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Original Article

Development of Unpaved Road Maintenance Management Strategy for Earth Reinforcement Using Fibre Geotextile and Cohesive Soil for Sandy Subgrade Improvement: A Case Study of Lindi District

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Unpaved Roads, Sandy Subgrade, Fibre Geotextile, Cohesive Soil, Subgrade Reinforcement, Lindi District, Road Maintenance Strategy, Earth Reinforcement

ABSTRACT

Unpaved rural roads in Lindi District suffer from poor performance due to weak sandy subgrades with low cohesion and high erosion risk, especially in coastal areas. Traditional stabilisation using cohesive soils has proven insufficient for long-term durability. This study aimed to develop a sustainable maintenance strategy by reinforcing sandy subgrades with cohesive soil and fibre geotextile. This study used an experimental research design to develop a cost-effective unpaved road maintenance strategy by stabilising overburden sandy subgrades with fibre geotextiles and cohesive soil in Lindi District, Tanzania. Through field sampling and laboratory testing, including CBR, UCS, Proctor compaction, and Atterberg limits, the study found that blending 30–45% cohesive soil with sand improved strength, moisture retention, and workability. Adding fibre geotextile further enhanced compressive strength, load distribution, and deformation resistance, with CBR values increasing from 3% to 14%. Based on these results, a maintenance strategy was proposed focusing on material selection, application methods, and performance monitoring. The study recommends that TARURA and TANROADS adopt this approach and implement a 250-meter trial section. Additional recommendations include training for engineers, preventive maintenance budgeting, and regular performance assessments. The findings offer a practical, cost-effective solution to improve the strength and durability of unpaved roads in sandy soil regions.

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INTRODUCTION

Rural earth roads in Tanzania, particularly in Lindi District, face persistent challenges related to the instability of sandy subgrades. These subgrades are inherently weak due to their low cohesion, high permeability, and vulnerability to erosion, especially in regions prone to fluctuating moisture levels and heavy rainfall (Ranjan & Rao, 2017). Such conditions significantly compromise the structural integrity and load-bearing capacity of roads, resulting in frequent deformation and high maintenance demands. The reliability of rural transport networks is vital for supporting socio-economic activities, especially in agricultural regions like Lindi, where communities depend on consistent road access for trade, health services, and education (Moghal et al., 2019).

Historically, the stabilisation of sandy subgrades has relied on the use of cohesive soils such as clay. These materials can improve subgrade strength by increasing cohesion and reducing permeability, thereby limiting erosion and deformation under loading conditions (Kumar, 2018). However, in coastal regions like Lindi, where water tables fluctuate and intense rainfall is common, cohesive soils can become saturated and lose their strength. Furthermore, the acquisition and transportation of cohesive soils pose logistical and environmental challenges, often increasing the cost and complexity of rural road maintenance (URT, 2020).

In response to these limitations, recent advancements in geosynthetic technology have introduced fibre geotextile materials as promising alternatives for subgrade stabilisation. Fibre geotextiles are synthetic polymeric products engineered to perform various geotechnical functions, including reinforcement, filtration, drainage, and separation (Chatrabhuj & Meshram, 2024). When used in road construction, they can significantly enhance load distribution, reduce settlement, and improve water management by acting as a barrier between subgrade layers. These properties are particularly beneficial in sandy soils, where managing erosion and deformation is critical to maintaining road performance over time (Gordon, 2017).

While the use of fibre geotextiles in civil engineering has gained popularity globally, their application in Tanzania, especially in rural and coastal contexts, remains limited and under-researched. Most existing studies have focused on urban applications or different soil types, leaving a gap in the understanding of their effectiveness in stabilising sandy subgrades in rural areas like Lindi (Hernandez, 2022). Moreover, comparative studies between fibre geotextile and traditional cohesive soil stabilisation methods are scarce, making it difficult for engineers and policymakers to make informed decisions on the most cost-effective and sustainable practices.

The Tanzania Rural and Urban Roads Agency (TARURA), which oversees the maintenance of over 100,000 kilometres of rural and urban roads, has acknowledged the challenges posed by poor

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subgrade conditions, lack of suitable construction materials, and funding constraints (TARURA, 2023). Despite the agency's efforts to implement routine maintenance and adopt technologies such as the District Roads Management System (DROMAS), issues such as erosion, road deformation, and limited access to durable materials continue to undermine the quality and longevity of rural roads (Kassim, 2022). The situation in Lindi, where sandy soils dominate the landscape, reflects the national struggle to implement sustainable road infrastructure solutions in rural areas.

Research Objectives

This research aimed to achieve the following objectives:

- To evaluate the properties of sandy soil, cohesive soil, and fibre geotextiles.
- To develop an unpaved road maintenance management performance strategy for earth reinforcement using fibre geotextile and cohesive soil for sandy subgrade improvement.
- To analyse and compare the cost-effectiveness of both methodologies for maintenance management.

This study evaluates and compares the performance of fibre geotextile materials and cohesive soil in stabilising sandy subgrades in Lindi District. Through a detailed analysis of load-bearing capacity, moisture retention, deformation characteristics, and erosion resistance, the research provided empirical evidence to support improved rural road maintenance strategies. The findings aim to inform engineers, planners, and policymakers about the viability of integrating fibre geotextiles into road projects, ultimately contributing to more resilient and sustainable infrastructure in Tanzania's rural coastal regions.

LITERATURE REVIEW

The stabilisation of sandy subgrades, particularly in rural coastal regions such as Tanzania's Lindi District, has been the subject of growing research interest due to the significant challenges these soils pose in road infrastructure development. Sandy soils are characterised by weak structural properties, poor water retention, high permeability, and extreme sensitivity to compaction, which collectively compromise the stability and durability of unpaved roads (Bruand, 2019; Osunbitan, 2005). These properties result in low load-bearing capacity, especially under variable moisture conditions common in coastal environments. Research shows that pure sands lose water rapidly as potential decreases, with coarser sands losing moisture at pressures between -0.1 and -1 kPa, and finer sands at pressures as low as -30 kPa (Panayiotopoulos, 1985). This hydraulic behaviour, along with low penetration resistance and ease of deformation, makes sandy soils unsuitable in their natural state for road subgrades.

Cohesive soils, especially clay-based, improve sandy subgrades by increasing strength and water retention but can degrade with moisture changes, causing shrinkage and erosion (Mitchell, 2005; Ranjan, 2017; Moghal, 2019). Fibre geotextiles, synthetic fabrics, reinforce soil, improve load distribution, and aid drainage while preventing erosion by retaining soil particles, making them effective for sandy, moisture-sensitive roads (Bhatia, 2018; Zhao, 2021; EcoGeoX, 2023). The performance of these materials under field conditions is also influenced by their degradation properties. Fibre geotextiles may be subject to physical, chemical, and biological degradation from factors such as UV exposure, microbial attack, and mechanical damage during installation or use. However, with proper selection and design, they can exhibit high endurance properties such as abrasion resistance, elongation, and clogging resistance, ensuring long-term functionality in road systems (EcoGeoX, 2023). These features make them

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particularly promising for unpaved road reinforcement, where long-lasting performance with minimal maintenance is desired.

In the context of road maintenance, a strategic approach to managing subgrade stability is crucial. Maintenance strategies can be broadly classified into preventive and corrective maintenance. Preventive strategies aim to address minor defects and delay deterioration, while corrective measures are implemented to fix critical failures and restore serviceability (Mohamed, 2005; BSI, 2010). Incorporating fibre geotextile materials and cohesive soils into maintenance strategies offers the potential for durable, cost-effective solutions. Studies have shown that the integration of these materials can increase bearing capacity, enhance resistance to water infiltration, and improve deformation behaviour under traffic loads (Ramanatha, 1988; Freitag, 1986; Subbarao, 1987). For instance, fibre reinforcement has been found to increase cohesion while slightly reducing the angle of internal friction, an indication of its ability to transform the mechanical behaviour of soil composites (Setty, 1987).

Research Gap

Research on the combined and individual effectiveness of fibre geotextiles and cohesive soils in sandy subgrades is limited, especially under real rural conditions, with most studies confined to labs lacking field validation (Sridharan, 2020). This gap is critical for areas like Lindi District, where soils are silty and erosion-prone (Mlingano Agricultural Research Institute, 2006). Despite TARURA and PO-RALG prioritising rural road upgrades, there is little guidance on integrating these materials into national frameworks (TARURA, 2023). Field studies are needed to assess engineering, economic, and environmental impacts under local conditions and improve Pavement Management Strategies (Johnson, 2017; Heine, 2006). Using fibre geotextiles with cohesive soil shows promise but requires more research to adapt to local rural sandy subgrades like those in Lindi District.

RESEARCH METHODOLOGY

This study used an experimental research design to develop a cost-effective unpaved road maintenance strategy by stabilising overburden sandy subgrades with fibre geotextiles and cohesive soil in Lindi District, Tanzania. Soil samples were collected from Kiwalala Village, an area prone to road failure due to poor subgrade conditions. Fieldwork involved excavating test trenches and sampling both sandy and cohesive soils, while fibre geotextile was sourced from NABAKI AFRIKA. Laboratory tests evaluated soil and geotextile properties, including CBR, swelling, permeability, and tensile strength. Data analysis compared untreated, cohesive-stabilised, and geotextile-reinforced samples, focusing on load-bearing capacity, deformation, moisture retention, and erosion resistance. Results supported the development of a sustainable maintenance strategy for unpaved roads in similar coastal environments.

RESULTS AND ANALYSIS

Laboratory Test for Sand Soil, Cohesion Soil, and Fibre Geotextile

Data collection for this research was divided into different stages. Soil samples were selected for sand, cohesive soil, and fibre geotextile.

Relevant Codes and Specifications Applied

a) Central Material Laboratory Testing Manual (CML)

b) Tanzania Standard Specification for Road works (2000)

(Section 4200, Bituminous Base Course and Asphalt Concrete Surfacing)

c) American Association of State Highway and Transportation Officials (AASHTO)

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d) American Society for Testing and Materials (ASTM)

e) British standards.

Test Methods

Sand Soil

Test methods for sand involved characterising its physical and mechanical properties in order to determine its suitability for the construction of an unpaved road. Sand test methods were classified based on laboratory tests, which were:

Determination of Sieve Analysis test

Title: Soil Gradation Test

Aim: To assess the particle size distribution of sand

Apparatus: Electronic balance, set of BS, sieves and pan

Material: sand soil

Method: the procedure involved preparation of the sample by wet sieving to remove silt and clay-sized particles, followed by dry sieving of the remaining coarse material. The mass of the sample was accurately determined. A stack of sieves having larger opening sizes was placed above the ones having smaller opening sizes. A pan was placed under the last sieve to collect the portion of aggregate passing through it. At the end, the mass of each sieve retained material was measured.

Conclusion: The Results obtained showed the particle size distribution of all sand sizes. Test results for the sieve analysis test, which determine the sand grading for all sand sizes.

Table 1: Laboratory Test Results for Analysis of Sand Soil

	Chainage	**km**				**Spec**
Sieve size	**0+020**	**0+250**	**0+500**	**0+750**	**1+000**	
37	100	100	100	100	100	100
28	100	100	100.0	100	100	100
20	100	100	100.0	100	100	94 -100
14	100	100	100.0	100	100	47.3-74.1
10	100	100	100	100	100	29.4-54.9
5	100	100	100	100	100	12.8-31.2
2.36	100	99.2	98.6	100	99.9	7.0 - 20
1.18	96.3	98.6	93.4	91.4	96.4	6.3 - 16
0.6	72.5	72.5	81.7	85.6	80.7	6 - 14
0.425	48.6	52.4	60.3	58.1	66.3	6-13
0.3	48.6	32.6	41.3	31.4	46.3	5 - 12
0.15	18.4	21	2.3	21.8	31.6	4 - 8
0.075	14.6	18.7	15.7	16.9	19.7	2 - 6

California Bearing Ration (CBR)

Title: Soil Gradation Test

Aim

- To determine the load-bearing capacity of soil
- To assess the suitability of the material for use in pavement subgrade

Apparatus: CBR mould assembly, loading machine, and dial gauge

Material: Soil sample

CBR value is the resistance to a penetration of 2.5 mm of a standard cylindrical plunger of 50 mm diameter, expressed as a percentage of the known resistance of the plunger to 2.5 mm .in

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Method: A Soil sample was prepared through a 20 mm sieve. Optimum moisture content was determined using a proctor compaction test. The soil was compacted into a CBR mould in layers, each layer being compacted to a standard of blows. The sample was soaked for 4 days to stimulate moisture conditions. After soaking, the plunger of 50mm diameter was penetrated into the soil at a rate of 1.25mm/min. Loading readings were recorded at standard penetration (2.5mm and 5.0 mm).

$$\text{CBR} = \left(\frac{\text{Measured load}}{\text{Standard load}}\right) \times 100$$

Table 2: Laboratory Test results for the CBR Test for Sand Soil

		A			B	C	D=C-B	E
S/N	Chainage Km	Chainage	Depth (mm)	Location side	CBR %	Average %	Difference %	CUSUM
1	0+020	0	200-800	LHS	13	14.80	1.8	1.8
2	0+0250	0.25	200-800	RHS	16	14.80	-1.2	0.6
3	0+500	0.5	200-800	LHS	16	14.80	-1.2	-0.6
4	0+750	0.75	200-800	RHS	15	14.80	0.2	-0.8
5	1+000	1	200-800	LHS	14	14.80	0.8	0.0
AVERAGE	**14.8**							

Figure 1: Presentation of CBR Test Results for Sand Soil from Sections 1 and 2

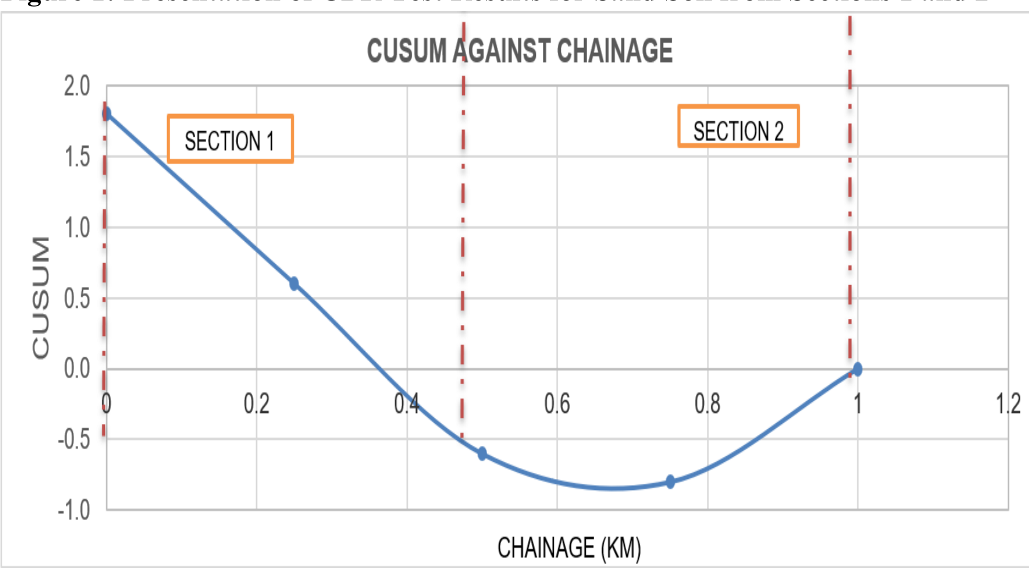

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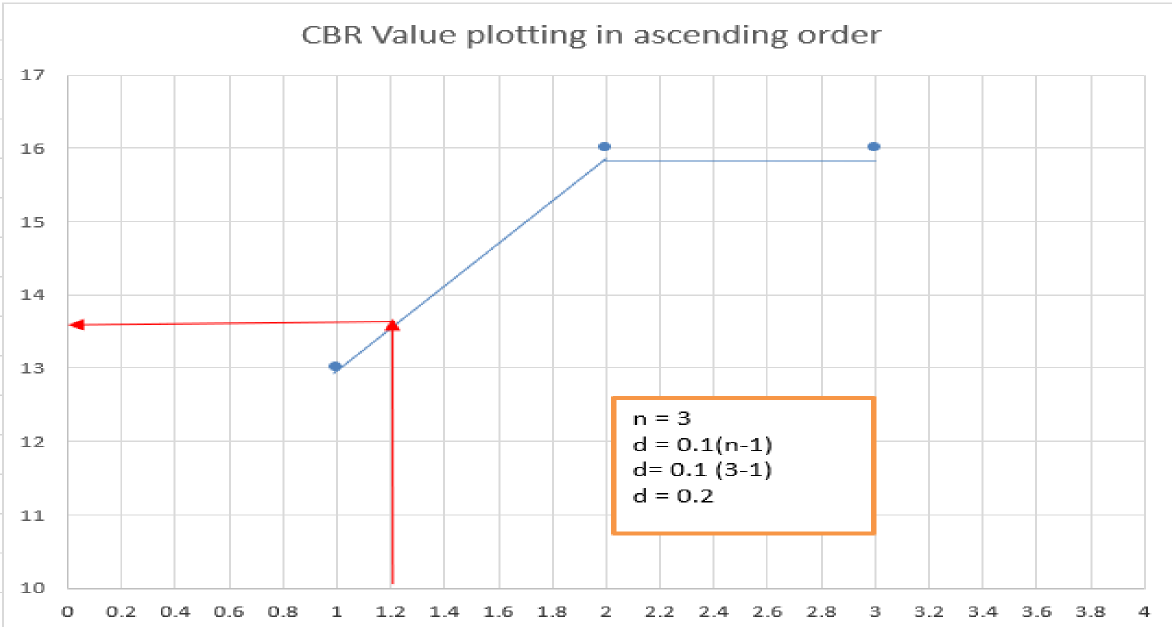
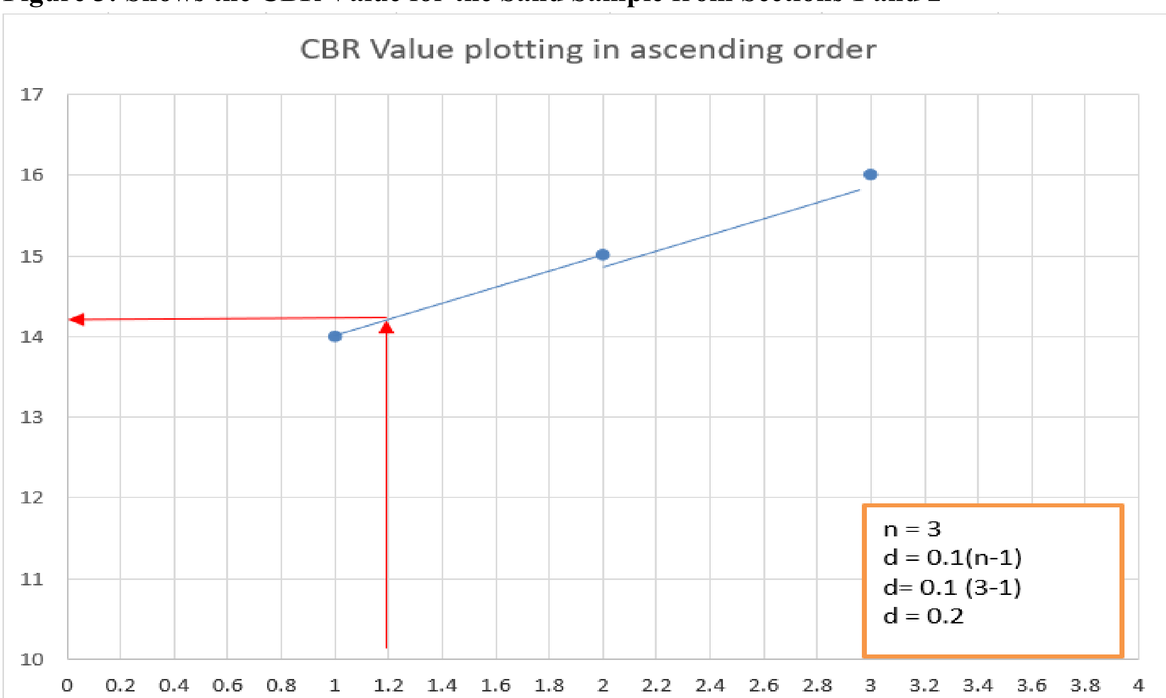
Figure 2: Presentation of CBR Test Results for Sand Soil from Section 1



90% -ile = 13.6

CBR design value = 14%

Figure 3: Shows the CBR Value for the Sand Sample from Sections 1 and 2



90% -ile = 14.2

CBR design value = 14%

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Table 3: Shows the Designed CBR of Subgrades for Sections 1 and 2

CHAINAGE				
SECTION	FROM	TO	DESIGN CBR	SUBGRADE CLASS
1	0+000	0+500	14	S7
2	0+500	1+000	14	S7

Cohesion Soil

Test methods for sand involved characterising its physical and mechanical properties in order to determine its suitability for the construction of an unpaved road. Sand test methods were classified based on laboratory tests, which were

Determination of Sieve Analysis test

Title: Soil Gradation Test

Aim: To assess the particle size distribution of sand

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Method: the procedure involved preparation of the sample by wet sieving to remove silt and clay-sized particles, followed by dry sieving of the remaining coarse material. The mass of the sample was accurately determined. A stack of sieves having larger opening sizes was placed above the ones having smaller opening sizes. A pan was placed under the last sieve to collect the portion of aggregate passing through it. At the end, the mass of each sieve retained material was measured.

Conclusion: The Results obtained showed the particle size distribution of all sand sizes.

Table 4: Test Result for Sieve Analysis Test, which Determines Sand Grading for All Sand Sizes

Sieve size	**Mass Retained**		**Percentage Retained**	**% Passing P_p**
Mm	**Actual**	**Corrected(M)**		
100	-	-	-	100
75	-	-	-	100
63	-	-	-	100
50	-	-	-	100
37.5	-	-	-	100
28	-	-	-	100
20	-	-	-	100
14	0.0	-	0.0	100.0
10	0.0	-	0.0	100.0
6.3	0.0	-	0.0	100.0
5.00	0.0	-	0.0	100.0
3.35	0.6	10.8	0.4	99.6
2.0	2.2	39.6	1.4	98.2
1.18	6.2	111.7	3.9	94.3
0.60	27.2	489.9	17.3	77.0
0.425	51.3	923.9	32.9	44.3
0.300	96.8	1743.4	61.6	-17.2
0.212	122.6	2208.0	78.0	-95.2
0.150	83.2	1498.4	52.9	-148.2
0.075	81.2	1462.4	51.7	-199.8
Passing 75 µm	10.8	194.5	6.9	
Total (checked with M4)		**482.10**		
Grading Modulus	GM	**3.6**		
Grading Coefficient	GM	**55.7**		

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Figure 4: Shows the Percentage Passing against the Particle Size Distribution of Soil

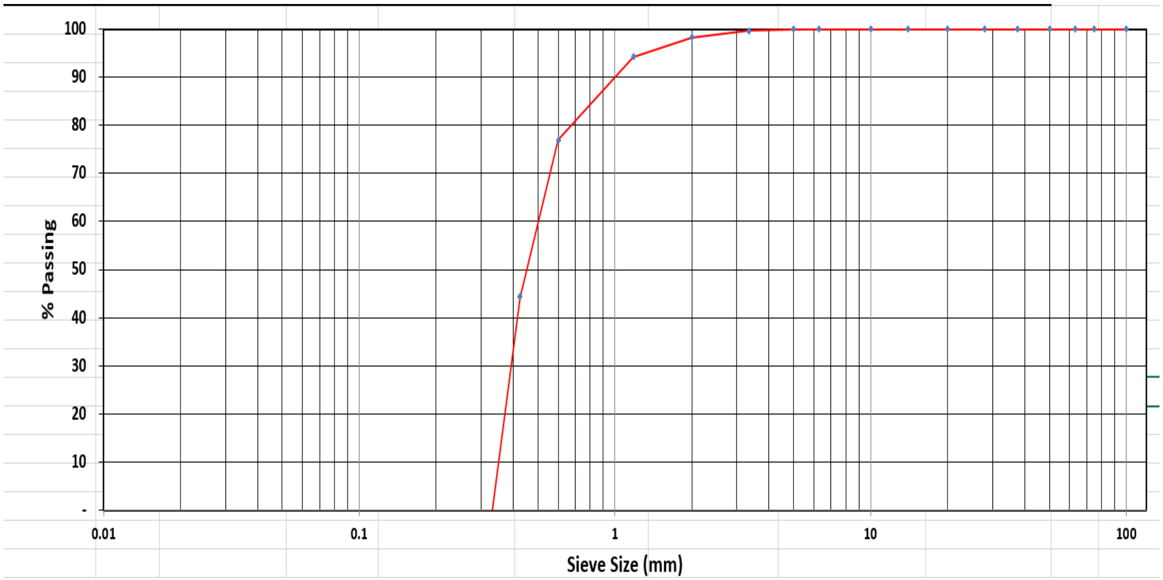

Table 5: Shows the Liquid Limit and Plastic Limit of the Soil

Property			**LIQUID LIMIT**				**PLASTIC LIMIT**
TEST NO.	1	2	3	4	1	2	**Average**
Initial gauge reading (mm)	0 0	0 0	0 0	0	0	0	0 0 0
Final gauge reading (mm)	16.23 22.33	16.11 22.25	16.05 18.21 22.36	18.24	18.42	20.24	20.32 20.13
Average penetration (mm)	16.1	18.3	20.2	22.3			
Container No:	L02	C01	C13	AR	T11		T4
A) Mass of wet soil + container (g)	71.4	84.0	85.2	80.2	31.5		31.4
B) Mass of dry soil + container (g)	56.2	64.3	64.5	60.5	27.2		27.2
C) Mass of container (g)	20.9	20.9	20.8	20.7	13.20		13.0
D) Mass of moisture (A-B) (g)	15.2	19.7	20.7	19.7	4.30		4.20
E) Mass of dry soil (B-C) (g)	3530	43.40	43.70	39.80	14.00	14.20	
Moisture content (W_N = 100×D/E) %	43.1	45.4	47.4 **30.1**	49.5	30.71		29.58

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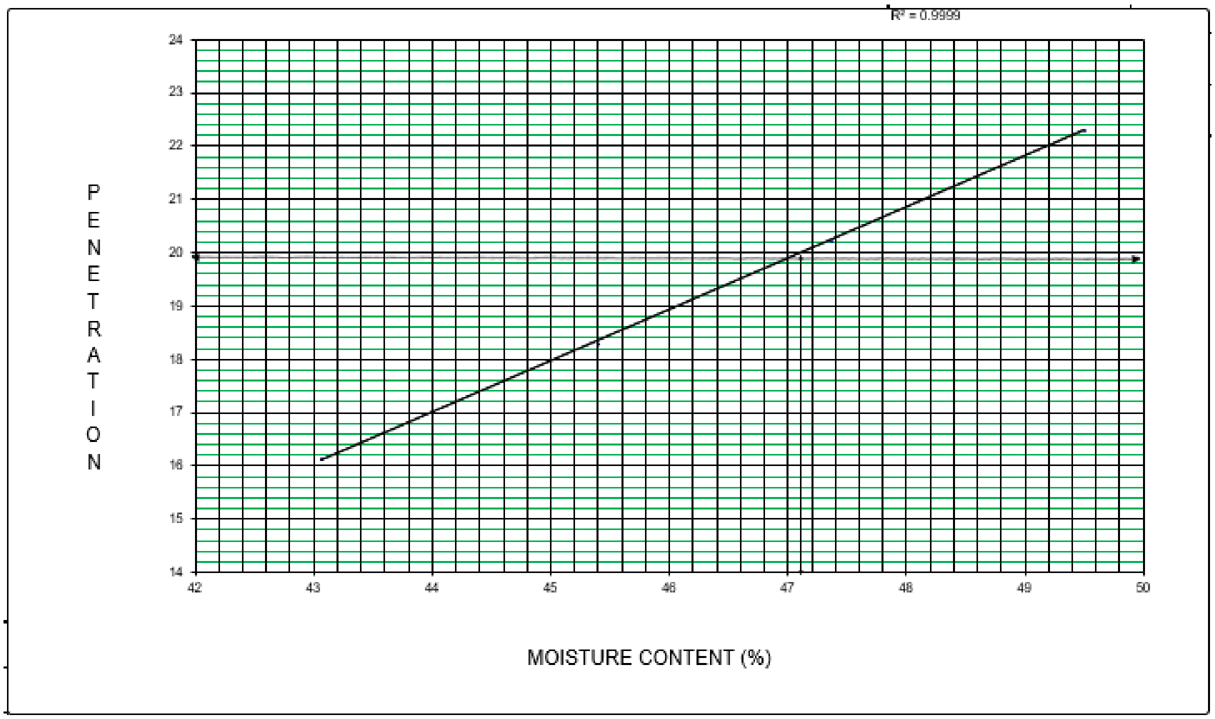
Table 6: Linear Shrinkage and Shrinkage Product

Specimen reference	E	
Initial length Lo	Mm	140.0
Oven-dried length LD	Mm	128.0
Linear Shrinkage, LS = 100(1-LD/LO)	%	8.6
Shrinkage Product, SP = LS x % < 425mm		380
Plasticity index, Piw = (PI x % < 425mm)/100		7.5

Figure 5: Show Penetration against Moisture Content for Cohesive Soil



Test Results

Table 7: Show Plasticity and Linear Shrinkage for Cohesive Soil

% < 425mm Sieve	44.3 %
Liquid Limit, LL	47.1%
Plastic Limit, PL	30.1
Plasticity Index, PI	17
Linear Shrinkage, LS	8.6%

Proctor Test

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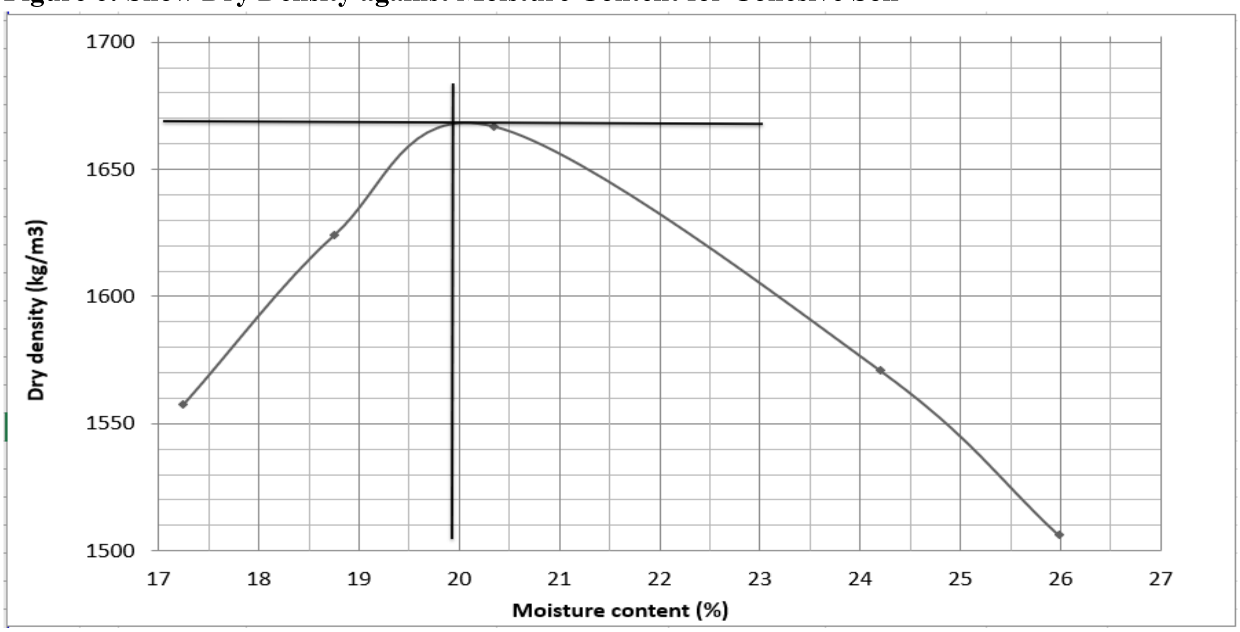
Table 8: Laboratory Test Results for the Proctor Test of Cohesive Soil

Test Method: Standard/ Modified		**No. of Blows/Layer:**			**No. of Layers:**		
Test No.	1	2	3	4	5		
No of blows	27	27	27	27	27		
No of Layers	5	5	5	5	5		
Mould No.	14	14	14	14	14		
Water Added %	8%	10%	12%	14%	16%		
Mass of Mould MM	1914.0	1914.0	1914.0	1914.0	1888.1		
Weight of Mould + Sample (g)	3731.2	3833.0	3910.0	3855.4	3802.1		
Mass of Wet Sample, MWS (B-A) (g)	1817.2	1919.0	1996.0	1941.4	1888.1		
Wet Density, (C/E) (kg/m3)	1826	1920	2006	1951	1898		
Volume of Mould: VM (cc)	995					NMC	
Moisture Container No.	T13	NX	Q	C11	D15	L02	D2
Weight of Container (g)	20.00	20.20	20.00	20.20	20.20	20.20	20.00
Weight of Container + Wet Soil (g)	94.10	92.40	82.10	90.00	109.90	85.40	81.80
Weight of Container + Dry Soil (g)	83.20	81.00	71.0	7.40	91.40	78.80	76.20
Weight of Water, (G - H) (g)	10.9	11.4	10.5	13.6	18.5	6.6	5.6
Weight of Dry Soil, (H - F) (g)	63.2	0.8	51.6	56.2	71.2	58.6	56.2
Moisture Content, Wi = (100 x J / K) (%)	17.2	18.8	20.3	24.2	2.0	11.3	10.0
Dry Density, DD (100 x D / 100 + Wi) (kg/m3)	1558	1624	1667	1571	1506		10.6

Proctor Test Results for Cohesive Soil

Maximum Dry Density (MDD)	1669 kg/m3
Optimum Moisture Content (OMC)	20.0%

Figure 6: Show Dry Density against Moisture Content for Cohesive Soil



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California Bearing Ratio

Title: CBR test

Aim

- To determine the load-bearing capacity of soil
- To assess the suitability of the material for use in pavement subgrade

Apparatus: CBR mould assembly, loading machine and dial gauge

Material: Soil sample

CBR value is the resistance to a penetration of 2.5 mm of a standard cylindrical plunger of 50 mm diameter, expressed as a percentage of the known resistance of the plunger to 2.5 mm .in

Method: A Soil sample was prepared through a 20 mm sieve. Optimum moisture content was determined using a proctor compaction test. The soil was compacted into a CBR mould in layers, each layer being compacted to a standard of blows. The sample was soaked for 4 days to stimulate moisture conditions. After soaking, the plunger of 50mm diameter was penetrated into the soil at a rate of 1.25mm/min. Loading readings were recorded at standard penetration (2.5mm and 5.0 mm).

Table 9: Shows the Compaction Results of the Blend Sand with Cohesive Soil

	C		B		A	
	62 heavy blows, 5-layer		**30 heavy blows, 5 layers**		**62 light blows, 3 layers**	
Compaction Data	**Bef. Soak**	**After Soak**	**Bef. Soak**	**After Soak**	**Bef. Soak**	**After soak**
Mould No	D	D	H	H	F	F
Mass of Mould (g)	2930.2	2930.2	2860	280	2922.2	2922.2
Mass of Mould + wet soil (g)	7423.8	7907.8	7047.8	7572.6	6921.6	7361.8
Mass of wet soil (g)	4493.6	4977.6	4187.8	4712.66	3999.4	4439.6
Volume of Mould (cc)	2303	2303	2303	2303	2303	2303
Wet Density (kg/m3)	1951.2	2161.4	1818.4	2046.3	1736.6	1927.7
Moisture Content	18.4	19.4	18.5	25.1	18.1	32.9
Dry Density (kg/m3)	1648.0	1810.2	1535.1	1636.0	1470.5	1450.6
Compaction (%)	99	108	92	98	88	87

Table 10: Show Compaction, Moisture Content for Cohesive Soil

Moisture Content Determination	**C**		**B**		**A**	
Container Number	D3	BB	C6	P	T8	Q
Wt of wet soil + container (g)	99.5	107.6	96.2	98.8	96.7	101
Wt of dry soil + container (g)	87.3	93.4	84.5	83	85.1	81
Wt of container (g)	21	20.2	21.1	20.0	21	20.2
Wt of water (g)	12.2	14.2	11.7	15.8	11.6	20
Wt of dry soil (g)	66.3	73.2	63.4	63	64.1	60.8
Moisture content (%)	18.4	19.4	18.5	25.1	18.1	32.9

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Table 11: Compaction Data for CBR Test

	C		**B**		**A**	
	62 heavy blows, 5 layer		30 heavy blows, 5 layers		62 light blows, 3 layers	
Compaction Data	Bef. Soak	After soak	Bef. Soak	After soak	Bef. Soak	After soak
Mould No	D	D	H	H	F	F
Mass of Mould (g)	2930.2	2930.2	2860	280	2922.2	2922.2
Mass of Mould + wet soil (g)	7423.8	7907.8	7047.8	7572.6	6921.6	7361.8
Mass of wet soil (g)	4493.6	4977.6	4187.8	4712.66	3999.4	4439.6
Volume of Mould (cc)	2303	2303	2303	2303	2303	2303
Wet Density (kg/m3)	1951.2	2161.4	1818.4	2046.3	1736.6	1927.7
Moisture Content	18.4	19.4	18.5	25.1	18.1	32.9
Dry Density (kg/m3)	1648.0	1810.2	1535.1	1636.0	1470.5	1450.6
Compaction (%)	99	108	92	98	88	87

Table 12: Penetration Results for CBR Test

	C		**B**		**A**	
Penetration Data	**62 heavy blows, 5 layers**		**30 heavy blows, 5 layers**		**62 light blows, 3 layers**	
Plunger Penetration (mm)	**Gauge Reading Load (KN)**	**Automatic**	**Gauge Reading Leading(KN)**	**Automatic**	**Gauge Reading Loading (KN)**	**Automatic**
0.0	0	0.0	0	0.0	0.0	0.0
0.5	54	1.2	10	0.2	4.0	0.1
1.0	69	1.5	15	0.3	8	0.2
1.5	76	1.6	18	0.4	11	0.2
2.0	81	1.8	20	0.4	15	0.3
2.5	86	1.9	23	0.5	19	0.4
3.0	91	2.0	26	0.6	23	0.5
3.5	94	2.0	29	0.6	26	0.6
4.0	96	2.1	32	0.7	28	0.6
4.5	98	2.1	35	0.8	30	0.7
5.0	100	2.2	37	0.8	32	0.7
5.5	102	2.2	39	0.8	34	0.7
6.0	103	2.2	42	0.9	37	0.8
6.5	104.0	2.3	44	1.0	39	0.8
7.0	105	2.3	45	1.0	43	0.9
7.5	106	2.3	46	1.0	43	0.9

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Table 13: CBR Calculation and Results

CBR Calculations	62 blows 5 layers	30 blows 5 layers	62 blows 3 layers
CBR at 2,5mm pen (%)	14.1	3.8	3
CBR at 5,0mm pen (%)	11	4	3
CBR (%)	**14**	**4**	**3**
Swell			
Initial dial gauge reading	5.140	2.920	4.150
Final dial gauge reading	6.720	4.570	5.830
Difference (swell)	1.580	1.65	1.68
Percentage swell	1.244	1.299	1.323

Table 14: CBR Soaked - Percent MDD Relationship

	CBR (%)	Comp. (%)
62 Heavy blows, 5 layers	14	99
30 heavy blows, 5 layers	4	92
62 light blows, 3 layers	3	88

Table 15: Test Summary Results

MDD / OMC	1660/22
CBR AT 90%	3
CBR AT 93%	4
CBR AT 95%	8
SWELL	1.244

Figure 7: Load against Penetration for CBR

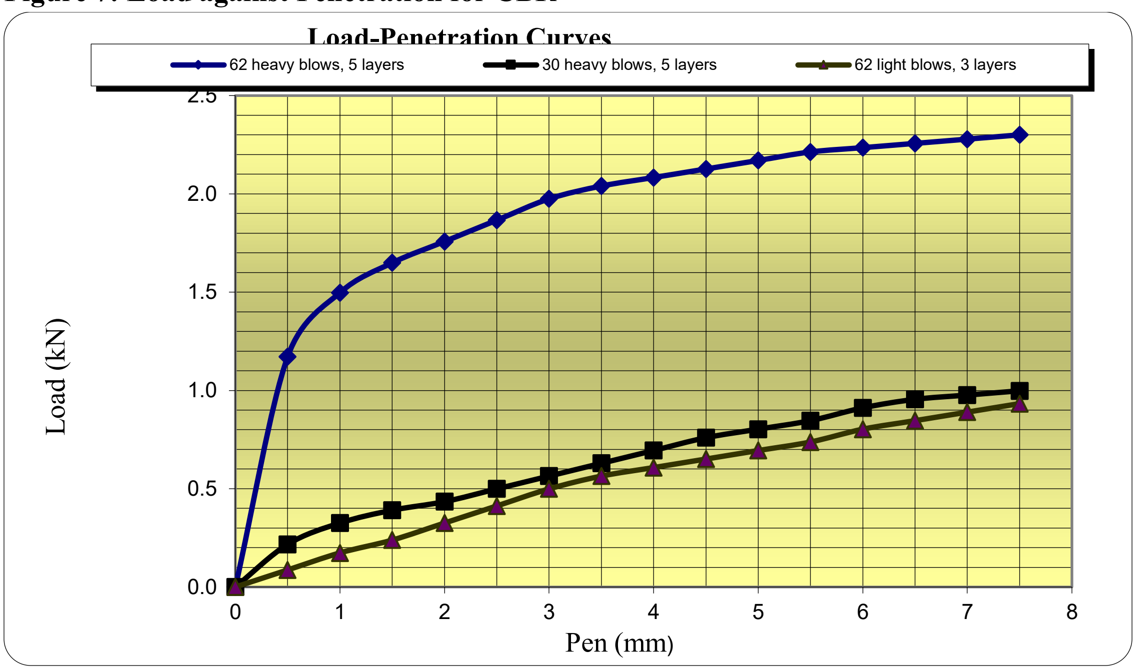

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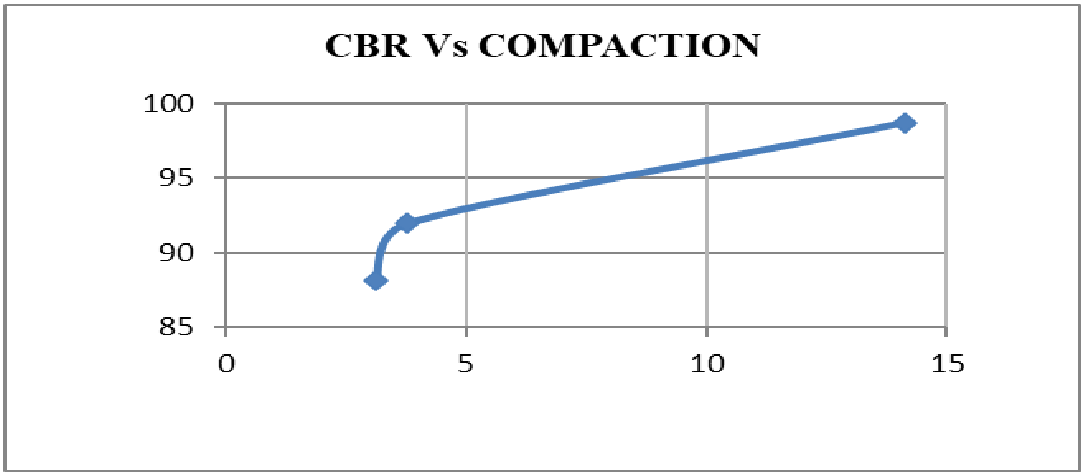
Figure 8: CBR against Compaction



Blending of Sandy and Cohesive Soil

The purpose of blending sand with cohesive soil was to improve the engineering properties of the soil, which are strength, drainage, and workability.

Material Selection

Materials used were sand and cohesive soil

- Sand contains granular material with minimal cohesion.
- Cohesive soil: clay or silt with high plasticity and water retention.

Laboratory tests conducted were

- Grain size distribution (sieve analysis)
- Atterberg limits (for cohesive soil)
- Moisture content
- Compaction test (Proctor test)

Determine Blending Ratio

Decide on the appropriate blending ratio (70%, 55% sand: 30%, 45% cohesive soil) based on:

- Desired shear strength
- Target CBR value or compaction density
- Field requirements

Laboratory trials may be done to identify the optimum mix ratio.

Site Preparation

- Clear and level the blending area.
- Ensure both materials are free from organic matter, debris, or oversized particles.

Layering and Mixing

- Spread the first layer of sand on the ground.
- Spread a proportional layer of cohesive soil on top.
- Use manual tools (hoes, shovels) or mechanical mixers (rotavator, grader) to blend the materials thoroughly.

Moisture Conditioning

- Add water gradually during mixing to reach the optimum moisture content (OMC) for compaction.
- Mix until a uniform, moist, and consistent blend is achieved.

Compaction

Compact the blended material using:

- Hand compactor (for small areas)

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- Vibratory roller or plate compactor (for large areas)
- Ensure compaction meets the desired density from the Proctor test.

Quality Control

Conduct tests on the blended soil:

- CBR test for strength
- Moisture-density relationship
- Permeability or cohesion tests (if required

Therefore

Increasing sand content improves drainage and reduces plasticity. Increasing cohesive soil content improves bonding and stability but may retain water. Always base ratios and moisture content on lab test results for optimal performance.

Table 16: Laboratory Test Results for Sand, Cohesive and Blended Materials

	CBR VALUE	Plastic Index	Moisture Content	Proctor
Sand soil	14	Non-plasticity	18.1	
Cohesion soil	4	17	19.5	MDD = 1569 kg/m3 OMC = 20.0%
Blended Material (mixing of sand and cohesion)	8.5	18.1	20.1	MDD = 1669 kg/m3 OMC = 21.3%

Unconfined Compressive Strength (UCS)

Title: UCS test

Aim

- To determine the compressive strength of the soil when subjected to traffic loading
- To determine the load stress and strain acting on the soil
- To evaluate the suitability of the material's ability to sustain traffic loading for use in pavement subgrade

Apparatus: UCS moulds assembly, rammer, trimming rod, loading machine and dial gauge

Material: Blended soil samples (Sandy soil, cohesive soil)

UCS value is the maximum axial compressive stress that a cylindrical specimen of material can withstand under unconfined conditions without any lateral support or confining pressure expressed as a MPa or kN/m².

Method: Soil samples were prepared through a 20 mm sieve in a mix ratio of 30% and 45%. Optimum moisture content was determined using a proctor compaction test in moulds with 127mm and 150mm diameters. The soil was compacted into a UCS mould in layers, each layer being compacted to a standard of blows and another sample was embedded with a geotextile layer. The UCS samples were detached from the base plates, weighed on a beam balance, and the readings were recorded on lab sheets.

The mould soil sample was removed from the UCS moulds carefully, and the samples were measured with a veneer carper on both bottom and top diameters with its length as L0. Then the samples were put into tight plastic bags to maintain their moisture content. Using a UCS machine, a plunger of 50mm diameter was gradually allowed to penetrate into the UCS soil samples at a rate of 1.25mm/min and axial loading stress readings were recorded at standard penetration (2.5mm and 5.0 mm).

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Meanwhile, stress effects were carefully observed until the failure of the sample occurred, and upon compression exertion, the compressive load readings were recorded, and the length of the moulded UCS sample after failure under compression was measured as L1. From a failure zone, a small cut of the sample for moisture content was taken and placed into the oven. All recorded readings of the UCS samples were used for further calculations, data analysis, and graph plotting.

Table 17: 30% Cohesive Soil Mixing, Compaction, and Densities for UCS Blended Subgrade without Application of Fibre Geotextile

TEST METHOD	CML TEST 1.2, ref. TMH1 -1986 -A14						
Procedure **4.5** Kg hand / mechanical rammer		MDD	1669	Kg/m3	OMC	**10.4**	%
Procedure **4.5** Kg hand / mechanical rammer		MDD	1669	Kg/m3	OMC	**21.3**	%
5 Layers **62** blows per layer, CBR mould		volume of mould				**2305**	cm3
A	Initial sample of moisture content	**10.8** %	B	Total of sample mass air dry		**6000**	(g)
C	Design percentage of Cohesive soil	**45.0** %	D	Total of oven-dry sample mass		**5352**	(g)
E	Total of cohesive soil mass E=D×(1+C)-D			2408			(g)
Mass of compaction specimen m_1	g	4389			4445	4418	
Bulk density $\rho=(m_1)/V$	kg/m^3	1904			1928	1917	
Container No.		L			J	S	
Mass of container	g	27.7			27.2	27.2	
Mass of wet sample + container	g	184.5			154.6	178.5	
Mass of dry sample + container	g	170			142.1	164.3	
Mass of moisture		21.6			19.3	21.7	
Mass of dry sample		142.3			114.9	137.1	
Moisture content	%	15.2			16.8	15.8	
Dry density $\rho_d=100*\rho/(100+w)$	kg/m^3	1653			1651	1655	
Load	KN	13.58			13.92	13.32	
Corrected Load (factor 1.0515 of machine		14.28			14.64	14.01	
Strength	Mpa	0.8			0.8	0.8	
Average Strength	Mpa	**0.8**					

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Table 18: Cohesive Soil 45% Mix, Compaction and Densities for UCS Blended Subgrade without the Use of Fibre Geotextile

TEST METHOD	CML TEST 1.21, ref. TMH1 -1986 -A14						
Procedure **4.5** Kg hand / mechanical rammer		MDD	1669	Kg/m3	OMC	**21.3**	%
5 Layers **62** blows per layer, CBR mould		volume of mould			**2305**		cm3
A	Initial sample of moisture content	**10.8**	%	B	Total of the sample mass air dry	**6000**	(g)
C	Design percentage of Cohesive soil	**45.0**	%	D	Total of oven-dry sample mass	**5352**	(g)
E	Total of cohesive soil mass E=D×(1+C)-D		2408				(g)
Test number			A	B	C		
Mass of compaction specimen	m_1	g	4304	4259	4408		
Bulk density $\rho=(m_1)/V$		kg/m^3	1862	1848	1912		
Container No.			D2	C1	F		
Mass of container		g	36.4	36.4	25.3		
Mass of wet sample + container		g	198.7	145.6	254.1		
Mass of dry sample + container		g	183.4	134.9	231.4		
Mass of moisture			21.1	20.3	22.7		
Mass of dry sample			147.0	98.5	206.1		
Moisture content		%	14.4	20.6	11.0		
Dry density ρ_d=100*ρ/(100+w)		kg/m^3	1633	1532	1723		
Load		kN	10.97	9.89	11.35		
Corrected Load (factor of machine =	1.0515		11.53	10.40	11.93		
Strength		Mpa	0.6	0.6	0.7		
Average Strength		Mpa	**0.6**				

Table 19: Cohesive Soil 30% Mix, Compaction and Densities for Blended Subgrade Embedded with Fibre Geotextile

TEST METHOD		**CML TEST 1.21,ref. TMH1 -1986 -A14**					
Procedure **4.5** Kg hand / mechanical rammer		MDD	1669	Kg/m3	OMC	**21.3**	%
5 Layers **62** blows per layer, CBR mould		volume of mould			**2305**	cm3	
A	Initial sample of moisture content	**10.8**	%	B	Total of sample mass air dry	**6000**	(g)
C	Design percentage of Cohesive soil	**30**	%	D	Total of oven-dry sample mass	**5352**	(g)
E	Total of cohesive soil mass E=D×(1+C)-D			2408			(g)
Test number			A		B	C	
Mass of compaction specimen m1		g	4418		4398	4390	
Bulk density $\rho=(m_1)/V$		kg/m^3	1917		1908	1905	
Container No.			60		H	M	
Mass of container		g	37.5		27.8	36.4	
Mass of wet sample + container		g	213.4		175.4	187.9	
Mass of dry sample + container		g	195.7		161.3	172.8	

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TEST METHOD		**CML TEST 1.21,ref. TMH1 -1986 -A14**		
Mass of moisture		17.7	14.1	15.1
Mass of dry sample		158.2	133.5	136.4
Moisture content	%	11.2	10.6	11.1
Dry density ρ_d=100*ρ/(100+w)	kg/m^3	1724	1726	1715
Load	KN	19.58	19.92	19.32
Corrected Load (factor 1.0515 of machine =		20.59	20.95	20.31
Strength	mpa	1.1	1.2	1.1
Average Strength	mpa	**1.1**		

Table 20: Cohesive Soil 45% Mix, Compaction and Densities for Subgrade Blended on Sandy Soil Embedded with Fibre Geotextile

TEST METHOD		CML TEST 1.21,ref. TMH1 -1986 -A14					
Procedure **4.5** Kg hand / mechanical rammer		MDD	1669	Kg/m3	OMC	**21.3**	%
5 Layers **62** blows per layer		CBR mould	volume of mould			**2305**	cm3
A	Initial sample of moisture content	**10.8**	%	B	Total of sample mass air dry	**6000**	(g)
C	Design percentage of Cohesive soil	**45.0**	%	D	Total of oven dry sample mass	**5352**	(g)
E	Total of cohesive soil mass E=D×(1+C)-D			2408			(g)

Test number		A	B	C
Mass of compaction specimen m_1	g	4323	4289	4372
Bulk density $\rho=(m_1)/V$	kg/m^3	1875	1861	1897
Container No.		S	60	R
Mass of container	g	27.2	37	44.3
Mass of wet sample + container	g	180.5	162.5	187.3
Mass of dry sample + container	g	168.4	152.4	175.6
Mass of moisture		12.1	10.1	11.7
Mass of dry sample		141.2	115.4	131.3
Moisture content	%	8.6	8.8	8.9
Dry density ρ_d=100*ρ/(100+w)	kg/m^3	1727	1711	1742
Percentage Compaction	%	122.7	121.6	123.4
Load	kN	16.97	15.89	16.35
Corrected Load (factor of 1.0515 machine =		17.84	16.71	17.19
Strength	Mpa	0.98	0.92	0.95
Average Strength	Mpa	**0.95**		

Compressive Strength

This is the maximum amount of compressive stress that a material can resist without failing or undergoing primary deformation.

Compressive strength (Cv) = Ultimate stress x Deviation value

= <u>Maximum loading</u> x Calibration value

Cross-sectional area

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Table 21: Adopted Methodology, Summary of UCS Data, Calculated Ultimate Load, UCS, Densities, MDD Values

		MATERIALS PROPERTIES AFTER STABILIZATION													
Methodology	Cohesive Soil	MDD	L1	Av. L1	Specimen No.	Weight of specimen	Volume of specimen	Area of specimen	Bulk density of the specimen	Moisture Cont. of specimen	Dry Density of the specimen	Relative compaction	Ultimate Load	UCS Value	Average UCS
	%	kg/m³	mm	mm	No.	g	cm³	mm²	kg/m³	%	kg/m³	%	KN	Mpa	Mpa
MATERIAL LOCATIONS:									KIWALALA						
Road without geotextile	30	1669	111.4	111.5	1. A	4389	2305	17663	1904	15.2	1653	99.0	14.28	0.81	0.81
			112.1		1. B	4445	2305	17663	1928	16.8	1651	98.9	14.64	0.83	
			110.9		1. C	4418	2305	17663	1917	15.8	1655	99.2	14.01	0.79	
	45	1639	110.5	110.4	2. A	4304	2305	17663	1867	14.4	1632	99.6	11.53	0.65	0.64
			110.4		2. B	4259	2305	17663	1848	20.6	1532	93.5	10.40	0.59	
			110.2		2. C	4408	2305	17663	1912	11.0	1723	105.1	11.93	0.68	
Road with geotextile	30	1669	115.8	115.1	3. A	4418	2305	17663	1917	11.2	1724	103.3	20.59	1.17	1.17
			114.6		3. B	4398	2305	17663	1908	10.6	1725	103.4	20.95	1.19	
			114.9		3. C	4390	2305	17663	1905	11.1	1714	102.7	20.31	1.15	
	45	1649	120.3	120.2	4. A	4323	2305	17663	1875	8.6	1727	104.7	17.84	1.01	0.98
			119.5		4. B	4289	2305	17663	1861	8.8	1710	103.7	16.71	0.95	
			120.7		4. C	4372	2305	17663	1897	8.9	1742	105.6	17.19	0.97	

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Figure 9: Show UCS against Percentage of Cohesive Soil Blending Impacts

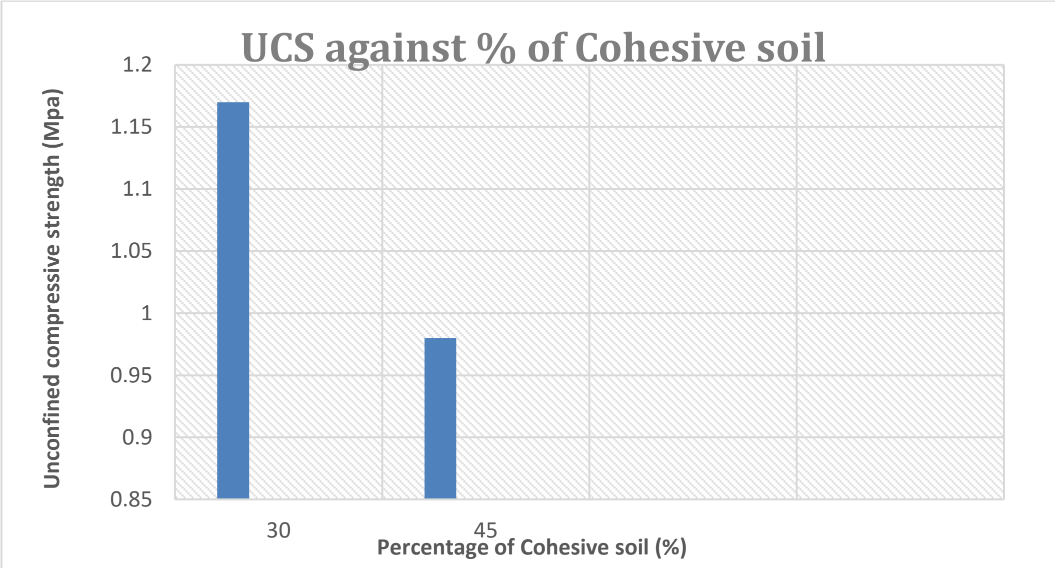
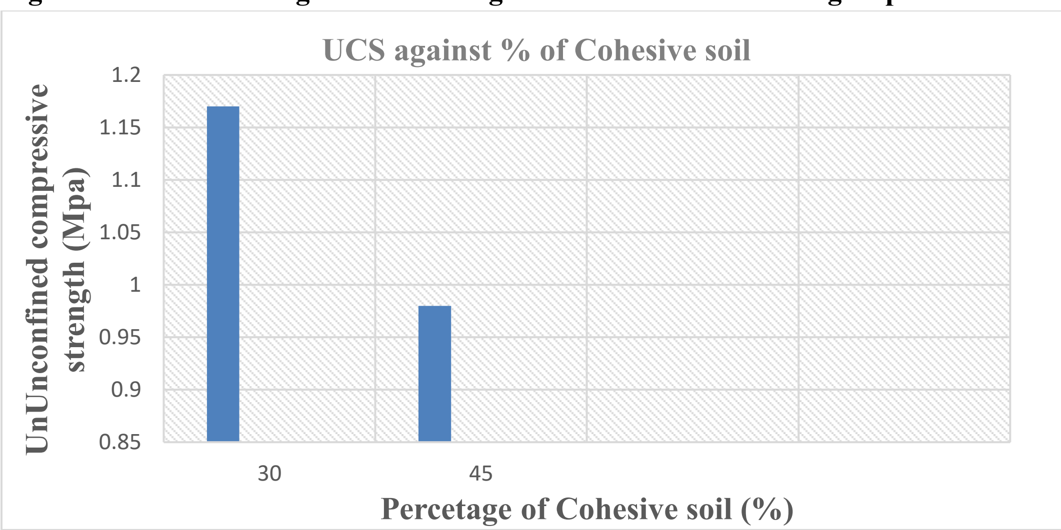


Figure 10: Show UCS against Percentage of Cohesive Soil Blending Impacts



Ultimate Stress

Ultimate stress is the maximum stress a material can withstand before it fails or fractures. It represents the maximum stress a material can withstand under traffic loading exerted on the surface of the road.

Ultimate stress ($\mathcal{E}_v$) = Av. Applied axial loading (F) =

Cross-sectional area (A)

= F in Mpa

A

Whereby;

Cross-sectional area (A) = Pi x radius of moulded sample

$A = \pi R^2$

Strained area (A_ε) = A_ε

$(1 - \mathcal{E})$

1 kN/m² = 0.001Mpa

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Compressive Strain

Ultimate strain refers to the maximum strain a material can withstand before it fails or breaks. It is a measure of how much a material can stretch or deform under compressive stress before it fractures.

Ultimate strain ($ð_v$) = $\underline{\text{Change in length}}$

Original Length

$ð = \underline{L_1 - L_0}$ x 100%

L_0

Table 22: Adopted Methodology, Summary of UCS Data, Calculations over Compressive Strain, and Ultimate Stress for Subgrade Soil Blended and Embedded with Fibre Geotextile

Methodology	Cohesive Soil	L0	L1	Change in length of specimen	Average Change in length of specimen	Strain	Area of specimen	Ultimate Load (P)	Ultimate stress (F)	Average Ultimate stress (F)
%	%	mm	mm	mm	Mm	%	m^2	kN	kN/m²	kN/m²
without Road geotextile	30	127	111.4	15.6	15.5	12.2%	0.17663	14.28	80.85	81.02
		127	112.1	14.9			0.17663	14.64	82.89	
		127	110.9	16.1			0.17663	14.01	79.32	
	45	127	110.5	16.5	16.6	13.1%	0.17663	11.53	65.28	63.90
		127	110.4	16.6			0.17663	10.40	58.88	
		127	110.2	16.8			0.17663	11.93	67.54	
with Road geotextile	30	127	115.8	11.2	11.9	9.4%	0.17663	20.59	116.57	116.72
		127	114.6	12.4			0.17663	20.95	118.61	
		127	114.9	12.1			0.17663	20.31	114.99	
	45	127	120.3	6.7	6.8	5.4%	0.17663	17.84	101.00	97.64
		127	119.5	7.5			0.17663	16.71	94.60	
		127	120.7	6.3			0.17663	17.19	97.32	

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Figure 11: Representation of the Impact Effects of 30% and 45% Mix of Cohesive Soil Blended Subgrade without Use of Fibre Geotextile versus Ultimate Stress and Compressive Strain.

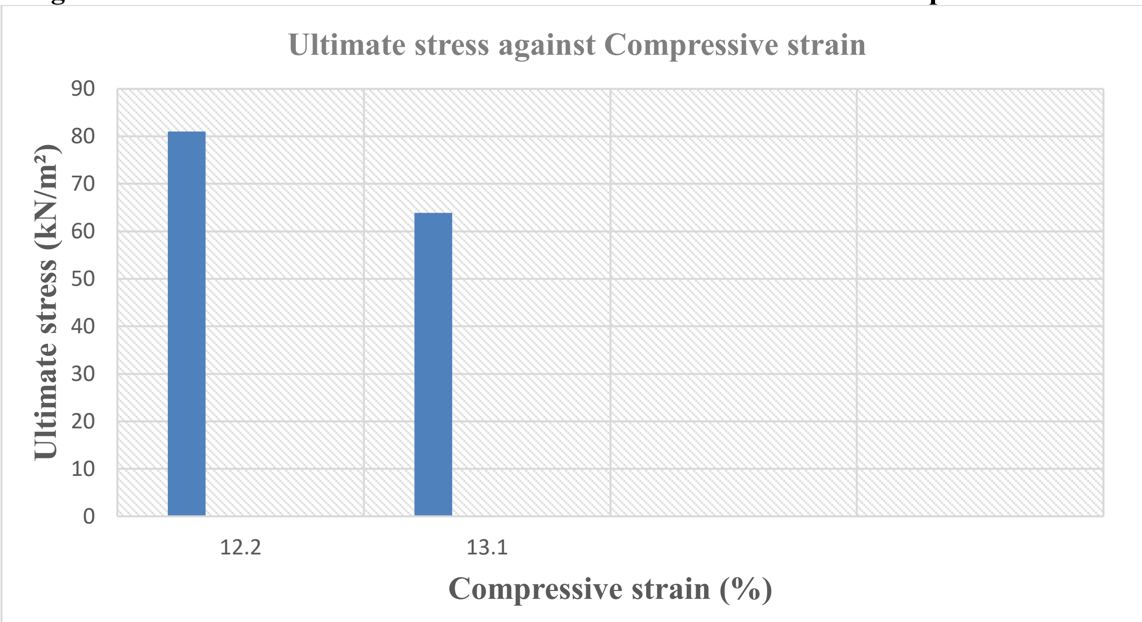
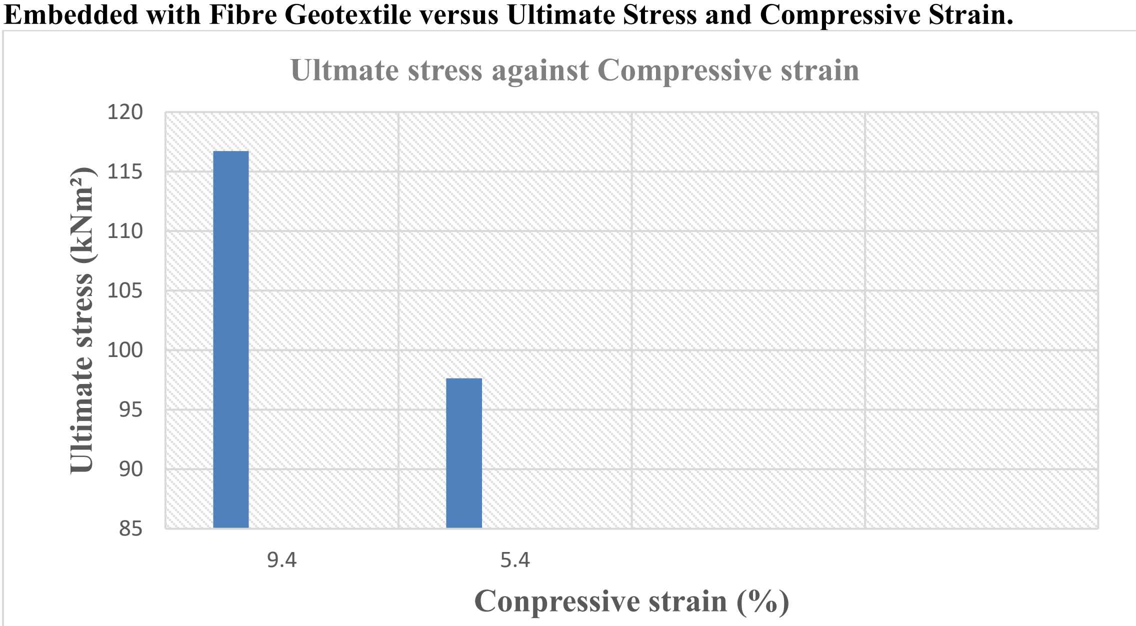


Figure 12: Represent Significant Effects of 30% and 45% Mix of Cohesive Soil on Blended Subgrade Embedded with Fibre Geotextile versus Ultimate Stress and Compressive Strain.



Fiber Geotextile

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Table 23: Results for Geotextile

PROPERTY	ASTM TEST METHOD	UNITS	PROPERTY VALUE
Weight	ASTM D5261	g/m^2	407
Grab Tensile	ASTM D4632	kN	1.33
Grab Elongation	ASTM D4632	%	50
Trapezoid Tear	ASTM D4533	kN	0.511
CBR Puncture Resistance	ASTM D6241	kN	3.78
Permittivity	ASTM D4491	Sec^{-1}	1
Water Flow	ASTM D4491	$1/min/m^2$	3055
A.O. S	ASTM D4751	Sieve mm	0.15
U.V. Resistance	ASTM D4355	%/hrs	70/500

Maintenance Strategy for Unpaved Roads

The maintenance strategy for unpaved roads using fibre geotextile and blended cohesive soil over sandy subgrade offers a cost-effective alternative to traditional soil mixing methods. By reinforcing the subgrade with geotextile and carefully blended materials, the approach enhances durability, stability, and overall pavement performance. The construction process involves systematic stages, from material selection and testing to layered installation, ensuring the strength and longevity of the road structure. Laboratory analysis confirmed the suitability of materials used, including their physical and mechanical properties, which are crucial for achieving the desired reinforcement effect.

Cost Analysis

The cost analysis reveals a significant financial advantage in using the fibre geotextile and cohesive soil blend. The total execution cost for this method is Tshs. 21,590,000.00, compared to Tshs. 29,200,000.00 for the traditional method using only gravel. This represents a 26% cost reduction, while also improving long-term performance and reducing future maintenance frequency. Therefore, incorporating fibre geotextile and cohesive soil blending in unpaved road maintenance proves to be not only technically superior but also economically beneficial.

DISCUSSION OF THE FINDINGS

The laboratory results for sand soil, cohesive soil, blended soil, and geotextile-reinforced soil highlight significant differences in geotechnical behaviour, directly influencing their suitability as subgrade materials.

Sand Soil

The sieve analysis confirmed that the sand soil was predominantly well-graded with most particles in the medium-to-coarse sand range. According to the Tanzania Standard Specification for Road Works (2000), soils with such gradation and CBR values above 8% fall under the S7 subgrade class, which indicates strong support conditions for road construction. The soaked CBR value of 14% obtained in this study confirms that sand soil alone provides adequate strength for subgrade applications (Central Materials Laboratory [CML], 2000; ASTM D1883, 2003). However, while strength is high, sand lacks cohesion, which could make it vulnerable to erosion and instability under saturated conditions if not properly confined (AASHTO, 1993).

Cohesive Soil

The cohesive soil was classified as medium plastic clay (CL) based on Atterberg limit results (LL = 47.1%, PI = 17). According to the AASHTO soil classification system, such soils often exhibit poor drainage, high compressibility, and swelling potential. The relatively low soaked CBR values (3–

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4%) confirm its weak load-bearing capacity, consistent with findings reported in CML (2000). Additionally, the measured swell of 1.24% exceeds the recommended limit of 1% set by TSSRW (2000), indicating that this soil is expansive and therefore unsuitable for direct use in road subgrades without modification. These results align with previous studies, which emphasise that fine-grained soils with PI > 12% often require stabilisation before use in pavement layers (BS 1377, 1990; ASTM D4318, 2017).

Blended Soil

Blending cohesive soil with sand improved compaction and reduced plasticity effects. The CBR value of 8.5% recorded for blended soil was significantly higher than that of the cohesive soil alone, though lower than that of the sand soil. This result demonstrates the beneficial role of blending in balancing strength, density, and moisture sensitivity (CML, 2000). According to TSSRW (2000), soils with CBR values between 7–15% may be classified under S5–S6 subgrade classes, which are acceptable for low- to medium-volume traffic roads with proper drainage. However, the blended soil's PI (18.1) suggests that plasticity challenges persist, and further stabilisation or reinforcement is recommended to ensure long-term performance.

Effect of Fibre Geotextile Reinforcement

The inclusion of fibre geotextile layers in blended soils significantly improved the unconfined compressive strength (UCS). For instance, UCS increased from 0.8 MPa to 1.1 MPa in the 30% cohesive mix and from 0.6 MPa to 0.9 MPa in the 45% cohesive mix. This improvement is consistent with the role of geotextiles in distributing stresses, reducing strain localisation, and increasing ductility of soil–geotextile composites (ASTM D2166, 2016; AASHTO, 1993). These findings align with the specifications provided in CML (2000) and international standards, which recognise geotextiles as effective reinforcement for subgrades with marginal soils.

Overall Interpretation

The results show that:

1. Sand soil alone is strong but erosion-prone.
2. Cohesive soil is weak and expansive, unsuitable without stabilisation.
3. Blending sand with cohesive soil improves bearing capacity but remains moderately plastic.
4. Fibre geotextile reinforcement significantly enhances soil strength and makes blended soil a feasible option for subgrade improvement.

Therefore, the integration of geotextile reinforcement provides a cost-effective stabilisation technique for road subgrades in Tanzania, especially in areas dominated by cohesive soils, and is consistent with CML (2000) and TSSRW (2000) recommendations for sustainable pavement design.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

This study demonstrates that integrating fibre geotextile and cohesive soil as earth reinforcement materials improves the structural performance and durability of unpaved roads built over sandy subgrades. The maintenance strategy developed, covering material selection, implementation, and monitoring, enhances road stability, reduces maintenance frequency, and lowers long-term costs. Laboratory results show that fibre geotextile improves load distribution and minimises deformation, while cohesive soil increases binding and moisture retention. Together, these materials offer a sustainable and cost-effective solution for maintaining unpaved roads in areas with weak subgrade conditions.

Recommendations

This study is strengthened by monitoring a 250m trial section to evaluate the long-term performance

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of blended cohesive and sandy soil with fibre geotextile. Regular observations help assess effectiveness in problematic sandy subgrades. Based on findings and lab results (Tables 18 and 19), the use of cohesive soil and fibre geotextile is recommended for pavement maintenance due to their strong performance and cost-effectiveness. Figure 1 shows a geotextile-reinforced road with lower maintenance costs compared to Figure 2. The use of fibre geotextile and cohesive soil blend is recommended to reduce overall maintenance expenses.

Adopt Earth Reinforcement Techniques in Road Maintenance

Road agencies like TARURA and TANROADS in road maintenance should integrate fibre geotextile and cohesive soil as standard reinforcement materials for unpaved roads constructed over sandy subgrades, to improve strength and reduce deformation of pavement.

Develop and Implement a Successful Maintenance Strategy

Implementing a successful maintenance management strategy specifically for unpaved roads constructed in areas which has problematic soil, using reinforced subgrades, should be implemented to ensure systematic inspection, repair planning, and resource allocation.

Use of Geosynthetics in Low-Volume Road Projects

Fibre geotextile should be recommended as a cost-effective and durable material in rural and low-traffic road networks, especially in regions or areas which has high erosion or weak soil conditions.

Provide Training for Local Engineers and Road Maintenance Team

Capacity building and modern programs should be introduced to train highway engineers and technicians on the proper application and maintenance of geotextile-reinforced road sections. So that they can manage well during project execution.

Allocation of Road Maintenance Budget for Preventive Maintenance Projects

Government and stakeholders should invest in preventive rather than reactive maintenance by allocating a budget for regular inspections and early interventions.

Assess the Performance of Reinforced Roads Evaluate

Assessment and performance monitoring systems to evaluate the long-term effectiveness of the reinforcement techniques and update the maintenance strategy should be done accordingly.

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