ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

# Evaluation of Sewage Effluent Effects on Subgrade Soil Performance: Case Study of St. Luke's Hospital, Anua, Uyo

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Publication Date: 2026/06/09

**Abstract: This study investigated the effect of sewage effluent on the geotechnical characteristics of adjacent soil, using St. Luke's Hospital, Anua, Uyo, Akwa Ibom State, Nigeria, as a case study. A comparative experimental approach was adopted in which effluent-affected soil samples collected at 1 m from a functional soakaway pit were analyzed against control samples obtained 50 m away. Laboratory investigations included particle size distribution, Atterberg limits, natural and air-dried moisture content, specific gravity, Standard Proctor compaction test, and California Bearing Ratio (CBR) test. Results revealed a 42.05% relative increase in fine particles in the effluent-affected soil, indicating possible particle migration and biological clogging. The liquid limit and plastic limit decreased by 12.12% and 13.15%, respectively, while the plasticity index reduced by 1.2%, suggesting alteration in soil consistency due to effluent interaction. Compaction characteristics showed a 1.61% increase in maximum dry density and an 8.33% decrease in optimum moisture content in the effluent soil. However, despite improved compaction density, the unsoaked CBR value decreased by 3.4%, indicating reduced load-bearing capacity. Specific gravity also reduced by 0.75%, suggesting the presence of organic infiltration. The findings demonstrated that prolonged sewage effluent exposure modified soil gradation and consistency characteristics and, more critically, reduced subgrade strength. The study concluded that soils surrounding sewage disposal systems may experience structural weakening despite apparent improvements in compaction parameters. It is therefore recommended that engineering construction near effluent discharge zones incorporate soil replacement, stabilization, or improved wastewater management practices to mitigate potential foundation and pavement failures.**

***Keywords:*** *Sewage Effluent, Soil Contamination, Compaction Characteristics, California Bearing Ratio, Geotechnical Properties, Subgrade Strength.*

**How to Cite:** Udechukwu John A.; Udeme Hanson Iron; Ndifreke Edem Udoh. (2026) Evaluation of Sewage Effluent Effects on Subgrade Soil Performance: Case Study of St. Luke's Hospital, Anua, Uyo. *International Journal of Innovative Science and Research Technology*, 11(5), 3737-3753. https://doi.org/10.38124/ijisrt/26may2106

## I. INTRODUCTION

Rapid urbanization and increased commercial activities have led to a significant rise in wastewater generation worldwide. Commercial buildings such as hospitals, hotels, markets, and office complexes generate large volumes of sewage effluent, which is often treated using onsite disposal systems such as septic tanks and soakaway pits. In many developing countries, including Nigeria, onsite sewage disposal systems remain the most common method of wastewater management due to limited centralized sewer infrastructure (World Health Organization, 2017; United Nations Environment Programme, 2016).

Sewage effluent typically contains dissolved organic matter, nutrients (nitrogen and phosphorus), suspended solids, pathogens, and various chemical constituents. When discharged into surrounding soils through infiltration systems, these constituents may alter the physicochemical and engineering properties of the soil (United States Environmental Protection Agency, 2002). Continuous percolation of effluent into the subsurface environment can influence soil structure, grain distribution, plasticity characteristics, moisture regime, density, and strength parameters.

From a geotechnical engineering perspective, soil properties such as moisture content, consistency limits, compaction characteristics, specific gravity, and bearing

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

capacity are fundamental determinants of foundation stability and pavement performance.. Any alteration in these properties due to sewage effluent contamination may compromise structural integrity, especially for buildings and pavements located near effluent discharge points.

Previous studies have shown that wastewater infiltration can reduce soil strength and bearing capacity due to increased pore water pressure and changes in soil fabric (Chittaranjan et al., 2021). Conversely, some controlled additions of treated sludge to clayey soils have been reported to improve compaction properties under specific conditions (Kavya & Arya, 2022). These findings suggest that the impact of sewage effluent on soil behavior is complex and may depend on soil type, effluent composition, and duration of exposure.

In Akwa Ibom State, particularly in Uyo metropolis, many commercial facilities rely on soakaway systems for sewage disposal. However, limited documented research exists on how prolonged exposure to sewage effluent affects the geotechnical performance of surrounding soils. This study therefore investigated the effect of sewage effluent from a commercial building (St. Luke's Hospital, Anua, Uyo) on the engineering properties of adjacent soil.

➢ *Statement of the Problem*

Sewage effluent discharged through soakaway pits infiltrates surrounding soil continuously over time. While such systems are designed primarily for wastewater disposal, little attention is often paid to their long-term geotechnical implications.

Field observations around commercial sewage discharge areas in Uyo suggest localized soil weakening, differential settlement, and surface instability. Changes in soil texture, moisture retention, and fine particle distribution may contribute to reduced bearing capacity and increased susceptibility to weathering.

Despite these concerns, there is insufficient empirical data quantifying the extent to which sewage effluent alters soil strength parameters such as Maximum Dry Density (MDD), Optimum Moisture Content (OMC), Plasticity Index (PI), Specific Gravity (Gs), and California Bearing Ratio (CBR). Without such data, engineering decisions regarding foundations and pavements near effluent disposal systems may lack adequate technical basis.This research therefore addresses the gap by experimentally comparing effluent-affected soil with uncontaminated control soil.

The main Aim of the research work was to evaluate the effect of sewage effluent from a commercial building on the geotechnical properties of surrounding soil.

➢ *The Specific Objectives were to:*

- Determine the natural and air-dried moisture contents of effluent-affected and control soil samples.
- Analyze particle size distribution of both samples.
- Determine the Atterberg limits (Liquid Limit, Plastic Limit, and Plasticity Index).
- Evaluate compaction characteristics (MDD and OMC).
- Determine the specific gravity of soil solids.
- Assess subgrade strength using the California Bearing Ratio (CBR) test.
- Compare the results to quantify the influence of sewage effluent on soil engineering performance.

➢ *Significance of the Study*

This study is significant in several respects:

- It provides empirical data on the geotechnical implications of sewage effluent infiltration.
- It assists civil and geotechnical engineers in making informed decisions regarding foundation design near sewage disposal systems.
- It contributes to environmental engineering knowledge concerning soil–wastewater interaction.
- It offers practical recommendations for soil replacement or stabilization where effluent-induced weakening is observed.
- The findings may also guide policymakers in improving wastewater disposal standards in rapidly urbanizing areas.

➢ *Scope of the Study*

The study is limited to:

- Soil surrounding a Hospital sewage disposal system (St. Luke's Hospital, Anua, Uyo).
- Laboratory determination of selected geotechnical properties.
- Comparison between effluent-affected soil (1 m from soakaway) and control soil (50 m away).
- Chemical analysis of effluent composition and long-term consolidation behavior were outside the scope of this study.

## II. METHODOLOGY

➢ *Study Area*

The study was carried out at St. Luke's Hospital, Anua, Uyo, Akwa Ibom State, Nigeria. The investigation focused on soil surrounding a functional on-site sewage treatment system (soakaway pit) serving commercial hospital facilities. The area lies within the coastal plain sands of the Niger Delta region, characterized predominantly by sandy soils with varying fines content.

➢ *Research Design*

An experimental laboratory-based comparative study design was adopted. Two categories of soil samples were investigated:

- Effluent-affected sample (ES): Collected at a radial distance of 1 m from the soakaway pit.
- Control sample (CS): Collected at a distance of 50 m away from the soakaway pit, assumed to be free from effluent influence.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

The comparative approach enabled evaluation of the influence of sewage effluent on selected geotechnical properties by using the control sample as baseline reference.

➢ *Sample Collection and Preparation*

Disturbed soil samplmanually using a hand auger at a depth of 0.5–1.0 m below ground level to minimize surface contamination effects. The samples were properly labeled, sealed in airtight polyethylene bags, and transported to the geotechnical laboratory for analysis.

In the laboratory

- Samples were air-dried at room temperature.
- Large clods were gently pulverized without crushing natural grains.
- Soil was sieved through a 4.75 mm sieve prior to testing, in accordance with standard soil preparation procedures (ASTM International, 2017; British Standards Institution, 1990).

➢ *Laboratory Tests Conducted*

All laboratory tests were performed in accordance with standard procedures specified by ASTM and BS codes.

➢ *Natural and Air-Dried Moisture Content*

Moisture content was determined using the oven-drying method in accordance with ASTM D2216 (ASTM, 2017).

The moisture content (w) was computed using eqn 1

$$W = \frac{(Ww - Wd)}{Wd} * 100 \qquad 1$$

Where:

- $W_w$ = Weight of wet soil
- $W_d$ = Weight of dry soil

This test was conducted for both natural and air-dried conditions to determine variation in water retention characteristics due to effluent influence.

➢ *Particle Size Distribution (Sieve Analysis)*

Grain size analysis was performed in accordance with ASTM D6913 (ASTM, 2017). A stack of standard sieves was arranged in decreasing aperture size and mechanically shaken for 10 minutes.

The percentage passing and retained were computed and plotted on semi-logarithmic graph sheets to obtain the grain size distribution curves for both samples.

This test helped determine:

- Relative proportions of coarse and fine fractions.
- Influence of effluent on soil gradation characteristics.

➢ *Atterberg Limits (Consistency Tests)*

The liquid limit (LL) and plastic limit (PL) were determined in accordance with ASTM D4318 (ASTM, 2017).

- *Liquid Limit (LL)*

Determined using the Casagrande apparatus at 25 blows.

- *Plastic Limit (PL)*

Determined by rolling soil threads to 3 mm diameter until crumbling.

The Plasticity Index (PI) was calculated with eqn 2

$$PI = LL - PL \qquad 2$$

These parameters were used to evaluate changes in soil consistency, workability, and plastic behavior resulting from sewage effluent exposure.

➢ *Specific Gravity Test*

Specific gravity (Gs) was determined using the density bottle method in accordance with ASTM D854 (ASTM, 2017) and calculated using eqn 3

$$Gs = \frac{W1 - W2}{(W4 - W1) - (W3 - W2)} \qquad 3$$

Where

- $W_1$ = Mass of the empty pycnometer/density bottle
- $W_2$ = Mass of the pycnometer + dry soil
- $W_3$ = Mass of the pycnometer + dry soil + water
- $W_4$ = Mass of the pycnometer filled completely with water only

This test is primarily used as a critical baseline value in geotechnical engineering to calculate essential weight-volume (phase) relationships as well as to calculate other essential soil parameters, such as void ratio, porosity, and degree of saturation.

➢ *Compaction Test*

Standard Proctor compaction test was conducted in accordance with ASTM D698 (ASTM, 2017).

The relationship between moisture content and dry density was established, and:

- Maximum Dry Density (MDD)
- Optimum Moisture Content (OMC)

Were obtained from the compaction curve.

The dry density was calculated with eqn 4

$$\gamma_d = \frac{\gamma}{1 + w} \qquad 4$$

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

Where:

- $\gamma_d$ = Dry density
- $\gamma$ = Bulk density
- $w$ = Moisture content

This test was essential in evaluating other crucial soil properties soil, such as void ratio, degree of saturation, and unit weight for foundation design as well as the extent to which the soil is affected

➢ *California Bearing Ratio (CBR) Test*

The CBR test (unsoaked condition) was conducted in accordance with ASTM D1883 (ASTM, 2017).

The CBR value was calculated with eqn 5

$$CBR = \frac{\text{Measured load}}{\text{Standard load}} \times 100 \quad (5)$$

The test evaluated subgrade strength characteristics and suitability for pavement applications in effluent-affected areas.

➢ *Data Analysis*

Results obtained from laboratory tests were:

- Tabulated and compared between effluent and control samples.
- Expressed as percentage increase or decrease relative to the control sample.
- Interpreted using established geotechnical principles

Descriptive statistical comparison was used to quantify the magnitude of variation attributable to sewage effluent exposure.

➢ *Validity and Reliability*

All tests were conducted in duplicate to ensure repeatability. Moreover, standardized testing procedures were strictly followed. Calibrated laboratory equipment was used throughout the investigation.

## III. RESULTS AND DISCUSSION

➢ *Particle Size Distribution (Gradation Test)*

The sieve analysis results revealed that the effluent-affected soil retained more fine particles than the control sample. Specifically, the weight of fines retained in the pan showed a 42.05% relative increase in the effluent soil compared to the control soil. Grain size distribution significantly influences permeability, compaction behavior, and strength characteristics of soils. An increase in fines content typically results in:

Reduced permeability, higher water retention and Greater susceptibility to volume change.

The higher fines content around the effluent source suggests that prolonged sewage infiltration may cause:

- Migration and deposition of fine particles.
- Biological clogging of soil pores due to organic matter. and
- Breakdown of soil aggregates under chemical interaction.

According to United States Environmental Protection Agency (2002), wastewater infiltration systems often lead to biomat formation and clogging at the soil interface, which alters natural soil gradation.

In contrast, the control sample showed a steeper medium-to-coarse grain curve, indicating better grading and improved drainage characteristics. Well-graded sandy soils generally provide better load distribution and foundation support (Soil Mechanics in Engineering Practice).

➢ *Engineering Implication*

Increased fines near the effluent discharge area may reduce drainage efficiency and increase long-term settlement risk.

➢ *Consistency Limits (Atterberg Limits)*

Consistency limits (Atterberg limits) are critical moisture thresholds that define how fine-grained soils behave as their water content changes. Depending on water content, soil exists in four states: solid, semi-solid, plastic, and liquid. The limits mark the transitions between these states and are fundamental in geotechnical engineering.

Table 1 Atterberg Limit Result

| Parameter | Effluent Soil | Control Soil |
|---|---|---|
| Plastic Limit (PL) | 18.5% | 21.3% |
| Liquid Limit (LL) | 29.0% | 33.0% |
| Plasticity Index (PI) | 10.5% | 11.7% |

The effluent soil recorded:

- 12.12% lower Liquid Limit
- 13.15% lower Plastic Limit
- Plasticity Index reduced by 1.2%

Atterberg limits reflect the water affinity and plastic behavior of fine-grained soils (Das, 2010). A reduction in LL and PL suggests: decreased clay activity, possible alteration of soil mineral structure and reduced cohesive behavior.

Sewage effluent contains organic matter and dissolved salts that can modify the electrochemical interactions between clay particles. Such interactions may reduce double-layer thickness and alter plasticity behavior.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

Research by Kavya and Arya (2022) reported that sewage sludge addition can either increase or decrease plasticity depending on soil type and sludge concentration. Similarly, Chittaranjan et al. (2021) observed that chemical interaction from sludge modifies consistency characteristics of expansive soils.

In this study, the reduced plasticity index indicates slightly lower compressibility but also potentially reduced cohesion. The Engineering implication is that reduced plasticity may lower swelling potential but can also decrease shear strength if cohesion is affected.

➢ *Compaction Characteristics (MDD and OMC)*

The MDD and OMC Characteristics are Presented in Table 2

Table 2 Compaction Test Result

| Parameter | Effluent Soil | Control Soil |
|---|---|---|
| MDD (kg/m³) | 1986 | 1954 |
| OMC (%) | 11 | 12 |

The effluent soil showed 1.61% increase in Maximum Dry Density (MDD) and 8.33% decrease in Optimum Moisture Content (OMC) compared to those of the control as indicated in Table 3 The compaction behavior is influenced by particle arrangement and moisture availability.

The increase in MDD suggests better particle packing, Possible lubrication effect of effluent residues during compaction and increased fine particle filling of voids.

The reduction in OMC implies that less water is required to achieve maximum density. This could result from pre-existing moisture and organic infiltration; and reduced clay-water interaction.

Mandlekar et al. (2020) reported similar findings where sewage sludge addition decreased OMC and increased MDD.

However, higher MDD does not necessarily imply higher strength. Strength depends on soil structure and bonding, not density alone (Terzaghi et al., 1996).

The Engineering implication is that even though compaction appears improved, it does not guarantee improved load-bearing capacity.

➢ *Moisture Content Analysis*

The moisture content results are presented in Table 3

Table 3 Moisture Content Result

| Sample | Effluent Soil | Control Soil |
|---|---|---|
| Avereage Natural Moisture Content (%) | 12.65 | 14.60 |
| Average air dried moisture content (%) | 0.57 | 1.59 |

The effluent soil recorded a 1.95% lower natural moisture content and a 1.02% lower air-dried moisture content as seen in Table 3 and Appendix 4. This result may initially appear counterintuitive because effluent exposure is often associated with higher moisture retention. However, possible explanations include:

- Enhanced drainage through coarse particle rearrangement
- Evaporation effects due to exposure
- Altered capillary behavior from organic deposition

Soil moisture equilibrium depends on both particle size distribution and pore structure.

The reduced moisture content aligns with the observed lower OMC in compaction tests. Lower natural moisture does not necessarily mean improved performance; it must be interpreted alongside strength parameters.

➢ *Specific Gravity*

The specific gravity of the effluent soil was 0.75% lower than that of the control soil as presented in Appendix 5. Specific gravity reflects the mineral composition of soil solids (Das, 2010). The slight reduction suggests the presence of organic matter and partial replacement of mineral particles with lighter organic components.

Organic contamination generally lowers specific gravity because organic particles are less dense than mineral grains.

The Engineering implication is that Slight reduction in specific gravity may indicate organic infiltration, which can negatively affect long-term durability and strength.

➢ *California Bearing Ratio (CBR)*

As presented in Appendix 6 (Tables 1 and 2), the unsoaked CBR test showed a 3.4% decrease in CBR value for effluent soil. Since CBR is a direct indicator of subgrade strength for pavement design (Terzaghi et al., 1996), a reduction in CBR confirms loss of shear resistance, reduced load-bearing capacity and potential weakening due to organic infiltration.

According to the United States Environmental Protection Agency (2002), prolonged wastewater infiltration can weaken soil strength due to structural alteration and microbial activity.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

Even though MDD increased slightly, the reduced CBR demonstrated that density improvement did not translate to strength improvement.Engineering wise, effluent-affected soil is less suitable as subgrade material without stabilization or replacement.

Table 4 Summary of Comparison Among the Different Geotechnical Properties

| Property | Effect of Effluent Against Control Soil Samples | Engineering Significance |
|---|---|---|
| Fines Content | Increased | Reduced permeability, potential clogging |
| Plasticity | Slightly reduced | Altered consistency behavior |
| MDD | Increased | Better compaction packing |
| OMC | Decreased | Less water required for compaction |
| Specific Gravity | Slightly reduced | Organic contamination presence |
| CBR | Decreased | Reduced bearing capacity |

Although the effluent soil exhibited slightly higher compaction density, the reduction in CBR and specific gravity indicates overall weakening in structural performance. The increase in fines and organic presence likely contributed to strength reduction despite improved particle packing.

This aligns with classical soil behavior theory that strength depends not only on density but on the interparticle bonding, Soil structure, and Effective stress conditions as well

## IV. CONCLUSION AND RECOMMENDATIONS

➢ *Conclusion*

The study confirmed that prolonged sewage effluent infiltration alters soil engineering properties in measurable ways. There is increased proportion of fine particles in the effluent-affected soil. Increased fines content may reduce permeability and influence long-term settlement behavior.

There were reductions in both Liquid Limit and Plastic Limit, resulting in a slightly reduced Plasticity Index. These indicate alteration in soil consistency behavior, likely due to chemical and organic interactions between sewage constituents and soil particles. There is increase in Maximum Dry Density (MDD) and a decrease in Optimum Moisture Content (OMC) in the effluent-affected soil.

The California Bearing Ratio (CBR) decreased in the effluent-affected soil. Although sewage effluent infiltration may slightly improve compaction density, it ultimately reduces subgrade strength and modifies soil gradation and consistency. Soils located in close proximity to sewage effluent discharge systems are susceptible to structural weakening and may require engineering intervention before construction activities.

➢ *Recommendations*

Based on the findings of this study, the following recommendations are proposed

- For road construction or foundation works near sewage effluent discharge zones, the effluent-affected soil should be replaced with suitable subgrade and sub-base materials where CBR values fall below acceptable design limits.
- Where removal is not economically feasible, stabilization with lime, cement, or other chemical stabilizers should be adopted to improve strength and durability.
- Commercial facilities should adopt improved sewage treatment and disposal systems to reduce uncontrolled infiltration into surrounding soils.
- Routine monitoring of soil properties around soakaway pits and onsite treatment systems should be conducted, especially in areas supporting structural loads.
- Environmental and engineering regulatory agencies should develop and enforce guidelines specifying minimum safe distances between sewage disposal systems and structural foundations.
- Future studies should be carried out to investigate the:

✓ Conduct long-term consolidation and shear strength tests.
✓ Include chemical and microbiological analysis of effluent-affected soils.
✓ Investigate the effect of effluent on different soil types (clayey, lateritic, and silty soils).

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International Journal of Innovative Science and Research Technology
ISSN No: -2456-2165
https://doi.org/10.38124/ijisrt/26may2106

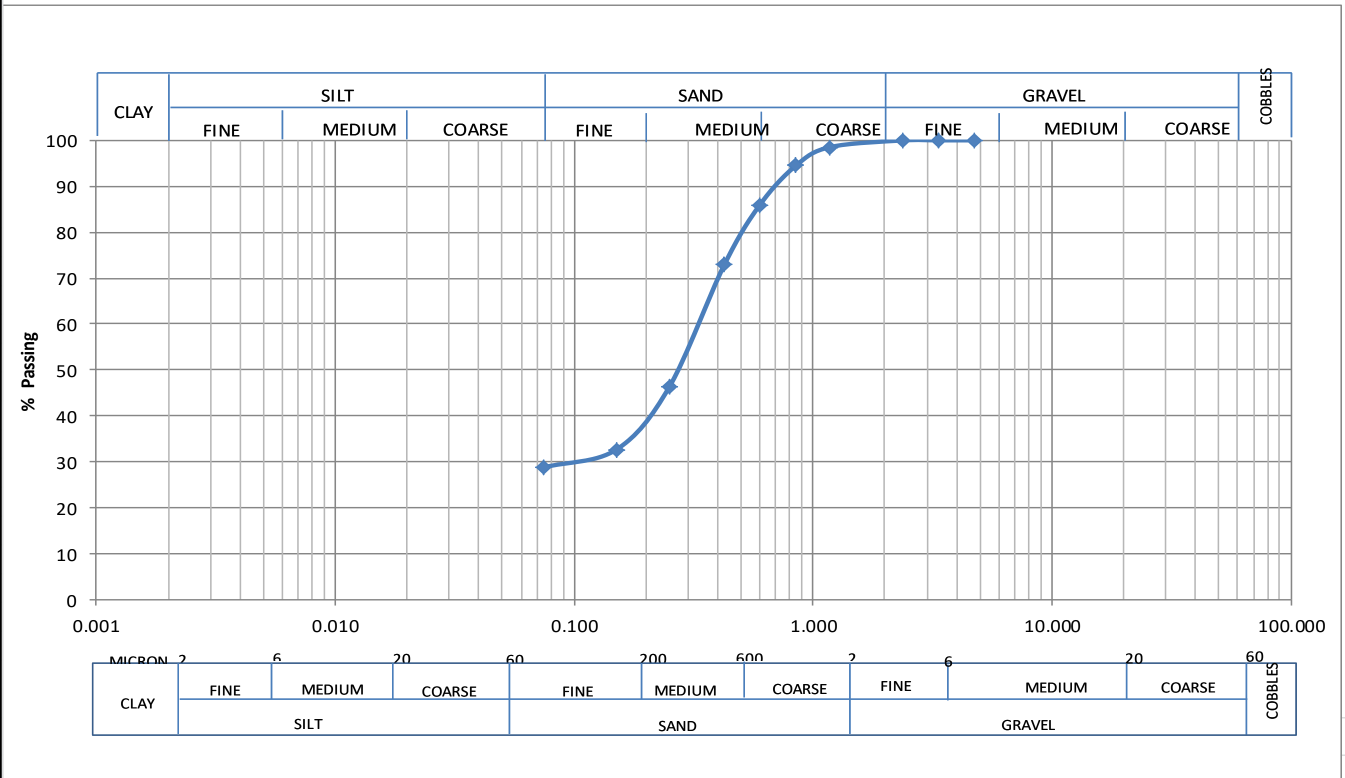
## APPENDIX

➢ *Appendix 1 Particle Size Distribution (Gradation) Test*

Table 5 Gradation Test Result on Effluent Soil

| | | | | |
|---|---|---|---|---|
| SAMPLE | EFFLUENT SOIL | | | |
| Wt. of Dry Sample. | 1000.0 | g | Date | 6/1/2023 |
| Wt. of washed sample. | 714.9 | g | Air-dry $M_c$ | 0.57% |
| Washed thro. Sieve 200:☐ | 285.1 | g | | |
| Absolute mass | 994.3 | g | Sample | |
| **Sieve Apperture (mm)** | **Weight Retained (g)** | **% Retained** | **Cum. % Retained** | **% Passing** |
| 4.750 | 0.00 | 0.00 | 0.00 | 100.00 |
| 3.350 | 0.00 | 0.00 | 0.00 | 100.00 |
| 2.360 | 0.30 | 0.03 | 0.03 | 99.97 |
| 1.180 | 14.30 | 1.44 | 1.47 | 98.53 |
| 0.850 | 39.70 | 3.99 | 5.46 | 94.54 |
| 0.600 | 85.10 | 8.56 | 14.02 | 85.98 |
| 0.425 | 130.50 | 13.12 | 27.14 | 72.86 |
| 0.250 | 264.70 | 26.62 | 53.76 | 46.24 |
| 0.150 | 135.20 | 13.60 | 67.36 | 32.64 |
| 0.075 | 37.90 | 3.81 | 71.17 | 28.83 |
| PAN | 8.80 | 0.89 | | |

**GRAIN SIZE DISTRIBUTION CURVE**

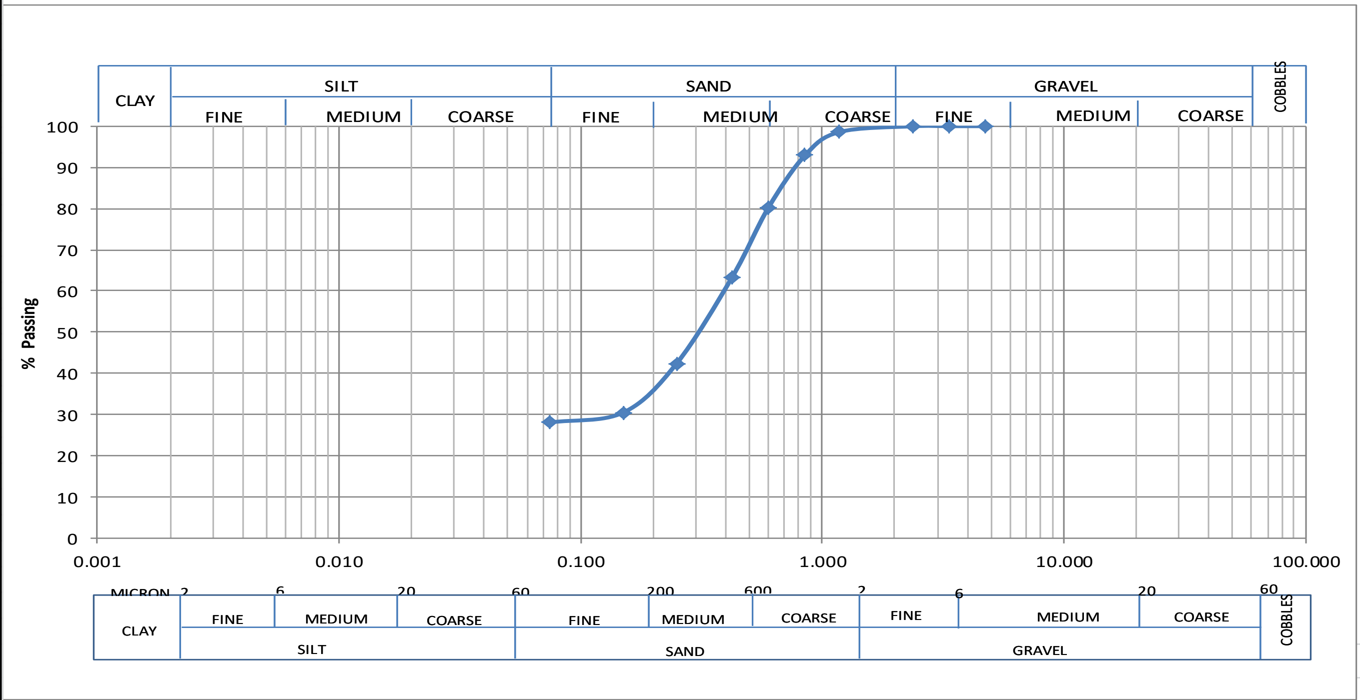


ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

Table 6 Gradation Test Result on Control

| | | | | |
|---|---|---|---|---|
| **SAMPLE** | **CONTROL** | | | |
| Wt. of Dry Sample. | 1000.0 g | | Date | 6/1/2023 |
| Wt. of washed sample. | 713.0 g | | Air-dry $M_c$ | 1.59% |
| Washed thro. Sieve 200:□ | 287.0 g | | | |
| Absolute mass | 984.3 g | | Sample | |
| **Sieve Apperture (mm)** | **Weight Retained (g)** | **% Retained** | **Cum. % Retained** | **% Passing** |
| 4.750 | 0.00 | 0.00 | 0.00 | 100.00 |
| 3.350 | 0.00 | 0.00 | 0.00 | 100.00 |
| 2.360 | 0.30 | 0.03 | 0.03 | 99.97 |
| 1.180 | 13.60 | 1.38 | 1.41 | 98.59 |
| 0.850 | 55.70 | 5.66 | 7.07 | 92.93 |
| 0.600 | 124.60 | 12.66 | 19.73 | 80.27 |
| 0.425 | 165.90 | 16.85 | 36.58 | 63.42 |
| 0.250 | 206.90 | 21.02 | 57.60 | 42.40 |
| 0.150 | 117.50 | 11.94 | 69.54 | 30.46 |
| 0.075 | 23.40 | 2.38 | 71.92 | 28.08 |
| PAN | 5.10 | 0.52 | | |

**GRAIN SIZE DISTRIBUTION CURVE**

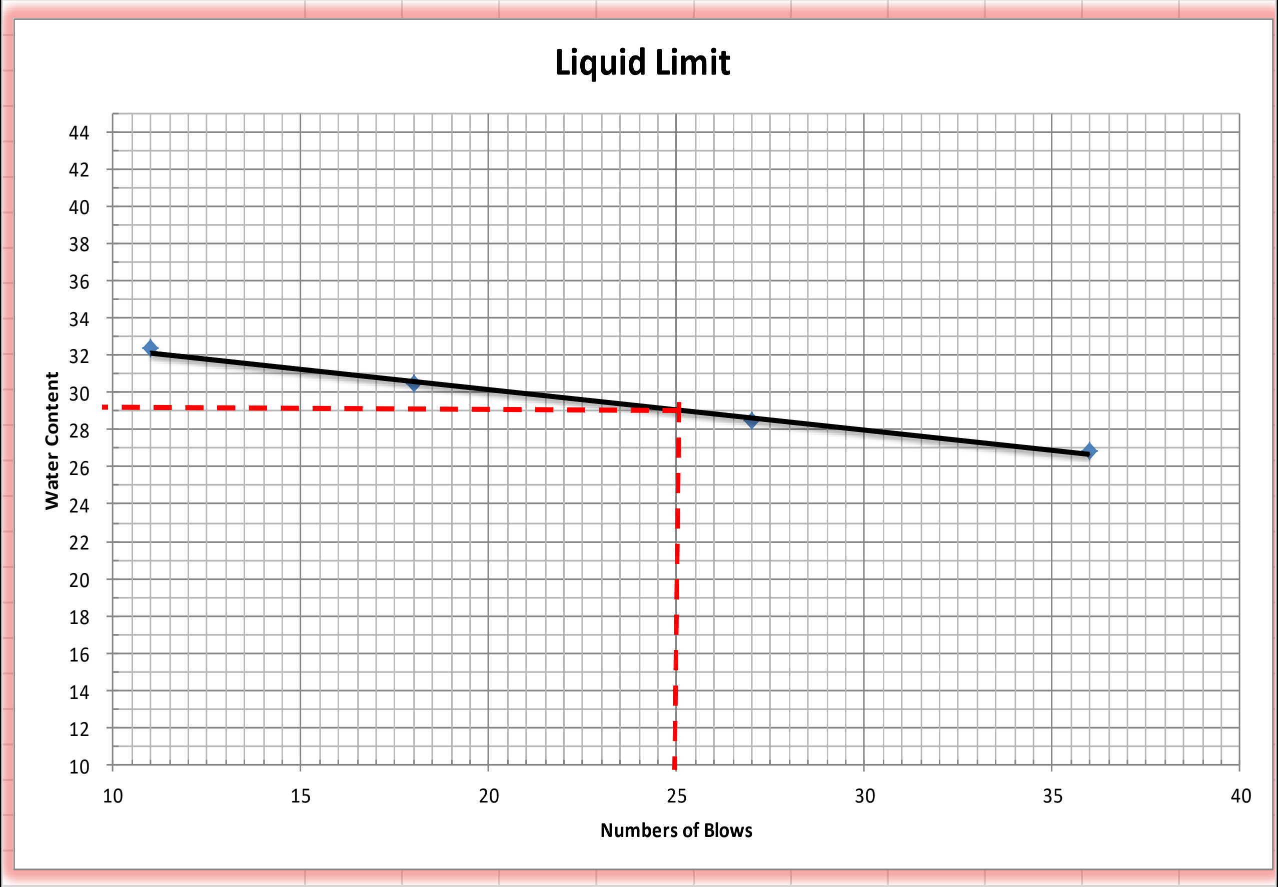


ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

➢ *Appendix 2 Consistency Test.*

Table 7 Consistency Test on Effluent Sample

| CONSISTENCY TEST | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| LOCATION | EFFLUENT SOIL | | | | | | | | | |
| Date of Test: | 6/1/2023 | | | | | | Sample : | | LATERITE | |
| | Liquid Limit | | | | | | | | Plastic Limit | |
| Number of blows | 11 | | 18 | | 27 | | 36 | | | |
| Container No. | AP | SCI | SPN | OPC | AQ | UP | WIT | NS | PTA | UU |
| Mass of Container, g | 17.30 | 18.10 | 18.40 | 21.40 | 21.20 | 17.50 | 18.10 | 22.20 | 17.90 | 21.20 |
| Mass of Wet Soil+Container, g | 26.00 | 27.80 | 33.10 | 28.60 | 36.40 | 26.60 | 27.90 | 40.40 | 26.10 | 32.30 |
| Mass of Dry Soil+Container, g | 23.90 | 25.40 | 29.70 | 26.90 | 33.00 | 24.60 | 25.80 | 36.60 | 24.80 | 30.60 |
| Mass of Moisture, g | 2.10 | 2.40 | 3.40 | 1.70 | 3.40 | 2.00 | 2.10 | 3.80 | 1.30 | 1.70 |
| Mass of Dry Soil, g | 6.60 | 7.30 | 11.30 | 5.50 | 11.80 | 7.10 | 7.70 | 14.40 | 6.90 | 9.40 |
| Moisture Content (%) | 31.82 | 32.88 | 30.09 | 30.91 | 28.81 | 28.17 | 27.27 | 26.39 | 18.84 | 18.09 |
| Av. Moisture Content (%) | 32.35 | | 30.50 | | 28.49 | | 26.83 | | 18.46 | |

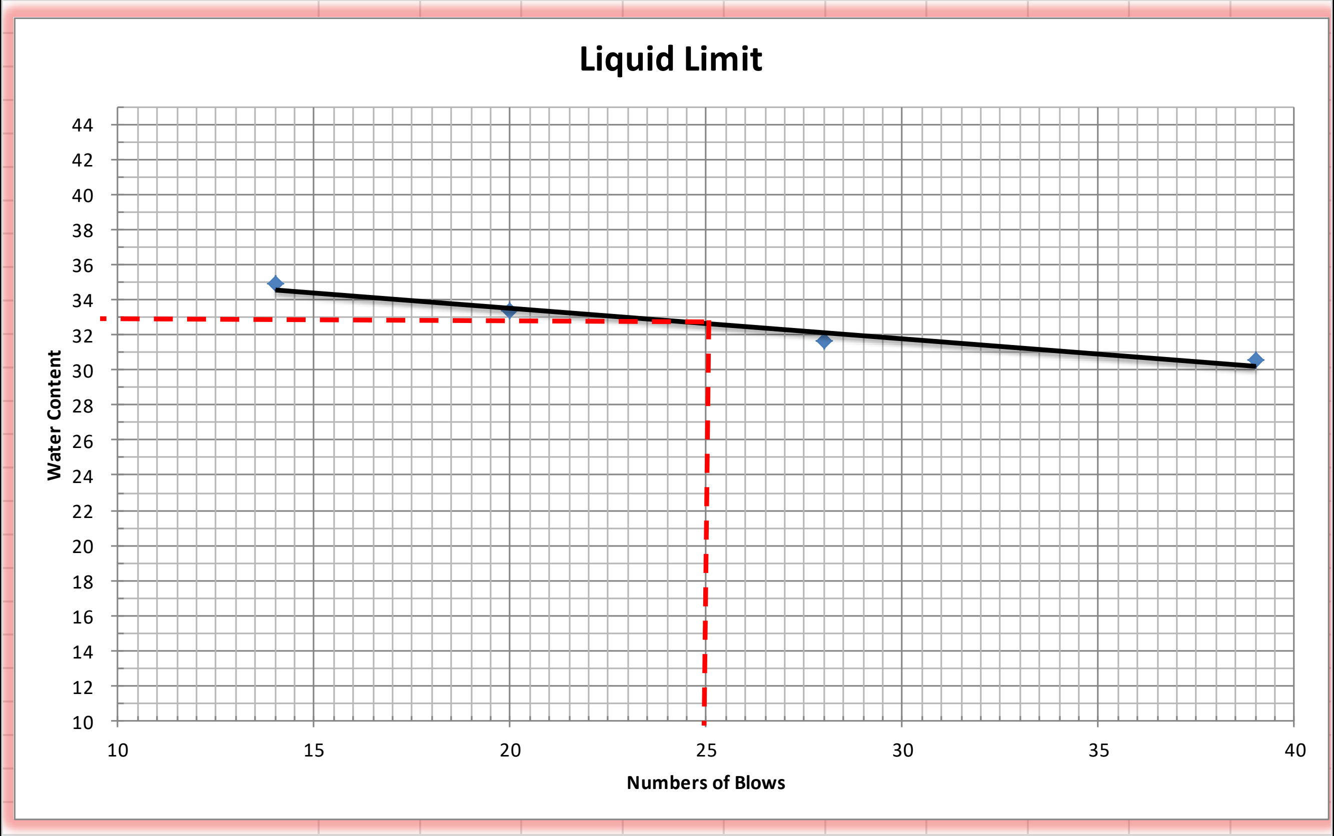



| | | | | |
|---|---|---|---|---|
| **Plastic Limit** | 18.5 % | | | |
| **Liquid Limit** | 29.0 % | **Plastic Index** | 10.5 % | |

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

Table 8 Consistency Test on Control Sample

| CONSISTENCY TEST | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| LOCATION | CONTROL | | | | | | | | | |
| Date of Test: | 6/1/2023 | | | | | | Sample : | | LATERITE | |
| | Liquid Limit | | | | | | | | Plastic Limit | |
| Number of blows | 14 | | 20 | | 28 | | 39 | | | |
| Container No. | DVD | CTO | ST | FO | RV | CV2 | TOI | ATA | TM | UU |
| Mass of Container, g | 21.70 | 17.30 | 17.30 | 21.40 | 17.50 | 18.00 | 21.40 | 21.40 | 20.90 | 17.80 |
| Mass of Wet Soil+Container, g | 37.60 | 25.40 | 28.40 | 37.90 | 33.70 | 30.50 | 36.80 | 32.50 | 34.50 | 30.40 |
| Mass of Dry Soil+Container, g | 33.50 | 23.30 | 25.60 | 33.80 | 29.80 | 27.50 | 33.20 | 29.90 | 32.10 | 28.20 |
| Mass of Moisture, g | 4.10 | 2.10 | 2.80 | 4.10 | 3.90 | 3.00 | 3.60 | 2.60 | 2.40 | 2.20 |
| Mass of Dry Soil, g | 11.80 | 6.00 | 8.30 | 12.40 | 12.30 | 9.50 | 11.80 | 8.50 | 11.20 | 10.40 |
| Moisture Content (%) | 34.75 | 35.00 | 33.73 | 33.06 | 31.71 | 31.58 | 30.51 | 30.59 | 21.43 | 21.15 |
| Av. Moisture Content (%) | 34.87 | | 33.40 | | 31.64 | | 30.55 | | 21.29 | |



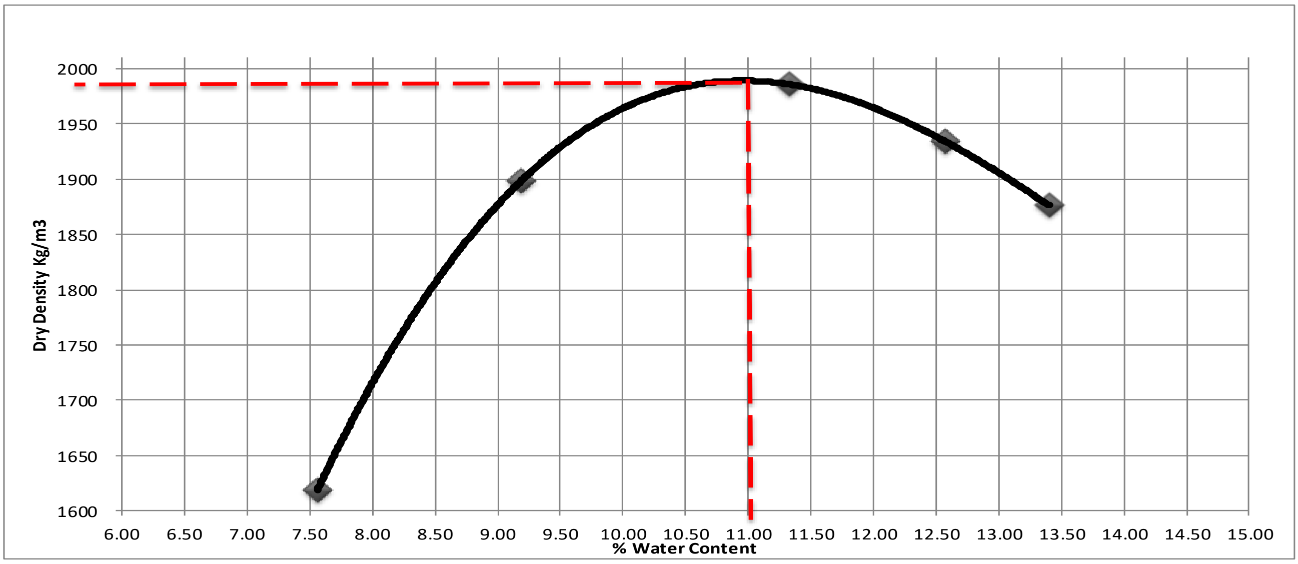

| | | | | |
|---|---|---|---|---|
| **Plastic Limit** | 21.3 % | | | |
| **Liquid Limit** | 33.0 % | **Plastic Index** | 11.7 % | |

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

➢ *Appendix 3 Compaction Test Report*

Table 9 Compaction Test Result on Effluent Sample

| COMPACTION TEST REPORT | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| LOCATION | | | | | | | | | | |
| | | | | | | | Rammer used | | 4.5Kg | |
| Sample | EFFLUENT SOIL | | | | | | Number of Layers: | | 5 | |
| Compaction Standard | WASC | | | | | | Blows Per Layer: | | 27 | |
| Date of Test: | 6/1/2023 | | | | | | | | | |
| | MOISTURE DETERMINATION | | | | | | | | | |
| Trail No. | 8% | | 10% | | 12% | | 14% | | 16% | |
| Tin No. | AQ | IT | DJ | E2B | AB | PUT | PTY | AIC | OP | SE |
| Weight of Tin | 18.30 | 21.70 | 21.90 | 18.00 | 21.60 | 18.20 | 17.60 | 17.50 | 21.50 | 21.50 |
| Tin + Wet Sample | 36.50 | 40.50 | 41.00 | 38.10 | 48.60 | 35.60 | 32.00 | 37.10 | 39.50 | 56.60 |
| Tin + Dry Sample | 35.20 | 39.20 | 39.40 | 36.40 | 45.90 | 33.80 | 30.40 | 34.90 | 37.40 | 52.40 |
| Water Content | 1.30 | 1.30 | 1.60 | 1.70 | 2.70 | 1.80 | 1.60 | 2.20 | 2.10 | 4.20 |
| Weight of Dry Sample | 16.90 | 17.50 | 17.50 | 18.40 | 24.30 | 15.60 | 12.80 | 17.40 | 15.90 | 30.90 |
| % of WC | 7.69 | 7.43 | 9.14 | 9.24 | 11.11 | 11.54 | 12.50 | 12.64 | 13.21 | 13.59 |
| Av. WC | 7.56 | | 9.19 | | 11.32 | | 12.57 | | 13.40 | |
| | DENSITY DETERMINATION | | | | | | | | | |
| Wt of Mould,Kg | 2.946 | | 2.946 | | 2.946 | | 2.946 | | 2.946 | |
| Wt of Mould + Sample,Kg | 6.596 | | 7.292 | | 7.580 | | 7.510 | | 7.406 | |
| Wt of Wet Sample,Kg | 3.650 | | 4.346 | | 4.634 | | 4.564 | | 4.460 | |
| Volume of Cylinder, V($m^3$) | 0.002096 | | 0.002096 | | 0.002096 | | 0.002096 | | 0.002096 | |
| Wet Density of Sample, Kg/$m^3$ | 1741 | | 2073 | | 2211 | | 2177 | | 2128 | |
| Dry Density of Sample, Kg/$m^3$ | 1619 | | 1899 | | 1986 | | 1934 | | 1876 | |




| M.D.D.: | 1986.00 | Kg/$m^3$ | O.M.C.: | 11.00 | % |
|---|---|---|---|---|---|

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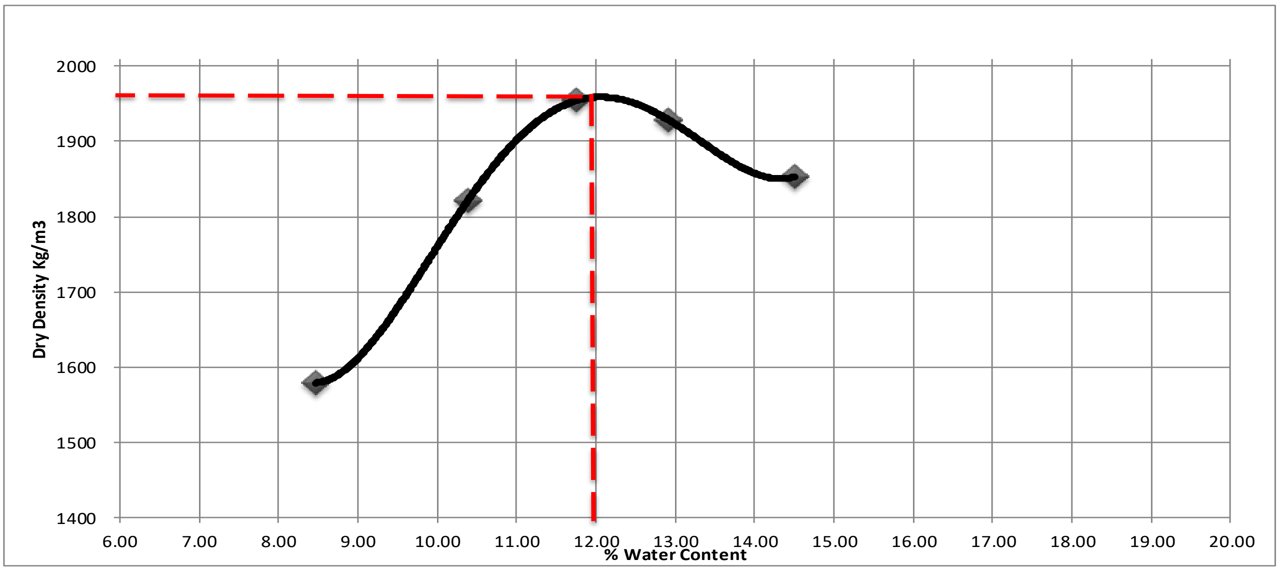
Table 10 Compaction Test Result on Control Sample

| COMPACTION TEST REPORT | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LOCATION | | | | | | | | | | | |
| | | | | | | | | Rammer used | | 4.5Kg | |
| Sample | | CONTROL | | | | | | Number of Layers: | | 5 | |
| Compaction Standard | | WASC | | | | | | Blows Per Layer: | | 27 | |
| Date of Test: | | 6/1/2023 | | | | | | | | | |
| | | | | MOISTURE DETERMINATION | | | | | | | |
| Trail No. | | | | 8% | | 10% | | 12% | | 14% | | 16% |
| Tin No. | | | | UD | POP | NY | E3C | UTD | 1A | KIC | USA | CWO | TB |
| Weight of Tin | | | | 20.80 | 18.20 | 20.10 | 17.20 | 20.30 | 21.60 | 17.20 | 21.80 | 20.20 | 21.10 |
| Tin + Wet Sample | | | | 34.00 | 31.90 | 38.50 | 28.70 | 35.70 | 43.20 | 34.80 | 38.30 | 52.00 | 46.00 |
| Tin + Dry Sample | | | | 33.00 | 30.80 | 36.80 | 27.60 | 34.10 | 40.90 | 32.80 | 36.40 | 47.90 | 42.90 |
| Water Content | | | | 1.00 | 1.10 | 1.70 | 1.10 | 1.60 | 2.30 | 2.00 | 1.90 | 4.10 | 3.10 |
| Weight of Dry Sample | | | | 12.20 | 12.60 | 16.70 | 10.40 | 13.80 | 19.30 | 15.60 | 14.60 | 27.70 | 21.80 |
| % of WC | | | | 8.20 | 8.73 | 10.18 | 10.58 | 11.59 | 11.92 | 12.82 | 13.01 | 14.80 | 14.22 |
| Av. WC | | | | 8.46 | | 10.38 | | 11.76 | | 12.92 | | 14.51 | |

| | DENSITY DETERMINATION | | | | |
|---|---|---|---|---|---|
| Wt of Mould,Kg | 2.946 | 2.946 | 2.946 | 2.946 | 2.946 |
| Wt of Mould + Sample,Kg | 6.536 | 7.158 | 7.524 | 7.510 | 7.394 |
| Wt of Wet Sample,Kg | 3.590 | 4.212 | 4.578 | 4.564 | 4.448 |
| Volume of Cylinder, V($m^3$) | 0.002096 | 0.002096 | 0.002096 | 0.002096 | 0.002096 |
| Wet Density of Sample, Kg/$m^3$ | 1713 | 2009 | 2184 | 2177 | 2122 |
| Dry Density of Sample, Kg/$m^3$ | 1579 | 1820 | 1954 | 1928 | 1853 |




| M.D.D.: | 1954.00 | Kg/$m^3$ | O.M.C.: | 12.00 | % |
|---|---|---|---|---|---|

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

➢ *Appendix 4 Moisture Content Report.*

Table 11 Natural Moisture Content.

| Date: 03- 01- 2023 | | NATURAL MOISTURE CONTENT | | | |
|---|---|---|---|---|---|
| SAMPLE | LATERITE | | | | |
| LOCATION | | CONTROL | | EFFLUENT | |
| Tin No. | | BOB | ATA | BOB | UC1 |
| Wt of Tin (g) | M1 | 17.6 | 21.5 | 17.9 | 18 |
| Weight of wet soil + tin (g) | M2 | 43.8 | 47.1 | 49.9 | 40.3 |
| Wt of dry soil + Tin (g) | M3 | 40.5 | 43.8 | 46.3 | 37.8 |
| Wt of moisture (g) | M4 = M2 -M3 | 3.3 | 3.3 | 3.6 | 2.5 |
| Wt of dried soil (g) | M5 = M3 - M1 | 22.9 | 22.3 | 28.4 | 19.8 |
| Moisture content (%) | (M4*100)/M5 | 14.4 | 14.8 | 12.68 | 12.63 |
| Average moisture content (%) | | 14.60 | | 12.65 | |
| Date: 06- 01- 2023 | | AIR -DRIED MOISTURE CONTENT | | | |
| SAMPLE | LATERITE | | | | |
| LOCATION | | CONTROL | | EFFLUENT | |
| Tin No. | | CTO | AP | UU | WIT |
| Wt of Tin (g) | M1 | 17.0 | 17.3 | 21.1 | 18.2 |
| Weight of wet soil + tin (g) | M2 | 37.5 | 35.2 | 39.6 | 34.8 |
| Wt of dry soil + Tin (g) | M3 | 37.2 | 34.9 | 39.5 | 34.7 |
| Wt of moisture (g) | M4 = M2 -M3 | 0.3 | 0.3 | 0.1 | 0.1 |
| Wt of dried soil (g) | M5 = M3 - M1 | 20.2 | 17.6 | 18.4 | 16.5 |
| Moisture content (%) | (M4*100)/M5 | 1.5 | 1.7 | 0.54 | 0.61 |
| Average moisture content (%) | | 1.59 | | 0.57 | |

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

- *Appendix 5 Specific Gravity Report.*

Table 12 Specific Gravity.

| | Specific Gravity (Ref: BS 1377: Part 2 : 1990) | | | |
|---|---|---|---|---|
| Date: 2023-01-06 | CONTROL | | | |
| Density bottle | | | 100ml | 50ml |
| Mass of Densitty Bottle | $m_1$ | g | 31.10 | 24.20 |
| Mass of Bottle + Soil | $m_2$ | g | 62.20 | 41.80 |
| Mass of Bottle + Soil + Water | $m_3$ | g | 151.30 | 87.00 |
| Mass of Bottle full of Water | $m_4$ | g | 131.90 | 76.00 |
| Mass of soil | $m_2 - m_1$ | g | 31.10 | 17.60 |
| Mass of Water in Full Bottle | $m_4 - m_1$ | g | 100.80 | 51.80 |
| Mass of water used | $m_3 - m_2$ | g | 89.10 | 45.20 |
| Volume of Soil Particles | $(m_4 - m_1) - (m_3 - m_2)$ | mL | 11.70 | 6.60 |
| Particle Density $r_s$ | $\frac{(m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_2)}$ | $g/m^3$ | 2.66 | 2.67 |
| Average Density | $r_s$ | $g/m^3$ | 2.66 | |
| | | | | |
| | | | | |
| | Specific Gravity (Ref: BS 1377: Part 2 : 1990) | | | |
| Date: 2023-01-06 | EFFLUENT | | | |
| Density bottle | | | 50ml | 100ml |
| Mass of Densitty Bottle | $m_1$ | g | 26.60 | 25.20 |
| Mass of Bottle + Soil | $m_2$ | g | 67.00 | 50.00 |
| Mass of Bottle + Soil + Water | $m_3$ | g | 153.30 | 90.60 |
| Mass of Bottle full of Water | $m_4$ | g | 128.20 | 75.20 |
| Mass of soil | $m_2 - m_1$ | g | 40.40 | 24.80 |
| Mass of Water in Full Bottle | $m_4 - m_1$ | g | 101.60 | 50.00 |
| Mass of water used | $m_3 - m_2$ | g | 86.30 | 40.60 |
| Volume of Soil Particles | $(m_4 - m_1) - (m_3 - m_2)$ | mL | 15.30 | 9.40 |
| Particle Density $r_s$ | $\frac{(m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_2)}$ | $g/m^3$ | 2.64 | 2.64 |
| Average Density | $r_s$ | $g/m^3$ | 2.64 | |
| | | | | |

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

➢ *Appendix 6: California Bearing Ratio Test (Unsoaked) Reports.*

Table 13 Effluent Sample Report.

## CALIFORNIA BEARING RATIO TEST (UNSOAKED)

| | | | |
|---|---|---|---|
| Sample : | EFFLUENT SOIL | Proving Ring No.: | 0.010 |
| LOCATION | OMC 11.00% | | |
| Date of Test: | 10/1/2023 | Compaction Standard: | WEST AFRICAN STANDARD |
| No. Layers | 5 | N0. Blows | 27 |

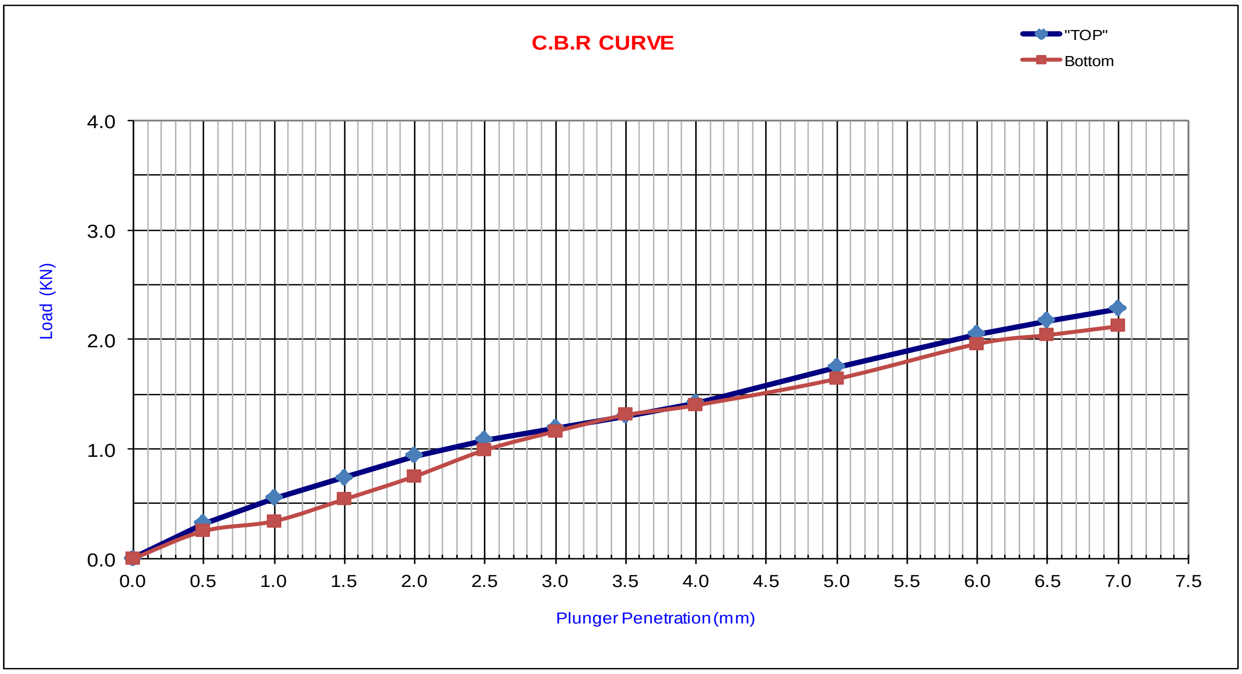
| Plunger Penetration | Top | | | Bottom | | |
|---|---|---|---|---|---|---|
| (mm) | Gauge Reading | Force on Plunger(N) | C.B.R Value | Gauge Reading | Force on Plunger(N) | C.B.R Value |
| 0.0 | 0.0 | 0.00 | | 0.0 | 0.00 | |
| 0.5 | 32.0 | 0.32 | | 25.0 | 0.25 | |
| 1.0 | 55.0 | 0.55 | | 34.0 | 0.34 | |
| 1.5 | 74.0 | 0.74 | | 54.0 | 0.54 | |
| 2.0 | 94.0 | 0.94 | | 75.0 | 0.75 | |
| 2.5 | 108.0 | 1.08 | 8.16 | 99.0 | 0.99 | 7.48 |
| 3.0 | 119.0 | 1.19 | | 116.0 | 1.16 | |
| 3.5 | 130.0 | 1.30 | | 131.0 | 1.31 | |
| 4.0 | 142.0 | 1.42 | | 140.0 | 1.40 | |
| 5.0 | 175.0 | 1.75 | 8.77 | 164.0 | 1.64 | 8.22 |
| 6.0 | 205.0 | 2.05 | | 196.0 | 1.96 | |
| 6.5 | 217.0 | 2.17 | | 204.0 | 2.04 | |
| 7.0 | 228.0 | 2.28 | | 212.0 | 2.12 | |
| C.B.R Value: | | | | 8.8 | % | |

**C.B.R Moisture**

| | Top | | Bottom | |
|---|---|---|---|---|
| Container No. | AQ | UU | AK | BOB |
| Wt of Container | 21.3 | 21.2 | 17.5 | 17.4 |
| Wt of wet soil+Container | 35.9 | 33.6 | 28.0 | 31.1 |
| Wt of dry soil+Container | 34.4 | 32.3 | 26.9 | 29.7 |
| Wt of Moisture | 1.5 | 1.3 | 1.1 | 1.4 |
| Wt of dried soil | 13.1 | 11.1 | 9.4 | 12.3 |
| Moisture Content (%) | 11.5 | 11.7 | 11.7 | 11.4 |
| Mean Moisture Content | 11.6 | | 11.5 | |

**Density Determination**

| | | |
|---|---|---|
| Wt of wet soil & Mould | g | 10.362 |
| Wt of Mould | g | 5.508 |
| Wt of wet soil | g | 4.854 |
| Volume of mould | $cm^3$ | 2305 |
| Wet density | $g/cm^3$ | 0.002106 |
| Dry density | $g/cm^3$ | 0.001710 |
| Maximum dry density | $g/cm^3$ | 1.99 |
| Optimum moisture Content (%) | | 11.00% |



ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26may2106

Table 14 Control Sample Report.

# CALIFORNIA BEARING RATIO TEST (UNSOAKED)

| | | | |
|---|---|---|---|
| Sample : | CONTROL | Proving Ring No.: | 0.010 |
| LOCATION | OMC 12.00% | | |
| Date of Test: | 10/1/2023 | Compaction Standard: | WEST AFRICAN STANDARD |
| No. Layers | 5 | N0. Blows | 27 |

| Plunger Penetration (mm) | Top Gauge Reading | Top Force on Plunger(N) | Top C.B.R Value | Bottom Gauge Reading | Bottom Force on Plunger(N) | Bottom C.B.R Value |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.00 | | 0.0 | 0.00 | |
| 0.5 | 54.0 | 0.54 | | 57.0 | 0.57 | |
| 1.0 | 83.0 | 0.83 | | 93.0 | 0.93 | |
| 1.5 | 115.0 | 1.15 | | 124.0 | 1.24 | |
| 2.0 | 135.0 | 1.35 | | 141.0 | 1.41 | |
| 2.5 | 163.0 | 1.63 | 12.31 | 154.0 | 1.54 | 11.63 |
| 3.0 | 180.0 | 1.80 | | 161.0 | 1.61 | |
| 3.5 | 191.0 | 1.91 | | 178.0 | 1.78 | |
| 4.0 | 203.0 | 2.03 | | 196.0 | 1.96 | |
| 5.0 | 230.0 | 2.30 | 11.52 | 220.0 | 2.20 | 11.02 |
| 6.0 | 260.0 | 2.60 | | 241.0 | 2.41 | |
| 6.5 | 269.0 | 2.69 | | 251.0 | 2.51 | |
| 7.0 | 275.0 | 2.75 | | 266.0 | 2.66 | |
| C.B.R Value: | | | | 12.2 | % | |

**C.B.R Moisture**

| | Top | | Bottom | |
|---|---|---|---|---|
| Container No. | NS | TDI | WIT | JJ |
| Wt of Container | 22.7 | 22.0 | 18.3 | 21.5 |
| Wt of wet soil+Container | 40.1 | 36.9 | 31.4 | 38.7 |
| Wt of dry soil+Container | 37.9 | 35.1 | 29.9 | 36.8 |
| Wt of Moisture | 2.2 | 1.8 | 1.5 | 1.9 |
| Wt of dried soil | 15.2 | 13.1 | 11.6 | 15.3 |
| Moisture Content (%) | 14.5 | 13.7 | 12.9 | 12.4 |
| Mean Moisture Content | 14.1 | | 12.7 | |

**Density Determination**

| | | |
|---|---|---|
| Wt of wet soil & Mould | g | 10.158 |
| Wt of Mould | g | 5.508 |
| Wt of wet soil | g | 4.65 |
| Volume of mould | $cm^3$ | 2305 |
| Wet density | $g/cm^3$ | 0.002018 |
| Dry density | $g/cm^3$ | 0.001591 |
| Maximum dry density | $g/cm^3$ | 1.95 |
| Optimum moisture Content (%) | | 12.00% |