Case Study on the Geotechnical Investigation for Pavement Rehabilitation of Karyambadi–Pulpally–Kenichira Road, Wayanad District in Kerala

Akhil Paul[1], Dr. M S Nagaraja Gupta[2]

[1]PG Scholar, Dept. of Civil Engineering, EWIT, Bangalore
[2]Professor and Head, Dept. of Civil Engineering, EWIT, Bangalore

---***---

Abstract - *The Karyambadi–Pulpally–Kenichira Road in Wayanad district, Kerala, serves as a vital corridor linking remote rural settlements to the broader state highway network. Over time, this stretch has undergone significant deterioration due to ageing pavement, heavy monsoonal rainfall, and weak subgrade conditions. This study presents a comprehensive geotechnical investigation undertaken to provide reliable design inputs for pavement rehabilitation using Bituminous Macadam (BM) and Bituminous Concrete (BC). Fieldwork included nine boreholes, Standard Penetration Tests (SPT), pavement condition surveys, and the collection of soil samples. Laboratory testing comprised grain size distribution, Atterberg limits, compaction tests, specific gravity, shear strength, and California Bearing Ratio (CBR) analysis. Results indicated a heterogeneous subsoil profile dominated by clayey sands, silty clays, and lateritic soils, with medium to high plasticity and high optimum moisture contents. Soaked CBR values at several locations were below 5%, classifying the subgrade as weak under IRC: 37–2018 guidelines. Structural recommendations include conservative pavement design with thicker sub-base and base layers, pile foundations for bridge locations underlain by weak clays, and enhanced drainage systems to mitigate moisture-related failures. The findings provide critical guidance for designing durable, cost-effective, and sustainable road infrastructure in high-rainfall hilly terrains.*

Key Words: Geotechnical investigation, Subgrade strength, CBR, Pavement rehabilitation

1. INTRODUCTION

Road networks play a vital role in enhancing connectivity, promoting trade, and supporting socio-economic development, particularly in rural and hilly regions. In Kerala, where agriculture and tourism dominate the economy, reliable road infrastructure is essential for the mobility of people and goods. The Karyambadi–Pulpally–Kenichira Road in Wayanad district is a critical corridor linking remote settlements to the state highway network. However, this stretch has undergone significant deterioration over the years due to heavy rainfall, poor drainage, and subgrade failure, resulting in alligator cracking, potholes, and unsafe riding conditions [1], [2].

Conventional overlay or resurfacing methods are inadequate in such terrains, as they do not address the fundamental issue of weak subgrade support. High rainfall in Wayanad, exceeding 6,900 mm annually, causes water ingress, swelling of clayey soils, and erosion of lateritic layers, which accelerate pavement distress (IMD, 2020). Previous studies have demonstrated that road failures in tropical and high-rainfall environments are closely associated with soil plasticity, poor drainage, and inadequate pavement thickness [3]. To ensure durable rehabilitation, it becomes essential to investigate the geotechnical characteristics of the underlying soils and to design pavement and foundation systems based on site-specific data rather than generic assumptions [4], [5].

This study presents the results of a comprehensive geotechnical investigation carried out along an 8.6 km stretch of the Karyambadi–Pulpally–Kenichira Road. Field investigations included borehole drilling, Standard Penetration Tests (SPT), and pavement condition surveys. Laboratory tests determined index properties, compaction behaviour, and California Bearing Ratio (CBR) values. The findings provide critical input for pavement rehabilitation, foundation recommendations for retaining walls and bridges, and drainage design, ultimately ensuring the long-term performance of this vital rural corridor [6],[8].

1.1 Literature Review

The strength and durability of the underlying soils strongly govern the performance of road pavements. Several researchers have highlighted that weak or highly variable subgrades are the primary causes of premature pavement distress. Boboc et al., [3] emphasised the significance of geotechnical investigations in rehabilitation projects, noting that accurate subsurface characterisation is essential for identifying problematic soil layers and determining appropriate structural solutions.

Lateritic and clayey soils, which are widely distributed across tropical regions, have been extensively studied in the context of pavement construction. Amadi et al., [4] investigated lateritic soils in Minna, Nigeria. They concluded that while these soils could provide satisfactory strength when well compacted, their high plasticity and moisture sensitivity often limit performance. Similarly, Olofinyo et al. [5] reported that residual soils in southwestern Nigeria exhibited variable engineering properties, necessitating stabilisation or increased pavement thickness to ensure durability. Studies in India and other tropical regions also highlight the impact of high rainfall on lateritic soils, which tend to soften rapidly under saturated conditions, resulting in reduced California Bearing Ratio (CBR) values and compromised subgrade performance [6].

Moisture ingress and drainage inadequacy have been identified as recurring factors in pavement failures. Fatoba et al. [7] observed that poor drainage and fluctuating groundwater conditions in Ogun State, Nigeria, accelerated subgrade distress, making overlay solutions ineffective. Sandven and Solberg [8] emphasised the importance of integrating geotechnical and geophysical methods to map weak soils and quick-clay deposits in highway projects, thereby underscoring the necessity for thorough subsurface evaluation before pavement rehabilitation.

In the Indian context, the Indian Roads Congress [1]provides CBR-based design guidelines, recommending thicker base and sub-base layers for subgrades with soaked CBR values below 5%. The Kerala PWD Manual [2] similarly stresses soil stabilisation and drainage measures, particularly in hilly terrains where lateritic and clayey soils dominate. With Wayanad receiving over 6,900 mm of rainfall annually (IMD, 2020), the local soils are highly vulnerable to erosion and weakening, which exacerbates pavement deterioration.

In summary, literature indicates that while lateritic soils are commonly used in road construction, their performance is highly dependent on compaction, plasticity, and moisture control. Weak subgrades and poor drainage remain critical challenges in tropical, high-rainfall terrains, underscoring the need for site-specific geotechnical investigations to design sustainable pavement and foundation solutions.

1.2 Methodology

The methodology employed in this project was designed to thoroughly evaluate the subsoil characteristics along the Kakkavayal–Kolavayal–Karyambadi–Kenichira–Pulpally Road in the Wayanad district. The approach consisted of sequential steps involving site inspection, field investigation, laboratory testing, data analysis, and interpretation for design input.

Soil investigation using rotary boring is a systematic process that aims to determine the subsurface characteristics of soil and rock layers to inform design decisions in civil engineering projects. Borehole investigations were conducted at six locations, with predefined intervals of approximately 1.5 meters or at every change in stratum. The drilling process is paused to collect soil samples. Disturbed samples are obtained using split-spoon samplers and stored in labelled bags or containers for laboratory testing. In cohesive soils, undisturbed samples are retrieved using thin-walled Shelby tubes, which allow for more accurate strength and consolidation tests. Simultaneously, in-situ tests such as the SPT are performed within the boreholes.

When hard strata or rock layers are encountered during drilling, rotary coring is employed. A diamond-tipped core barrel cuts through the rock, and the recovered cores are carefully extracted and stored in core boxes. These cores are subsequently analysed for unconfined compressive strength and classified based on factors such as rock type, degree of weathering, and the presence of fractures. Throughout the investigation, the depth of the groundwater table is monitored by observing water inflow into the borehole.

To investigate the pavement structure more closely and collect representative samples for testing, trial pits measuring 1.0 m × 0.60 m were excavated, with half of the pit extending onto the carriageway and the other half into the shoulder. The pits were dismantled carefully to expose the full depth of the pavement, enabling a clear identification of individual layers and their thicknesses. Disturbed soil samples required for the CBR test were then collected from the exposed subgrade levels, typically between 0.5 m and 1.0 m depth, since this is the critical layer that supports pavement loads. Sampling was conducted using hand shovels, augers, or split-spoon samplers, depending on the field conditions. Care was taken to ensure that the collected samples were free from biological matter, oversized particles, and debris, so that they accurately represented the in-situ subgrade material. Immediately after collection, the soil was placed in clean, airtight polythene bags or sealed containers to minimise changes in natural moisture content and density. Every sample was cautiously named with details such as location, chainage, depth, trial pit or borehole number, and date of collection, ensuring traceability and reliability during subsequent testing. These soil samples were later conveyed to the laboratory for determining engineering properties, with a particular focus on the CBR test, which provides vital input for evaluating subgrade strength and planning pavement rehabilitation strategies.

The tests conducted on disturbed and undisturbed soil samples include:

1. Grain Size Distribution (Sieve Analysis)
2. Atterberg Limits – including:
   a. Liquid Limit (LL)
   b. Plastic Limit (PL)
   c. Plasticity Index (PI = LL – PL)
3. Moisture Content
4. Bulk Density and Dry Density.
5. Specific Gravity of Soil Particles.
6. Shear Strength Characteristics.
7. California Bearing Ratio (CBR) Test.
8. Proctor Compaction Tests –
   a. Standard Proctor Test
   b. Modified Proctor Test

Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).

Tests were conducted on soil samples from the pit in accordance with the relevant Indian Standard specifications. All procedures followed the guidelines outlined in SP: 36 (Part-1), 1987, of the Bureau of Indian Standards (BIS), ensuring the reliability and consistency of the results. These tests provided essential information on the physical and chemical properties of the soils, forming a critical basis for evaluating their suitability for pavement and foundation design

2. RESULTS AND DISCUSSIONS

The subsurface data across the investigated 8.6 km corridor indicate a heterogeneous profile dominated by clayey sands (SC), silty clays (CI/MH) and lateritic horizons, with intermittent weathered/hard rock at shallow to moderate depths (refusal depths and measured UCS values). Standard Penetration Test (SPT) ‘N’ values and laboratory index tests reveal a broad range of engineering behaviour, from very soft/low-strength fine-grained layers to medium–dense sandy units and competent rock (UCS: 41–55 N/mm^2, recorded at different boreholes). The dataset includes borehole logs and index-property tables, grain-size curves, and Atterberg limits as given in Tables 1 and 2. The compaction results (MDD/OMC) and soaked CBR test results are presented in Table 3, Chart 1 and Chart 2. The soil samples collected from the borehole are given in Figure 1.

Fig-1: Soil samples collected from the hole

Table -1: Soil type and Atterberg limits of collected samples

Borehole	"N" Value	Depth in m	Type of Sample	Description of soil	Natural water Content (%)	IS Classification	LL %	PL %	Plasticity index
BOREHOLE 1	2	1.00	DS	Clayey Sands - (with Gravel) Laterite - Yellowish Red	26	SC	-	-	--
	>50	2.00	DS	Inorganic Clays, Silty Clays	32	CI	-	-	-
	-	2.30	Without Sample						
	9	3.00	DS	Clayey Sands-Fine Sand	18	SC	-	-	-
		3.90	SOFT ROCK						
		7.90	HARD ROCK						
BORE HOLE 2	"N" Value	Depth in m	Type of Sample	Description of soil	Natural water Content (%)	IS Classification	LL %	PL %	Plasticity index
	02	1.00	DS	Clayey Sands	22	SC	-	-	-
	02	2.00	DS	Clayey Sands	27	SC	-	-	-
	>50	3.00	DS	Clayey Sands - (with Gravel) Laterite - Yellowish Brown	18	SC	-	-	
			Hard Rock			Unconfined Compressive Strength- 49 N/mm^2			
BORE HOLE 3	"N" Value	Depth in m	Type of Sample	Description of soil	Natural water Content (%)	IS Classification	LL %	PL %	Plasticity index
	2	1.00	DS	Inorganic clay- Silty Clay	36	CI	29	20	9

BORE HOLE 5	BORE HOLE 4								
"N" Value		>50	10	"N" Value	-	>50	25	-	1
Depth in m		1.50	1.00	Depth in m	6.6	5.50	4.00	2.80	2.00
Type of Sample	Hard Rock	SPT-REBOUNDED	DS	Type of Sample	SPT-REBOUNDED	DS	DS	SPT-REBOUNDED	DS
Description of soil			Clayey Sands - Laterite Yellowish Brown	Description of soil			Clayey Sand -Fine sand		Inorganic clay- Silty clay
Natural water Content (%)		Without Sample	20	Natural water Content (%)	Without Sample	Poorly graded Sand with weathered soil	21	Without Sample	29
IS Classification	Unconfined Compressive Strength- 49 N/mm²		SC	IS Classification		21	SC		CI
LL %			-	LL %		SP/SM	-		29
PL %			-	PL %		-	-		20
Plasticity index			-	Plasticity index		-	-		9

BORE HOLE 6						
-	"N" Value	-	>50	21	-	9
1.00	Depth in m	4.70	4.50	3.00	2.00	1.00
SPT- REBOUNDED	Type of Sample	HARD ROCK	DS	DS	SPT-REBOUNDED	DS
Without Sample	Description of soil			Clayey Sands -(with Gravel) Laterite - Yellowish Brown		Inorganic silts of High Plasticity - Laterite - Brownish Yellow
22	Natural water Content (%)	Unconfined Compressive Strength- 55 N/mm²	Clayey Sands -(with Gravel) Laterite - Yellowish Brown	24	Without Sample	22
SC	IS Classification		22	SC		MH
-	LL %		SC	35		53
-	PL %		31	22		31
-	Plasticity index		20	13		22

	10	2.00	DS	Inorganic clays, Silty Clays of Medium Plasticity-Yellow	27	SC	-	-	-
	>50	3.00	DS	Clayey Sands	18	SC	-	-	-
		3.10	Hard Rock			Unconfined Compressive Strength- 41 N/mm²			

Table -2: Grain Size distribution and properties of soil samples

BH No:		BORE HOLE 1				BORE HOLE 2		
Depth in m		1	2	2.3	3	1	2	3
Grain size distribution % of	58	56	-	-	38	39	40	40
	85	86	-	-	86	90	72	72
	100	100	-	-	100	99	90	90
Specific gravity		2.5	2.6	-	-	2.6	2.6	2.6
Bulk Density g/cm²		0.0015	0.0015	-	-	0.0016	0.0016	0.0015
Cohesion c kg/cm²		-	0.04	-	-	-	-	-
Angle of internal friction ø		6	29	-	-	5	15	34
BH No:		BORE HOLE 3				BORE HOLE 4		
Depth in m		1	2	2.8	4	1	1.5	1
Grain size distribution % of retention	57	58	-	40	50	-	57	40
	83	83	-	83	55	-	83	72
	96	98	-	100	100	-	96	90
Specific gravity		2.5	2.4	-	2.6	2.7	-	2.5
Bulk Density g/cm²		0.0016	0.0014	-	0.0015	0.0014	-	0.0016
Cohesion c kg/cm²		0.05	0.02	-	0.08	0.05	-	0.05
Angle of internal friction ø		5	2	-	24	11	-	5
BH No:		BORE HOLE 5				BORE HOLE 6		
Depth in m		1	2	3	4.5	1	2	3
Grain size distribution % of	59	-	34	42	56	38	56	40
	84	-	40	46	96	93	96	72
	98	-	26	12	100	100	100	90
Specific gravity		2.4	-		2.5	2.5	2.4	2.5
Bulk Density g/cm²		0.0015	-	0.0014	0.0014	0.0014	0.0014	0.0014
Cohesion c kg/cm²		0.12	-	0.07	0.05	0.05	0.07	0.05
Angle of internal friction ø		12	-	24	32	10	32	10

The uppermost 0–3 m is commonly clayey sand or lateritic crust; pockets of inorganic silts/high-plasticity clays (MH/CI) occur at shallow depths in some boreholes. Several boreholes encountered weathered to hard rock between ~3–8 m; reported unconfined compressive strengths (UCS) for hard rock range from 41 to 55 N/mm², indicating generally competent rock for socketing piles. Recorded SPT N-values span very low (N approximately from 1–5) in soft clay/silt zones to moderate/high (N > 20) in dense sand/weathered zones; several re-bounded/refusal readings indicate rock. This contrast demonstrates alternating weak and competent layers within short vertical distances, which is a key design concern for both pavement support and foundations.

Liquid limits recorded in boreholes range from about ~29% up to 53%, with plasticity indices commonly in the ~7–22% range (e.g. BH-5: LL ≈ 53%, PI ≈ 22%). These values indicate medium to high plasticity in several fine-grained deposits, with correspondingly higher susceptibility to volume changes (shrinkage–swelling) and reduced bearing capacity when saturated. Grain-size curves show dominance of sand fractions in many samples (sand > fine fractions in clayey-sand layers) but significant fines in silty/clayey units. The mixed texture explains the variable SPT/C.W. (consistency) results. High LL and PI in near-surface layers indicate a potential for swelling and strong moisture sensitivity; granular sandy bands are locally favourable but discontinuous. Pavement subgrade behaviour will therefore vary along the alignment, as some stretches will be highly compressible/weak when wet, while others will be reasonably stable.

Table -3: California Bearing Ratio test

Sample ID	Test	Test Result	Test Method
I	MDD, (Maximum Dry Unit Weight)	1.66 g/cm³	IS-2720 Part-7-2020
	OMC %	21	IS-2720 Part-2-2020
	CBR at 100% MDD	4	
II	MDD, (Maximum Dry Unit Weight)	1.87 g/cm³	IS-2720 Part-7-2020
	OMC %	16	IS-2720 Part-2-2020
	CBR at 100% MDD	9	IS 2720-16-1987

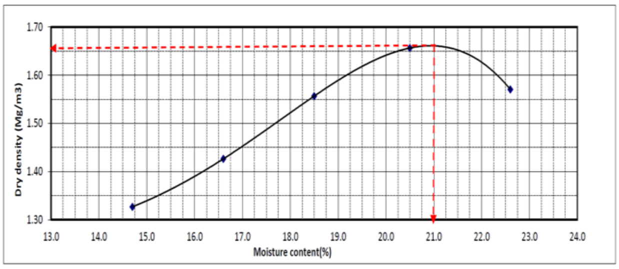

Chart -1: Dry Density v/s Moisture content for Sample I

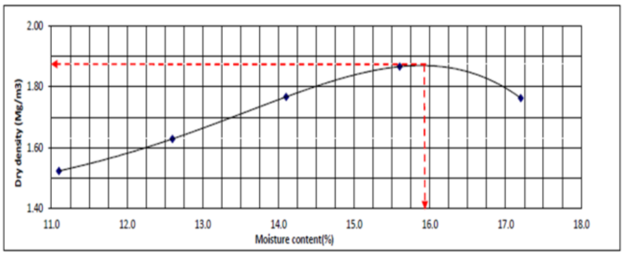

Chart -2: Dry Density v/s Moisture content for Sample II

Modified Proctor results for representative samples indicate MDD values of ~1.66–1.87 g/cm^3, with OMC ≈ ranging from 16% to 21%. Higher MDD correlates with higher CBR in the provided samples (1.87 g/cm^3 → 9% CBR versus 1.66 g/cm^3 → 4% CBR), showing typical dependence of stiffness/CBR on compaction. Nonetheless, even the better sample (CBR ≈ 9%) is marginal for base support; several locations are well below the acceptable base design thresholds, especially under soaked conditions.

3. CONCLUSIONS

The findings revealed that the subsoil profile varies significantly across the alignment. Predominantly, the soil is composed of silty clays and clayey sands, with occasional gravelly layers and weathered rock strata at deeper levels. The Atterberg limit tests presented that the fine-grained soils have medium to high plasticity, indicating moderate swelling and shrinkage tendencies, which can adversely affect subgrade stability under fluctuating moisture conditions. The results of the compaction test exposed that the soils achieve a moderate MDD while requiring a relatively high OMC. This shows that the soils have a behaviour to retain water and are prone to volume changes when exposed to variations in moisture.

The SPT N-values recorded across the boreholes highlighted variability in soil consistency, ranging from soft to medium stiff in clayey zones and medium dense to dense in sandy strata. At specific depths, refusal was encountered, confirming the presence of highly weathered rock and bouldery strata. These outcomes propose that while specific stretches are underlain by competent material suitable for shallow foundations, other stretches will require strengthening measures before they can safely sustain design traffic loads.

The CBR test results, which form the cornerstone of pavement design, indicated relatively low subgrade strength, especially under soaked conditions. Soaked CBR values in several test locations were below 5%, which falls within the weak subgrade category as per IRC:37–2018 recommendations. This reinforces the need for adequate pavement thickness and the provision of well-draining sub-base and base layers to prevent premature failures such as rutting, cracking, and potholing. Furthermore, the presence of a high groundwater table at some locations necessitates careful drainage design, including side drains, cross-drainage structures, and subsurface drains in critical stretches.

REFERENCES

[1] Indian Roads Congress (IRC:37–2018). Guidelines for the Design of Flexible Pavements. New Delhi: IRC.

[2] Kerala Public Works Department (2019). Kerala PWD Manual – Roads and Bridges. Government of Kerala.

[3] Boboc, V., et al. (2017). Site Soil Investigations for Road Rehabilitation. Procedia Engineering, 189, 304–311.

[4] Amadi, A. N., et al. (2015). Assessment of Geotechnical Properties of Lateritic Soils in Minna, North Central Nigeria for Road Design and Construction. Journal of Geotechnical and Geological Engineering, 33, 125–135.

[5] Olofinyo, O. O., et al. (2019). Engineering Properties of Residual Soils in Southwestern Nigeria: Implications for Road Foundation. Environmental Earth Sciences, 78, 507.

[6] Umar, I. H., et al. (2024). Soil Characterisation and CBR Modelling for Road Subgrades: A Case Study of Yobe

State, Nigeria. International Journal of Pavement Engineering.

[7] Fatoba, J. O., et al. (2015). Influence of Subgrade Properties on Pavement Failures in Ogun State, Nigeria. Construction and Building Materials, 94, 640–647.

[8] Sandven, R., Solberg, I.-L. (2014). Geophysical and Geotechnical Investigations for a Major Highway in a Quick-Clay Area. Engineering Geology, 181, 15–27.

[9] Indian Meteorological Department (IMD, 2020). Annual Climate Summary for Kerala.

[10] IRC: SP:72–2015. Guidelines for the Design of Flexible Pavements for Low Volume Rural Roads.