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Research Article

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Effect of Soil Compaction on the Subgrade Strength of Road Pavement

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Abstract Investigations were carried out on how different compactible efforts affected the subgrade strength of road pavements. At a depth of 1.0 m, soil samples were taken, and subsequently subjected to compaction and California bearing ratio (CBR) tests. For the standard and modified Proctor compaction tests, the soil samples were poured into a mould in three and five equal layers, respectively. With 25, 30, 35, 40, 45, 50, 55, and 60 blows of the 2.5kg and 4.5kg rammer with a drop of 300mm and 450mm, respectively, under light and heavy compaction conditions, the standard and modified Proctor hammers compacted each layer uniformly. According to the proctor compaction test results, dry density increased with moisture content up to a maximum point before decreasing with additional increase in moisture content for the different numbers of blows. Additionally, the results of measuring the soil's Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) with varying numbers of blows using 2.5 kg and 4.5 kg rammers revealed that while the maximum dry density increased with increasing number of blows, the optimum moisture content value decreased. Finally, with the 2.5kg and 4.5kg rammers, the results of the CBR test at various numbers of blows at 25, 30, 35, 40, 45, 50, 55, and 60 revealed an increase in CBR with increasing number of blows. According to the aforementioned findings, compaction increases soils' CBR, which has an effect on the subgrade strength of road pavement since it reduces pavement thickness and cost.

Keywords California Bearing Ratio, Pavement, Soil Compaction, Subgrade

1. Introduction

One of the most prevalent and easily accessible construction materials for roads in Nigeria is clay soil, a sedimentary rock deposit formed by the weathering of rocks. It is a naturally occurring material that is mostly made of fine-grained minerals and has tiny particles with plastic and adhesive capabilities. Due to its stiffness and low strength, clay frequently presents construction challenges (Latifi et al., 2017; Rosa et al., 2017; Chen et al., 2017; Disfani et al., 2017; Awarri et al., 2022). These unstable soils can lead to cracks along the road surface, thus it has created serious problems (UiTM, 2014). Natural rock, the ideal foundation for constructing roadways, is not always available in nature. Most of the time, the ground is unstable and has insufficient bearing capacity. As a result, the course underlying the new road needs to be adequately prepared.

The material beneath a constructed road or pavement is known as the subgrade and is often referred to as the formation level. It is commonly compacted prior to constructing a road or pavement, and it often determines how well a pavement performs (Jeya et al., 2019). The performance of subgrade depends on: (1) the subgrade's ability to withstand loads that are transferred from the pavement is determined by its load bearing capability. The degree of compaction, soil type, and moisture content all have an impact on the subgrade's bearing capacity. (2) When the subgrade is exposed to too much moisture, the volume changes. Depending on their moisture level, some clay soils can shrink and swell. If the subgrade is not sufficiently compacted, it will typically continue to compress, deform, or erode after construction, leading to cracks and distortion in the pavement (Amir et al., 2019).

In the process of road construction, soil compaction is very important. It aims to reduce the volume of water- and air-filled pores in the soil that has to be compacted (Ravindra et al., 2018). A well-compacted soil increases stability; resistance to stresses induced by traffic and the environment, and decreases its propensity to swell as a result of water absorption. A subgrade that is not properly compacted invites problems since asphalt or concrete may be difficult to maintain and may eventually bulge, buckle, or crack. This implies that the road will need to be replaced or maintained at great expense. The integrity of the finished roadway is protected by well-compacted soil (Emerzon & Mary Ann, 2021).

Proctor compaction and California Bearing Ratio (CBR) tests, the latter of which measures the strength of the subgrade of a road or other paved area and of the material used in its construction, enable the process of compaction in the laboratory. A series of proctor compaction and CBR tests performed on a clay soil sample showed the impact of the test's compactible effort on the soil. The maximum dry unit weight increases with compaction, but the optimum moisture content decreases (Mehrab et al., 2008).

This research work aims to investigate the effect of different numbers of blows on soil compaction and how that affects the subgrade strength of road pavement.

2. Materials and Methods

The samples of clayey soil used in this study were taken from Rivers State University in Port Harcourt, Nigeria, at a depth of 1.0 meter. These material samples were then taken to Civil Engineering Laboratory of the University for laboratory tests.

The American Society for Testing and Materials (ASTM D698-12; D1557-12, 2021), the American Association of State Highway and Transportation Officials (AASHTO T 99, 2019; T 180, 2020), and the British Standard (BS 1377: 1990) were all followed while conducting laboratory tests and analyzing data for soil testing. The index properties of the clayey soil such as specific gravity, Moisture content, Atterberg limit, and Particle size distribution were carried out. Additionally, soil tests for CBR and compaction (with standard and modified proctors) at various blow counts were performed.

2.1 Proctor Compaction Test at Varying Numbers of Blows

For the compaction test, a 6 kg sample of air-dry soil was collected. The soil lumps were then broken and sieved. The soil received water and was properly stirred. The Proctor mould's combined weight with the base plate (without the collar) was calculated. The collar was then attached to the mould's top while the soil was added in three equal layers for the standard Proctor compaction test and five layers for the modified proctor, respectively.

Six (6) set of trials each at varying number of blows and weight of rammer for the soil samples were prepared for compaction test as shown in table 1.

Table 1: Number of Blows and Weight of Rammer for the Soil Samples

Number of blows	**No. of trials**	**Weight of rammer (kg)**	**No. of samples**
25, 30, 35, 40, 45, 50, 55 and 60	6	2.5	48
25, 30, 35, 40, 45, 50, 55 and 60	6	4.5	48
Total Samples			**96**

The calculation of moisture content (w_n) and dry density (γ_d) for each trial as shown in equations (2.1) – (2.2)

- Moisture content (w_n %) = $\frac{mass\ of\ water}{mass\ of\ dry\ solid}\ X\ 100$ (2.1)
- Dry density (γ_d) = $\frac{\gamma_b}{1+w_n}$ (2.2)

Thereafter, the compaction curve was drawn for each trial from which their Maximum dry density (MDD) and Optimum moisture content (OMC) were obtained.

2.2 CBR Test at Varying Numbers of Blows

After the compaction tests were completed, a filter paper was fixed to the perforated base plate, and the mould was turned upside down so that the specimen's surface, which had been facing downward and in contact with the spacer disc during compaction, was now facing upward. This was the unsoaked condition for the penetration test. The sample was positioned under the penetration piston with a 4.5kg total surcharge weight. After then, 1.25 mm of load was applied to the plunger per minute. At penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10.0, and 12.5 mm, readings of the load were taken. The soil's water content was obtained using the available readings, and a load against deformation curve was drawn. The California bearing Ratio (CBR) values were calculated from equation (2.3);

California bearing Ratio (CBR %) = $\frac{P_t}{P_s} x\ 100$ (2.3)

Where,

Pt = corrected unit (or total) test load corresponding to the chosen penetration

Ps = unit (or total) standard load for the same depth of penetration

The CBR values are usually calculated for penetration of 2.5mm and 5.0mm. The result shows that the CBR values of 2.5mm were greater than 5.0mm and as such, the former was taken as CBR for design purpose.

3. Results and Discussion

3.1 Index Properties of the Soil

For general engineering purposes, Table 2 shows index properties of the soil which aids in identifying and classifying the soil.

Table 2: Index Properties of the Soil

Property	Values
Moisture content (%)	23.80
Bulk density kN/m^3	16.85
Specific gravity – soil	2.75
Liquid Limit (%)	32.80
Plastic Limit (%)	13.60
Plasticity index (%)	19.20
Unified soil classification system	CL
AASHTO classification	A-7-6

3.2 Proctor Compaction at Varying Numbers of Blows

The compaction curve in Figures 1 and 2 shows the results of the standard and modified Proctor compaction test at various blow counts of 25, 30, 35, 40, 45, 50, 55, and 60. The compaction curve obtained from varying number of blows shows an increase in dry density as moisture content increases to a maximum value, followed by a reduction as moisture content increases.

The injection of water was thought to have lubricated the particles, increasing the material's dry density and thus resulting in a denser material. Due to the replacement of solids with water, the effectiveness of the water addition decreased at the optimum condition, as shown by a decrease in dry density. This is consistent with the findings trend seen in (Ojuri, 2016).

Figures 3 and 4 respectively illustrate the soil's Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) after receiving various numbers of blows from rammers weighing 2.5 kg and 4.5 kg. The findings show that as the number of blows increased, the optimum moisture content value decreased. While the maximum dry density increased as the number of blows increased.

This is due to the displacement of air and water from the soil pores caused by the change in blows from 25, 30, 35, 40, 45, 50, 55, and 60 blows, which caused the soil's moisture content to decrease and the dry density to subsequently increase.

Because of its higher weight, the 4.5kg rammer's application is seen to produce better results than the 2.5kg one.

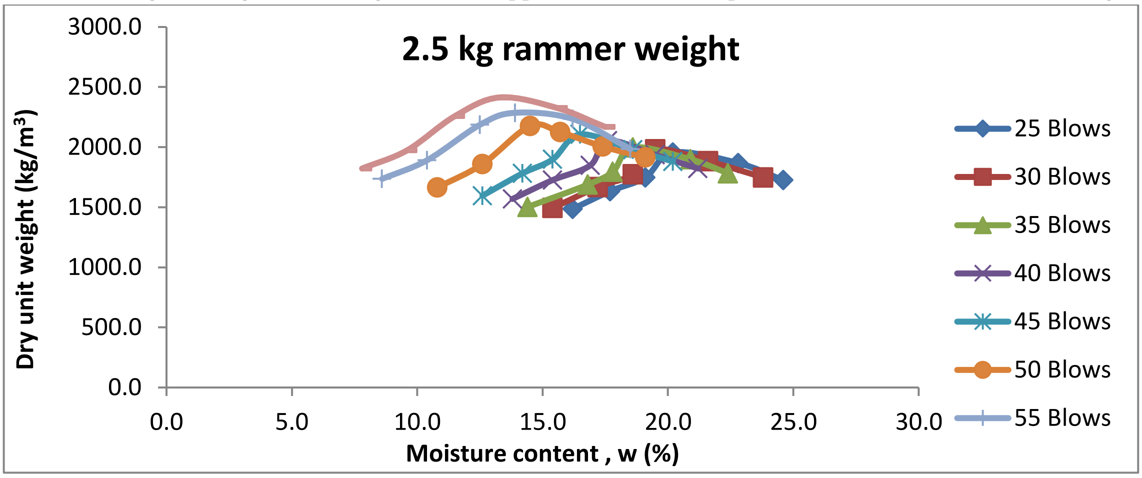

Figure 1: Compaction Curves for the Varying Number of Blows using 2.5kg Rammer

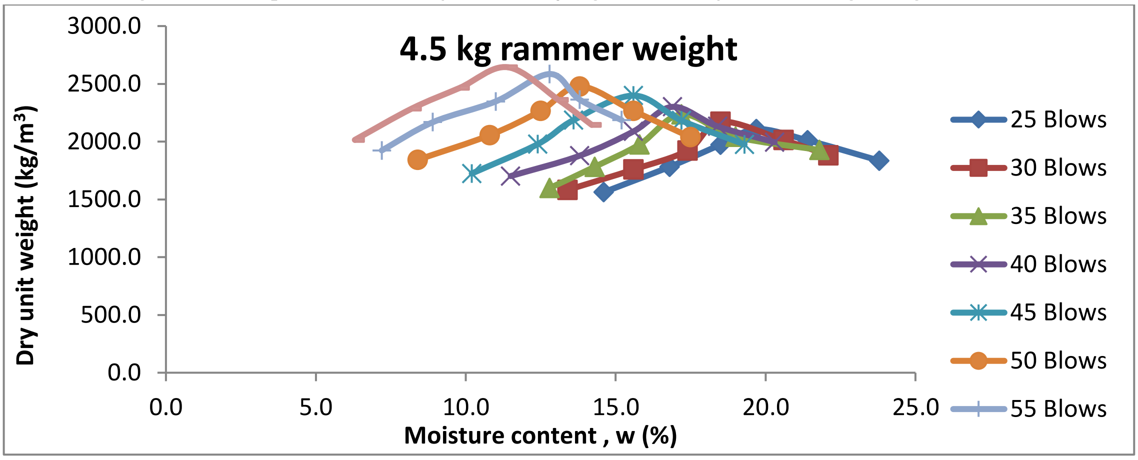

Figure 2: Compaction Curves for the Varying Number of Blows using 4.5kg Rammer

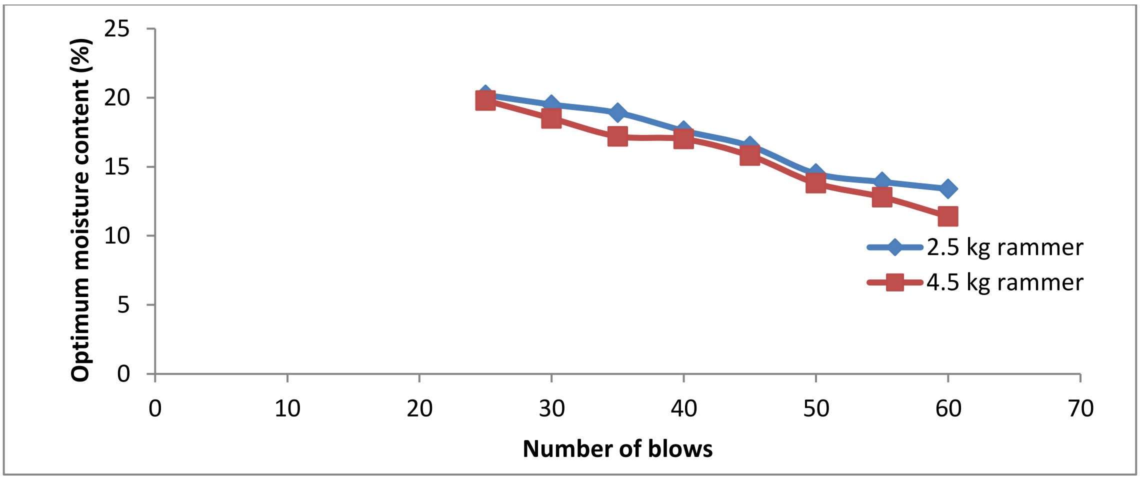

Figure 3: Optimum Moisture Content (OMC) versus Varying Number of Blows using 2.5kg and 4.5kg Rammer

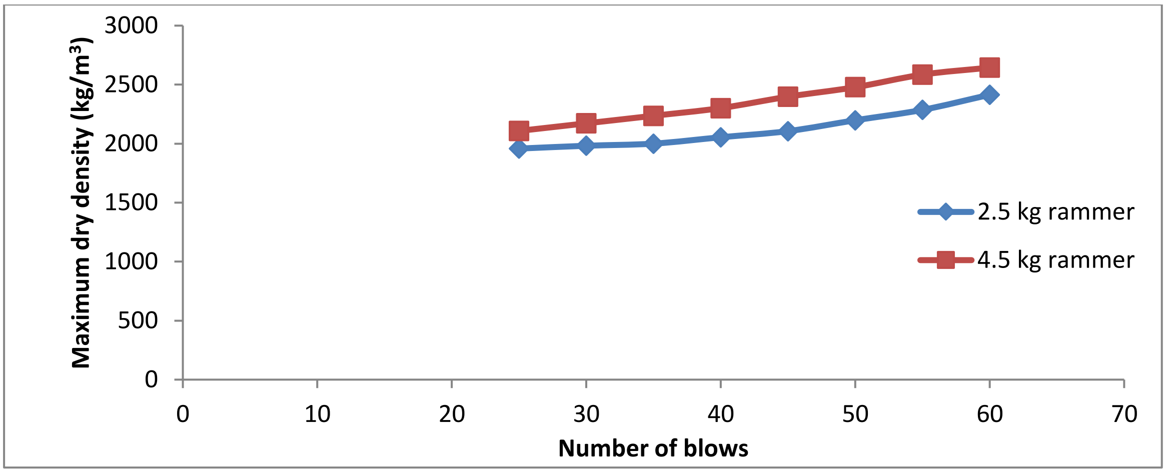

Figure 4: Maximum Dry Density (MDD) versus Varying Number of Blows using 2.5kg and 4.5kg Rammer

3.3 CBR at Varying Numbers of Blows

Figure 5 shows the results of the CBR test with 2.5kg and 4.5kg rammers at 25, 30, 35, 40, 45, 50, 55, and 60 blows. The behavior of the penetration curve obtained from various numbers of blows shows an increase in CBR with increasing number of blows. The increase in CBR was attributed to the increasing effect of compaction, which caused the soil to become denser by removing water and air, increasing the soil's strength and decreasing shear failure.

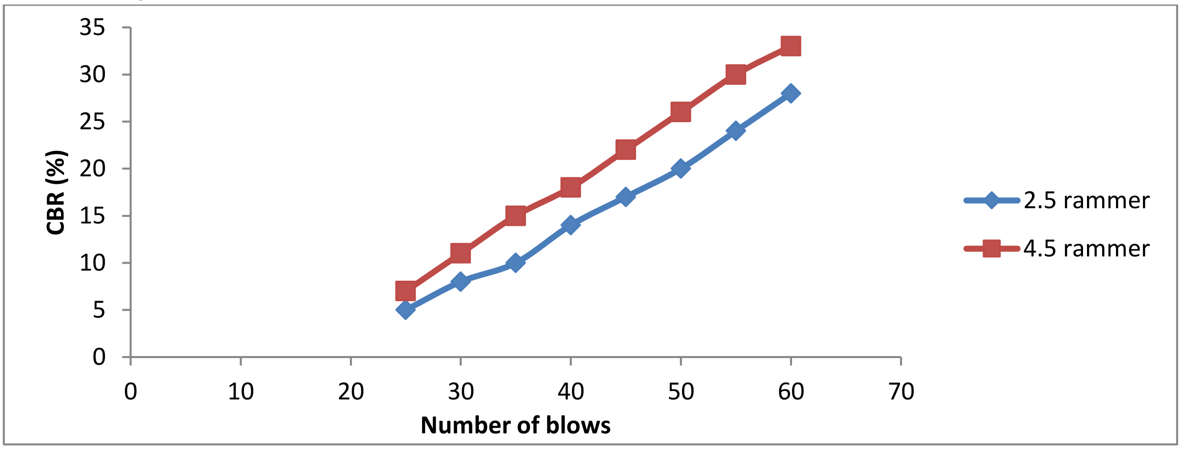

Figure 5: California Bearing Ratio (CBR) versus Varying Number of Blows using 2.5kg and 4.5kg Rammer

4. Conclusions

In light of this research, the accompanying conclusions can be drawn

1. Increased number of blows (compaction) results in the increase in CBR of soils and hence has effect on the subgrade strength of road pavement as shown in the result
2. Increase in the compaction/CBR would significantly reduce the total thickness of the pavement; hence, the total cost of the project.

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