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Relationship Between CBR Value and Soil Compaction Under Various Number of Blows

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Abstract

Subgrade is one of the essential components in road pavement construction, particularly in flexible pavement. This is because the subgrade serves as the foundation that supports the overall load above it. Therefore, it must have a high bearing capacity with a minimum California Bearing Ratio (CBR) value of 6%. To achieve this requirement, efforts to increase the CBR value are needed, one of which is through soil embankment and compaction. In this study, soil compaction was carried out to obtain the desired CBR value. The sample consists of 18 samples with each impact variation (25, 35, 45, 55, 65, and 75 times) being three samples. The fill soil comes from the Gandus area, Palembang city. The test results showed the lowest CBR value of 2.79% at 25 blows with a dry density of 1.51 g/cm³, and the highest value of 14.23% at 75 blows with a dry density of 1.95 g/cm³. At 45 blows, a CBR value of 8.05% with a dry density of 1.78 g/cm³ was obtained, which already meets the subgrade requirement. It can thus be concluded that the greater the number of blows, the higher the CBR value. However, the dry density did not significantly increase beyond 55 blows, indicating that the soil had reached a sufficient level of compaction with minimal air voids, and further compaction was unnecessary since the standard CBR value had been achieved.

Keywords: California Bearing Ratio (CBR), Embankment Soil, Dry Density, Compaction.

1. Introduction

Roads are one of the most essential infrastructures for transportation, serving as the main facilities for the movement of people and goods from one place to another. The development of strong and safe roads requires an appropriate pavement structure to ensure durability and riding comfort. Pavement functions as a structural layer that distributes vehicle loads evenly to the subgrade while providing a smooth surface for traffic[1]. The strength and stability of a pavement structure are highly dependent on the materials used and the quality of the subgrade soil, which should have a sufficiently high California Bearing Ratio (CBR) value. Thus, the subgrade plays a crucial role in determining the overall performance and lifespan of a pavement structure[2].

Soil is a natural material found on the Earth's surface, composed of a mixture of mineral particles and organic matter derived from the surrounding environment[3]. To understand soil behavior and characteristics, classification systems such as the American Association of State Highway and Transportation Officials (AASHTO) and the Unified Soil Classification System (USCS) are commonly used[4].

According to the USCS system, soils are divided into coarse-grained and fine-grained categories. A soil is categorized as coarse-grained if less than 50% passes through the No. 200 sieve. Fine-grained soils are classified as silt (M) when their liquid limit and plasticity index lie below the A-line, clay (C) when they lie above the A-line, and organic (O) when they contain a high amount of organic matter. In

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the AASHTO classification, granular soils are grouped into classes A1 to A3, where less than 35% passes through the No. 200 sieve. Class A1 represents well-graded soils (A-1-a and A-1-b), while A3 consists of poorly graded, non-plastic fine sands. Fine-grained soils are grouped into A4 to A7, with subgroups A7-5 (PL > 30) and A7-6 (PL < 30)[5], [6]. These classifications are used to determine the appropriate soil type and its suitability for road construction.

From a civil engineering perspective, the subgrade must possess sufficient strength and bearing capacity to support and distribute loads from the pavement layers above [6]. The subgrade must have strong load-bearing characteristics and capacity to support and distribute the applied loads[7]. If the subgrade is weak or improperly treated, the pavement may experience excessive deformation, cracking, or even structural failure. Therefore, ensuring adequate soil strength and stiffness through proper testing and stabilization is essential before road construction begins.

The Province of South Sumatra, particularly Palembang City, presents a challenging condition for road construction. The city is surrounded by water bodies such as rivers, swamps, and flood-prone areas. It is reported that around 52.24% of Palembang's land area remains inundated by water[8]. Most of the soil in this region consists of clay with alluvial deposits, where approximately 15% is seasonally flooded and 35% remains waterlogged throughout the year. These conditions result in low soil bearing capacity and poor drainage, which make the subgrade unsuitable for carrying heavy loads[9]. Consequently, soil stabilization and compaction are required to improve soil density and strength before the subgrade can be used for pavement construction. Compaction increases the soil's dry density by reducing air voids, thereby enhancing its load-bearing capacity and resistance to deformation.

Given the variations in soil conditions, laboratory testing is necessary to evaluate the physical properties of the soil and to determine its CBR value, which indicates the soil's bearing capacity[3]. According to the standards, the minimum recommended CBR value for subgrade soils in flexible pavement construction is 6%[10]. Achieving or exceeding this value ensures that the subgrade can adequately support traffic loads and maintain pavement performance over time.

Based on these considerations, this study focuses on analyzing the effect of different numbers of compaction blows on the CBR value of the soil. The aim is to determine the optimal compaction effort required to achieve the target CBR value in field conditions. The findings are expected to provide useful insights for improving soil compaction practices and ensuring the stability and durability of road pavement structures.

2. Method

This study used soil samples taken from Gandus, Palembang City, consisting of both disturbed and undisturbed samples. The location was selected because the soil type in Gandus meets the requirements for road construction, as it consists predominantly of coarse-grained material with minimal clay content. The CBR compaction test was conducted using variations of 25, 35, 45, 55, 65, and 75 blows, with three samples for each variation. The testing procedure followed the SNI 1744-2012 standard regarding laboratory CBR testing[11]. The stages of testing and data processing are as follows:

2.1 Soil Physical Properties Test

This test aims to ensure that the material used meets the required standards and specifications. The stages of the soil physical properties testing conducted in the soil laboratory are as follows:

2.1.1 Sieve Analysis

Sieve analysis is conducted to separate coarse-grained soils, either by washing or dry sieving, in order to determine the particle size distribution[2]. In this test, the coefficient of uniformity and the coefficient of gradation are also calculated.

2.1.2 Water Content[11]

The purpose of the water content test is to determine the moisture content of a soil sample, which is obtained by comparing the weight of water to the weight of dry soil, measured in grams [9].

$$\text{Water Content} = \frac{W1-W2}{W2-W3} \times 100 \quad (1)$$

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2.1.3 Specific Gravity

Specific gravity is defined as the ratio of the unit weight of soil solids to the unit weight of water [10]. The typical range of Gs values is between 2.58 and 2.75, depending on the type of soil. This test is conducted to determine the specific gravity of soil samples and is carried out in accordance with the relevant SNI standards[12].

$$\text{Spesific Gravity} = \frac{W2 - W1}{(W4 - W1) - (W3 - W2)} \times 100 \quad (2)$$

2.1.4 Atterberg Limits[13]

This limit consists of three tests, namely shrinkage limit, plastic limit and liquid limit[11].

$$IP = LL - PL \quad (3)$$

2.2 Density Test

2.2.1 Proctor Test

The Proctor Test is one of the laboratory methods used to determine soil compaction characteristics. This test aims to obtain the optimum moisture content at which the soil reaches its maximum dry density[14].

2.2.2 Sandcone Test

The Sand Cone method is a field testing technique used to determine soil density. The test uses Ottawa sand, which passes through a No. 10 sieve and is retained on a No. 200 sieve as a reference material. This type of sand is selected because it is hard, clean, dry, and free from binding materials, allowing it to flow freely[13].

$$\gamma_d = \frac{W}{V} \quad (4)$$

$$\gamma_b = \frac{\gamma_d}{(1+w)} \quad (5)$$

2.2.3 Standard Compaction Test

The calculations used in the standard compaction test are as follows:

$$\gamma_d = \frac{W}{V} \quad (6)$$

$$\gamma_b = \frac{\gamma_d}{(1+w)} \quad (7)$$

$$ZAV = \frac{\text{spesify gravity}}{(1+(\text{spesific gravity} \times \text{water content})} \quad (8)$$

2.2.4 California Bearing Ratio

CBR is one of the methods used to evaluate the strength of soil, which can be performed both in the laboratory and in the field[15]. In laboratory CBR testing, there are two types of tests, namely the unsoaked test (without soaking) and the soaked test (with soaking).

$$CBR_1 = \frac{\text{load}}{3000} \times 100 \quad (9)$$

$$CBR_2 = \frac{\text{load}}{4500} \times 100 \quad (10)$$

Note:

CBR_1 = CBR value at 0.1 inch or 2.54 mm penetration
CBR_2 = CBR value at 0.2 inches or 5.08 mm penetration
Load = Load at 0.1 inch or 0.2 inch penetration

P-ISSN: 1411-3414
E-ISSN: 2549-9815

2.3 Data Analysis

From the test results, relationships were obtained between the number of blows and the unit weight, the correlation between the number of blows and the CBR value, and the correlation between density and the CBR value. Subsequently, regression analyses were performed on these graphs to determine the accuracy of the test results. Two types of equations were used in the data analysis: linear and polynomial equations, as follows:

$$y = ax + b \quad (11)$$
$$y = ax^2 + bx - c \quad (12)$$

Note:
y = variables on the y-axis,
x = variables on the x-axis,
c = constant

3. Result and Discussion

3.1 Material Test Result

Before conducting the CBR test, material testing was carried out first. This was done to ensure the physical condition of the material. The results of several material tests conducted in the laboratory are presented in Table 1 below.

Table 1. Results of Soil Physical Properties Testing

No.	Observation	Result
1	Specific Gravity	2.68
2	Water Content (%)	24.12
3	Liquid Limit (%)	34.26
4	Plastic Limit (%)	22.45
5	Plasticity Index (%)	11.81
6	Sieve Analysis	
	a. Passing No. 200 Sieve (%)	1.14
	b. Passing No. 4 Sieve (%)	92.48
	c. Coefficient of Gradation (Cc)	5.33
	d. Coefficient of Uniformity (Cu)	1.203

From the test results shown in Table 1, it can be concluded that the soil obtained from Gandus is classified as coarse-grained soil, categorized as poorly graded sand with medium plasticity.

3.2 Soil Compaction Test Result

3.2.1 Standard Compaction

Before conducting the compaction test, a moisture content test was performed. Before compaction is carried out, a water content test is first conducted. This test is carried out to determine the optimum water content used for compaction by adding water content to the compacted sample.

Table 2. Standard Compaction Water Content Test Results

Cup No.	I	II	III	IV	V
Wet soil + cup (g)	56.72	52.38	55.44	50.21	56.34
Dry soil + cup (g)	50.06	46.36	48.56	44.38	48.83
Water weight (g)	6.66	6.02	6.88	5.83	7.51
Cup weight (g)	20.48	20.89	21.54	20.72	21.09
Dry soil weight (g)	29.58	25.47	27.02	23.66	27.74

Water content (%)	22.52	23.64	25.46	24.64	27.07
Average water content (%)	23.08	25.05	27.87	29.71	32.04

Table 2 shows that the testing met the requirements of SNI 1742:2008[15], where an increase of about 2–3% was observed. Subsequently, a compaction test was conducted, and the results are presented in the following table.

Table 3. Compaction Standard Density Test Results

Compaction	I	II	III	IV	V
Mold + wet soil (g)	6915	6980	7030	7030	6985
Mold weight (g)	5240	5240	5240	5240	5240
Wet soil weight (g)	1675	1740	1790	1790	1745
Mold volume (cm³)	933	933	933	933	933
Wet density (g/cm³)	1.797	1.865	1.918	1.918	1.870
Dry density (g/cm³)	1.459	1.491	1.500	1.479	1.416
Zero Air Void (ZAV) (g/cm³)	1.656	1.603	1.534	1.492	1.442

From Table 3, it can be observed that there was an increase in dry density from the first to the third sample, followed by a decrease in the fourth and fifth samples, with the dry density values being lower than the Zero Air Void (ZAV) values. This indicates that no air voids remained after the soil was compacted. The results are illustrated more clearly in the following Figure 1.

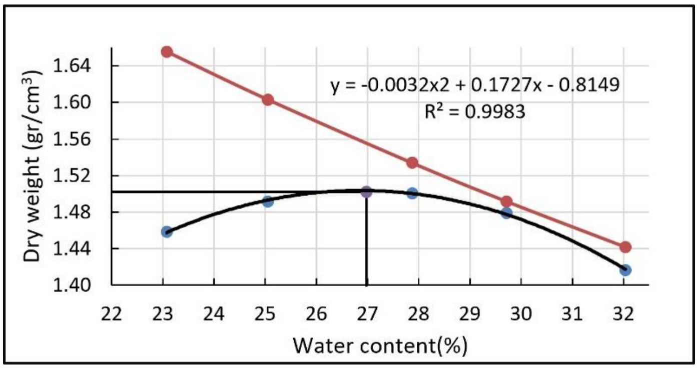

Figure 1. Standard Compaction Results Graph

3.2.2 Sandcone Test

This test aimed to determine the field density value of the soil. The testing technique is to use standard sand into a cone-shaped instrument. The sand is allowed to fill the cone space until full. The results of the test are presented in Table 4 below.

Table 1. Sand Cone Water Content Test Results

Cup No.	X	Y	Z	Unit
Wet soil + cup (W1)	58.70	60.50	46.60	g
Dry soil + cup (W2)	51.75	53.15	41.87	g
Water weight (W1–W2)	6.95	7.35	4.73	g
Cup weight (W3)	20.60	21.90	20.80	g
Dry soil weight (W2–W3)	31.15	31.25	21.07	g
Water content (%)	22.31	23.50	22.45	%
Average water content (%)	22.76			

The average water content was 22.76%, which is lower than the laboratory test results. This difference was influenced by the weather conditions during sample collection. The samples were taken

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under hot weather conditions at a depth of approximately 10 cm, which resulted in a lower water content due to evaporation, especially near the ground surface.

Table 2. Results of Field Density Test – Sand Cone Method

Parameter	X	Y	Z	Unit
Bottle + water (W1)	1537.6	1537.6	1537.6	g
Bottle + remaining water (W2)	154.5	167.8	270.5	g
Wet soil from hole (W3)	1638.3	1645.6	1612.6	g
Hole volume (Wt = W1 – W2)	1383.1	1369.8	1267.1	cm³
Dry soil weight	1339.5	1332.3	1317.0	g
Wet unit weight (W3 – Wt)	1.18	1.20	1.27	g/cm³
Dry density	0.97	0.97	1.04	g/cm³

Note: X, Y, Z = Sample

From the results of the field density test using the sand cone method shown in Table 5, the average field wet density was 1.22 g/cm³. The field test results showed a lower density compared to the laboratory compaction test. This indicates that the soil can still be further compacted.

3.3 CBR Test Result

The CBR test was conducted on 18 samples with varying numbers of blows: 25, 35, 45, 55, 65, and 75 blows. Each variation consisted of three samples. This was intended to obtain more reliable results and reduce data error. The CBR test aims to determine the bearing capacity of the soil after compaction. The results of the CBR test are presented in Table 6.

Table 3. CBR- Test Result (Correlation test between CV, CBR and Wet Density

Compaction Variation (CV)	CBR (%)	Wet Density (g/cm³)
25 Blows	2.79	1.51
35 Blows	5.48	1.69
45 Blows	8.05	1.78
55 Blows	9.85	1.92
65 Blows	11.36	1.94
75 Blows	14.23	1.95

Based on Table 6, it can be observed that at 45 blows, the soil compaction meets the minimum requirement for subgrade soil in flexible pavement construction, with a CBR value ≥ 6%. The obtained CBR value was 8.05%, which satisfies the standard requirement.

3.4 Data Analysis

The following section presents the results of data analysis for the relationship between compaction variations (number of blows) and CBR values.

3.4.1 Correlation between the Number of Blows and CBR Values

From the graph (Figure 2), it can be observed that there is a positive correlation between the number of blows and the CBR value, represented by the equation $y = 0.219x – 2.3225$ with a coefficient of determination $R^2 = 0.991$. This indicates that the greater the number of blows, the higher the CBR value.

P-ISSN: 1411-3414
E-ISSN: 2549-9815

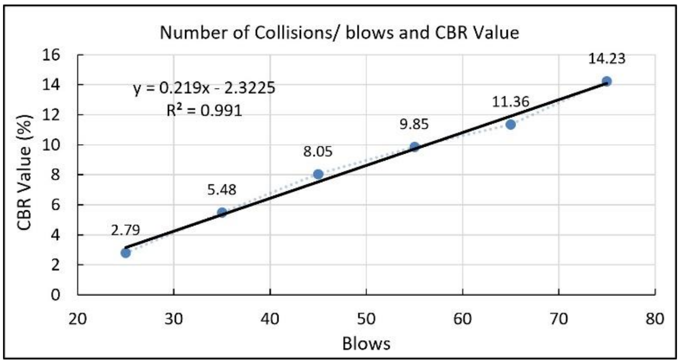

Figure 1. Number of Collisions/Blows and CBR Value Graph

3.4.2 Relationship between Number of Blows and Unit Weight

Based on Figure 3, it can be concluded that the soil density increases as the number of blows increases. However, the increase in density does not occur significantly or eventually stops once the soil has reached its maximum density condition.

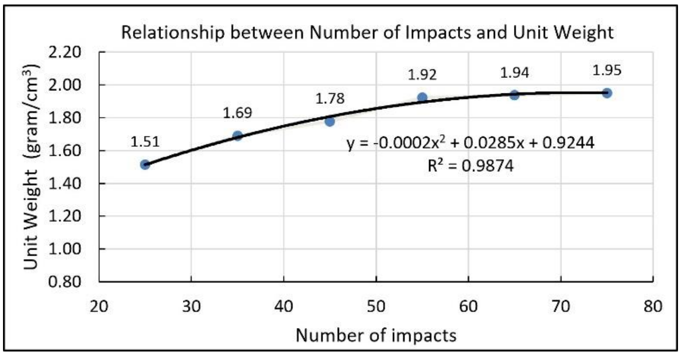

Figure 2. Relationship between Number of Impacts and Unit Weight Graph

3.4.3 Correlation between Density and CBR Value

From Figure 4, it can be seen that the CBR value increases with the increase in unit weight. However, the increase in unit weight does not rise significantly after 55 blows. The rise in unit weight is not directly proportional to the increase in CBR value, which continues to increase significantly. This indicates that the tested soil has begun to reach a dense condition, resulting in only a slight increase in unit weight, while the CBR value continues to rise.

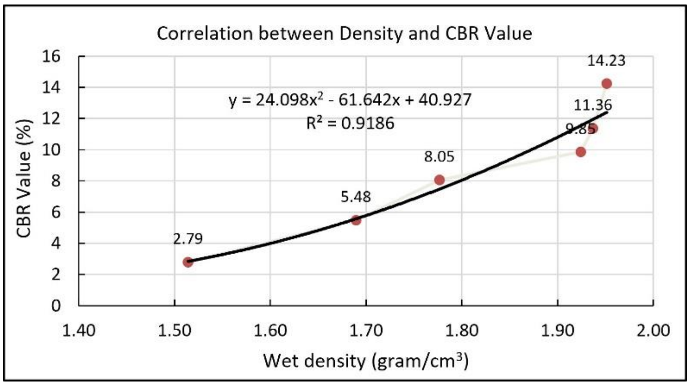

Figure 3. Correlation between Density and CBR Value Graph

3.5 Discussion

From the data analysis, it can be observed that there is a correlation between the number of blows and the CBR value. The CBR value increases as the number of blows increases; however, soil density

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has a maximum compaction limit. The density value does not show a significant increase even when the number of blows continues to rise. This occurs because the remaining air voids in the soil become minimal, causing the soil to become denser and approach its maximum compaction level. This test can be applied in field compaction work, where the CBR value can be improved by increasing the number of passes during the compaction process. The more passes performed, the higher the CBR value that can be achieved, even if the soil quality is not particularly high. However, the soil used as embankment material must first be ensured to meet the required.

4. Conclusion

From the tests conducted both in the field and in the laboratory, it can be concluded that the required CBR value was achieved at 45 blows, with a CBR value of 8.05%. The soil density increased as the number of blows increased, with the lowest wet density recorded at 1.51 g/cm³ and the highest at 1.95 g/cm³. However, the density did not increase significantly after 55 blows, while the CBR value continued to rise, reaching 14.23% at 75 blows. This indicates that although the unit weight remained relatively constant, increasing the number of blows enhances the soil's strength and stability.

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