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Geotechnical Analysis and Performance Evaluation of Subgrade Materials in Road Construction

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Abstract

Geotechnical engineering plays a pivotal role in the design, construction, and long-term maintenance of infrastructure, particularly in road construction, where subgrade conditions are directly linked to pavement performance, durability, and overall structural integrity. The performance of a road is heavily influenced by the geotechnical properties of the subgrade, making it essential to thoroughly assess these properties in the planning and construction phases. This study comprehensively investigates the geotechnical characteristics and performance of subgrade materials used in road construction, with a particular focus on enhancing the sustainability, resilience, and longevity of road infrastructure, especially in regions with diverse and challenging soil types. Soil samples were carefully extracted from varying depths and multiple locations along a proposed highway section and subjected to detailed laboratory analyses. Key parameters evaluated include moisture content, particle size distribution, Atterberg limits, compaction characteristics, and California Bearing Ratio (CBR), all of which are critical in determining the suitability of subgrade soils for supporting road pavements. The results highlight the substantial impact of subgrade properties on pavement design and long-term performance, emphasizing the need for targeted interventions such as material stabilization, advanced drainage control measures, and effective moisture management techniques. These recommendations are particularly vital in regions where problematic soil conditions, such as expansive clays or highly plastic soils, can significantly contribute to premature pavement failures. This research offers valuable insights and practical recommendations that could lead to more efficient road construction practices and facilitate the design of more resilient and durable pavements, even in the face of complex geotechnical challenges.

Keywords: Subgrade materials, geotechnical properties, road construction, soil stabilization, California Bearing Ratio (CBR), moisture content, particle size distribution, soil plasticity, pavement design, soil compaction, expansive soils, drainage control, highway engineering, pavement performance, soil classification, lime stabilization, cement stabilization, soil mechanics, compaction tests

INTRODUCTION

In road construction, the subgrade is regarded as one of the most critical layers, serving as the foundation upon which the pavement structure is built. The subgrade quality significantly affects the ability of the pavement to carry traffic loads and withstand environmental stresses, such as moisture fluctuations and temperature variations. Poor subgrade conditions often result in early pavement failures, leading to excessive maintenance costs, reduced service life, and compromised road safety [8].

The complexity of subgrade behavior, especially in regions with diverse soil types, necessitates a thorough investigation of soil properties during the design phase. Geotechnical issues, such as

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excessive plasticity, poor drainage, and low bearing capacity, can lead to subgrade failure, which manifests as cracking, rutting, and other forms of pavement distress [12]. Climate change and increasing traffic volumes have heightened the need for subgrades that can resist these stresses over time [13].

This study aims to analyze the geotechnical properties of subgrade materials along a proposed highway in a region with varying soil types. By evaluating the physical and mechanical properties of the soils, this research seeks to provide targeted recommendations for improving subgrade performance. Specifically, the study focuses on soil stabilization techniques, drainage control systems, and moisture management to mitigate the challenges posed by problematic soils, such as expansive clays, that are prone to swelling and shrinkage [3].

LITERATURE REVIEW

The relationship between soil properties and pavement performance has been extensively studied in geotechnical engineering. One of the most commonly used methods for evaluating subgrade strength is the California Bearing Ratio (CBR) test, which measures the resistance of a soil sample to penetration under standardized conditions [2]. The CBR value provides crucial information about the load-bearing capacity of the soil, which is used to determine the thickness of pavement layers needed to accommodate expected traffic loads.

Expansive soils, particularly clays with high plasticity, pose significant challenges in road construction. These soils exhibit shrink-swell behavior due to moisture fluctuations, causing substantial changes in volume, which can lead to pavement deformation and cracking [5]. lime stabilization is a widely used technique for mitigating the plasticity of clayey soils, improving their load-bearing capacity, and reducing swelling potential. Similarly, cement and fly ash have been employed in soil stabilization to enhance the mechanical properties of weak subgrade soils [11].

Drainage control is another critical factor that directly influences the performance of subgrade materials. Inadequate drainage can lead to water infiltration into the subgrade, reducing its shear strength and resulting in pavement failure [4]. Sherard et al. (1976) emphasize that soils with high moisture content are particularly vulnerable to strength reduction, as water reduces friction between soil particles, leading to decreased load-bearing capacity. Consequently, effective drainage systems, including subsurface and surface drainage measures, are essential to maintaining subgrade stability [14].

Previous studies have also explored the role of compaction in improving subgrade performance. Compaction increases soil density, reducing void spaces and enhancing the soil's load-bearing capacity [6,7]. However, the moisture content of the soil during compaction is equally important, as inadequate moisture control can result in either over-compaction or under-compaction, both of which adversely affect subgrade performance.

MATERIALS AND METHODS

Study Area and Sampling

The study area is located along a proposed highway section that traverses regions with varied soil types, including silty sands, clayey soils, and expansive clays. A total of 40 soil samples were collected from depths ranging between 30 cm and 60 cm at 5 km intervals along the highway alignment. These depths were chosen to capture the typical subgrade conditions encountered during construction. The soil samples were air-dried for a period of two weeks to ensure that excess moisture, which could affect test results, was eliminated [1-7].

Abbreviations

- *LL:* Liquid Limit
- *PL:* Plastic Limit
- *CBR:* California Bearing Ratio

This Table 1 provides a concise summary of the key properties, such as soil type, moisture content, Atterberg limits, compaction characteristics (MDD and OMC), and CBR values for both soaked and unsoaked conditions, which are critical for understanding the subgrade performance in road construction.

This Table 2 summarizes various soil stabilization techniques, highlighting the materials used, target soil types, and their impact on key subgrade properties such as plasticity, compaction, and CBR improvement. It also lists additional benefits associated with each method, helping guide the selection of appropriate stabilization techniques for different soil conditions.

The layers of pavement including asphalt, base, subbase, and subgrade. The subgrade layer shows varying soil types, such as clayey and sandy soils, with annotations highlighting moisture content, compaction techniques, and the installation of subsurface drainage systems to improve stability and prevent water infiltration Figure 1.

Table 1. Summary of geotechnical properties of subgrade materials.

Sample Location	Depth (cm)	Soil Type	Moisture Content (%)	Atterberg Limits	Maximum Dry Density (g/cm³)	Optimum Moisture Content (%)	CBR (Unsoaked) (%)	CBR (Soaked) (%)
Location 1	30-60	Clayey Sand	14.5	LL = 35, PL = 22	1.65	12	10.5	4.2
Location 2	30-60	Silty Clay	18.0	LL = 42, PL = 25	1.58	15	8.2	3.1
Location 3	30-60	Sandy Loam	12.2	LL = 28, PL = 16	1.80	10	11.7	6.3
Location 4	30-60	Silty Sand	11.8	LL = 32, PL = 19	1.75	11	12.0	5.7
Location 5	30-60	Clay	20.3	LL = 45, PL = 30	1.55	18	5.6	2.8

Table 2. Soil stabilization techniques and their effects on subgrade properties.

Stabilization Method	Materials Used	Target Soil Type	Effect on Plasticity	Effect on Compaction	Improvement in CBR (%)	Other Benefits
Lime Stabilization	Lime (quicklime/hydrated)	Clay, Silty Clay	Reduces plasticity	Increases maximum dry density	50–200% increase	Reduces swelling and shrinkage in expansive soils
Cement Stabilization	Cement	Clay, Sandy soils	Significantly reduces	Improves compaction characteristics	100–300% increase	Enhances strength and durability
Fly Ash Stabilization	Fly Ash	Silty and Clay soils	Moderately reduces	Improves compactibility	40–150% increase	Environmentally friendly and cost-effective
Bituminous Stabilization	Bitumen	Granular soils, Sands	Little to no effect	Slightly improves	30–100% increase	Improves moisture resistance and binding strength
Geosynthetics Reinforcement	Geotextiles, Geogrids	All soil types	No direct effect	Enhances compaction and load distribution	Varies (depends on design)	Provides structural support and prevents erosion

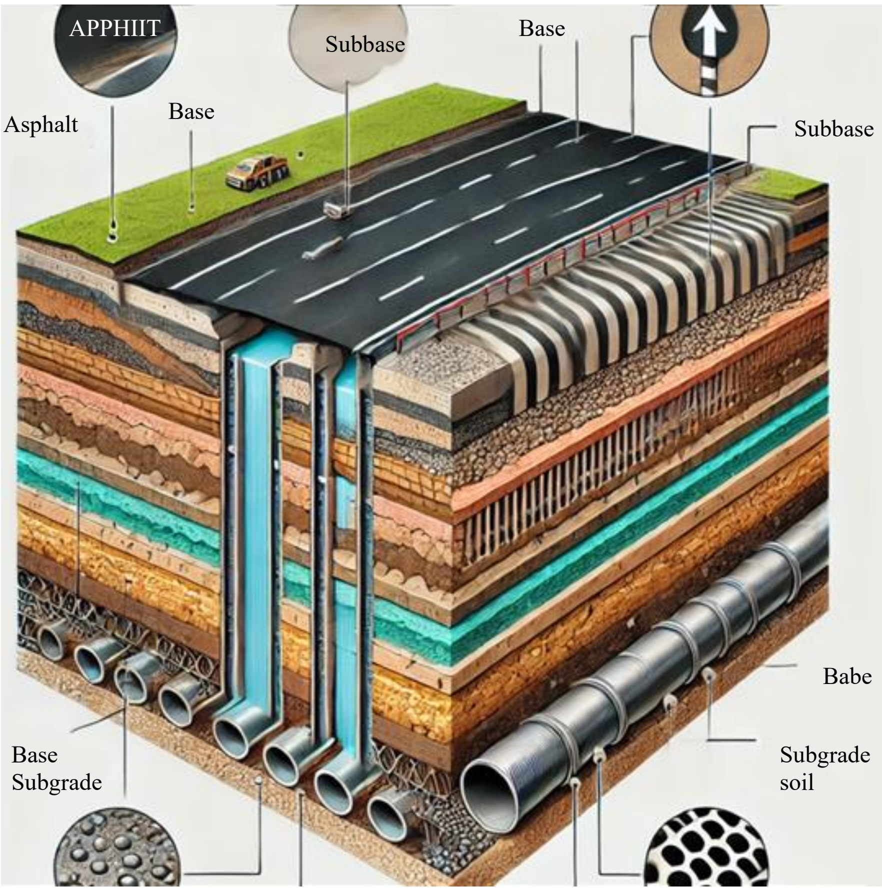

Figure 1. Cross-sectional diagram of a typical highway construction project,

Laboratory Testing

The following tests were conducted according to the British Standard BS 1377 (1990) guidelines for soil testing:

1. *Moisture Content:* Moisture content was determined using the oven-drying method. The moisture content is a critical factor in determining the compaction characteristics and bearing capacity of subgrade soils. Soils with high moisture content often exhibit poor load-bearing capacity [4].
2. *Particle Size Distribution:* Wet sieving and hydrometer analysis were used to determine the particle size distribution of the soil samples. The relative proportions of clay, silt, and sand fractions significantly affect soil strength and compressibility (ASTM D422-63).
3. *Atterberg Limits:* The liquid limit, plastic limit, and plasticity index were determined to evaluate the plasticity of the soil. Soils with high plasticity tend to exhibit greater deformation under load, making them more susceptible to pavement distress [6,7].
4. *Compaction Tests:* The maximum dry density (MDD) and optimum moisture content (OMC) were determined using the modified Proctor compaction test. Achieving the correct compaction during construction is essential for ensuring the long-term stability of the subgrade.
5. *California Bearing Ratio (CBR):* The CBR test was conducted on both soaked and unsoaked samples to evaluate the strength of the subgrade materials under wet and dry conditions. The CBR values are used to determine the required thickness of pavement layers based on empirical design charts.

Data Analysis

The results were analyzed using the AASHTO soil classification system and the Unified Soil Classification System (USCS) to categorize the soils according to their geotechnical properties. CBR values were used in conjunction with pavement design charts to recommend appropriate pavement thicknesses for different sections of the highway [8-13].

RESULTS AND DISCUSSION

Soil Classification and Properties

The particle size distribution results revealed that the subgrade soils were primarily composed of silty sands and clayey soils. Clay content ranged from 10% to 45%, with the highest clay content observed in the southern section of the highway, indicating the potential for swelling and shrinkage [9] The presence of expansive clay in these regions suggests that these areas are at higher risk of subgrade instability due to moisture fluctuations.

Atterberg limits showed that the soils had low to moderate plasticity, with plasticity index values ranging from 5% to 22%. Soils with high plasticity are prone to excessive deformation under load, which can lead to premature pavement failure [10].

The compaction test results indicated that the maximum dry density (MDD) of the soils ranged from 1.5 g/cm³ to 2.2 g/cm³, while the optimum moisture content (OMC) values varied between 10% and 18%. These results suggest that soils with higher clay content require more precise moisture control during compaction to achieve the desired compaction density [13].

California Bearing Ratio (CBR)

The CBR values for the subgrade soils ranged from 3% to 12%, with the lowest values observed in the southern clayey soils. The soaked CBR values were significantly lower than the unsoaked values, underscoring the negative impact of water infiltration on subgrade strength (Terzaghi, Peck & Mesri, 1996) [15]. Based on these results, it was determined that the southern section of the highway would require thicker pavement layers to accommodate traffic loads.

Subgrade Improvement Recommendations

Several recommendations were proposed to improve the performance of subgrade materials along the highway alignment:

1. *Soil Stabilization:* Lime or cement stabilization is recommended for sections with high clay content. These additives help reduce soil plasticity and increase its load-bearing capacity, thereby improving overall pavement stability [5, 11].
2. *Drainage Control:* Effective drainage systems are essential, particularly in areas with high moisture content and low CBR values. Subsurface drainage systems should be installed to prevent water infiltration into the subgrade, and surface drainage systems should be designed to direct runoff away from the pavement [14, 15].
3. *Compaction Control:* High-energy compaction equipment should be used to achieve the required density during construction. Special attention must be given to moisture control during compaction to ensure the soil is compacted at or near its optimum moisture content [4].

CONCLUSION

The geotechnical analysis of subgrade materials along the proposed highway revealed significant variability in soil properties, particularly with regard to clay content, moisture content, and bearing capacity. Soils with high clay content exhibited low CBR values, indicating poor subgrade quality and the need for stabilization and drainage control measures. Proper compaction and moisture management during construction are essential to achieving the desired subgrade performance.

The findings of this study highlight the importance of conducting thorough geotechnical investigations during the planning and design stages of road construction projects, particularly in regions with problematic soil conditions. By implementing appropriate stabilization and drainage strategies, it is possible to significantly enhance subgrade performance, reduce maintenance costs, and improve the longevity and safety of road infrastructure.

REFERENCES

1. Bell FG. Lime stabilization of clay minerals and soils. Eng Geol. 1996;42(4):223-37.
2. Bowles JE. Foundation analysis and design. 5th ed. New York: McGraw-Hill; 1992.
3. Chen FH. Foundations on expansive soils. Amsterdam: Elsevier; 1975.
4. Das BM. Principles of geotechnical engineering. 7th ed. Boston: Cengage Learning; 2010.
5. Fredlund DG, Rahardjo H. Soil mechanics for unsaturated soils. New York: John Wiley & Sons; 1993.
6. Holtz RD, Kovacs WD. An introduction to geotechnical engineering. Englewood Cliffs (NJ): Prentice-Hall; 1981.
7. Holtz RD, Kovacs WD, Sheahan TC. An introduction to geotechnical engineering. 2nd ed. Upper Saddle River (NJ): Pearson; 2011.
8. Huang YH. Pavement analysis and design. 2nd ed. Upper Saddle River (NJ): Pearson Education; 2004.
9. Jones C, Jefferson I. Expansive soils. In: Burland J, Chapman T, Skinner H, Brown M, editors. ICE manual of geotechnical engineering. Volume 1. London: ICE Publishing; 2012. p. 413-39.
10. Lambe TW, Whitman RV. Soil mechanics. New York: John Wiley & Sons; 1969.
11. Little DN. Handbook for stabilization of pavement subgrades and base courses with lime. Arlington (VA): National Lime Association; 1995.
12. Pavement Interactive. Subgrade and subbase [Internet]. 2017 [cited 2024 Oct 9]. Available from: https://www.pavementinteractive.org
13. Rahman MA, Hossain I, Hoque MM. Geotechnical characterization of subgrade soils. J Mater Civ Eng. 2021;33(4):04021019.
14. Sherard JL, Dunnigan LP, Decker RS. Identification and nature of dispersive soils. J Geotech Eng Div. 1976;102(4):287-301.
15. Terzaghi K, Peck RB, Mesri G. Soil mechanics in engineering practice. 3rd ed. New York: John Wiley & Sons; 1996.

