

Impact of Specific Gravity on Soil Compaction Characteristics for Road-Base

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Abstrak

Studi ini menyelidiki peran berat jenis, kepadatan kering maksimum (MDD), dan kadar air optimum (OMC) dalam mengevaluasi pemadatan tanah untuk konstruksi lapisan dasar jalan menggunakan sampel dari tiga kelompok dan satu kelompok kontrol. Kelompok 3 menunjukkan berat jenis tertinggi (2,61), MDD yang konsisten (2,03 g/cm³), dan OMC rendah (10,25%), menunjukkan sifat granular yang ideal. Kelompok 1, dengan berat jenis sedikit lebih rendah (2,54), mencapai MDD tertinggi (2,04 g/cm³) dan OMC stabil (10%), menunjukkan pemadatan yang baik karena gradasi yang menguntungkan. Kelompok 2, meskipun memiliki berat jenis sedang (2,57), memiliki MDD terendah dan OMC tertinggi, menunjukkan tanah halus yang sensitif terhadap kelembapan. Kelompok Kontrol menunjukkan pemadatan sedang tetapi variabilitas tinggi. Analisis korelasi mengungkapkan hubungan yang lemah dan tidak signifikan antara berat jenis dan parameter pemadatan, menyoroti pengaruh faktor lain seperti ukuran butir dan plastisitas. Studi ini menyimpulkan bahwa berat jenis penting tetapi harus dinilai bersama dengan sifat tanah lainnya. Grup 3 dan Grup 1 paling cocok untuk penggunaan langsung.

Abstract

This study investigates the role of specific gravity, maximum dry density (MDD), and optimum moisture content (OMC) in evaluating soil compaction for road base construction using samples from three groups and a control. Group 3 exhibited the highest specific gravity (2.61), consistent MDD (2.03 g/cm³), and low OMC (10.25%), indicating ideal granular properties. Group 1, with slightly lower specific gravity (2.54), achieved the highest MDD (2.04 g/cm³) and stable OMC (10%), suggesting good compaction due to favorable gradation. Group 2, despite moderate specific gravity (2.57), had the lowest MDD and highest OMC, pointing to fine, moisture-sensitive soils. The Control group showed moderate compaction but high variability. Correlation analysis revealed weak, insignificant relationships between specific gravity and compaction parameters, highlighting the influence of other factors like grain size and plasticity. The study concludes that specific gravity is important but should be assessed with other soil properties. Group 3 and Group 1 are most suitable for direct use.

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INTRODUCTION

In geotechnical engineering, it is important to know how different soil qualities affect how the soil behaves when it is compacted. This knowledge is necessary for the successful design and construction of things like highways, buildings, and earthworks. Specific gravity, which measures how dense soil solids are compared to water, is one of the most important soil metrics used to assess and anticipate how well soil will perform. Specific gravity is a basic measure of the minerals in soil and gives an idea of how well it works in engineering, especially when it comes to compaction (Das, 2016; Budhu, 2015). Compaction logistically is making soil denser by minimising air gaps through mechanical effort. This is a common way to make soil stronger, stiffer, and better able to hold weight. A lot of soil variables, like particle size distribution, moisture content, flexibility, and most importantly, specific gravity, have a big effect on how well compaction works.

Mineral soils usually have a specific gravity between 2.60 and 2.80, however this can change a lot depending on whether there are lighter minerals like quartz or heavier minerals like iron oxides (Bowles, 1992). When compacted, soils with higher specific gravity tend to have heavier and denser minerals, which makes the dry unit weights higher. On the other hand, soils with lower specific gravity may have organic matter or softer minerals in them, which might make compaction less effective and less stable over time (Craig, 2004). Specific gravity isn't a direct measure of strength, but it has a big effect on other parameters like maximum dry density (MDD) and optimum moisture content (OMC), which makes it an important part of compaction analysis. MDD is the highest dry density a soil may reach with a certain amount of compaction, and OMC is the amount of moisture at which this density is reached. Both are important factors in figuring out how strong and long-lasting compacted soil layers will be in building (Lambe & Whitman, 1979).

Recent research has looked into how specific gravity can be used to predict parameters linked to compaction, like maximum dry density (MDD) and optimum moisture content (OMC). In theory, specific gravity is linked to the maximum density that a soil may reach. However, new research shows that its actual effect in real-world situations, especially for building road bases, is more complicated. Spagnoli & Shimobe (2020) made a big addition to this topic by reviewing more than 400 publications that looked at real-world links between basic soil parameters and compaction indices. Their results showed that G_s is widely utilised as an input in prediction models, although it doesn't have as big of an effect as other factors like grain size distribution and Atterberg limits. This conclusion is in line with the statistical results of a number of experimental studies that looked at individual gravity and compaction factors on their own and found minor connections between them. Soltani et al. (2021), on the other hand, took a new method by adding the specific gravity ratio to their models of fine-grained soils mixed with recycled tyre pebbles. Their research indicated that taking G_s into account together with void ratio and gradation factors makes anticipated OMC and MDD values much more accurate. The authors stressed that lightweight additions, like rubber grains, can change how compaction works, and that taking G_s into consideration helps to make these changes more natural.

Rimbarngaye, Mwero, and Ronoh (2022) looked at how sand-lime stabilised soils compact and found that the specific gravity values changed after stabilisation. Their study found that employing lime to stabilise modifies the mineral composition and the moisture-density connection, which in turn changes the specific gravity. Changes in G_s were closely linked to improvements in MDD. This shows that changes in particular gravity, whether through stabilisation or blending, can show changes in how engineering works. Pakir et al. (2024) looked examined coastal clay that had been treated with cement and coal ash. The soil that hadn't been treated had a lot of water in it and didn't compact well. The specific gravity went up after treatment, and the OMC went down while the MDD went up. The authors discovered that specific gravity was a good way to measure how well stabilisation worked. These results show that G_s are not only a static index feature, but also a dynamic indication of changes

in the soil. Many studies show that there is a positive link between G_s and MDD in coarse-grained or treated soils. However, this relationship is less clear in finer soils. Attom et al. (2023) looked at sandy subgrade materials that have been contaminated with rubber tire particles. Their results showed that pollution lowered the specific gravity, which changed the compaction curves. Even if G_s went down, the compaction properties didn't all get worse at the same time. This means that particle shape and texture should be taken into account along with density.

Di Matteo & Spagnoli (2024) also talk about this idea of multifactorial influence. They say that while specific gravity is important in compaction energy conversion models, it doesn't have as big of an effect as other factors like dry unit weight and relative compaction. Their suggested models were able to accurately anticipate how soil would behave when it was compacted at different energy levels. However, they didn't find that adding G_s to the models was very useful when soil classification and gradation data were already available. Awarri and Otto (2023) looked at subgrade soils in tropical areas and gave a regional view. Their research showed that soils with higher G_s (>2.60) usually compacted better and needed less OMC. But this pattern didn't hold true for clayey soils, where the ability to absorb water was more important than the effect of G_s . Ige and Ogundipe (2021) looked at tropical lateritic soils and found similar results. They saw that specific gravity alone couldn't predict how plastic soils would compact since moisture retention and swelling behaviour became more important.

The Iowa DOT Soils Manual (2022) and the Iowa State InTrans Manual (2021) are two examples of institutional manuals that support the idea that G_s is a necessary parameter in laboratory assessments but works best when combined with Proctor test results, grain-size distribution, and moisture content when predicting field compaction. These resources give engineers baseline values for G_s , which are usually between 2.60 and 2.75 for granular soils. However, they stress that G_s should not be used alone. The Gilson (2020) Proctor test guide and other educational materials make it clear that specific gravity affects the calculation of void ratio and theoretical maximum density. However, the moisture content at the moment of compaction has a much bigger effect on the actual compaction curve. This shows that we need to test things in real time instead of just looking at index characteristics. On the other hand, Alhassan and Mustapha (2020) gave strong support for G_s -based assessment. They found that soils with G_s values above 2.60 had far higher dry densities and needed less moisture than soils with G_s values below 2.50. Their results show that specific gravity can be a good way to forecast how well compaction will work in clean, granular soils. Rahman et al. (2019) said the same thing, saying that well-graded granular soils with moderate-to-high G_s values had higher dry densities, which lowered the risk of settlement and subgrade failure. These insights are especially important for base course layers where it is very important to compact them well. Eyo and Omoregie's (2022) multivariate modelling methods have moved the study further by combining G_s with plasticity index, particle size, and compaction effort into instruments that can make predictions. Their results show that G_s alone doesn't do a good job of predicting, but when it's paired with other variables, it makes the model work much better. They want a complete soil categorisation system that sees G_s as a secondary component in predicting compaction. Zhang et al. (2020) used boxplots and scatter matrices to look at how different types of soil compact. Their results demonstrated that there were substantial visual links between compaction parameters and gradation, but moderate visual or statistical trends with specific gravity. This shows even more why G_s is best seen as a secondary indicator: it can help check that the soil is uniform or find problems, but it can't give you a precise prognosis of how it will behave.

These review shows that specific gravity is a significant factor in determining how compacted the soil is for use as a road basis, however this depends on the situation. In coarse-grained, well-graded soils, high specific gravity usually means a larger MDD and a lower OMC, which supports what geotechnical experts already know. But in soils with small particles or that have been chemically changed, G_s has less of an effect than things like plasticity, water content, and the type of treatment.

These studies all agree that specific gravity should be looked at along with other soil factors, especially moisture content, gradation, and Atterberg limits, in order to make accurate predictions about how well compaction would work. For road engineers and geotechnical designers, this means that G_s is still a good way to tell what minerals are in a material and how dense it might be, but it needs to be looked at in a bigger geotechnical context to help choose materials, change them, and control compaction when building a road base. Adding specific gravity to multivariate models, testing in the field, and testing in the lab will make soil compaction and pavement design more dependable and performance-based. When building roads, the quality of the subgrade and base layers has a big effect on how strong and long-lasting the pavement is. This is because the specific gravity has a big effect on compaction. Not enough compaction can cause the road to settle, crack, and let water in, all of which make it less effective (Terzaghi, Peck, & Mesri, 1996). So, it's important to fully grasp how particular gravity and compaction behaviour are related in order to choose the right soils and use the right compaction methods. In areas with different types of soil, this information is even more important since engineers need to know whether to accept, change, or replace local soils to fulfil engineering standards (Akpokodje, 2018; Osinubi & Amadi, 2017).

Even though specific gravity seems to have a big effect on compaction, there aren't many localised research that directly link specific gravity to MDD and OMC in field circumstances. A lot of the studies that are out there give generic results without taking into account how soil qualities can change from one place to another. Engineers and contractors that work in certain areas have a hard time since they don't have enough site-specific data to predict and regulate how the soil would behave during compaction (Zhang, Liu, & Li, 2020). Also, to make compaction forecasts more reliable, the relationship between specific gravity and other elements that affect it, like particle shape, plasticity index, and gradation, needs to be better understood (Eyo & Omoregie, 2022).

This study attempts to fill this gap by looking at how soil specific gravity affects compaction properties, such as maximum dry density and optimum moisture content. To do this, it will use samples from three different soil groups and a control group. The goal is to find out how specific gravity affects how soil compacts under standard Proctor compaction effort and to figure out which soil types are best for use as road base based on their geotechnical reaction. The study approach includes testing for specific gravity and compaction qualities in the lab, using statistical correlation analysis, and looking at boxplots and scatterplots to see what they mean. The study wants to find patterns and outliers in the results from different groups that could help engineers choose better materials and compact them better on projects.

In the end, this study adds to what we know about how soil behaves and gives geotechnical engineers who work on roads and earthworks useful advice. The results will help make design protocols that are more efficient and dependable, especially in areas where differences in soil mineralogy and composition affect how well building goes. The study makes it possible to evaluate soil in a more complete way by showing how specific gravity affects compaction characteristics. This includes not only laboratory tests but also the effects of soil structure, compactive effort, and moisture management in the actual world.

METHODS

The methodology adopted in this study was designed to evaluate the specific gravity and compaction characteristics of different soil samples to assess their suitability for road base construction. The approach involved the systematic collection of soil samples, laboratory testing to determine geotechnical properties, and analytical procedures to interpret the results using both statistical and visual tools.

Soil Sampling

A total of 21 soil samples were collected and categorized into four distinct groups based on their geographical origin and collection sequence. These included Group 1 (1A–1F), Group 2 (2A–2F), Group 3 (3A–3F), and a Control group (C1–C3). The sampling locations were selected based on preliminary geotechnical relevance and accessibility. Samples were collected using augers and stored in moisture-proof containers to preserve their natural conditions until laboratory analysis.

Laboratory Testing

All laboratory tests were conducted in accordance with standard procedures established by the American Society for Testing and Materials (ASTM). The primary geotechnical properties evaluated were:

- a. **Specific Gravity of Soil Solids:** Specific gravity was determined using the pycnometer method, conforming to ASTM D854. This test measured the relative density of soil particles by comparing the weight of soil solids to the weight of an equivalent volume of water. Each sample was oven-dried at 105°C and finely ground before testing to ensure accuracy.
- b. **Compaction Test (Standard Proctor Test):** Compaction characteristics were assessed using the Standard Proctor Test as outlined in ASTM D698. This involved compacting soil at varying moisture contents within a standard mold and measuring the dry density after each compactive effort. From this, the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were determined for each sample by plotting dry density against moisture content and identifying the peak point on the compaction curve.

Data Processing and Analysis

The data from laboratory testing were compiled and organized using Microsoft Excel and Python-based data science tools. Descriptive statistics were calculated for each group to determine average values of specific gravity, MDD, and OMC. Pearson correlation analysis was performed to assess the relationship between specific gravity and the compaction parameters (MDD and OMC), while group-wise averages provided insight into the comparative performance of the sample groups.

In addition to numerical analysis, boxplots and scatterplots were generated to visualize trends and distributions. These plots offered a graphical representation of data variation within and between groups, enabling intuitive interpretation of soil behaviour.

Grouping Criteria

Samples were grouped based on similarities in source location and expected geological conditions. Group 1 and Group 2 soils were obtained from areas previously used for road construction or earthworks, while Group 3 samples originated from a less disturbed, naturally compacted zone. The Control group was included to represent a baseline of undisturbed or unclassified soil conditions for comparative evaluation.

Quality Control

To ensure data reliability, all tests were repeated at least twice, and average values were used in the final analysis. Any significant discrepancies between repetitions prompted a retest to eliminate experimental error. Equipment calibration and operator consistency were strictly maintained throughout the testing process.

This methodological approach provided a robust framework for evaluating soil suitability for road base construction, enabling a thorough understanding of the compaction behaviour of each sample group.

RESULT AND DISCUSSION

It is very important to look at the specific gravity and compaction properties of soil, especially when deciding if soils are good for building road bases. The information given (Table 1) shows how three separate groups of soil samples (Groups 1, 2, and 3) and a control group (C1–C3) acted in terms of their specific gravity, Maximum Dry Density (MDD), and Optimum Moisture Content (OMC). When you know how these attributes are related to one other, you can make better decisions about how well soils will hold up under compaction. Specific gravity is the ratio of the density of soil particles to the density of water. It shows the mineral makeup and density of the soil solids. The specific gravity values of Group 1 samples (1A–1F) range from 2.54 to 2.55, which suggests that the mineralogical profile is consistent and may be mostly made up of quartz and feldspar with low quantities of heavy minerals. Group 2 shows a small rise, with values between 2.56 and 2.58. Group 3 has the most consistent and highest values, with all samples showing a specific gravity of 2.61. The control samples show more variation, going from 2.39 (C1) to 2.60 (C3). This suggests that the mineral composition is not uniform or that the samples are contaminated by human sources.

Table 1. Specific Gravity and Compaction Data

No	Sample Group	Specific Gravity	MDD (g/cm ³)	OMC (%)
0	1A	2.55	2.01	10
1	1B	2.55	2.03	10
2	1C	2.54	2.04	10
3	1D	2.54	2.05	10
4	1E	2.54	2.06	10
5	1F	2.54	2.06	10
6	2A	2.58	2	10.2
7	2B	2.57	1.97	11.1
8	2C	2.57	1.94	12
9	2D	2.56	1.93	12.5
10	2E	2.56	1.91	13
11	2F	2.56	1.91	13
12	3A	2.61	1.99	10.8
13	3B	2.61	2.01	10.4
14	3C	2.61	2.03	10.2
15	3D	2.61	2.04	10.1
16	3E	2.61	2.05	10
17	3F	2.61	2.05	10
18	C1	2.39	2.03	11.3
19	C2	2.5	2.01	11.2
20	C3	2.6	1.99	11.2

When it comes to compaction, Group 1 shows an increase in MDD from 2.01 g/cm³ to 2.06 g/cm³ across samples, with a constant OMC of 10%. This means that the soils in this group respond well to compaction and need the same amount of moisture to densify properly. On the other hand, Group 2 exhibits the opposite trend: MDD goes down from 2.00 g/cm³ to 1.91 g/cm³, while OMC goes up from 10.2% to 13.0%. This means that the grains are probably smaller and have more silt or

clay, which tends to hold more water and compress to a lower dry density. The slow decrease in MDD and rise in OMC strengthens the link between how fine the soil is and how well it can hold water.

Group 3 shows a pattern that is a little different. The MDD values go up from 1.99 g/cm³ to 2.05 g/cm³, whereas the OMC values slowly go down from 10.8% to 10.0%. The high specific gravity (2.61) of this group is linked to higher MDD values, which supports the basic geotechnical idea that denser particles tend to have greater dry densities when they are compacted. The lower OMC means that less water is needed to make the soil compact, which is something that happens with coarse-grained soils or well-graded granular materials. The control samples act in different ways. C1 has a specific gravity of 2.39, an MDD of 2.03 g/cm³, and an OMC of 11.3%. C2 and C3 have specific gravities that are slowly going up and MDDs that are slowly going down, while OMC stays about the same (11.2%). The control group had a larger range of specific gravities and irregular compaction behaviour. This could be because they were exposed to the environment without control or because they mixed soil from multiple sources, which makes them less predictable for engineering reasons.

A favourable relationship can be seen when plotting specific gravity against MDD. Soils having a greater specific gravity tend to have a higher MDD, which means that denser mineral compositions help with compaction. On the other hand, there is a negative link between specific gravity and OMC. Soils with greater specific gravity usually need less moisture to accomplish maximum compaction. This is probably because coarse or well-graded soils have less pore space and hold less water.

The way that specific gravity, MDD, and OMC interact with each other shows the soil's natural properties, such as its mineralogy, texture, and grain-size distribution. Group 3 soils seem to be the best for road base since they have a high specific gravity and compact well. At the same time, the different performance in Group 2 and control samples means that the soil needs to be classified more carefully and maybe treated before it can be used in structural layers. This study shows how important it is to do a full geotechnical examination before using soil in civil engineering projects.

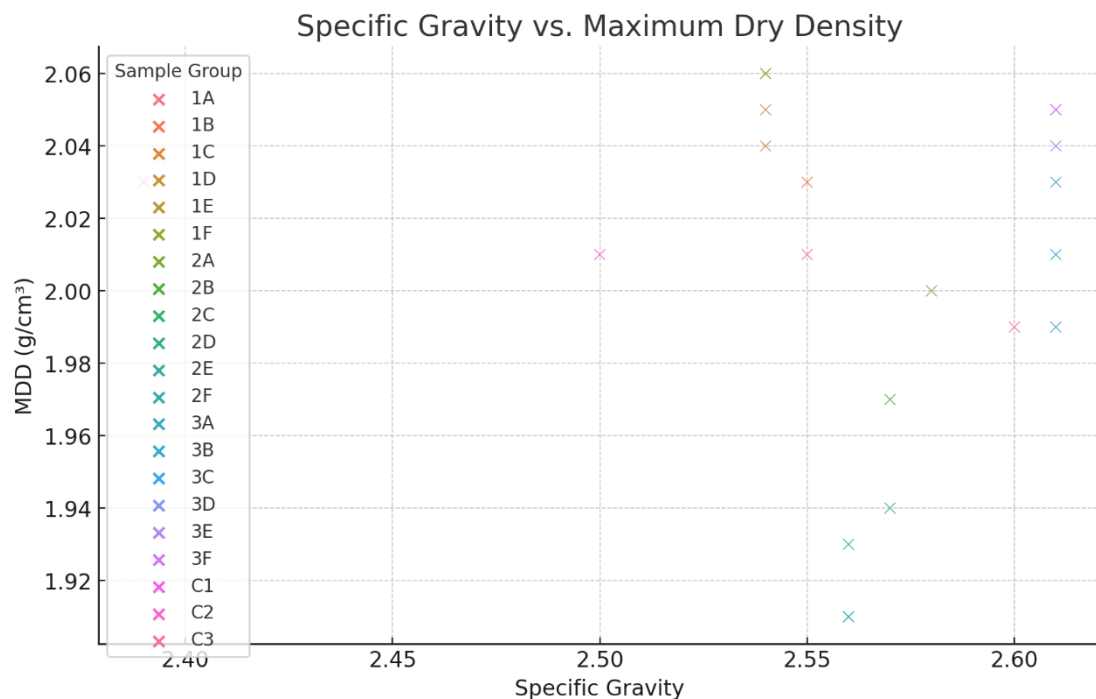


Figure 1. Specific Gravity vs. Maximum Dry Density

The link between specific gravity and maximum dry density (MDD) is an important idea in soil mechanics. It is often used to figure out how compactable and good soils are for building things,

especially when they are used as road basis. Specific gravity is the ratio of the density of soil solids to the density of water. It shows the mineral makeup of the soil and gives us an idea of how heavy the soil particles are compared to each other. MDD, on the other hand, tells you how dense a soil can get when it is compacted normally. It is an important factor in figuring out how strong and stable a soil is.

The research shows (Figure 1) a definite positive relationship between MDD and specific gravity. For example, Group 3 samples, which had the highest specific gravity values (2.61), always had higher MDD values, which ranged from 1.99 to 2.05 g/cm³. This pattern backs up the idea that when soil particles are denser, like those made up of heavier minerals like iron oxides or basaltic pieces, they have a higher dry unit weight when they are compressed. On the other hand, Group 1 samples exhibited MDD values that were a little lower (2.01–2.06 g/cm³) than the specific gravity values, which were around 2.54–2.55. This means that the minerals in these samples were less dense, presumably because they were mostly quartz or feldspar. The control samples show this link much more. C1, which had the lowest specific gravity (2.39), had an MDD of 2.03 g/cm³. C3, which had a specific gravity of 2.60, had an MDD of 1.99 g/cm³, which was a little lower. This exception could be caused by various factors, such the form of the particles, the way the soil is graded, or the way the moisture is spread out, which can sometimes change the expected pattern.

Previous research has also found that soils with higher specific gravity tend to have heavier mineral components and compact better because they have fewer voids when they are under load. Also, these soils usually have greater load-bearing properties, which is very important for designing pavements and building foundations.

In short, specific gravity is a good way to tell how likely it is that soil will become compacted. The evidence confirms that the maximum dry density goes up when the specific gravity goes up, albeit there are times when this isn't the case because of other considerations. Understanding this link improves the ability to forecast outcomes in geotechnical design, allowing engineers to make smart decisions about the appropriateness of soil and the treatment measures needed for construction purposes.

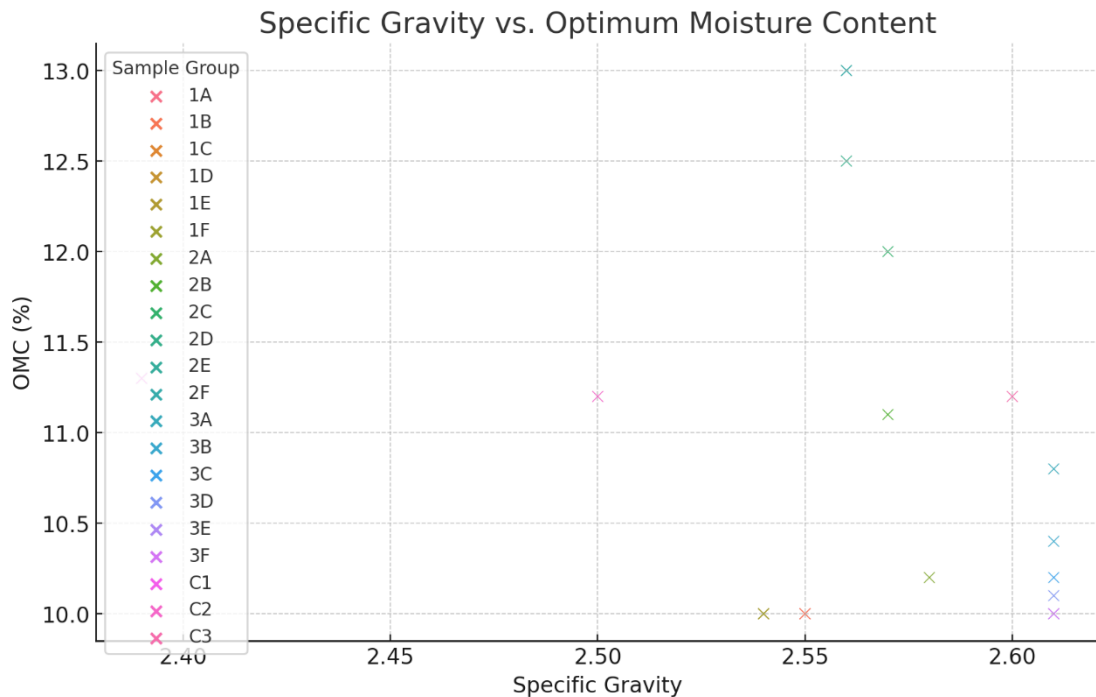


Figure 2. Specific Gravity vs. Optimum Moisture Content

The link between specific gravity and Optimum Moisture Content (OMC) is very important in geotechnical engineering, especially when it comes to soil compaction and whether or not it is good for building. Specific gravity shows how dense soil particles are compared to water. It is a way to measure the mineral content and natural weight of the soil solids. On the other side, the Optimal Moisture Content is the amount of moisture in the soil that lets it reach its Maximum Dry Density (MDD) with a certain amount of compactive effort. When you know how these two factors affect each other, you may learn a lot about how various soils function when they are compacted in the field.

The experimental findings (Figure 2) show that there is an inverse link between specific gravity and OMC. When specific gravity goes up, the amount of moisture needed for optimal compaction usually goes down. For instance, all of the Group 3 samples had a specific gravity of 2.61 and OMC values that were rather low, between 10.0% and 10.8%. This means that soils in this group that are denser and maybe have coarser grains need less water to reach their best compaction state. Coarse soils usually have less surface area and fewer pores to soak up water, which makes them easier to compact with less water. On the other hand, Group 2 samples had somewhat lower specific gravity values (2.56–2.58), but their OMC levels were greater, ranging from 10.2% to 13.0%. This tendency shows that the soils are finer-grained, like silts or clays, which have more surface area and pore space. These smaller particles need more water to keep the grains from sticking together during compaction and to fill the tiny spaces in the soil matrix. This means that more water is needed to reach maximum density. The control samples support this pattern even more. C1 has a low specific gravity of 2.39 and a high OMC of 11.3%, while C3 has a specific gravity of 2.60 and a lower OMC of 11.2%.

This inverse correlation is in line with what we know about geotechnical concepts. Soils with high specific gravity are usually granular and may be compacted with little moisture. Soils with low specific gravity, on the other hand, generally include organic matter or small particles in them and need more water to be compacted well. Understanding this connection helps engineers figure out how much compaction is needed in the field, improve moisture conditioning, and choose the best methods for changing the soil. In the end, a full understanding of this relationship leads to better soil performance and more effective road base construction.

Using the Pearson correlation coefficient, we looked at the link between specific gravity and the two main compaction parameters (Table 2): Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). The purpose was to find out if changes in specific gravity could accurately anticipate differences in how the soil samples behaved when they were compacted.

Table 2. Statistical Correlation Analysis

Variables	Pearson Correlation Coefficient	P-value
Specific Gravity vs. MDD	-0.06906	0.766126
Specific Gravity vs. OMC	-0.1683	0.465855

The research showed that there was a weak negative relationship between specific gravity and MDD, with a Pearson correlation coefficient of -0.069 and a p-value of 0.766. This means that there is almost no linear relationship between the two variables in the dataset, and the correlation that was found is not statistically significant at any normal level of confidence. This result goes against what is usually said in geotechnical literature, which says that higher specific gravity is linked to higher MDD. Other things, like different grain size distributions, sensitivity to moisture, or particle morphologies that weren't taken into consideration in the specific gravity calculations, could also explain the inconsistency.

The same was true for the association between specific gravity and OMC, which was again weakly negative, with a Pearson correlation coefficient of -0.168 and a p-value of 0.466. Again, the link is not statistically significant, which means that specific gravity does not have a big effect on the amount of moisture needed to have the best compaction in this dataset. This could be because the soil types, minerals, or methods of compaction utilised during testing were different.

By comparing the averages for specific gravity, maximum dry density (MDD), and optimum moisture content (OMC) for each group, we may learn more about how the different soil groups behave and how well they are engineered. The four sample groups—Group 1, Group 2, Group 3, and the Control—were tested, and their geotechnical properties were found to be significantly different (Table 3). These differences are important for deciding if they may be used as road base. Group 1 had the second-lowest average specific gravity (2.543) and the greatest average MDD (2.042 g/cm³). The fact that all the samples had the same OMC of 10.0% shows that the soil's composition and how it compacts are rather stable. These numbers show that the soils in Group 1 are very compactable and hold moisture well, even though they have a slightly lower mineral density. This behaviour could be due to a good gradation and low clay content, which makes packing easier when compactive effort is applied.

Table 3. Group-wise Average Comparisons

Group	Specific Gravity	MDD (g/cm ³)	OMC (%)
Control	2.496667	2.01	11.23333
Group 1	2.543333	2.041667	10
Group 2	2.566667	1.943333	11.96667
Group 3	2.61	2.028333	10.25

Group 2 had the highest average specific gravity (2.567), but it also had the lowest MDD (1.943 g/cm³) and the highest OMC (11.97%). This opposite behaviour, where more specific gravity didn't lead to improved compaction, implies that mineral density alone isn't the only thing that affects how soil compacts. Soil fineness and moisture sensitivity are also important. The higher OMC means that there are finer particles or clayey elements that need more water to fill in gaps and lubricate particles, which makes it harder for the soil to reach a high dry density.

With an average specific gravity of 2.610 and a moderate MDD of 2.028 g/cm³, as well as an OMC of 10.25%, Group 3 stood out. These numbers back up the idea that this group has denser, perhaps coarser-grained soils that compact well without too much water. The high specific gravity and adequate MDD suggest that the soil structure is balanced and good for building roads. It has a lot of density and doesn't need a lot of water. The Control group had the lowest average specific gravity (2.497), a moderate MDD (2.010 g/cm³), and the second-highest OMC (11.23%). The differences in the control samples are probably due to less regulated collecting settings or soil types that are mixed together. In general, Group 3 has the best balance of geotechnical qualities. On the other hand, Group 2's high moisture needs and low MDD make it less suitable for structural applications. These comparisons show how important it is to look at things in groups when doing geotechnical studies.

Boxplots are a great way to quickly show the central tendency, spread, and any outliers in a set of data. In this geotechnical study (Figures 3-5), boxplots for specific gravity, maximum dry density (MDD), and optimum moisture content (OMC) show important information on how soil parameters vary and are spread out among four groups: Group 1, Group 2, Group 3, and the Control group. These graphs make it easier to see how soil behaves differently in different sample groups and assist confirm the results of average comparisons and statistical analysis. The boxplot for specific gravity shows the differences in mineral density between the groups very clearly. Group 3 stands out because

all of its samples have a very high and constant specific gravity (2.61), as shown by the narrow interquartile range and lack of outliers. This shows that the soil has a consistent mineral makeup, probably with denser parts. Group 1 also has a small range around a mean of 2.54, which means that the mineral composition is quite uniform. On the other hand, the Control group had the biggest range, from 2.39 to 2.60, which means that the soil composition is very different. Group 2 has a modest amount of variation, with specific gravity values ranging from 2.56 to 2.58. The pictures show that Group 3 soils are the most stable and dense in terms of minerals, which makes them better for engineering uses.

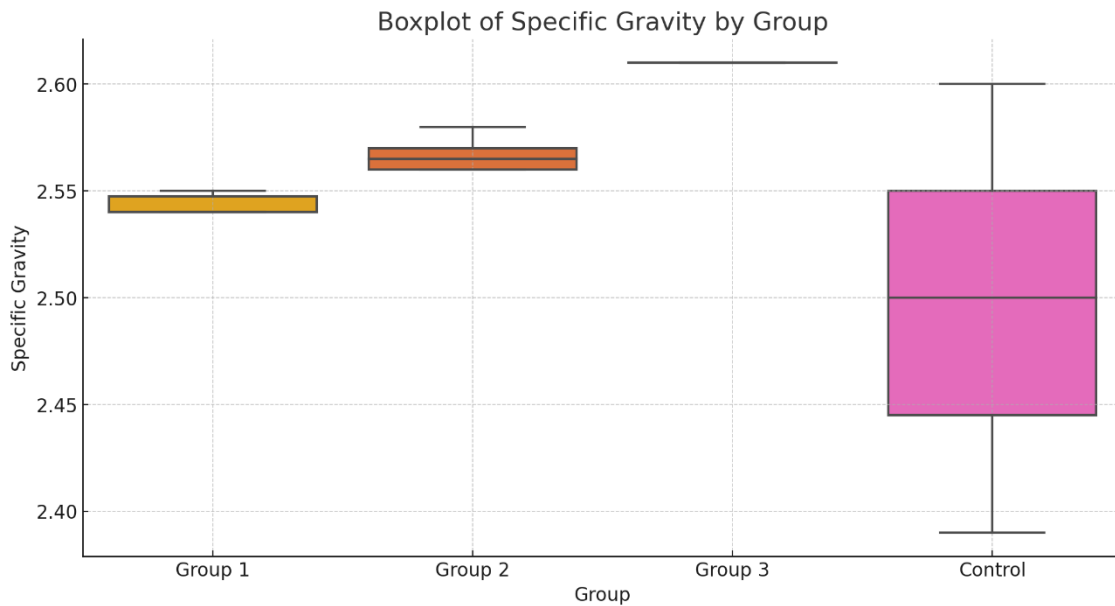


Figure 3. Boxplot Specific Gravity by Group

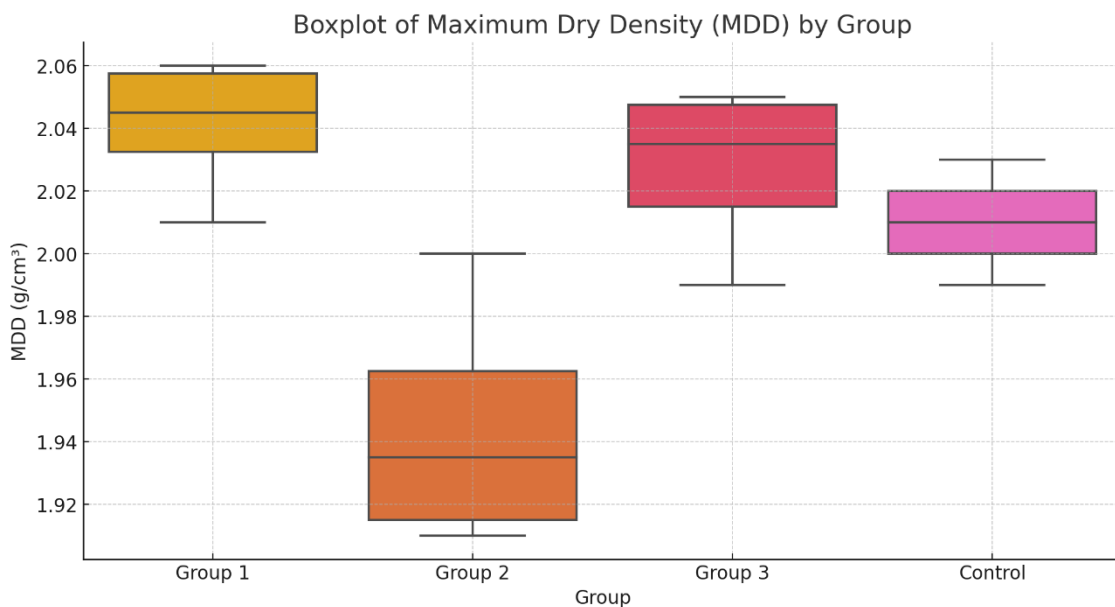


Figure 4. Boxplot MDD by Group

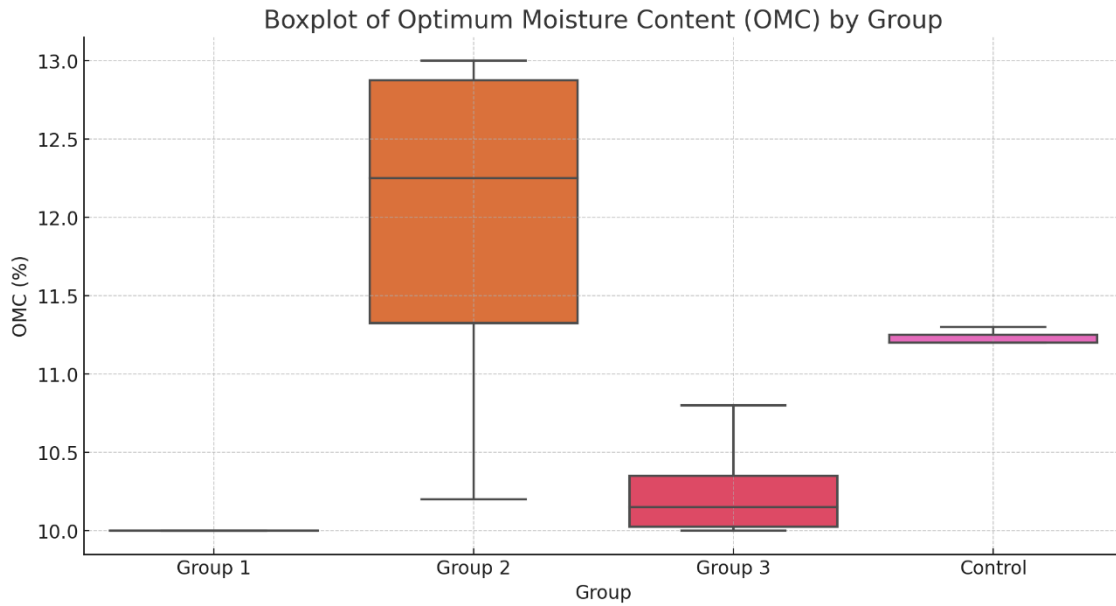


Figure 5. Boxplot OMC by Group

The MDD boxplot shows that the way things become compacted is really different. The central tendency is strongest in Group 1, where the dry densities are between 2.01 and 2.06 g/cm³. This close grouping shows that the samples all compacted well and consistently. Group 3 is next, with a median MDD that is a little lower and not much variation. Group 2, on the other hand, has the lowest and most changeable MDD values. This suggests that its soil structure is less good for compaction, which could be because it has more small particles or is more sensitive to moisture. The Control group is in the middle of Groups 2 and 3 in terms of both median and spread. This shows that there is more variability, which is probably because the samples were not taken in a controlled way or the dirt came from different places. These patterns back up the earlier finding that Group 1 soils are the easiest to compact with normal effort. The boxplot shows a different picture for OMC. Once again, Group 1 exhibits very little variation, with all samples needing 10% moisture for the best compaction. Group 3 comes next, with a little greater variation but still staying within a restricted range of moisture needs (10.0–10.8%). Group 2 had the most spread and the highest values, with OMC values between 10.2% and 13.0%. This proves that there are finer soils that are sensitive to moisture and need more water to stay lubricated and dense. The Control group likewise has a relatively high OMC with a moderate spread, which supports the concept that soil behaves differently because of differences in composition or contamination. The boxplots confirm what we saw in prior statistical and numerical data. Group 3 stands out as the most engineering-reliable group because it has a steady and dense specific gravity and good compaction properties. Group 1 likewise does well in compaction, but the minerals are a little less dense. Group 2 has a higher specific gravity, but it doesn't compact well since it needs too much moisture. The Control group's unpredictability makes it less predictable and possibly not good for structural uses without more treatment or classification

These visual summaries show how useful boxplots are for geotechnical study because they make it easy to see patterns and outliers in soil behaviour that would not be clear from averages or correlations alone. The way the soil compacts is very important for how well it works as a road base. The study looked at the specific gravity, maximum dry density (MDD), and optimal moisture content (OMC) of four different soil groups: Group 1, Group 2, Group 3, and a Control group. The results show important geotechnical parameters that affect how well the soil can be compacted and how it behaves when used in engineering. These discoveries have big effects on building, especially when it

comes to figuring out which soils are best for use as subgrade and base course materials. Combining these observations with new research gives us a better idea of how useful the data is in real life. Specific gravity is a way to tell what minerals are in the soil in geotechnical engineering. Higher specific gravity soils usually have heavier, denser minerals in them, which is often linked to superior engineering performance. Group 3 had the highest average specific gravity (2.61) and a comparatively high MDD (2.03 g/cm³), but a low OMC (10.25%). This link fits with what we would predict based on theory and what Alhassan and Mustapha (2020) found. They said that soils with specific gravities over 2.60 and a granular texture are more likely to compress well and use less water during field compaction. These kinds of soils are better at holding up weight and not changing shape, which are both important for building roads. Group 1 had the best compaction behaviour, with a consistent OMC of 10%. It also had the highest average MDD (2.04 g/cm³) and an average specific gravity of 2.54. The data's consistency shows that the soil has a homogeneous texture, low flexibility, and a good distribution of particle size. These traits are good for base course materials because they make it easy to condense them without changing the amount of moisture in them. This observation backs up what Rahman et al. (2019) found, which stressed how important it is to use well-graded granular materials to get the highest dry densities and keep pavements stable over time.

On the other hand, Group 2 had the worst compaction properties, with the lowest average MDD (1.94 g/cm³) and the greatest OMC (11.97%), even though it had a slightly higher specific gravity (2.57). This opposite trend is because the soil has finer particles or clay in it, which makes it hold more water and lowers its dry density. Fine-grained soils tend to hold water inside their structure, which makes it harder to compact them. However, they typically make a mass that is less dense and easier to compress. Ige and Ogundipe (2021) also saw this behaviour. They said that clayey soils with high plasticity indices need larger OMCs yet yield lower MDDs because water gets into the clay lattice, which stops the grains from moving around effectively under compactive force.

The Control group acted in a way that was in between the other two groups, with an average specific gravity of 2.50, an MDD of 2.01 g/cm³, and an OMC of 11.23%. However, the wide range of values in the control samples suggests that the soil types are not all the same and may have been affected by natural or human-made events. This variation in how the soil behaves is a problem for building roads, where consistent performance is very important. The results are in line with what Akpokodje (2018) saw and said about not utilising unclassified or highly variable soils in base course layers since they are hard to forecast when it comes to compaction and strength.

The correlation analysis between specific gravity and MDD showed a modest and statistically insignificant link ($r = -0.069$, $p = 0.766$). Also, the relationship between specific gravity and OMC was weak and negative ($r = -0.168$, $p = 0.466$). These findings show that general tendencies may be present, but specific gravity alone is not a good way to forecast how soil samples will compact. Eyo and Omoregie (2022) came to the same conclusion. They observed that compaction properties are affected more by a mix of parameters such grain size distribution, plasticity, and moisture content than by specific gravity alone. The boxplots make these conclusions even stronger. The MDD and OMC values for Group 1 and Group 3 were close together, which means that the compaction performance was consistent. Group 2, on the other hand, had a lot of variation in OMC and a low MDD, which made it even less suitable for high-performance applications. These kinds of graphical analyses are quick ways to diagnose problems in engineering evaluations. This is also shown by the method employed in the study by Zhang et al. (2020), which used boxplots and scatter matrices to look at trends in soil compaction in urban subgrades.

When you look at these results from a practical point of view, the meaning is clear: Group 3 and Group 1 soils are the ideal for building roads since they have high and stable dry densities and don't need much water. Their performance makes the pavement stable for a long time, requires less care, and is less likely to fail because of moisture. To fulfil road building standards, Group 2 soils with high

OMC and low MDD would need to be stabilised by adding lime, cement, or fly ash. This is something that Osinubi and Amadi (2017) also suggested in their work on improving lateritic soil.

CONCLUSION

This study looked at the specific gravity and compaction properties of soils from three main groups and a control group. The evaluation looked at three main factors: specific gravity, Maximum Dry Density (MDD), and Optimum Moisture Content (OMC). We learnt a lot about how the soil samples behaved in engineering terms and what that means for building roads by comparing them in groups, using boxplots to visualise the data, and doing statistical analysis. The results showed that Group 3 soils, which had a high and uniform specific gravity of 2.61, were good at compacting because they consistently had high MDD values (an average of 2.03 g/cm³) and low OMC (10.25%). These traits suggest that the soil is made up of tightly packed, well-graded grains, which is great for building roads because it can support heavy loads and doesn't hold moisture as well. Group 1 also did well, getting the greatest average MDD (2.04 g/cm³) at a steady and low OMC (10.0%), even though their specific gravity was a little lower. This means that things other than mineral density, such as particle size and soil texture, are very important for how well compaction works.

On the other hand, Group 2 had the worst compaction performance, with the lowest MDD (1.94 g/cm³) and the greatest OMC (11.97%), even though it had a reasonably high specific gravity. This opposite behaviour shows that there are fine particles or materials with stronger plasticity that need more moisture to compact but make the dry densities lower. These kinds of soils might be good for stabilisation, but they are not the best choice for use as base material right away.

The control samples did okay, but their specific gravity and compaction data varied, which made us worry about how consistent and reliable they would be for structural use without further classification or treatment. There were weak and statistically insignificant links between specific gravity and the compaction parameters when we looked at them together. This shows that specific gravity should not be seen as a separate predictor, but rather in the context of other geotechnical parameters.

In conclusion, the study shows that Group 3 and Group 1 soils are the ideal for road base applications because they have a high dry density, good moisture needs, and are consistent. These results show how important it is to do a full geotechnical investigation before choosing soil for road building. For a better prediction of how different types of soil would compact, future studies should look into combining mineralogical and plasticity analyses.

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