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Performance Based Evaluation of Borrow Pit Soils for Pavement Engineering Applications: A Case Study of Argungu

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ABSTRACT
This study assessed the geotechnical properties of soils from three borrow pits in Argungu Environs—Gwazange, Tiggi, and Felandé to determine their suitability for highway construction. Soil samples were collected and subjected to laboratory tests including natural moisture content, sieve analysis, Atterberg limits, compaction, and California Bearing Ratio (CBR) in accordance with BS 1377 standards. Results showed that natural moisture contents ranged from 1.35% to 6.68%, indicating generally stable soils. Sieve analysis classified Tiggi and Felandé soils as well-graded, while Gwazange contained both well- and poorly graded samples. Atterberg limits identified the soils as low-plasticity clays and silts (CL/ML), suitable for subgrade applications. Compaction tests gave Maximum Dry Density (MDD) values between 1.89–2.08 g/cm³ and Optimum Moisture Content (OMC) of 8–15%, with Felandé soils performing best. CBR values are within AASHTO and Nigerian Highway standards, confirming good bearing capacities. Overall, Felandé borrow pit was found most suitable for road construction, Tiggi soils were adequate with proper compaction, while Gwazange required stabilization or moisture control. The study provides valuable data for engineers and contractors in selecting borrow materials for sustainable and durable road projects in Argungu and similar environments.

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INTRODUCTION

Highway construction is one of the most critical aspects of national development, as it provides access to trade, education, healthcare, and overall economic growth. The quality and lifespan of any highway depend significantly on the materials used in its construction, particularly the soil materials forming the subgrade, subbase, and base layers. In Nigeria, and particularly in rural communities like Argungu in Kebbi State, construction materials are commonly sourced from nearby borrow pits. These borrow pits are surface excavations from which soil is removed for use in engineering projects.

Although borrow pits offer a convenient and economical source of construction material, their use is often not preceded by adequate engineering evaluation. In many rural projects, soil materials are excavated and used with little or no laboratory analysis to determine their strength, durability, and suitability. This has led to several cases of road failures, cracks, uneven settlement, and rapid deterioration of newly constructed pavements, especially in Northern Nigeria.

To ensure quality construction and long-lasting roads, it is essential that soil materials from borrow pits be properly assessed using standardized engineering tests. This research is designed to investigate the engineering properties of borrow pit soils in three locations in Argungu: Gwazange, NSK Farms Area, and Felandé. By conducting proper tests such as Atterberg limits, grain size analysis, compaction, specific gravity, and California Bearing Ratio (CBR), this study aims to determine whether the soils from these pits are suitable for highway construction.

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The research is limited to technical analysis only, with no focus on environmental impacts or post-excavation rehabilitation. The results are expected to provide useful data for highway engineers and contractors involved in road projects across Argungu and surrounding areas (Ojefia et al.,2020).

LITERATURE REVIEW

Borrow pits are excavated areas from which earth materials such as soil or lateritic soils are removed to be used as fill, subbase or subgrade material in road-construction and other civil works (Aka et. al 2022). These pits are commonly found in both rural and urban areas and serve as essential sources of fill materials for roads, embankments, and earthworks.

In the context of highway construction, borrow pits are often used to supply subgrade and base course materials. However, the quality of soil from these pits can vary greatly depending on the location, depth, and soil type. Without proper assessment, the use of poor-quality materials from borrow pits can lead to premature pavement failure, structural deformation, and costly maintenance. The performance of highway pavements largely depends on the engineering properties of the subgrade and base soils. Soil testing allows engineers to determine whether a material is suitable for use under expected traffic loads and environmental conditions. According to Khalid and Rehman (2018) the key soil properties (moisture content, compaction parameters, grain size distribution, Atterberg limits) must be evaluated for soil suitability before construction begins

According to Baus and Wang (2001), the AASHTO (American Association of State Highway and Transportation Officials) classification system is commonly used in highway design and construction. It classifies soil based on particle size distribution and Atterberg limits. Soils are grouped from A-1 to A-7, with further subgroups such as A-2-4, A-2-6, etc.

1. Group A-1: Well-graded gravel and sand with low plasticity. Excellent for subgrade.
2. Group A-2: Silty or clayey gravel and sand with moderate plasticity. Generally good.
3. Group A-3: Fine sand with non-plastic fines. Fair to good.
4. Group A-4 to A-7: Silts and clays. Generally poor, especially A-7.

Holtz and Kovacs (1981) describe the Unified Soil Classification System (USCS) as a method that classifies soil based on particle size, gradation, and plasticity. It groups soils into three major categories: coarse-grained, fine-grained, and organic soils. According to Bowles (1997), the Group Index (GI) is an empirical formula used in the AASHTO classification system to further evaluate the quality of fine-grained soils. The GI provides a numerical value representing the expected performance of soil as a subgrade material the higher the GI, the lower the quality.

Several soil properties affect its performance in highway construction. These include:

1. **California Bearing Ratio (CBR) Test**
   The CBR test is a penetration test used to determine the bearing capacity of soil by measuring the pressure required to penetrate a soil sample with a standard plunger compared to a standard crushed rock.
2. **Sieve Analysis (Wet Method)**
   Sieve analysis is a particle size distribution test in which soil is washed and passed through a series of sieves with progressively smaller openings to determine the proportion of different grain sizes in a soil sample.
3. **Moisture Content Test**
   Moisture content test is a gravimetric method used to determine the percentage of water present in a soil sample by comparing its weight before and after oven drying.
4. **Compaction Test (Standard Proctor Test)**
   The compaction test is a laboratory procedure used to determine the maximum dry density and the optimum

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moisture content at which a soil can be compacted using a standard amount of compactive effort.

5. **Atterberg Limits Test**
Atterberg Limits test refers to a set of three procedures (Liquid Limit, Plastic Limit, and Shrinkage Limit) used to define the consistency limits of fine-grained soils as they transition between solid, plastic, and liquid states.

Previous investigations across Nigeria have extensively examined borrow pit soils to determine their suitability for pavement and earthwork applications. Ehujuo (2019) reported that lateritic soils from borrow pits in Eastern Nigeria can be effectively utilized for pavement construction when appropriately stabilized. Similarly, Omotosho and Eze-Uzomaka (2008) observed that, in the Niger Delta region, borrow pit materials generally exhibit low CBR values, indicating the necessity for stabilization to meet highway engineering requirements.

In Southwestern Nigeria, Adetoro et. al (2022) highlighted the critical role of soil plasticity in governing the performance and suitability of borrow materials for road construction. Despite these regional assessments, published data on borrow pit soils in Kebbi State remain limited, particularly within the Argungu locality. To address this gap, the present study evaluates the engineering characteristics of borrow pit soils from Gwazange, NSK Farms Area, and Felande, with the aim of determining their suitability for use in highway pavement construction.

According to FMWH (20130, guidelines specify the following:

1. Minimum CBR of 10–15% for subgrade
2. PI should not exceed 20% for subbase materials
3. Soils with high clay content or poor drainage are generally unsuitable
4. Maximum dry density should meet compaction requirements

METHODOLOGY

This part outlines the procedures, materials, and methods used in assessing the engineering properties of borrow pit soils from Gwazange, NSK Farms Area, and Felandé for highway construction in Argungu. It describes the sampling techniques, laboratory testing protocols, equipment used, and the standards applied for evaluating soil suitability for pavement layers. All methods adopted in this study conform to internationally recognized practices such as BS 1377 (1990) and relevant specifications of the Federal Ministry of Works and Housing (FMWH).

Study Area Description

The study was conducted in Argungu, a historical town in Kebbi State, Northwestern Nigeria. Argungu is located within the Sudan Savanna belt, characterized by open grasslands, scattered trees, and predominantly sandy soils. The area experiences a semi-arid climate with a pronounced dry season and a short rainy season, typically between May and September. Average annual rainfall ranges between 500 mm to 800 mm. The topography of the area is relatively flat, which favors road construction and agricultural activities.

Due to increased urban development and road infrastructure expansion, the demand for borrow materials has risen significantly in Argungu. As such, the selection of suitable soils for use in embankment, subgrade, and base construction is critical. For this study, three active and accessible borrow pits were selected within Argungu and its surrounding environments. These locations were chosen based on their existing use in road works, proximity to ongoing highway projects, and the diversity in their soil types.

Gwazange Borrow Pit

GPS Coordinates:

Latitude 12.7385° N, Longitude 4.5162° E

Description:

The Gwazange borrow pit is situated to the northwestern part of Argungu, along the local feeder road leading to nearby farmlands. The soil in this location is reddish-brown in color, moderately cohesive, and has been previously used in minor rural road construction. The area is relatively flat with minor vegetation cover.

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Evidence of previous excavation was observed, indicating ongoing use. The pit is about 1.2 meters deep and reveals a layer of sandy clay soil. The material is easily accessible with good hauling routes, making it a viable source for highway fill and subgrade materials.

NSK Farms Area Borrow Pit

GPS Coordinates:

Latitude 12.7254° N, Longitude 4.5017° E

Description:

This borrow pit is located near the popular NSK Farms axis, to the southwest of Argungu town center. The site is close to agricultural fields and has been excavated occasionally by local contractors for road base and rural pathway construction. The soil is light brown with some dark patches, mostly silty sand, and moderately compact.

During field observation, the presence of gravels and a mix of fine and coarse particles was noted, indicating potentially suitable material for road layers. Its location near farmland, however, calls for controlled excavation to avoid interference with agricultural productivity.

Felande Borrow Pit

GPS Coordinates:

Latitude 12.7139° N, Longitude 4.4881° E

Description:

Felande is located towards the southern fringe of Argungu, accessible via a gravel road. The borrow pit here is located in an open, less disturbed area, where the soil appears dark grayish-brown with a high content of clayey material. The terrain is slightly undulating, and surface runoff during rains could pose challenges to long-term excavation.

This site is known for producing fine-grained soils with high plasticity. Preliminary inspections suggest it may require treatment or stabilization before being used in road construction, especially for upper subgrade layers. However, the accessibility and volume of soil available make it useful for bulk fill materials.

Sampling Procedure

Soil samples were collected using the disturbed sampling method. At each location, three different points were selected to ensure spatial representation. The topsoil was removed to a depth of approximately 1.0–1.5 meters to access undisturbed strata used in highway construction. Approximately 20–30 kg of soil was collected per site and sealed in labeled polythene bags. Samples were transported to the Civil Engineering Laboratory of Waziri Umaru Federal Polytechnic, Birnin Kebbi for testing.

Laboratory Testing

The laboratory tests were conducted on soil samples collected from the three borrow pits. These tests were aimed at evaluating the engineering properties of the soils and their suitability for use in highway construction. The following laboratory tests were carried out:

California Bearing Ratio (CBR) Test

Purpose: To determine the soil's ability to support road pavement layers and assess whether the soil requires improvement or stabilization.

Importance in Highway Construction: The CBR value assists in the design of flexible pavements by indicating the load-bearing capacity of the soil. Higher CBR values reflect better strength and suitability for pavement construction.

Sieve Analysis (Wet Method)

Purpose: To classify soil based on the proportion of gravel, sand, silt, and clay.

Importance in Highway Construction: Knowing the gradation of soil helps in determining its compaction characteristics, permeability, and suitability for use in subgrade, sub-base, or base layers.

Moisture Content Test

Purpose: To determine the natural moisture condition of the soil at the time of sampling.

Importance in Highway Construction: The moisture content influences compaction efficiency and strength. Knowing the in-situ

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moisture helps determine if the soil needs conditioning before placement in road construction.

Compaction Test (Standard Proctor Test)

Purpose: To find the best moisture content for achieving maximum soil strength through compaction.

Importance in Highway Construction: Proper compaction is critical for minimizing settlement and increasing load-bearing capacity. The OMC and MDD values obtained serve as benchmarks for field compaction during road construction.

Atterberg Limits Test

Purpose: To evaluate the plasticity characteristics of the soil.

Importance in Highway Construction: High plasticity indicates potential for shrinkage, swelling, and poor load-bearing behavior. These values help determine the stability of soils and guide decisions on stabilization or replacement.

Method of Analysis

The laboratory test results were analyzed and interpreted using relevant engineering formulas and standards to assess the suitability of the borrow pit soil for highway construction. The key analyses and formulae include:

Moisture Content (MC)

To determine the natural water content of the soil.

Water Content: $MC = \frac{Ww}{Wd} \times 100$ Eqn. (1)

Where:

W_w = Weight of water

W_d = Weight of dry soil

Grain Size Distribution (Cu and Cc)

Used for classifying soils based on particle size.

Coefficient of Uniformity (Cu):

$Cc = \frac{(D30)^2}{D10 \times D60}$ Eqn. (2)

Coefficient of Curvature (Cc):

$Cu = \frac{D60}{D10}$ Eqn. (3)

Atterberg Limits and Plasticity Index (PI)

To evaluate soil consistency and plasticity.

Plastic index: PI = LL-PL Eqn. (4)

Where:

LL = Liquid Limit

PL = Plastic Limit

Compaction Characteristics (Dry Density)

From the Standard Proctor Test:

Dry density: $\gamma_d = \frac{Wd}{V}$ Eqn. (5)

Where:

W_d = Dry weight of compacted soil

V = Volume of the mould

California Bearing Ratio (CBR)

To assess the strength of subgrade or subbase material:

$CBR = \frac{Load\ of\ sample}{Standard\ load} \times 100$ Eqn. (6)

Equipment and Materials Used

The laboratory tests conducted in this study required the use of several specialized tools and materials to ensure accuracy and reliability. Below is a description of the major equipment and materials utilized:

1. CBR Mould and Loading Machine
2. Sieve Set and Shaker (Wet Sieving Apparatus)
3. Oven (105–110°C)
4. Weighing Balance
5. Compaction Mould and Rammer (Standard Proctor Apparatus
6. Casagrande Apparatus and Grooving Tool
7. Glass Plate and Spatula

Standards and Guidelines

The following standards were strictly followed:

1. BS 1377:1990 – Methods of Test for Soils for Civil Engineering Purposes
2. FMWH Nigeria – Highway Material Specifications

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3. AASHTO T89, T90, T99, T180 – For soil testing procedures
4. USCS and AASHTO systems – For soil classification

Data Analysis and Interpretation

Results from each laboratory test was tabulated and analyzed. Soil classifications were made using:

USCS symbols (e.g., CL, SP, SM)
AASHTO groups (e.g., A-2-6, A-4)
CBR values, plasticity index, and compaction properties were compared with FMWH standards to evaluate the suitability of each borrow pit for highway construction.

RESULTS AND DISCUSSION

Moisture Content

From the Figure 1, Tiggi soils recorded the lowest natural moisture content values (1.35–2.01%, average 1.78%), Felandé soils had moderate values (1.51–4.49%, average 2.74%), while Gwazange soils showed the highest values (2.60–6.68%, average 4.47%). The overall range of all samples was 1.35–6.68%, and the grand average was 3.00%.

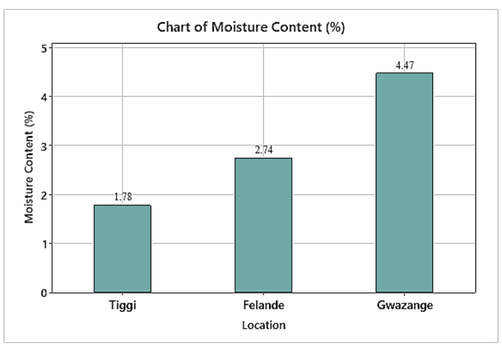

Figure 1: Natural Moisture Content of Borrow Pits Samples

Sieve Analysis Results

Sieve analysis was conducted on nine soil samples obtained from the Tiggi, Gwazange and Felandé borrow pits to evaluate their gradation characteristics and assess their suitability for highway pavement applications. The key particle-size parameters and classification outcomes are presented in Table 1. As noted by Das (2016), well-graded soils typically contain a wide distribution of particle sizes and fewer fines (i.e., <35% passing the 0.075 mm sieve), which enhances their compaction behaviour, load-bearing capacity, and overall engineering performance. Conversely, soils with poor gradation or excessive fines generally exhibit inferior mechanical properties and may require stabilization before use in pavement layers.

The results indicate that all samples obtained from the Tiggi borrow pit (S1–S3) satisfy the criteria for well-graded soils based on their coefficients of uniformity (Cu) and curvature (Cc). This suggests that Tiggi soils possess favourable packing and compaction characteristics and are therefore suitable for use as subbase or fill materials in road construction. In contrast, the Gwazange borrow pit exhibited greater variability: only Sample S1 met the requirements for well-graded soils, whereas Samples S2 and S3 displayed low Cu values indicative of poor gradation. Such variability reduces the reliability of materials from this pit and may necessitate blending or stabilization to achieve the desired performance. The Felandé borrow pit demonstrated the most consistent quality among the three locations, with all samples classified as well graded. This consistency indicates that Felandé represents a dependable source of borrow material for pavement works.

Table 1: Summary of Sieve Analysis Results for Selected Borrow Pits

Location	Sample	Cc	Cu
Tiggi	S1	0.505	**25**
	S2	0.712	**11.54**
	S3	0.806	**62.66**
Gwazange	S1	0.501	**8.89**
	S2	0.912	**3.411**
	S3	1.05	**2.941**
Felande	S1	0.509	**33**
	S2	0.603	**57384**
	S3	1.01	**38.823**

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Atterberg Limits

The Atterberg limit results presented in Table 2 provide insights into the plasticity characteristics of the soil samples collected from the Gwazange, Tiggi and Felandé borrow pits. The measured Liquid Limits (LL), ranging between 16.8% and 25.6%, classify the soils within the low to medium plasticity range, consistent with typical lateritic and silty clay materials used in pavement construction. The Plastic Limits (PL) varied considerably across the samples, from 5.10% to 27.46%, while the corresponding Plasticity Indices (PI) were predominantly between 3.4% and 11.7%. These PI values indicate that most samples fall within the low-plasticity category, with only a few exhibiting moderate plasticity (approximately 10–12%), which may require stabilization to meet subgrade performance requirements. One sample from Gwazange (Sample 1) exhibited a negative PI, likely due to experimental inconsistency or procedural error, as negative PI values are not physically meaningful.

Classification on the Unified Soil Classification System (USCS) plasticity chart places the majority of the soils within the CL (low-plastic clay) and ML (silt) categories. These soil types typically exhibit favourable workability, limited swelling potential, and moderate strength, making them generally suitable for use as subgrade materials in road construction. Overall, the Atterberg limit results suggest that the borrow pit soils from the study area possess acceptable plasticity levels for pavement applications, although local stabilization may be necessary for samples with PI values approaching the upper end of the medium plasticity range. These findings align with established geotechnical understanding that low-plasticity soils tend to offer improved compaction and reduced volume-change behaviour, both of which are critical for long-term pavement performance.

Table 2: Summaries of Atterberg Limits Test Results for Selected Borrow Pits

Location	Samples	LL (%)	PL (%)	PI (%)	Classification
Tiggi	S1	23.8	16.66	7.14	CL
	S2	21.5	13.82	7.68	CL
	S3	16.8	5.1	11.7	CL
Felande	S1	25	21.35	3.65	ML
	S2	25.6	17.32	8.28	CL
	S3	17	8.84	8.16	CL
Gwazange	S1	23.8	27.46	3.66	CL
	S2	24.5	23.44	1.06	ML
	S3	21.9	18.5	3.4	ML

California Bearing Ratio (CBR)

The CBR test results for soils obtained from Tiggi, Felandé, and Gwazange borrow pits and compared to AASHTO/Nigerian Highway standards are presented in Table 3. The soils generally demonstrate high bearing capacities, exceeding the minimum requirements for pavement design. Tiggi soils recorded CBR values ranging from 27% to 52%, indicating suitability as good subgrade material. Felandé soils exhibited the highest values (29–76%), suggesting that they can be used as subgrade and even sub-base material without stabilization. Gwazange soils also showed strong performance with CBR values between 40% and 73%, confirming their suitability for pavement construction.

Comparison with standard specifications (AASHTO and Nigerian Highway standards) reveals that all tested soils exceed the minimum recommended CBR of 10% for subgrade and ~30% for sub-base layers. Ranking

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the soils by strength, Felandé soils are the strongest, followed by Gwazange, with Tiggi soils slightly lower but still adequate for subgrade purposes. These findings indicate that the natural soils from these borrow pits are suitable for highway construction without additional treatment.

Table 3. CBR Test Results of Soils from Borrow Pits

Location	CBR (%)	Classification	Suitability for Pavement
Tiggi	27–52	Good subgrade	Subgrade
Felandé	29–76	Very high quality	Subgrade/Sub-base
Gwazange	40–73	High quality	Subgrade/Sub-base

Note: Minimum CBR recommended by AASHTO/Nigerian Highway standards:
10% for subgrade, ~30% for sub-base.

Compaction Test Result

The compaction tests were conducted on soil samples from Gwazange, NSK Farms, and Felandé borrow pits to establish the relationship between dry density and moisture content, and to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for each location. These parameters are essential in assessing the compaction characteristics of soils and their suitability for highway construction. According to Head (2006), soils with MDD values greater than 1.80 g/cm³ are considered dense and strong enough for road construction, while soils below 1.60 g/cm³ are weak. The OMC should ideally fall within 8–15% to facilitate proper compaction.

The results (Table 4) indicate that Gwazange soils had moderate densities (MDD ≈ 1.89–1.95 g/cm³) and higher OMC (12.5–15%), reflecting a higher fines content requiring more water for compaction. Tiggi soils exhibited higher densities (MDD ≈ 2.03–2.06 g/cm³) and lower OMC (8–11.5%), suggesting a more granular composition that compacts easily. Felandé soils performed best, with the highest density (MDD ≈ 2.08 g/cm³) and medium OMC (11–13%), indicating a good balance of fines and sand suitable for road construction.

Table 4. Compaction Test Results of Soils from Borrow Pits

Location	Maximum Dry Density (g/cm³)	Optimum Moisture Content (%)
Gwazange	1.89–1.95	12.5–15
Tiggi	2.03–2.06	8–11.5
Felandé	2.08	11–13

CONCLUSION

Laboratory investigations on soils from Tiggi, Gwazange, and Felandé borrow pits provided insights into their geotechnical suitability for road construction. The soils exhibited low natural moisture content (1.35–6.68%), indicating stability with minimal shrink–swell potential. Sieve analysis showed that Tiggi and Felandé soils are well-graded, while Gwazange soils displayed a mix of well- and poorly-graded fractions. Atterberg limits classified the soils primarily as low-plasticity clays and silts (CL/ML), suitable for subgrade applications. California Bearing Ratio (CBR) values exceeded AASHTO and Nigerian Highway minimum standards, with Felandé soils demonstrating the highest bearing capacity. Compaction tests further indicated that Felandé soils, with the highest Maximum Dry Density (≈2.08 g/cm³) and moderate Optimum Moisture Content (≈11–13%), are most suitable for pavement construction, followed by Tiggi, while Gwazange soils remain a viable source with slightly higher moisture requirements. Overall, the soils from all three borrow pits are adequate for use as subgrade and sub-base materials in highway construction.

RECOMMENDATIONS

Based on the geotechnical investigations of soils from Tiggi, Gwazange, and

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Felandé borrow pits, the following recommendations are made for highway construction:

1. Primary Material Source: Felandé borrow pit should be prioritized as the main source of construction material due to its superior strength, high Maximum Dry Density, and favorable compaction characteristics.
2. Use of Tiggi Soils: Soils from Tiggi are suitable for subgrade and sub-base applications, provided that proper compaction practices are followed to achieve optimal density and moisture content.
3. Use of Gwazange Soils: Gwazange soils should be used with caution. Stabilization or careful moisture control is recommended in areas where soil properties may vary or where higher fines content could affect compaction.
4. Quality Control: Continuous quality control at borrow pits is essential to minimize variability in soil properties and ensure consistent performance during construction.
5. Material Blending: For large-scale road projects, blending soils from different borrow pits can be considered to optimize performance and achieve uniform construction quality.

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