials or rocks, including feldspar, mica, and limestone. The minerals formed depend on the parent rock, topography, climate, nearby vegetation, weathering duration, and other factors. The changes that occur on the surface of the earth are called weathering, and on the seabed, halmyrolysis. These changes include disintegration, oxidation, hydration, and melting.

The most important characteristic of fine-grained soils is their mineral composition. Three important clay mineral groups are (Nelson and Miller, 1992):

1. Non-expansive clay minerals. These clay minerals are non-expansive because of the strong hydrogen bonds that hold each clay particle together. The kaolinite group is non-expansive.
2. Mica-like minerals, such as illite and vermiculite, can be expansive, but generally don't cause significant problems. Illite contains weak potassium bonds, allowing for some expansion.
3. Smectite minerals, including montmorillonite, are highly expansive and are the most problematic clay minerals because the particles are only weakly bonded.

The California Bearing Ratio Test, also known as the CBR test, is a test that can be performed in a laboratory or in the field to determine the bearing capacity of the soil. This test yields a CBR value, which is the ratio of the penetration load of a material being tested to a standard load, expressed as a percentage. The CBR value indicates the hardness of the material being tested; therefore, the harder the material, the higher the CBR value. Laboratory CBR is measured under two conditions: unsoaked (CBR unsoaked) and soaked (CBR soaked). Soaked CBR values are generally lower than unsoaked CBR values. However, soaked conditions are more common in the field, and therefore, in building construction calculations, soaked CBR values are used as the basis for calculations, as water always affects building construction.

In highway pavements, the CBR value can be used as a parameter to determine the suitability of a soil material for pavement layers. The CBR value determines the soil's ability to support and transmit the loads applied to it. The

CBR value of each soil varies depending on its hardness. Table 8 below shows soil classification based on CBR value.

Table 1. Soil Classification Based on CBR Value

CBR	*General Rating*	*Uses*	*Classification System*	
			Unified	**AASHTO**
0 – 3	*Very poor*	*Subgrade*	OH, CH, MH, OL	A5, A6, A7
3 – 7	*Poor to fair*	*Subgrade*	OH, CH, MH, OL	A4, A5, A6, A7
7 – 20	*Fair*	*Subbase*	OL, CL, ML, SC, SM, SP	A2, A4, A6, A7
20 – 50	*Good*	*Base, subbase*	GM, GC, SW, SM, SP, GI	AIb, A2-5, A3, A2-6
> 50	*Excellent*	*Base, subbase*	GW, GM	AIa, A2-4, A3

Table 1 above shows that soil is classified into five groups based on its CBR value: very poor, poor to fair, fair, good, and excellent. For use as a pavement base layer, soil must be classified as fair, good, or excellent. Meanwhile, very poor and poor soils must first be stabilized before they can be used as a pavement base layer. The modified test for expansive soils was developed to assess the effect of soil swelling on density and strength and cannot be used to identify potential soil swelling behavior. Table 2 shows the classification of subgrade volume changes for embankments based on the degree of swelling that occurs during the submerged CBR test. In this table, the Weighted Plasticity Index (WPI) is the product of the plasticity index (PI) and the material passing a 425 µm sieve, or

WPI=PI x percentage of material passing through the sieve 425 µm (no.40) *(8)*

The WPI value can be used as a preliminary assessment of the subgrade. In addition, the submerged CBR value also provides a good indicator of potential landslides. Soils with a low degree of swelling tend to have a higher CBR (Hardiyatmo, 2017).

Table 2. Volume Change Classification

Weighted Plasticity Index, WPI (%)	Pengembangan CBR terendam (%)	Klasfikasi perubahan volume tanah-dasar	Keterangan
< 1200	< 1	Sangat rendah	Bisa untuk *sub-base*
1200 – 2200	1 – 2	Rendah	Bisa untuk *capping layer*
2200 – 3200	2 – 3	Sedang	Dirancang untuk bergerak sedikit
3200 – 5000	3 – 5	Tinggi	Tidak cocok langsung di bawah perkerasan
> 5000	> 5	Sangat tinggi	Harus dibongkar dan diganti atau distabilisasi

METHODOLOGY

The soil used in this study was collected from the Faculty of Engineering, Hasanuddin University, Gowa Regency, South Sulawesi Province. The bentonite used as a mixing material was imported from Bandung City. The sampling and testing locations during the study were conducted at the Soil Mechanics Laboratory, Faculty of Engineering, Hasanuddin University, Gowa Regency, South Sulawesi Province. The research timeframe was determined based on the established intervals and durations and the testing standards used. Data collection was conducted on the soil material used in the study to prepare the test samples. At the beginning of the study, the location for the soil sample collection was selected and determined. After the soil samples were collected, their characteristics were identified visually and through laboratory testing. Characteristic testing of the soil samples was necessary to achieve the objectives of this study. This study analyzed the effect of a mixture of high-plasticity clay with varying bentonite content on the California Bearing Ratio (CBR) of the tested soil. Characteristic data from each material and mechanical testing data, namely CBR testing from each soil sample in this study will be used as a basis for analyzing research results and drawing conclusions from the research conducted.

RESULTS

Based on tests conducted in the laboratory, data on the physical and mechanical characteristics of embankment soil samples, bentonite, and variations of bentonite mixtures were obtained. Details can be seen in Table 3. The results of the unsoaked California Bearing Ratio (CBR) test are shown in Table 4. The 100% fill soil sample yielded CBR values of 8.5% for γd, 13.5% for γd 90%, and 18.5% for γd 100%. The 25% Bentonite – 75% Soil sample yielded CBR values of 7.0% for γd 80%, 12.5% for γd 90%, and 18.0% for γd 100%. The 50% Bentonite – 50% Soil sample yielded CBR values of 9.3% for γd 80%, 13.5% for γd 90%, and 18.3% for γd 100%. Bentonite – 25% Soil obtained CBR values of 9.0% for γd 80%, 13.0% for γd 90%, and 18.5% for γd 100%, and the 100% Bentonite sample obtained CBR values of 11.0% for γd 80%, 15.8% for γd 90%, and 18.2% for γd 100%.

Table 3. Summary of Physical and Mechanical Property Test Results

Pengujian	**Hasil Pengujian**				
	Tanah Timbunan 100%	75 % Tanah - 25 % *Bentonite*	50 % Tanah - 50 % *Bentonite*	25 % Tanah - 75 % *Bentonite*	*Bentonite* 100%
Pengujian Sifat Fisis					
Kadar Air (%)	37.73	2.09	2.72	1.62	28.50
Berat Jenis (*GS*)	2.61	2.61	2.62	2.65	2.67
Analisa Saringan					
a. *Gravel* (%)	4.00	4.00	0.00	0.00	0.00
b. *Sand* (%)	8.00	16.00	35.00	14.00	4.00
c. *Silt* (%)	36.00	32.00	22.00	36.00	32.00
d. *Clay* (%)	52.00	48.00	43.00	50.00	50.00
Batas – Batas Atterberg					
a. Batas Cair (*LL*)	76.79	118.41	130.19	170.15	238.44
b. Batas Plastis (*PL*)	58.05	60.12	61.61	62.48	71.46
c. Indeks Plastis (*PI*)	18.74	58.29	68.58	107.67	166.98
d. Batas Susut (*SL*)	24.91	13.85	11.61	11.17	10.26
Pengujian Free Swell index (%)	10.00	82.58	132.14	202.38	278.57
Pengujian Sifat Mekanis					
Kompaksi					
a. Kepadatan Maksimum (gr/cm3)	1.31	1.31	1.31	1.31	1.29
b. Kadar Air Optimum (%)	36.00	36.00	35.50	35.50	35.00
CBR Desain Unsoaked (%)					
a. Kepadatan 100 %	18.5	18.0	18.0	18.0	18.0
b. Kepadatan 90 %	13.5	12.5	13.5	13.5	15.5
c. Kepadatan 80 %	6.8	7.0	8.0	8.5	10.8
CBR Desain Soaked (%)					
a. Kepadatan 100 %	7.1	2.0	1.7	1.5	1.3
b. Kepadatan 90 %	4.5	1.4	1.2	1.2	1.0
c. Kepadatan 80 %	2.0	0.7	0.8	0.7	0.7

Tabel 4. Recapitulation of Unoaked CBR test results

Pengujian CBR *Unoaked*	Nilai CBR (%)				
	Tanah Timbunan 100%	25% *Bentonite* - 75% Tanah	50% *Bentonite* - 50% Tanah	75% *Bentonite* - 25% Tanah	*Bentonite* 100%
a. γd 100 %	18.5	18.0	18.3	18.5	18.2
b. γd 90 %	13.5	12.5	13.5	13.0	15.8
c. γd 80 %	8.5	7.0	9.3	9.0	11.0

The results of the California Bearing Ratio (CBR) Soaked test can be seen in Table 5. Where the CBR value obtained was 2.0% for γd 80%, 4.6% for γd 90%, and 7.2% for γd 100%, in the 25% Bentonite – 75% Soil sample the CBR value was 0.9% for γd 80%, 1.4% for γd 90%, and 2.0% for γd 100%, in the 50% Bentonite – 50% Soil sample the CBR value was 0.7% for γd 80%, 1.2% for γd 90%, and 1.7% for γd 100%, in the 75% Bentonite – 25% Soil sample the CBR value was 0.9% for γd 80%, 1.2% for γd 90%, and 1.5% for γd 100%, and for the 100% Bentonite sample, CBR values were 0.7% for γd 80%, 1.0% for γd 90%, and 1.3% for γd 100%.

Table 5. Summary of Soaked CBR Test Results

Pengujian CBR *Soaked*	Nilai CBR (%)				
	Tanah Timbunan 100%	25% *Bentonite* - 75% Tanah	50% *Bentonite* - 50% Tanah	75% *Bentonite* - 25% Tanah	*Bentonite* 100%
a. γd 100 %	7.2	2.0	1.7	1.5	1.3
b. γd 90 %	4.6	1.4	1.2	1.2	1.0
c. γd 80 %	2.0	0.9	0.7	0.9	0.7

DISCUSSION

From the test results, the mechanical behavior for each sample variation with three density levels, namely 80% γd, 90% γd, and 100% γd, can be explained. The details are explained as follows:

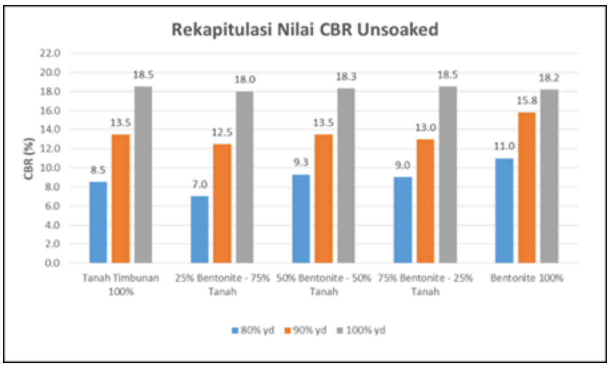

Figure 1. Unsoaked California Bearing Ratio (CBR) Test Results

Based on the unsoaked CBR test results shown in Figure 1, the CBR value of the sample with the bentonite mixture decreased slightly compared to the sample without bentonite, but it was still considered good for use as a subgrade, with a value range of 7%–20%.

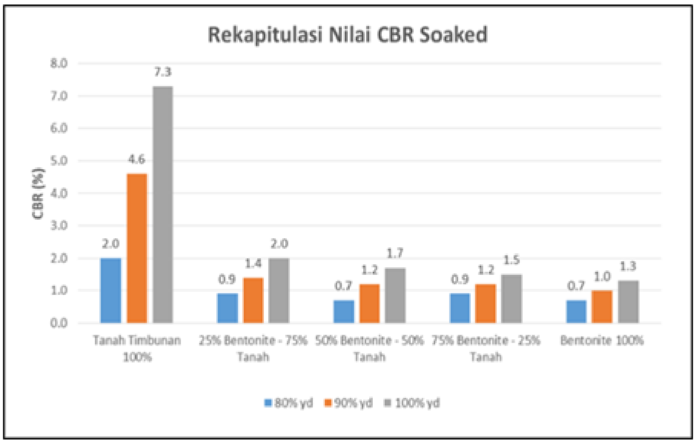

Figure 2. California Bearing Ratio (CBR) Soaked Test Results

The results of the soaked CBR test are shown in Figure 2. The CBR value of the sample with the bentonite mixture was lower than that of the sample without bentonite, which is considered poor. Therefore, it is not recommended for use as a subgrade because it has a CBR value of less than 6%.

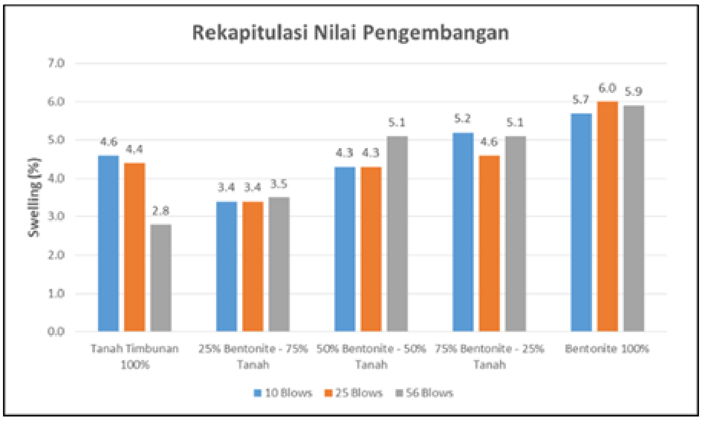

Figure 3. Swelling Test Results with California Bearing Ratio (CBR) Soaked

The results of the soaked CBR test in Figure 3 show that the swelling value of the sample with the bentonite mixture was higher than that of the sample without bentonite. This is due to bentonite's high water absorption capacity. Compaction energy also influences the amount of swelling; the sample with 56 impacts had a higher swelling value than the samples with 10 and 25 impacts because the larger volume of material was compacted, resulting in a greater change in soil volume.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results and discussion, the following conclusions can be drawn.

1. From the physical property testing results, it was found that the 100% fill soil, 25% bentonite – 75% soil, 50% bentonite – 50% soil, 75% bentonite – 25% soil, and 100% bentonite samples were fine-grained soils classified as CH (clay with high plasticity) based on the USCS system. Based on the AASHTO classification system, the fill soil, bentonite, and bentonite mixture samples were fine-grained soils classified as A-7-5 (clayed soils) with a percentage passing the No. 200 sieve of more than 50%.
2. Based on the unsoaked CBR test results, the CBR value of the sample with the bentonite mixture decreased slightly compared to the sample without bentonite, but was still considered good for use as a subgrade, with a value range of 7% – 20%. Meanwhile, the results of the soaked CBR test showed that the CBR value of the sample with the bentonite mixture was the lowest compared to the sample without bentonite, which is categorized as poor and therefore not recommended for use as a subgrade due to its CBR value of less than 6%.
3. The results of the soaked CBR test showed that the swelling value of the sample with the bentonite mixture experienced higher swelling than the sample without bentonite, this is because bentonite has a high water absorption capacity. Compaction energy also affects the amount of swelling; the sample with 56 impacts had a greater swelling value than the samples with 10 and 25 impacts because the volume of material compacted is greater, resulting in a greater change in soil volume.

FURTHER STUDY

This research still has limitations, so it is necessary to conduct further research related to the topic of Behavior of Clay Soil Mixed with Bentonite Viewed Through CBR Values in order to perfect this research and increase insight for readers.

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