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Case Report

Assessment of the Causes of Pavement Failure Due to Sub-Base and Sub-Grade Materials Along Nekemte-Bedele Road

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Abstract: The Nekemte-Bedele road section is experiencing various flexible pavement failures, and a study is needed to determine the causes. The study will involve desk research, field inspections, and laboratory tests to identify the reasons for the failures in sub-base and subgrade materials. During field observations, different types of pavement failures were noted, such as rutting, potholes, edge cracking, transversal cracking, and raveling. Representative samples were taken from the deteriorated sections to perform laboratory tests like Atterberg limit, gradation or sieve analysis, compaction, and CBR. The laboratory results showed that most of the soil materials used along the road did not meet standard specifications. The plasticity indexes and liquid limits were high for all sub-base, selected fill, and natural subgrade soil samples, except for a few. The OMC was almost between 11.90 - 27.80%, and the MDD values ranged from 1.30 kg/m³ - 1.92 kg/m³. Most of the CBR values for the selected fill soil materials met specification requirements, while those of sub-base and natural subgrade soil materials did not meet the specifications, except for a few samples. The pavement failure was due to weak/poor soil pavement layer performance in different failed locations. The field recorded high, medium, and low levels of severity.

Keywords: Flexible Pavements, Field Tests, Laboratory Tests, Nekemte-Bedele Pavement Failure, Sub-base Materials

1. Introduction

A flexible pavement is a structure used for transportation, allowing pedestrians and vehicles to travel from one place to another. It consists of asphalt layers and a strong sub-base layer built over a well-compacted sub-grade foundation [1]. The purpose of flexible pavements is to provide a smooth surface for vehicles, adequate friction, and support for wheel loads. The design and construction of road pavements aim to find the most cost-effective combination of layers that can handle the stresses imposed by traffic without becoming overstressed during the highway's lifespan [2].

Roads play a crucial role in the social and economic development of a country, connecting people from different corners of the world. Flexible pavements are a vital component of civil construction, involving multiple layers of materials subjected to varying traffic loads and environmental conditions [3]. They provide a smooth and skid-resistant surface, improve tire traction, and reduce vehicle wear and tear. Flexible pavements are safe, cost-effective, and long-lasting, allowing for quick construction and minimizing costs associated with traffic delays. Additionally, asphalt pavements are recyclable, as old materials can be reprocessed and reused [4].

In Ethiopian history, roads and bridges were constructed in early times, with emperors making efforts to clear forests and level difficult terrains for their trips. Roads have been crucial for transportation, protecting the country and showcasing the ruling dynasty's strength [5]. Road construction has evolved alongside the social development of mankind, with emperors like Fasil, Tewdros, Yohannes, and minilikes playing significant roles in expanding territories and ensuring national unity. Over the past twenty years, Ethiopia has seen an increase in population and demands, resulting in the construction of roads that have failed to sustain their design life [6].

Many flexible pavements in Ethiopia require surface repairs or periodic maintenance every few years. Traffic volume and loads have been increasing globally, demanding better-performing roads for efficient transportation. Repetitive traffic loading and environmental factors cause deformation, fatigue cracking, instability, and other forms of deterioration, leading to reduced serviceability and durability of pavement structures [7].

Flexible pavements have played a crucial role in the economic and industrial development of first-world nations, with over 85% of road networks worldwide being asphalt pavements. However, asphalt pavements have faced various problems since their construction began in the early 20th century [8]. These problems include early cracking, rutting, moisture damage, and a perception that they are not long-lasting or cost-effective. The pavement industry has invested significant resources in finding remedies for pavement distress [9].

The Nekemte-Bedele road project, signed between the Ethiopian government and China Highway Group Limited, is a 96 km road segment with a two-lane carriageway and shoulders on either side. This project is a priority for the Ethiopian government, aiming to improve the country's road network and stimulate economic growth [10]. However, the constructed road project has failed due to design-related factors. This study aims to assess the causes of pavement failure specifically related to sub-base and sub-grade material properties.

So, a road pavement is basically a structure built on natural soil to handle traffic and weather with minimal damage and cost. These flexible pavements are designed to handle traffic that will come through during the road's lifespan. Factors like traffic, climate, materials, construction quality, and structure all impact the road's performance [11]. In Ethiopia, roads are failing due to poor materials, weather, traffic, and construction quality, leading to problems like cracking and potholes. Before maintenance and rehabilitation, it's important to assess the causes of pavement failures to use resources and budgets wisely [12]. When layers of the pavement fail due to, aging, inadequate design, poor construction, low-quality materials, or heavy traffic, the road can no longer handle the weight of vehicles [13]. Knowing the causes of failure can save money on construction and maintenance costs. The Nekemte-Bedele road project was supposed to contribute to the country's sustainable development and agriculture, but it's already deteriorating, which affects the public in terms of maintenance costs and access to markets and social services.

This study aims to assess the causes of pavement failures due to sub-base and sub-grade materials properties along Nekemte-Bedele road. The specific objectives are to identify the types of pavement failures, their severity levels, and the major causes of pavement failures due to sub-base and sub-grade materials properties.

2. Materials and Methods

2.1. Location and Description of the Study Area

The study area is located in Oromia national regional state, west Ethiopia. The Nekemte-Bedele road connects East Wollega and Buno Bedele zones of the Oromia state. The length of the road segment is about 96 km. The Latitude and longitude of the start of the road segment are 09°05’09.40” N and 36°32’58” E Respectively and the latitude and longitude of the end of the road segment is 08°27’55.07” N and 36°21’01” E Respectively, and the range of the altitude of the study area is 2008m to 2087m with a temperature range of 11 to 27°C.

The road section from Nekemte-Bedele is presented in Figure 1.

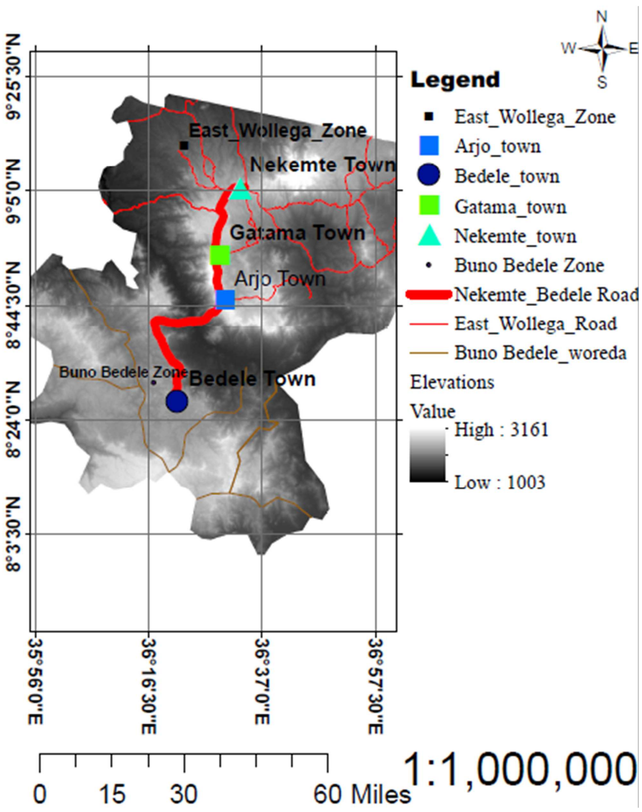

Figure 1. *Location of Naqamte-Beddelle road (23/01/ 2021, 5:38:10 PM).*

2.2. Terrain Classifications

The project road traverses through different terrains with an altitude of 2088m at the beginning near the town of Getema, it then drops to 2142m and then rises to 2566m at its end in Bedele town. The terrain along which the project road traverses can be classified as flat, rolling, and mountainous where the largest portion being classified as Mountainous as indicated below.

Table 1. *Terrain classifications of the study area.*

Typesof train	Road length (km)	Proportion (%)
Flat	35	36.5
Rolling	16	16.7
Mountainous	45	46.8

2.3. Climatic Condition of the Area

The climatic condition of the study area was classified as Weina Dega (Temperate) and Kolla (Warm climatic) zones. The records on the Engineering report, as obtained from the meteorological stations at Nekemte, Getema, Arjo, and Bedele towns show the following:

The mean monthly minimum temperature in the project area is in the range of 10 – 11°C, occurring during November to January while the mean monthly maximum temperature in the project area is in the range of 27 – 31°C, occurring during February to April.

The mean annual rainfall in the area is 1222 mm for Nekemte, 2,142 mm for Getema 2566 mm for Arjo, and 2566 mm for Bedele towns.

2.4. Land Cover of the Study Area

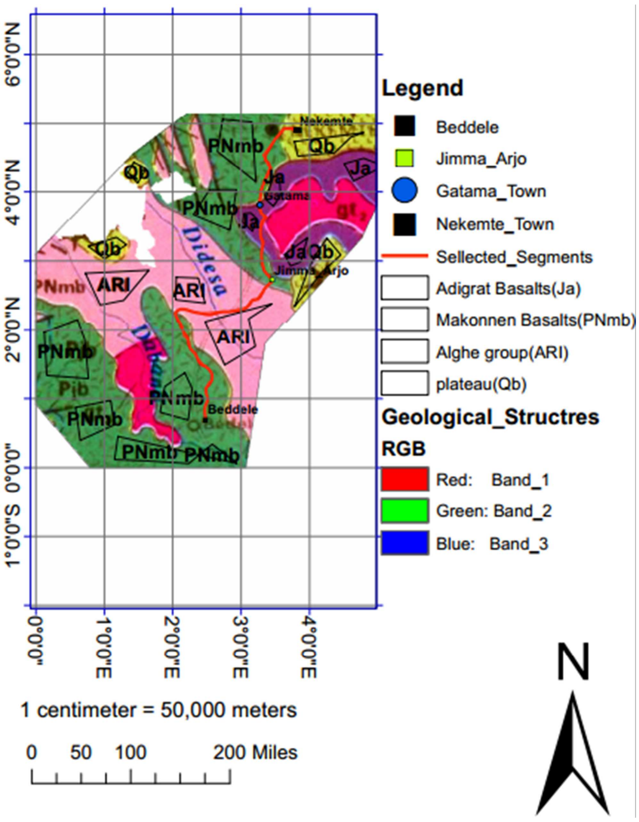

Figure 2. *Geological structure of the study area (12/12/2020, 8:34:32 PM).*

According to the Consultant's field assessment most of the land along the project road is intensively used for crop cultivation, livestock grazing, and settlement. The major crops that have been grown along and in the vicinity of the project area include maize, sorghum, teff, and coffee. Coffee is a good cash crop that grows near Nekemte and also Nug (oil crop) is growing in the area as a cash crop. The remaining land covers are grazing/grassland, bush, forest, and urban or rural settlement area. The eucalyptus tree plantation is widely observed on either side of the existing road in proximity and within the road limits as well [12].

2.5. Geological Structure of the Study

According to the Geological Map of Ethiopia, the following four types of formations are encountered along the Road Nekemte-bedele road, where the project road is part of it.

1. Quaternary Plateau Basalts (Qb1): The formation consists of alkaline basalts and trachytes and is found along the first 10 km of the project.
2. The Quaternary sediments are mainly found from around km 10 to around km 40.
3. Algh e Group (ARI): The Precambrian Alghe Group consists mainly of biotite, hornblende, and gneiss and extends from about km 10 to 20 km. Nekemte is covered with the Mekonen Basalts.

Mekonen Basalts (PNmb): The group consists of Tertiary Flood Basalts overlying the crystalline basement and is mainly found from around km 30 to 40km and from around 80 km to 90 km. Bedele town is covered with the Alghe Group rocks.

The Geological Structure of Nekemte-Bedele is presented in figure 2.

2.6. Study Period and Study Design

Generally, the study period was conducted from July to September 2021. Experimental and field (observation study) methods will be employed. The research methodology is performed by collecting raw samples and laboratory tests. Qualitative and Quantitative methods will be employed to analyze data obtained from the field through observation and in the laboratory respectively. Flow chart of the study methods is given in Figure 3.

2.7. Materials

The selection of appropriate quality materials for the selected road section affects the determination of the capital and whole life costs of the road. To fulfill this material from each section should test and compare with different specifications. The materials and the equipment used in the study include Meter tape, a digital camera for documentation, MS Word, and Excel to display research data and CBR machine, compaction mold, glass plate, soil mixing equipment, cup, scraper, etc. for laboratory analysis, respectively.

2.8. Study Variables

Independent variables:-the independent variable for this study was: moisture content, CBR test, maximum dry density, moisture content, sieve analysis, atterberg limit test, and proctor test.

Dependent variable: - Pavement failure.

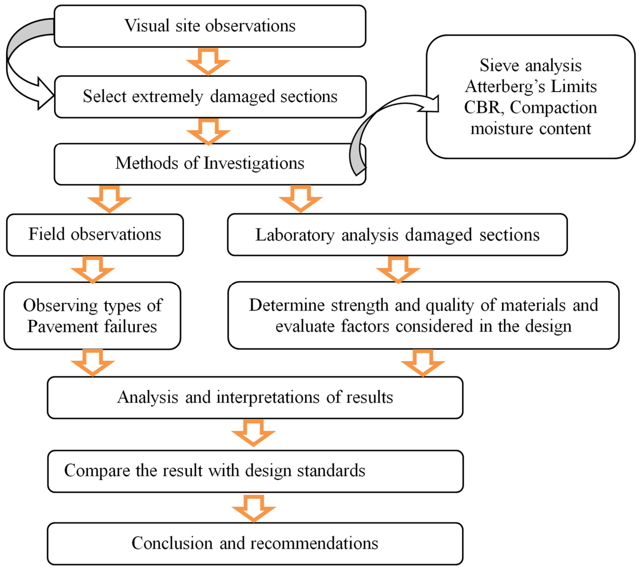

Figure 3. *Flow chart of the study method.*

2.9. Sampling Techniques

Purposive sampling technique was used by selecting particular parameters to make sure that the parameters have certain characteristics as applied for this study. It was projected to be normally targets at particular geotechnical parameters. Samples were collected by test pit along the deteriorated sections and transported to ERCC Nekemte District laboratory.

2.10. Data Collection

Samples were collected from the flexible pavement along with Nekemte-Bedele road segments from the area where the failures have occurred. The representative samples were collected from the flexible pavement layers of sub-base and sub-grade layers.

2.11. Laboratory Analysis

The collected samples in the field were transported to the ERCC Nekemte district laboratory. The types of tests performed in this laboratory to analyze results were Atterberg limit test, CBR test, Proctor test, and gradation test. The classification and analysis of the samples are based on the laboratory test and AASHTO and other standards. The analysis of obtained laboratory value and the classification in parallel to determine the index properties, bearing capacity, and MDD of different soil layers along the failed road surfaces. By comparing the laboratory analysis with different pavement design manuals it will be attempted to identify the causes of poor pavement. Types of tests performed during laboratory tests were discussed below.

a. Atterberg Limit Tests

Atterberg limit tests are used to determine the clay content in terms of LL, PL and settlement characteristics of the soil sample. Atterberg limit tests can be grouped into three main groups. These are the LL test, PL test, and PI.

The liquid limit test is the water content corresponding to the behavioral change between liquid and plastic state. The In the laboratory, the liquid limit is determined using specific devices. It represents the water content at which a part of the soil is cut by a groove of standard dimensions with 25 blows. The plastic limit, on the other hand, is the water content at which silt or clay will just begin to crumble when rolled into a specific diameter. The plasticity index is calculated by subtracting the plastic limit from the liquid limit. (i.e., PI = LL- PL).

For determination of the LL, the soil sample passing through a 0.425 mm sieve, weighing 200 g was mixed with water to form a thick homogeneous paste. The paste was collected inside the Casangrade"s apparatus cup with a grove created and the number of blows to close it was recorded. Similarly, for plastic limit determination, the soil sample weighing 200 g was taken from the material passing the 0.425 mm test sieve and then mixed with water till it became homogenous and plastic to be shaped to the ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3 mm diameter. The 3 mm diameter sample was placed in the oven at 105°C to determine the plastic limit.

Figure 4. *Atterberg's Limit (photo taken by Kasahun 10.10.2020@10:40AM).*

b. Gradation Test (Sieve Analysis)

A sieve analysis test was used to determine the distribution of the particle size of the soils. A representative sample was used for the test after washing and oven-dried. The sample was washed using the BS 200 sieve and the fraction retained on the sieve was air-dried and used for the sieve analysis. The sieving was done by the mechanical method using an automatic shaker and a set of sieves.

c. California Bearing Ratio

The California bearing ratio (CBR) test is a penetration test carried out to evaluate the mechanical strength of a sub-base, selected fill, and natural subgrade soil material. The soaked method of CBR was conducted to characterize the soil for use as a sub-base and selected fill material. A portion of air-dried soil sample was mixed with optimum moisture content. This was put in CBR mold in 5 layers with each layer compacted with 56 blows using a 4.5 kg hammer (Modified proctor test). The compacted soil and the mold were weighed and placed under the CBR machine and a seating load was applied. Load was recorded at penetration of 0.625, 1.25, 1.875, 2.54, 3.75, 5.08, 7.5, 10 and 12.5 mm.

Figure 5. *CBR test (photo taken by Imiru 17/10/2020@11:15 AM).*

d. Proctor Test (Modified Compaction

Figure 6. *Proctor test (Photo taken by Kasahun 25/10/202.*

Compaction tests were performed for sub-base, selected fill, and natural subgrade soil materials based on the AASHTO T-180 test procedure for compaction. The densification of soil with mechanical equipment thereby rearranging the soil particles which makes them more closely packed increasing the ratio of horizontal effective size to the vertical effective stress. The degree of compaction is measured in term of its dry weight and it increasing the bearing capacity of road foundation, stability slopes, controls undesirable volume changes, and curb undesirable settlement of structures. The mold is filled and compacted with soil in five layers of a 4.5 kg rammer.

3. Results and Discussion

In order to determine the types of pavement failure and degree of deterioration the visual site observations are performed. The laboratory test was carried out to determine the cause of pavement failure due to sub-base and sub-grade material properties. Such as; sub-base material, selected subgrade (fill material), and natural subgrade soil using the AASHTO standard method in relation to the generation specification for roads. For the design and construction of highway and airfield, it is imperative to carry out tests on construction materials. The inherent economy in construction depends upon the maximum use of local material. The prime objective of the different tests in use is to know and to classify the pavement materials into different groups depending upon their physical and strength or stability characteristics.

3.1. Field Observation Results

Types of Pavement Failure

The observation results and relevant remarks about the condition of the cracks are presented in Table 4. From the field visual inspection, station one (22+440) up to station two (28+890) medium to severe pavement failures observed, station three (35+890) high severe, and the last two stations means that station four and five shows the low severe. Samples were collected from these stations.

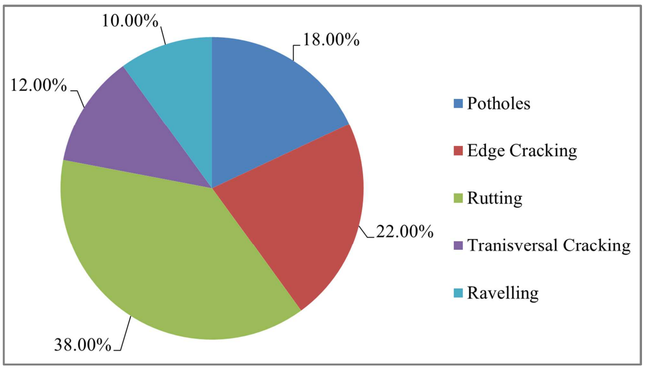

Figure 7. *Types of pavement failures and their respective percentage along Nekemte – Bedele road.*

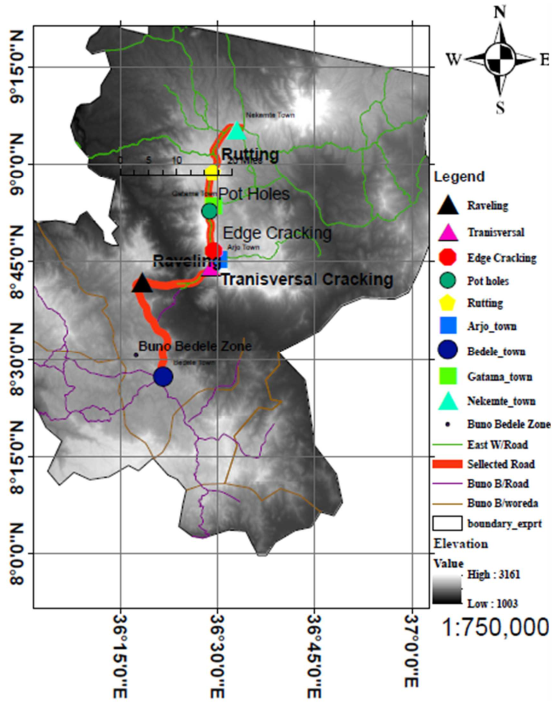

Figure 8. *Point locations sampling stations along the road segment (23, 2021, 5:38:10 PM) (source: Ethiopian map agency).*

Table 2. *Test pit location and severity of the road segments.*

No.	Station	Side	Sample date	Coordinate (x, y)	Failure type	Severity level
1	22+440	Right	25/09/2020	$36^0$29’25”, $8^0$57’08”	Rutting	Medium
2	28+890	Left	26/09/2020	$36^0$28’44”, $8^0$50’48”	Potholes	Medium
3	35+890	Left	04/10/2020	$36^0$29’03”, $8^0$46’28”	Edge cracking	High
4	44+700	Right	06/10/2020	$36^0$29’21”, $8^0$44’16”	Transversal Cracking	Low
5	46+090	Left	21/10/2020	$36^0$25’35”, $8^0$41’01”	Raveling	Low severe

Figure 7 shows the type and level of pavement failure along Nekemte-Bedele road. Different major types of deterioration were observed along the selected segment of Nekemte - Bedele road segments. 36.48 km of rutting types of pavement failures occur, 17.28 km of potholes types of failures occur, 21.12 km of Edge cracking, 11.52 km of Transversal cracking, 9.6 km of raveling types of pavement failures occur. When these failures are described in percent Rutting (38%), Potholes (18%), Edge Cracking (22%), Transversal cracking (12%), Raveling (10%). The causes of the observed failure could be poor workman skill, poor compaction, low quality of materials, poor drainage structure as described by the research [14].

The assessment has revealed that different types and degrees of deterioration (levels of severity) observed on the pavement surface. Based on the visual field inspection the following results are investigated. Station one (22+440) and station two (28+890) shows medium severe, station three (35+890) shows high or more severe and the last two stations means that station four and five shows that less or low severe.

3.2. Engineering Properties of Sub-base Materials

3.2.1. Atterberg Limit

The properties of the samples collected from different layers of the pavement are given in Table 3. The Ethiopian Road Authority and design manual specified that liquid limits of 30% maximum, the plastic limit of 30% maximum, and the plasticity index of 15% maximum for sub-base materials. Table 3 shows that the liquid limits of the sub-base soils located between 29.3 to 65.7% while the plastic limit located between 21 to 40.9% and the plasticity index located between 2.7 to 37.1%. Based on this specification none of the sub-base soil samples met these required specifications except sample 5.

Table 3. *Atterberg limit values of the representative soil the samples.*

Samples	Pavement layers	Atterberg limits		
		LL (%)	PL (%)	PI (%)
1	Sub- base	59.2	47.8	11.4
	Selected fill	61.9	40.9	21.0
	Natural subgrade	61.9	40.9	21.0
2	Sub- base	65.7	28.6	37.1
	Subgrade	51.2	40.1	11.1
	Natural subgrade	72.11	39.9	33.04
3	Sub- base	50.7	48.0	2.7
	Selected fill	36.0	28.6	7.4
	Natural subgrade	36.02	28.6	7.42
4	Sub- base	59.8	33.3	26.5
	Selected fill	40.8	25	15.8
	Natural subgrade	40.82	25.0	15.82
5	Sub- base	29.3	21	8.3
	Selected fill	73.4	37	36.4
	Natural subgrade	31.85	26.0	5.85

3.2.2. Gradation Test Results (Sieve Analysis)

The sieve analysis test results for sub-base material shown from the laboratory test result. They are more or less within the limits of the specification. The specification limits are shown in Table 4. According to the project specification, all sub-base materials couldn't fulfill the project specifications. The result of particle size analysis described in Table 5 indicates that the soil clay content for all sub-base samples located between 7.42 to 29.32%. According to the Pavement Design Manual, the clay content for sub-base materials must not exceed 34.9%. The high clay content could be responsible for the instability of road pavement in the area. So, from test results, all sub-base materials are fulfilling the specifications.

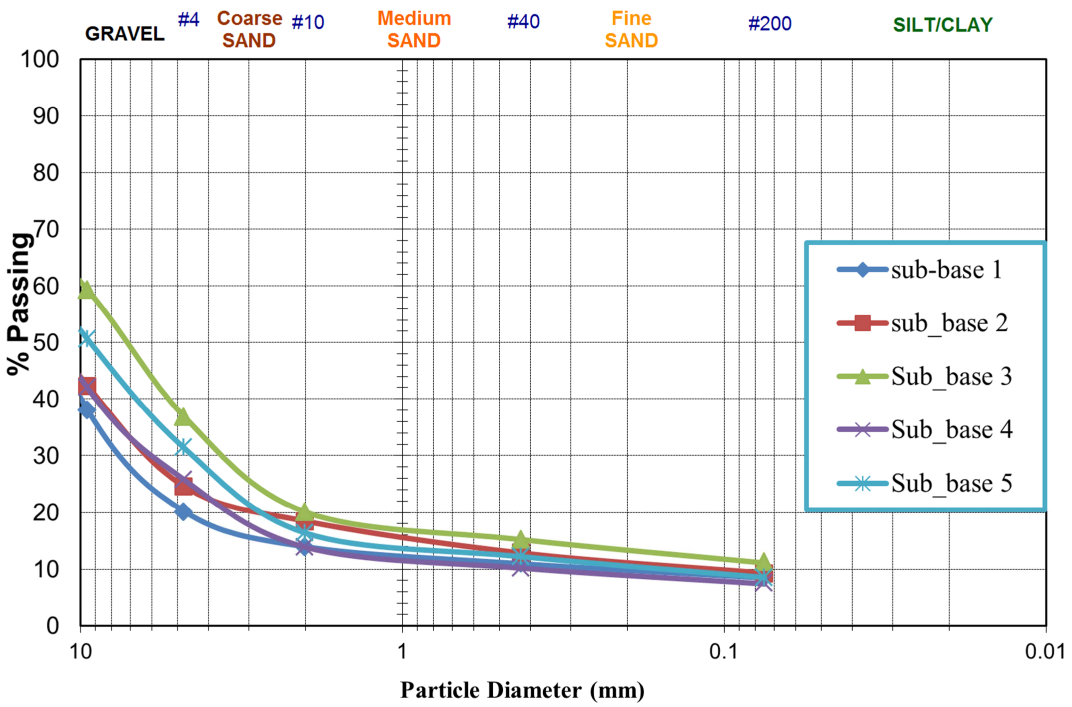

Figure 9. *Graphs of particle size analysis of sub-base materials.*

Table 4. *Gradation requirements for the sub-base material based on the specification of Nekemte – Bedele road rehabilitation project.*

Sieve size, mm	Specifications
50	80 – 100
25	55 – 90
19	51 – 84
9.5	43 – 73
2.00	24– 50
0.425	30 – 60
0.075	10 – 30

Table 5. *The Sieve Analysis Test Results of Sub-base Materials.*

Types of materials	Sub-base				
Samples	**1**	**2**	**3**	**4**	**5**
Sieve seize	Percentage passing				
50	100	100	100	100	100
25	88.06	85.16	84.61	81.90	82.89
9.5	38.06	42.34	59.30	41.93	50.58
4.75	20.15	24.56	36.83	25.72	31.03
2.00	13.94	18.45	20.06	13.86	16.36
0.425	10.95	12.83	15.19	10.17	12.20
0.075	8.46	29.32	11.09	7.42	8.55
pan	0.00	0.00	0.00	0.00	0.00

3.2.3. California Bearing Ratio

Table 6 shows that the range of four days soaked CBR values of sub-base soil materials, which is from 2.1 to 43%. The Ethiopian Road Authority (ERA), Nekemte – Bedele Rehabilitation Project material specified CBR greater than or equal to 30% for sub-base materials. Based on these specifications, sub-base soil samples 1, 4, and 5 were not suitable as a sub-base material. Only samples 2 and 3 were suitable for the specifications. The detailed results of CBR were given in Table 6.

Table 6. *Four day soaked sample of California Bearing Ratio test result values.*

Soil Sample	Pavement Layers	Soaked CBR (%)	
		2.5 mm	**5.08 mm**
	Sub- base	2.095	1.92
1	Selected fill	44.5	16.3
	Natural subgrade	31.7	26.9
	Sub- base	43	19.4
2	Selected fill	43	40.2
	Natural subgrade	3.4	3.3
	Sub- base	41.5	40.7
3	Selected fill	42	41
	Natural subgrade	16.5	22.1
	Sub- base	23.65	21.1
4	Selected fill	4	3.5
	Natural subgrade	3	2.5
	Sub- base	10	9.15
5	Selected fill	38	30
	Natural subgrade	50.58	48.82

3.2.4. Compaction Test (Proctor Test)

Table 6, shows that the maximum dry density (MDD) of the sub-base soil materials ranged between 1.30 and 1.92 kg/m³, while the optimum moisture content (OMC) ranged from 15.90% to 21.30%. The Ethiopian road authority specified OMC less than 18% for sub-base soil materials. Based on these specifications, all sub-base soil samples are not suitable except sample two.

Table 7. *Values of proctor test for all soil samples in the study area.*

Soil Sample	Pavement Layers	Modified Proctor Test	
		MDD (Kg/m³)	**OMC (%)**
	Sub- base	1.81	21. 3
1	Selected fill	1.50	27.80
	Natural subgrade	1.66	22.50
	Sub- base	1.30	15.90
2	Selected fill	1.68	27.50
	Natural subgrade	1.33	22.50
	Sub- base	1.42	18.20
3	Selected fill	1.62	17.90
	Natural subgrade	1.73	18.90
	Sub- base	1.92	19.20
4	Selected fill	1.66	17.10
	Natural subgrade	1.43	22.90
	Sub- base	1.71	20.30
5	Selected fill	1.76	21.2
	Natural subgrade	1.96	12.80

3.3. Engineering Properties of Selected Fill (Subgrade Materials)

3.3.1. Atterberg Limit

According to Ethiopian Road Authority (ERA), Nekemte–Bedele rehabilitation project material specification requirements the selected fill material or subgrade materials have PI ≤ 25.

Table 4 shows that the liquid limit of the selected fill soils ranged from 36 to 73.4% while the plastic limit ranged from 25 to 40.9% and the plasticity index ranged from 7.4 to 36.4%. All selected fill soil samples met these required specifications except sample 2.

3.3.2. Gradation Test (Sieve Analysis)

Table 8. *The table below shows the Sieve Analysis Test Results of Subgrade Materials.*

Material type	Sub-grade				
Sample	**1**	**2**	**3**	**4**	**5**
Sieve seize	**Percentage passing**				
50	100	100	100	100	100
25	82.98	88.36	87.13	83.12	81.45
9.5	45.59	37.65	40.71	40.84	61.16
4.75	30.14	21.51	23.39	25.15	37.20
2.00	15.65	16.08	17.85	18.31	27.82
0.425	12.38	11.94	13.89	14.45	24.44
0.075	8.82	9.09	10.43	10.76	17.59
pan	0.00	0.00	0.00	0.00	0.00

The sieve analysis test results for selected fill material shown from the laboratory test result. They are more or less within the limits of the specification. The specification limits are shown in Table 4. But ERA, (2002) recommended grading criteria are not given for selected fill soil materials [15]. The result of the particle size analysis contained in Table 8 indicates that the soil's clay content for all selected fill samples ranged from 8.82 to 17.59%. According to the Ethiopian Road Authority specification, the clay content for selected fill soil materials must not exceed 35%. The high clay content could be responsible for the instability of road pavement in the area. So from test results for all selected fill materials are fulfilling the specification.

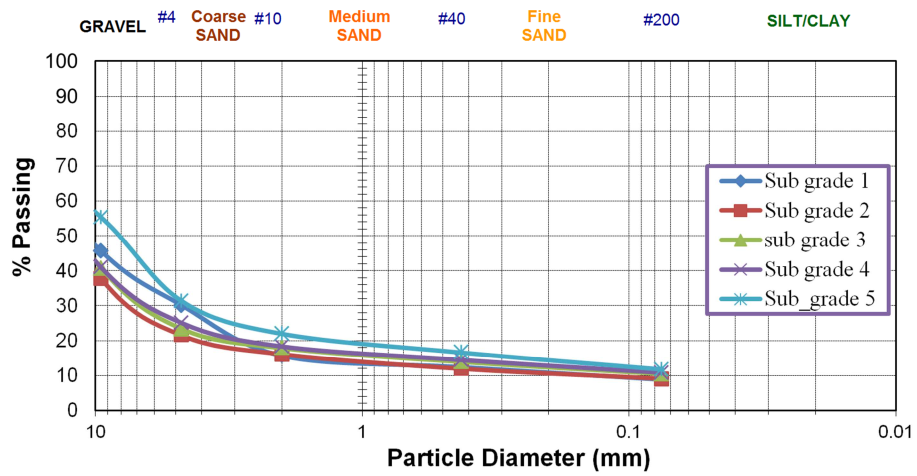

Figure 10. *This graph shows the test result of subgrade materials.*

3.3.3. Modified Proctor

Table 7, described MDD of the selected fill soil materials located between 1.50kg/m³ and 1.76 kg/m³, while the OMC located between 17.10 and 27.80%. The Ethiopian Road Authority specified OMC less than 18% for selected fill soil materials. Based on these specifications, selected fill soil sample 1, 2 and 5 are not suitable as selected fill material and sample three and four are suitable.

3.3.4. California Bearing Ratio

Table 6, shows that the four days soaked CBR values of selected fill soil materials ranged from 4 to 44.5%. The Ethiopian Road Authority (ERA), Nekemte – Bedele rehabilitation project material specified CBR greater than or equal to 15% for selected fill materials. Based on these specifications, selected fill soil sample 4 are not suitable as selected fill material.

3.4. Engineering Properties of Natural Subgrade Soils

3.4.1. Atterberg Limit Test

According to the Ethiopian Road Authority (ERA), Nekemte – Bedele rehabilitation project material specification requirements, Natural subgrade material PI $\leq$ 30. Based on these specifications, natural subgrade soil samples 2, 4, and 5 are not fulfill the requirements.

The plasticity charts for natural subgrade soils in the study area are presented in Table 3. According to these charts, soils with liquid limits less than 30% are categorized as having low plasticity and compressibility, those with liquid limits between 30% and 50% are considered to have medium plasticity, and those with liquid limits exceeding 50% are classified as having high plasticity and compressibility. Based on this classification, natural subgrade soil samples 1, 3, and 5 fall within the medium plasticity category, while samples 2 and 4 fall within the high plasticity/compressibility range of the plasticity chart.

Table 9. *AASHTO soil classification of representative Natural Subgrade soil sample.*

Soil Sample	Soil type	ATTERBERG LIMITS			AASHTO SOIL CLASSIFICATION
		Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Group classification
1	Natural Subgrade	61.09	40.09	21.00	A-2-7
2	Natural Subgrade	71.05	38	33.05	A-2-7
3	Natural Subgrade	36.02	28.60	07.42	A-2-4
4	Natural Subgrade	40.82	25.00	15.82	A-7-5
5	Natural Subgrade	31.85	26.0	05.85	A-2-4

Table 10. *USCS soil classification of representative Natural Subgrade soil sample.*

Soil Sample	Soil Type	ATTERBERG LIMITS			USCS SOIL CLASSIFICATION	
		Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Group symbols	Typical names
1	Natural subgrade	47.4	29.05	18.35	SM	Silty sands
2	Natural subgrade	71.05	38	33.05	OH	Organic clays of a medium of high Plasticity
3	Natural subgrade	41.09	22.9	18.19	SC	Clayey sands
4	Natural subgrade	74.35	25.1	49.25	CH	Inorganic clays of high plasticity
5	Natural subgrade	38.05	21.2	16.85	SC	Clayey sands

In addition, the AASHTO soil classification for highway construction indicates that A-1, A-3, and A-2 soils are excellent to good for highway use, with a percentage passing Sieve No. 200 not exceeding 35%. On the other hand, A-4 to A-7 soils are considered to be fair to poor for highway construction, with a percentage passing Sieve No. 200 greater than 35%. Based on this classification, natural subgrade soil samples 1, 3, and 5 may be classified as excellent to good subgrade soils, while samples 2 and 4 are categorized as fair to poor for subgrade use.

3.4.2. Gradation (Sieve Analysis)

The result of the particle size analysis contained in Table 11 indicates that the soil's clay content for most natural subgrade samples ranged from 8.46 to 29.8%. According to the Ethiopian Road Authority specification, the clay content for natural subgrade soil materials must not exceed 35%. The high clay content could be responsible for the instability of road pavement in the area. Based on these specifications, all natural subgrade soil samples are suitable for the embankment. Also, general rating as sub-grade (in accordance with AASHTO (1986)) is fair to poor materials. They have significant constituent materials of mainly clayey soils while few are silty or clayey gravel and sand whereby the% passing № 200 sieve is <35%.

Table 11. *The Sieve Analysis Test Results of Natural sub- grade.*

Types of materials	Natural Sub-grade				
Samples	**1**	**2**	**3**	**4**	**5**
Sieve seize	Percentage passing				
50	100	100	100	100	100
25	85.21	89.65	81.87	80.95	89.34
9.5	38.06	80.9	62.7	77.4	76.23
4.75	20.15	60.7	43.0	52.8	68.4
2.00	13.94	46.9	31.3	41.8	57.4
0.425	10.95	36.5	21.7	33.2	44.6
0.075	8.46	26.9	12.7	19.6	29.8
Pan	0.00	0.00	0.00	0.00	0.00

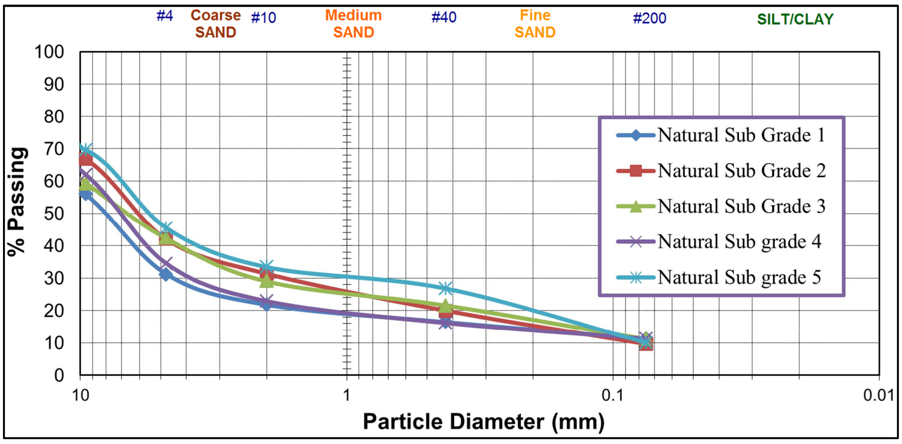

Figure 11. *Sieve Analysis test graphs of Natural subgrade soil samples.*

3.4.3. Compaction Test (Proctor Test)

According to Table 7, the natural subgrade soil materials have a maximum dry density (MDD) ranging from 1.33 kg/m³ to 1.96 kg/m³, and the optimum moisture content (OMC) ranges from 12.8% to 22.9%. The Ethiopian Road Authority has specified that the OMC for natural subgrade soil materials should be less than 18%. Based on these specifications, it is determined that all natural subgrade soil samples are not suitable for use as subgrade (embankment) material, except for sample 5.

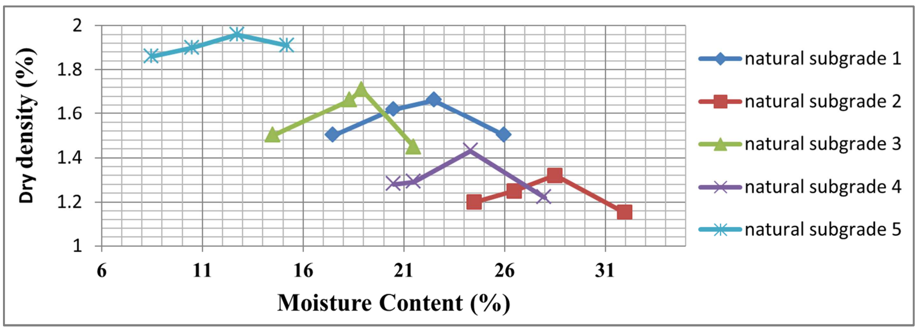

Figure 12. *Compaction test graphs of natural subgrade soil sample.*

3.4.4. California Bearing Ratio

Table 6, shows that the four days soaked CBR values of the natural subgrade soil materials have a plasticity index ranging from 3 to 50.58%. The specifications for the Ethiopian Road Authority (ERA), Nekemte – Bedele rehabilitation project require a California Bearing Ratio (CBR) greater than or equal to 5% for natural subgrade materials. Based on these specifications, it is noted that natural subgrade soil samples 2 and 4 do not meet the requirements.

3.5. Observations and Proposed Remedial Measures

Observations and laboratory analysis have identified various types of pavement failures, which are likely related to the presence of water in the subgrade and sub-base. This includes issues such as percolation of water beneath the ground to the subgrade and infiltration of rain onto the pavement surface. The presence of water, combined with heavy loads passing over the pavement surface, has been identified as a primary cause of pavement failures. To address these issues, it is recommended that proper materials be used to fill voids beneath the pavement with high-softening under-sealing asphalt to prevent water intrusion into the subgrade and sub-base.

Remedial measures for the area affected by failures should include reconstruction of the layers up to the subgrade level to carry out repairs. Additionally, in areas where cracks and other failures have occurred, sealing of cracks with bitumen or other suitable materials is recommended to prevent further cracking and minimize water infiltration during rainy seasons.

Table 12. *Observed failures and proposed remedial measures.*

Types of failures	Description	Proposed Remedial Measures
Rutting	Refers to longitudinal surface depression in the wheel-paths of the asphalt pavement.	Level the pavement by filling the channels with hot plant- mixed asphalt material. Follow with a thin asphalt plant-mixed overlay
potholes	Bowl-shaped holes of various sizes in the pavement surface.	Temporary repair through filling with pre-mixed asphalt patching material and Permanent repair through filling with new base and surface material.
Edge cracking	This edge cracking typically starts as crescent shapes at the edge of the pavement, which will expand from the edge until they begin to resemble alligator cracking.	The possible remedial measures of this edge cracking type deterioration are elimination of the excess moisture by building shoulders and providing proper drainage with good materials.
Transversal cracking	Cracks perpendicular to the pavement's centerline or lay down direction. Usually type of thermal cracking.	Improve drainage by removing the source that traps the water Seal crack or fill with asphalt emulsion slurry or light grade of asphalt mixed with fine sand. Provide side drainage ditches Crack seal/fill
Raveling	The wearing away of the pavement surface caused by the dislodging of aggregate particles.	Surface treatment, such as seal coating, surface dressing, thin overlaying of Bituminous Surface Course.

4. Conclusion and Recommendations

4.1. Conclusion

This study aims to assess the causes of pavement failure due to sub-base and subgrade material properties along with the Nekemte-Bedele Road segments by conducting field visual inspection and laboratory tests. From the field visual inspection, the following results are drawn.

the types of pavement failure that occurred along the selected segments are Rutting, potholes, Edge cracking, Transversal cracking and raveling types of pavement failures have occurred along the Nekemte-Bedele road segments.

The assessment has revealed that different types and degrees of deterioration (levels of severity) observed on the pavement surface. Based on the visual field inspection the following results are investigated.

Station one and station two shows medium severe, station three shows high or more severe and the last two stations means that station four and five shows that less or low severe. Based on the laboratory test results, it is evident that different tests were conducted to assess the real causes of pavement failure due to sub-base and subgrade materials. These tests included sieve analysis to check soil grain size distribution, Atterberg limit test to determine the plasticity index of the soil, modified compaction test to find out the maximum dry density and optimum moisture content of the soil, and California bearing ratio test to assess the strength of the soil properties.

The soil clay content for all sub-base samples ranged from 7.42 to 29.32%, and it is noted that the high clay content could be responsible for the instability of the road pavement in the area. However, it is indicated that all sub-base materials fulfilled the specifications. The soil's clay content for all selected fill samples ranged from 8.82 to 17.59%, and these samples also met the specifications.

The results of the particle size analysis of the soil's clay content for most natural subgrade samples ranged from 8.46 to 29.8%. The liquid limit of the sub-base soils ranged from 32.3 to 59.8%, while the plastic limit ranged from 21% to 48%, and the plasticity index ranged from 2.7 to 33.05. It is mentioned that none of the sub-base soil samples met these required specifications except for sample 5. Additionally, the liquid limit of the selected fill soils ranged from 36 to 73%, while the plastic limit ranged from 25 to 40.9%, and the plasticity index ranged from 7.4 to 36.4%. None of the selected fill soil samples met these required specifications.

The range of CBR for sub-base material is 2.1 to 43%. According to the project specifications, the CBR value is greater than or equal to 30%. Based on the specification sample 1, 4, and 5 couldn't fulfill the specification. Only samples 2 and 3 fulfill the specifications. For selected fill materials the CBR value is ranged from 4 to 44.5%. A CBR greater or equal to 15% is recommended from project specifications. All samples fulfill the specifications except sample 4. The MDD of selected fill materials were ranged from 1.50 to 1.76 Kg/m^3, while the optimum moisture content ranged from 17.10 to 27.80%. Based on the specification all the samples do not fulfill the specifications except sample 3 and 4.

According to Table 7, the natural subgrade soil materials have a maximum dry density (MDD) ranging from 1.33 kg/m^3 to 1.96 kg/m^3, and the optimum moisture content (OMC) ranges from 12.8% to 22.9%. The Ethiopian Road Authority has specified that the OMC for natural subgrade soil materials should be less than 18%. Based on these specifications, it is determined that all natural subgrade soil samples are not suitable for use as subgrade (embankment) material, except for sample 5.

Based on these specifications, all-natural subgrade soil samples are not suitable as subgrade (embankment) material except sample five.

4.2. Recommendations

When planning road construction, it is important to avoid using materials with high swell potential in the subgrade. If expansive soils are present, proper treatment methods such as excavation and replacement to a depth where moisture variation is minimal should be incorporated. Sufficient cover should also be provided to overcome the swell pressure caused by moisture increase under the subgrade.

In cases where road segments have failed, it is crucial to replace the pavement materials with suitable alternatives and ensure they are compacted to the required minimum density. Stabilizing agents should be used for the subgrade soil, especially for clayey soils, and any materials used for road maintenance and rehabilitation must adhere strictly to specified values.

Timely maintenance and rehabilitation of roads are essential to prevent the escalation of pavement failures, which can have a significant impact on both the road's longevity and the country's economic budget.

While the present study focused on investigating the causes of pavement failure due to sub-base and subgrade materials, future research should consider the following:

1. Detailed investigation of poor drainage conditions and the effects on pavement distress.
2. Examination of the impact of poor shoulder conditions on various types of pavement failures.

Expanding the scope of research to include these factors will provide a more comprehensive understanding of the challenges and potential solutions for road pavement failures.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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