Journal of Civil Engineering, Science and Technology

Volume 13, Issue 2, September 2022, 112 – 135

INVESTIGATING CAUSES OF FLEXIBLE PAVEMENT FAILURE: A CASE STUDY OF THE BAKO TO NEKEMTE ROAD, OROMIA, ETHIOPIA

Desta Degu[1], Basha Fayissa[2], Anteneh Geremew[2*] and Gelata Chala[1]

[1] Ambo University, School of Civil and Environmental Engineering, 19 Ambo, Ethiopia
[2] Jimma University, Faculty of Civil and Environmental Engineering, 378 Jimma, Ethiopia

Date received: 10/12/2021, Date accepted: 09/05/2022
*Corresponding author's email: antjiren@gmail.com
DOI: 10.33736/jcest.4332.2022

Abstract — Most of the roads constructed in Ethiopia fail prematurely before serving the design life due to various causes arising from many factors. One of the roads that failed before reaching its design lifetime is the Bako to Nekemte Trunk Road. This road was constructed and opened to traffic in 2013. The design pavement life was estimated at 20 years. However; pavement failures have manifested since 2014 after it was opened for traffic. The main objective of this research was to investigate the cause for the failure of flexible pavement on the Bako to Nekemte road segment. To achieve this objective, the study was followed by the experimental research type and purposive sampling method. Also, field observation and pavement condition survey methods for data collection were used. The asphalt, base course, subgrade, and sub-base layer material sampled from the road segment are the material used for this study. Different pavement failures such as rutting, pothole, alligator cracking, raveling, edge cracking, depression, and corrugation were observed along the road section. For estimations of pavement condition index, the road was divided into five different sections based on distress densities, which were measured during the pavement condition survey. From those five sections, four sections were selected for the determination of the Pavement Condition Index (PCI). Using systematic random sampling 159 sample units were evaluated for Pavement Condition Rating (PCR) and the result shows 1.89% excellent, 8.18% very good, 20.13% good, 31.45% fair, 18.87 % poor, 18.24% very poor, and 1.26% failed. Based on PCI value, samples of pavement layer were taken from failed surface condition (1), poor surface condition (2), and none distressed area (1) for comparison purposes. Different quality tests like Atterberg limit, wash gradation, soil classification, compaction test, California Bearing Ratio (CBR), Los Angeles Abrasion (LAA), Flakiness Index (FI), Aggregate Crushing Value (ACV), Ten percent fines value (TFV), bitumen content, and gradation of asphalt were carried out. The results of these tests were compared with ERA specifications to identify the probable cause of pavement failure. The study found that the cause for failure of flexible pavement in the case of Bako to Nekemte was: insufficient and absence of side drainage structure, traffic loading, poor gradation of base course and sub-base material, and poor quality of subgrade soil. The study also recommended that the road urgently needed routine maintenance as a treatment option to reduce further deterioration and extend its service time.

***Keywords*:** Pavement failure, pavement condition index, pavement condition rating, traffic loading, routine maintenance

1.0 INTRODUCTION

Pavement failure is the process by which distresses are formed in pavement by the effects of traffic loading and environmental conditions. The distress developed in the pavement greatly affects the serviceability, safety and riding quality of the road. Road pavement deteriorates with age as a result of use. Therefore, they need to be maintained to ensure that the requirements for safety and durability are satisfied [1–3]. Developing countries have lost billions of dollars in infrastructure as a result of the deterioration of their roads. If they do not repair their motorways correctly and promptly, they will lose billions of dollars more. In dry and semi-arid regions, these forms of damage are more common. Damage can be seen in the form of cracks in sidewalks and roads, as well as tilted retaining walls and pavement constructions. The quantity of damages can escalate to a point where one or all pavement structures break by diminishing the road's structural safety. Maintenance and repair expenditures can easily exceed the cost of the road itself, putting a financial strain on developing countries. In most cases, these damages result in economic losses for the entire country [4–6]. Inadequate drainage, a lack of acceptable pavement design, and an excessive amount of water in the sub-grade contribute to sub-grade failure, poor subgrade soil, and a lack of normal maintenance by the responsible body [7, 8]. According to [9]. Fatigue cracking, caused by excessive vertical compressive and horizontal tensile strain at the top subgrade and bottom of the asphalt layer due to repeated traffic loading, and rutting deformation, caused by densification and shear deformation of the subgrade, are the two main causes of road failure in asphalt pavement. Excess vertical surface deflections in flexible pavements have long been a source of concern and a design requirement. The majority of pavement distress results from different factors such as environment, quality of materials, construction techniques, and/or structural causes, and so on. However, it is essential to identify between these factors to pick the most effective maintenance and/or rehabilitation techniques [10, 11]. Based on the study [12] investigated how traffic loads and climate variables affect the deterioration of flexible pavements. Pavement deterioration is influenced by the technique and materials used in road construction, but it is also influenced by traffic loads and volumes. In addition, inadequate drainage and an increase in moisture diminish the pavement's strength, resulting in pavement failure. The key to preventing road deterioration is identifying vehicle uses and applications, particularly for industrial transportation. Understanding traffic volume and size (especially in the case of overload) is critical for road safety and can help to prevent pavement damage.

Under the combined action of traffic, environment, and climatic circumstances, flexible pavement is prone to cracking at some time throughout its life [13]. The Wisconsin Department of Transportation researches pavement fatigue caused by the number and weight of axle loads, as well as how wheel loads, truck axles, truck tires, sub-grade quality, pavement thickness, and changing seasons affect pavement fatigue. Potholes, fractures, edge flaws, depressions, and corrugation are also common road problems along highway corridors. The Federal Democratic Republic of Ethiopia by the road sector development strategy has intended to upgrade the Gedo to Nekemte road as part of its Road, Sector Development Program II that included Bako to Nekemte road before eight (8) years ago. The Gedo to Nekemte road project has been used as the country's truck road network that connects the capital city, Addis Ababa with Nekemte town and has 81 km length. Soon after construction, the road has been showing several pavement failures before the expected design life. So, this study was carried out to investigate the causes of the failure of this road segment.

Deterioration of highway pavement is a serious problem that causes traffic congestion, distorts pavement aesthetics, raises the cost of road maintenance and results in a loss of highway investment, damages vehicles, and, most importantly, causes road traffic accidents that result in the loss of lives and property [14]. Deformation of the pavement surface has an impact on safety and ride quality since it can lead to premature breakdown. Deterioration of flexible pavement (bituminous roads) is common in many developing countries, a tendency that both road users and road authorities are concerned about. The majority of roadway pavements collapse soon after construction, much before their planned life, and this has been linked to several causes. Inadequate building materials, design and specification, road usage, poor drainage, and Geotechnical problems are among them [9]. Pavement failures can be caused by a lack of highway infrastructure, a lack of local standards of practice, poor laboratory and in-situ soil studies, and a lack of local professional groups involved in highway design, construction, and management [1]. The majority of Ethiopian roads failed before they reach their design life due to a variety of causes resulting from a variety of variables. The Bako to Nekemte Trunk Road was one of the highways that failed before it reached its design life span. The construction of the road was finished and opened to traffic in the year 2013. The design, pavement life was estimated at 20 years, however; pavement failures have been manifested since 2014 after one year opened to traffic. The different pavement failures such as Rutting, Pothole, Alligator cracking, raveling, Edge cracking, depression, and corrugation were observed along the road section. These failures caused discomfort to road users like riding, long travel time, maintenance cost, vehicle operating cost, and traffic accidents. According to a pavement condition survey conducted by the Nekemte ERA district the maintenance cost of Bako to Nekemte is estimated at 53 million ETB in 2006 [15]. This is a huge loss for the country's budget. Drainage problems, poor quality of pavement material, Poor workmanship (ignoring project specification), and traffic load can be a cause for the existence of failures on this road segment. It is important to know the real cause of failure of this road segment for successful pavement maintenance and to provide data for improving construction techniques. Therefore, this study was conducted on the cause of failure of flexible pavement a case study of Bako to Nekemte road segment.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was conducted on the Bako to Nekemte road which is found in the eastern part of Wollega Oromia regional state as shown in Figure 1. The area is characterized by cold to moderate climate conditions. The road connects the town such as Bako, Ano, Sire, Cheri, Jalele, Chingi, Gaba Jimata, Gute, and Nekemte. The maximum and minimum daily temperature of Bako town is 89°F and 61°F respectively, while the maximum and minimum monthly rainfall of a town is 1341mm and 152mm respectively. While the average daily temperature of Nekemte town is 52.2°F to 78.8°F and receives an average annual rainfall of 1854.9 mm. The total length of the road is about 81 km asphalt pavement. The carriageway width of the road is 7.0m paved with asphalt concrete (AC) and 1.5m wide shoulders of single bituminous surface treatment on each side for sections in rural areas. In the larger towns, the carriageway width is 14m paved with AC and 2.5m walkway single bituminous surface treatment on each side. In other smaller towns, the carriageway width is reduced to 13m and the walkway to 2-m with the same type of construction as the largest town. Bako to Nekemte road is used as the center of the road network in the Western part of Ethiopia. The design standard of the road is DS3 asphalt concrete paved and its functional classification is a truck road with AADT 1000 to5000 with a design period of 20 years.

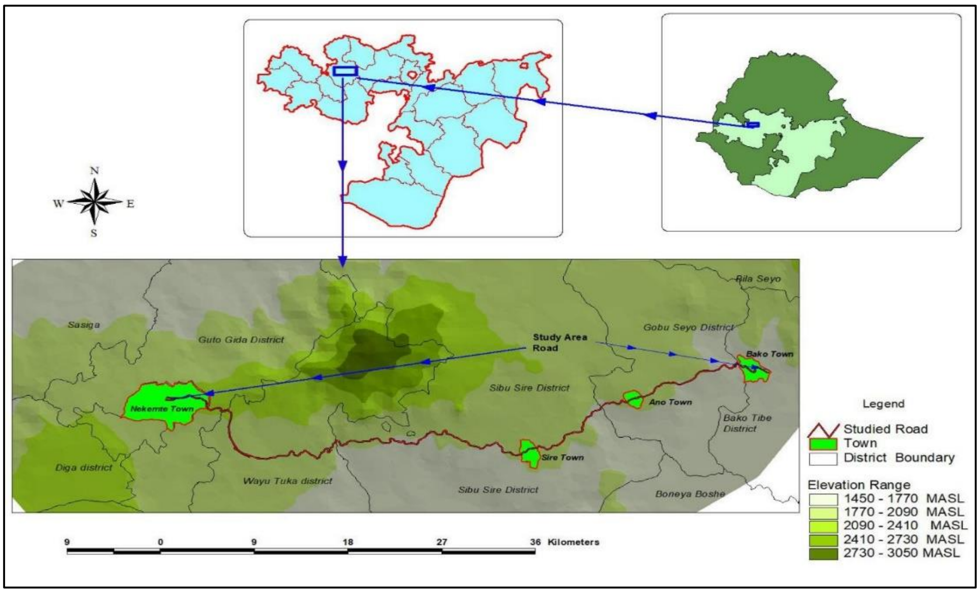

Figure 1 Map of the study area

2.2 Research Design

The procedure applied throughout the conduct of this research study was as followed: Review of the related literature on important areas of the cause of failure of flexible pavement, which includes research articles, reference books, research papers, lecture notes, project specifications, and standard specifications like ERA, AASHTO, and ASTM. Necessary data collection, organization, comparison, and analysis were obtained, and then the results were subsequently compared with pre-existing literature and standard specifications. A conclusion and recommendation were drawn based on the findings of the causes of failure of the asphalt pavement. The study was used experimental, analytical, applied, described, quantitative, and qualitative types of research directly and indirectly. The experimental design was used in this study because; samples taken from a field were tested in the laboratory. The research also used qualitative research because; the study investigated the cause of failure of flexible pavement.

2.3 Pavement Condition Survey

The condition survey was used for identifying pavement failure types and levels of severity and extent associated with each failure. The pavement condition survey was done according to the procedure of (ASTM 6433, 2007). Distress types, severity levels, and quantity were recorded in the format of flexible pavement condition Survey Data Sheet for the Sample unit. Sample unit inspection or distress recording was taken with a difference of 100m length along with the road segments as shown in Figure 2. The type of distress and level of severity was identified by visual observation and the quantity of distress was measured by tape. The different types of failures observed and with their unit of measurement used are shown in Table 1.

Table 1 Distress type and unit of measurement

S/N	Distress type	Unit
1	Rutting	m^2
2	Pothole	No
3	Alligator cracking	m^2
4	Edge cracking	M
5	Depression	m^2
6	Corrugation	m^2
7	lane/shoulder drop	M
8	Raveling	m^2

Figure 2 Pavement failure types were observed along the road segment.

2.4 Sampling Technique for PCI

PCI determination of the road segment was done according to ASTM D6433. First, the pavement was divided into five sections based on the condition of the pavement. This was done by a preliminary site visit with visual observations of the whole road section. Each section was again divided into sample units with an equal length of 100m. The type and severity of pavement distress were identified by visual inspection of the pavement. The distress data were used to calculate the PCI for each sample unit. The PCI of the pavement section was determined based on the PCI of the inspected sample units within the section. Hence, the road was sectioned into five (5) different sections as shown in Table 2. From the five (5) sections, 1-4 sections were selected for PCI determination. The 5th section was not selected because it has a similar pavement condition as others.

Table 2 Identification of severity level for distresses

S/N	Station	Severity level	Pavement condition survey
1	0+000-8+600	Good	Conducted
2	8+600-16+400	Low	Conducted
3	16+400-32+900	Medium	Conducted
4	32+900-54+500	High	Conducted
5	54+500-80+000	Good	Conducted, but not selected for PCI

2.5 Sample size for PCI

According to ASTM D6433, 2007 manual, this study used a systematic random sampling technique to determine the number of sample units of the pavement sections selected for PCI determination. The minimum number of sample units (n) that were surveyed within given sections to obtain a statistically adequate estimate (95 % confidence) of the PCI of the sections was estimated using equation (1).

$$n = \frac{NS^2}{((e^2/4)(\mathrm{N}-1)+S^2)} \quad (1)$$

Where: e = acceptable error in estimating the section PCI; commonly, e = ±5 PCI points;

s = standard deviation of the PCI from one sample unit to another within the section.

When performing the initial inspection the standard deviation was assumed to be ten for AC pavements. This assumption was checked as described below after PCI values were determined. For subsequent inspections, the standard deviation from the preceding inspection has been used to determine n; and, N = total number of sample units in the section. Obtaining the 95 % confidence level was critical and the adequacy of the number of sample units surveyed were also confirmed.

The number of sample units were estimated based on an assumed standard deviation. The actual standard deviation (s) is estimated using equation (2).

$$s = (\sum_{n=1}^{n}(\mathrm{PCIi}-\mathrm{PCIs})/(\mathrm{n}-1))^{1/2} \quad (2)$$

Where: PCI_i= PCI of surveyed sample units i,

PCIs = PCI of section (mean PCI of surveyed sample units), and

n = total number of sample units surveyed.

The revised minimum number of sample units surveyed was estimated from the standard deviation. The additional random sample unit was selected and surveyed when the revised number of sample units surveyed is greater than that of existed before. Once the number of sample units inspected has been determined, the spacing interval of the units using systematic random sampling was estimated. Hence, the samples within different sections were spaced equally throughout the sections with the first sample selected at random. The spacing interval (i) of the units to be sampled was determined using equation (3).

$$i = \frac{N}{n} \quad (3)$$

Where: N = total number of sample units in the section, and

n = number of sample units to be inspected.

The first sample unit inspected was selected at random from sample units 1 through i. The sample units within the sections that were successive increases of the interval I after the first randomly selected unit was inspected. Therefore, the next steps such as the determination of the PCI value of each sample unit and the average PCI value of each section were continued after the sample units of each section were determined. The total number of sample units exists and the total number of sample units inspected in each section is presented in Table 3.

Table 3 Number of sample units taken on the road section.

Section	Station	Number of sample units (N)	Sample unit inspected (n)	Spacing (km)	Additional sample surveyed	Total number of sample units surveyed
1	0+000-8+600	86	13	0.6	21	34
2	8+600-16+400	78	13	0.6	19	32
3	16+400-32+900	65	14	1.2	26	40
4	32+900-54+500	216	14	1.5	39	53

2.6 Sample size and Sampling technique for Laboratory test

The site selections for collecting samples for laboratory tests were performed based on the pavement condition (PCI) of a section. Accordingly, samples were taken from failed, poor, and no distressed pavement conditions. The sample were taken from 32+900-54+500 station section (failed surface condition), from 16+400-32+900 station (poor surface condition), from 8+600-16+400 station (poor surface condition) and finally from 0+000-8+600 station (no distress) for comparison purpose. For the Asphalt test, the surface course was taken at two places (poor surface condition) by cutting AC at a near test pit. The location of the test pit and sample of material taken are shown in Table 4.

Table 4 Location of test pits

S/N	Station	PCR	Station	Surface condition	Sampled materials	Dominant distress
1	32+900-54+500	Poor	38+900-39+000	Failed	Base course, Sub-base and Sub-grade	high severity raveling, pothole
2	16+400-32+900	Fair	18+300-18+400	Poor	Asphalt, Base course, Sub-base and Sub-grade	Rutting and alligator crack
3	8+600-16+400	Fair	9+200-9+300	Poor	Asphalt, Base course, Sub- base and Sub-grade	Rutting and Edge cracking
4	0+000-8+600	Fair	5+400-5+500	no distress	Base course, Sub-base and Sub-grade	No distress

2.7 PCI determination for Sample of units

In this research, the pavement condition data were analyzed using the method of (ASTM D6433, 2007): To calculate PCI of the sample unit the following steps were adopted.

1) Add up the total quantity of each distress type at each severity level, and record them in the "Total Severities" section. The units for the quantities may either be in square feet (square meters), linear feet (meters), or several occurrences, depending on the distress type.
2) 2) Divide the total quantity of each distress type/severity level of the total area of the sample unit and multiply by 100 to obtain the percent density of each distress type and severity.
3) 3) Determine the deduct value (DV) for each distress type and severity level combination of the distress deduct value curves.
4) Determine the maximum corrected deduct value (CDV). The following procedure was used to determine the maximum CDV.

    a) If none or only one individual deduct value is greater than two, the total value is used in place of the maximum CDV in determining the PCI; otherwise, maximum CDV must be determined using the procedure described below.

    b) List the individual deducts values in descending order.

c) Determine the allowable number of deducts value (m), using equation (3.1).

$$m = 1 + (9/98)(100 - HDV) \leq 10 \quad (3.1)$$

Where:

m = allowable number of deducts including fractions (must be less than or equal to 10).

HDV = highest individual deducts value.

d) The number of individual deduct values are reduced to the m largest deduct values, including the fractional part.

e) Determine maximum CDV iteratively

i. Determine total deduct value by summing individual deduct values. The total deduct value is obtained by adding the individual deduct values in d,
ii. Determine q as the number of deducts with a value greater than 2.0.
iii. Determine the CDV from total deduct value and q by looking up the appropriate correction curve for AC pavements in appendix l.
iv. Reduce the smallest individual deduct value greater than 2.0 to 2.0 and repeat i-iii until q = 1.
v. Maximum CDV is the largest of the CDVs.

5) Calculate PCI by subtracting the maximum CDV from 100: PCI = 100-max CDV.

2.8 Determination of section PCI

PCI of a section was determined according to the procedure of ASTM 6433, 2007. From surveyed random sample units and surveyed additional sample units PCI of a section was calculated using Equation (4).

$$\text{PCIs} = \frac{\text{PCIr}\left(\text{A} - \sum_{i=1}^{m} \text{Aai}\right) + \text{PCIa}\left(\sum_{i=1}^{m} \text{Aai}\right)}{\text{A}} \quad (4)$$

Where: PCIa = area-weighted PCI of additional sample units,

PCIr = area-weighted PCI of randomly surveyed sample units

Aai = area of additional sample unit i,

A = area of the section, m = number of additional sample units surveyed, and

PCIs = area-weighted PCI of the pavement section.

2.9 Field Work

A preliminary visual survey was undertaken along the Bako to Nekemte road segment and the road was divided into five sections based on the condition of pavement as shown in Figures 3 and 4. Next, the detailed Pavement condition survey was performed according to ASTM 6433, 2007. From pavement condition survey data (distress data), PCI of the sections was found. Representative samples were taken from the first four sections. According to the Pavement condition rating, which showed failed, poor and no distress pavement was selected for the sampling of AC, base course, subbase, subgrade, and approximately 250 kg of the sample were collected from each pit.

Figure 3 Sample was taken at 38+900-39+000

Figure 4 Sample was taken at 18+300-18+400

2.10 Experimental work

Representative samples were collected from failed pavement conditions, poor surface conditions, and non-distress pavement. Then, after taking samples from the road section of the study area, those samples were transported to the laboratory center of the CGCOC china company, which is working currently on Mana- Begna- Fincha- Shambu Road Upgrading Project, about 125km from the study area. Before starting the Laboratory test, the samples were first air-dried under the sun. The following tests were undertaken in the collected samples: Atterberg Limits, Grain size Analysis, Compaction Tests, California Bearing Ratio (CBR), Aggregate crushing value (ACV), Ten percent fines value (TFV), Los Angeles abrasion value (LAA), flakiness index), Bitumen content of asphalt and gradation of asphalt. Tests were conducted to understand the general behavior of the materials as per the standard specification shown in Table 5.

Table 5 Test type and test method

S/N	Test Type	Test Method
1	Soil classification	AASHTO
2	Sieve Analysis	AASHTO M -145
3	Atterberg limit	AASHTO T -90
4	Compaction test	AASHTO T -180
5	CBR value	AASHTO T -193
6	Aggregate Crushing Value	BS 812 Part 110:1990
7	Aggregate ten percent fines value	BS 812 Part 111:1990
8	Los Angeles abrasion value	AASHTO T -96
9	Flakiness Index	BS 812 Part 105:1990
10	Quantitative extraction of asphalt binder from Asphalt mixture	ASTM D 2172
11	Pavement condition index with rating	ASTM 6433,2009

3.0 RESULT AND DISCUSSIONS

3.1 Distress type and quantity

The Pavement condition survey of the study road resulted in distress such as rutting, pothole, alligator cracks, raveling, corrugation, Edge cracking, and depression. This shows the absence of periodic and routine maintenance along the road sections. As shown in Table 6, the rutting failure was observed along the road segment in large quantities. Out of pavement area affected by distress above 85% is rutting failure. This shows that the cause of failure of a road segment may be either be due to consolidation of pavement layer or traffic load exceeding design load. Corrugation is the second large quantity existing on the road. This distress occurred following the path of rutting failure or along with rutting. Raveling and Alligator cracking also have a large quantity. But, depression failure was observed in a small amount. Even though, Pothole did not cover a large area of the road it has a huge hazard to traffic. Along the road segment, a place where poor drainage system and large flow of water occurred, edge cracking distress was observed. From pavement condition survey (distress data measurement), pavement condition index was determined and resulted in different pavement condition ratings (PCR) like very good, good, fair, poor, very poor, and failed condition surface of the pavement. Based on the estimated PCI, the location of material sampling and the treatment or maintenance needed along the road segment was identified.

Table 6 Quantity of distress on the road section

S/N	Distress type	Unit	Quantity
1	Rutting	m^2	19616.9
2	Pothole	No	80
3	Alligator cracking	m^2	231
4	Edge cracking	M	177
5	depression	m^2	40
6	Corrugation	m^2	961
7	Raveling	m^2	390.1

3.2 PCI and PCR from 0+000 to 8+600

The pavement condition survey of this road section was carried out from station 0+000 to 8+600, which is 8.6 km long. Thirteen (13) random sample units were taken from the assumed standard deviation and twenty-one (21) additional sample units were taken from the total actual standard deviation value. The additional random sample unit was selected and surveyed because the revised number of sample units surveyed was greater than that existing before (13). Then, the total number of sample units already existed was greater than the minimum required sample unit, which was obtained by using the actual or calculated total sample standard deviation. Therefore, the adequacy of the number of sample units surveyed was confirmed. Each sample unit has a length of 100m. The average PCI value of the random sample unit and additional sample unit is 55.31% and 55.76 % respectively, which both values indicate the fair surface condition. The total numbers of 34 sample units were surveyed. From the estimated sample units, 2.94% were obtained in excellent, 17.64% is very good, 35.29% is good, 23.52% is fair, 17.64% is poor, 2.94% is in very poor conditions, and there is no failed sample unit. The minimum and the maximum PCI Value of the sample unit is 22% and 100% respectively. The weighted average PCI of a section is 55.42%. This value indicates that the total length of a section 8.6km is in fair condition. The detailed summary of PCI for this section is shown in Table 7 and 8.

Table 7 PCI and PCR of random sample units from 0+000-8+600

S/N	Station	PCI	PCR
1	0+300 - 0+400	74	Very good
2	0+900 - 1+000	56	Good
3	1+500 - 1+600	52	Fair
4	2+100 - 2+200	32	Poor
5	2+700 - 2+800	46	Fair
6	3+300 - 3+400	70	Good
7	3+900 - 4+000	43	Fair
8	4+500 - 4+600	33	Poor
9	5+100 - 5+200	82	Very good
10	5+700 - 5+800	65	Good
11	6+300 - 6+400	33	Poor
12	6+900 - 7+000	33	Poor
13	7+500 - 7+600	100	Excellent

Table 8 PCI and PCR of additional sample units from 0+000-8+600

S/N	Station	PCI	PCR
1	0+400 - 0+500	56	Good
2	1+200 - 1+300	74	Very good
3	1+400 - 1+500	82	Very good
4	1+600 - 1+700	63	Good
5	2+200 - 2+300	56	Good
6	2+200 - 2+300	56	Good
7	3+100 - 3+200	64	Good
8	3+300 - 3+400	65	Good
9	3+400 - 4+500	52	Fair
10	3+500 - 3+600	47	Fair
11	3+600 - 3+700	58	Good
12	3+700 - 3+800	79	Very good
13	3+800 - 3+900	43	Fair
14	4+000 - 4+100	43	Fair
15	4+100 - 4+200	46	Fair
16	4+200 - 4+300	60	Good
17	4+400 - 4+500	40	Poor
18	4+600 - 4+700	33	Poor
19	4+800 - 4+900	22	Very poor
20	4+900 - 5+000	56	Good
21	6+00 - 6+100	76	Very good

3.3 PCI and PCR from 8+600 to 16+400

The pavement condition survey of this road section was carried out from station 8+600 to 16+400, which is 7.8 km long. A total of thirteen (13) random sample units were taken from the assumed standard deviation and nineteen (19) additional sample units were taken from the actual standard deviation value. The additional random sample unit was selected and surveyed because the revised number of sample units surveyed was greater than that existing before (13). Then the total number of sample units already surveyed was greater than the minimum required sample unit, which was obtained by using the actual total sample standard deviation. Therefore, the adequacy of the number of sample units surveyed was confirmed. Each sample unit has a length of 100m. The total numbers of 32 sample units were surveyed and a majority of the sample units are in fair condition (37.5%) and there is no failed sample unit. Others are; 25% in good condition, 15.63% in very poor, 12.5% poor, 6.25% are in a very good condition and 3.12% excellent. PCI of random sample unit surveyed and additional sample unit surveyed resulted in 52.46% and 46.15%, which both values show the fair condition of a pavement. The area-weighted PCI of a section is 50.92%.

This value indicates that the total length of a section 8.6km is in fair condition. Therefore, this section needs routine maintenance as a treatment option. The summary of PCI for this section is shown in Table 9 and 10.

Table 9 PCI and PCR of random sample units from 8+600-16+400

S/N	Station	PCI	PCR
1	8+600 - 8+700	20	Very poor
2	9+200 - 9+300	40	Poor
3	9+800 - 9+900	54	Fair
4	10+400 - 10+500	55	Fair
5	11+000 - 11+100	43	Fair
6	11+600 - 11+700	74	Very good
7	12+200 - 12+300	100	Excellent
8	12+800 - 12+900	43	Fair
9	13+400 - 13+500	50	Fair
10	14+000 - 14+100	54	Fair
11	14+600 - 14+700	56	Good
12	15+200 - 15+300	65	Good
13	15+800 - 15+900	28	Poor

Table 10 PCI and PCR of additional sample units from 8+600-16+400

S/N	Station	PCI	PCR
1	10+300 - 10+400	62	Good
2	11+700 - 11+800	25	Very poor
3	11+800 - 11+900	25	Very poor
4	11+900 - 12+000	18	Very poor
5	12+000 - 12+100	56	Good
6	12+100 - 12+200	56	Good
7	12+900 - 13+000	43	Fair
8	3+100 - 13+200	43	Fair
9	13+000 - 13+100	53	Fair
10	13+100 - 13+200	60	Good
11	14+500 - 14+600	54	Fair
12	14+800 - 14+900	50	Fair
13	14+900 - 15+000	22	Very poor
14	15+000 - 15+100	77	Very good
15	15+100 - 15+200	62	Good
16	15+300 - 15+400	42	Fair
17	15+700 - 15+800	27	Poor
18	15+900 - 16+000	65	Good
19	16+100 - 16+200	39	Poor

3.4 PCI and PCR from 16+400 to 32+900

The pavement condition survey of this road section was carried out from station 16+400 -32+900, which is 16.5 km long. Fourteen (14) random sample units were taken from the assumed standard deviation and twenty- six (26) additional sample units were taken from the actual standard deviation value. The additional sample unit was selected and surveyed because the revised number of sample units surveyed was greater than 14. Then the total number of sample units already surveyed was greater than the minimum required sample unit, which was obtained by using the actual total sample standard deviation. Each sample unit has a length of 100m. The total numbers of 40 sample units were surveyed. Out of the total surveyed samples, about 50% of sample units are in fair condition. Others are: 10% in good condition, 25% in very poor, 12.5% poor, 7.5% are in a very good condition. The section has no failed and excellent pavement condition. This shows that the condition of pavement varies from very poor to good throughout the section. The average PCI of the surveyed random sample unit is 45.21% (fair condition).

And that, of the additional sample unit result, 43.8% (fair condition). The area-weighted PCI of a section is 44.98%, which is rated fair and the section needs routine maintenance. The detailed summary of PCI for this section is shown in Table 11 and 12.

Table 11 PCI and PCR of random sample units from 16+400 -32+900

S/N	Station	PCI	PCR
1	16+400 - 16+500	25	Very poor
2	17+600 - 17+700	20	Very poor
3	18+800 - 18+900	16	Very Poor
4	20+000 - 20+100	43	Fair
5	21+200 - 21+300	45	Fair
6	22+400 - 22+500	42	Fair
7	23+600 - 23+700	74	Very good
8	24+800 - 24+900	20	Very Poor
9	26+000 - 26+100	55	Fair
10	27+200 - 27+300	45	Fair
11	28+400 - 28+500	51	Fair
12	29+600 - 29+700	72	Very good
13	30+800 - 30+900	66	Good
14	32+000 - 32+100	43	Fair
4	20+000 - 20+100	43	Fair
13	30+800 - 30+900	66	Good
14	32+000 - 32+100	43	Fair

Table 12 PCI and PCR of additional sample units from16+400-32+900

S/N	Station	PCI	PCR
1	16+500 - 16+600	25	Very poor
2	16+600 - 16+700	25	Very poor
3	16+700 - 16+800	19	Very poor
4	18+300 - 18+400	26	Poor
5	18+400 - 18+500	44	Fair
6	19+100 - 19+200	40	Poor
7	19+700 - 19+800	55	Fair
8	19+800 - 19+900	55	Fair
9	20+500 - 20+600	16	Very poor
10	21+100 - 21+200	16	Very poor
11	21+300 - 21+400	48	Fair
12	24+700 - 24+800	36	Poor
13	24+900 - 25+000	53	Fair
14	25+300 - 25+400	46	Fair
15	25+400 - 25+500	46	Fair
16	25+500 - 25+600	61	Good
17	28+600 - 28+700	44	Fair
18	28+700 - 28+800	52	Fair
19	28+900 - 28+900	23	Very poor
20	28+900 - 29+000	72	Very good
21	29+000 - 29+100	66	Good

22	29+100 - 29+200	66	Good
23	29+200 - 29+300	52	Fair
24	30+900 - 30+100	45	Fair
25	30+100 - 30+200	36	Poor
26	31+600 - 31+700	50	Fair

3.5 PCI and PCR from 32+900 to 54+500

The pavement condition survey of this road section was carried out from station 32+900 -54+500, which is 21.6 km long. Fourteen (14) random sample units were taken from the assumed standard deviation and thirty-nine (39) additional sample units were taken from the actual standard deviation value. The additional sample unit was selected and surveyed because the revised number of sample units surveyed was greater than 14. Then, the total number of sample units already surveyed was greater than the minimum required sample unit, which was obtained by using the actual total sample standard deviation. Each sample unit has a length of 100m. A total number of 53 sample units were surveyed. From the estimated sample units, (32.07%) were obtained in poor condition, 3.77% in failed, 3.77% in very good, 24.52% in very poor condition, 18.86% in fair, 15.09% is good, and 1.88 % is excellent. The average PCI of random sample units surveyed and PCI of additional sample units surveyed resulted in a 39.65 %poor condition) and 35.46% (poor condition) respectively. The section failed at two stations (33+900-34+00 and 38+900-39+000) and these stations need reconstruction. The area-weighted PCI of a section is 39.05%, which shows the overall section length of 21.6 km is in poor condition. Therefore, the section requires urgent maintenance specifically routine. The detailed summary of PCI for this section is shown in Table 13 and 14.

Table 13 PCI and PCR of random sample units from 32+900 -54+500

S/N	Station	PCI	PCR
1	32+900 - 32+900	27	Poor
2	34+400 - 34+500	60	Good
3	35+900 - 36+000	60	Good
4	37+400 - 37+500	28	Poor
5	38+900 - 39+000	8	Failed
6	40+400 - 40+500	15	Very poor
7	41+900 - 42+000	28	Poor
8	43+400 - 43+500	60	Good
9	44+900 - 45+000	50	Fair
10	46+400 - 46+500	95	Excellent
11	47+900 - 48+000	11	Very poor
12	49+400 - 49+500	34	Poor
13	50+900 - 51+000	40	Poor
14	52+400 - 52+500	42	Fair

Table 14 PCI and PCR of additional sample units 32+900 -54+500

S/N	Station	PCI	PCR
1	33+000 - 33+100	75	Very good
2	33+700 - 33+800	12	Very poor
3	33+900 - 34+000	6	Failed
4	34+100 - 34+200	11	Very poor
5	34+300 - 34+400	42	Fair
6	35+100 - 35+200	46	Fair
7	37+600 - 37+700	64	Good
8	37+700 - 37+800	28	Poor
9	37+800 - 37+900	38	Poor
10	37+900 - 38+000	27	Poor
11	38+000 - 38+100	39	Poor
12	38+100 - 38+200	65	Good
13	40+100 - 40+200	38	Poor

14	40+200 - 40+300	27	Poor
15	40+300 - 40+400	15	Very poor
16	40+500 - 40+600	15	Very poor
17	40+600 - 40+700	46	Fair
18	40+700 - 40+800	78	Very good
19	41+100 - 41+200	62	Good
20	41+300 - 41+400	18	Very poor
21	41+400 - 41+500	34	Poor
22	43+500 - 43+600	57	Good
23	43+600 - 43+700	44	Fair
24	45+100 - 45+200	17	Very poor
25	45+200 - 45+300	45	Fair
26	15+100 - 15+200	62	Good
27	15+300 - 46+100	47	Fair
28	46+500 - 46+600	12	Very poor
29	48+600 - 48+700	28	Poor
30	48+700 - 48+800	24	Very poor
31	48+800 - 48+900	24	Very poor
32	49+900 - 50+000	16	Very poor
33	50+100 - 50+200	34	Poor
34	50+200 - 50+300	43	Fair
35	50+300 - 50+400	47	Fair
36	50+500 - 50+600	29	Poor
37	51+000 - 51+100	40	Poor
38	51+100 - 51+200	33	Poor
39	54+400 - 54+500	24	Very Poor

Based on the estimated PCI, all sections are in fair condition except station 32+900 -54+500 which is in poor condition. Finally, the above all results are only about the four selected sections out of the total five sections. The remaining one section has a similar surface condition with the surveyed four sections. So, it can be concluded that the whole section (81km) of the road is rated as fair condition and it needs routine maintenance works.

3.6 Experimental Results and Discussion

To understand the general behavior of the road materials and to observe or check whether they may affect/cause pavement distresses or not, the following laboratory tests are conducted on the existing pavement materials such as subgrade, sub-base, and base coarse of the road.

3.6.1 Plastic Index properties of existing pavement materials

The plastic index results of the existing subgrade, sub-base, and base course of the pavement are shown in Table 15. According to ERA Manual, 2013, soils with PI values less than 30% and LL< 60 are suitable sub-grade materials. The PI of the sub-grade soil meets the minimum requirement set by ERA. Therefore, a sample of sub-grade soils which were taken from distress pavement and no distress pavement have shown suitable sub-grade materials. Also, the suitable sub-base materials shall have a maximum Plasticity Index of 6 or 12 when determined by AASHTO T-90. The PI value of sub-base samples ranges from 5.6% to 10.5%. Therefore, all the results of this test have shown that sub-base material constructed were suitable sub-base materials. The fine fraction of a GB1 material shall be non-plastic or have a maximum Plasticity Index of 6 when determined by AASHTO T-90. Therefore, these test values show that the materials constructed fulfilled the minimum requirement of ERA specification. The high numerical value of PI of pavement material means high ability to deform and indicates high compressibility of the material when subjected to loading. Similarly, a low value of PI shows low compressibility. The high compressibility of the material can cause deformation of pavement like Rutting, Depression, and corrugation. Since the PI value of testing samples of pavement material is the minimum requirement of ERA specification, distress was observed along the road section. Rutting and corrugation were not due to the plastic index property of the pavement material.

Table 15 Plastic Index properties of existing pavement materials

S/N	Station	PCR	PI (%)		
			Sub-grade	Sub-base	Base coarse
1	38+900-39+000	Failed	25.7	6.8	4.46
2	18+300-18+400	Poor	16.8	5.6	5.5
3	9+200-9+300	Poor	30	8	3.8
4	5+400-5+500	Normal	14.3	10.5	2.54

3.6.2. Sub-grade soil classification

The sieve analysis for subgrade is widely used in the classification of subgrade soils and its procedure for classifying soils into seven groups based on laboratory determination of particle-size distribution, liquid limit, and plasticity index. The AASHTO Soil Classification System is used for highway construction. The sieve sizes for the test which have been used are 2mm, No. 40 (425-µm), No.200 (75-µm) to determine the categories of soil. Table 16 shows the results of the sub-grade soil type according to the AASHTO classification system. From the AASHTO soil classification of soil samples for highway, A-1, A-3, and A-2 soils are rated excellent to good condition for highways with percentage passing Sieve No. 200 not more than 35%, while A-4 to A-7 soils is fair to poor with percentage passing Sieve No. 200 greater than 35%. Based on this, all-natural sub-grade soil Samples are classified as fair to poor subgrade soils and types of significant constituents of the materials are silty soils and clayey soils. In other ways, the number in the bracket shows the group index of the soil and the greater the group index (GI), the less desirable a soil is for highway construction. A GI of 0 indicates a good subgrade material while a GI of 20 or more indicates a very poor subgrade material. According to this soil at failed pavement (38+900-39+00) and at (poor condition) are very poor subgrade soils. Poor sub-grade soils are clay soils that exhibit swell-shrink behavior. The more water they absorb the more their volume increases. Clay soils also shrink when they dry out. This shrinkage or movement in sub-grade soils causes settlement in pavement layers, failure of pavement structures, and can result in distress like rutting, Depression, alligator cracking and pothole (which can be formed from alligator cracking). From this, it is possible to conclude that potholes occurred at station 38+900-39+00 (failed condition) and rutting observed at station 9+200-9+300 (poor condition) were due to the construction of pavement layers of very poor subgrade soils (Clay).

Table 16 Sub-grade soil classification (AASHTO)

S/N	Station	PCR	PI	Sieve #200 pass (%)	Soil type
1	38+900-39+000	Failed	25.7	69.6	A-7-6 (30)
2	18+300-18+400	Poor	16.8	96.8	A-7-5 (13)
3	9+200-9+300	Poor	30	96.8	A-7-6 (30)
4	5+400-5+500	Normal	14.3	79.4	A-7-5 (14)

3.6.3 Grain size analysis of existing base course

This test was performed to determine the percentage of different grain sizes contained within the Base course materials. Figure 5 and 6 show the sieve analysis test results of Base Course Materials. From 38+900-39+000 stations (failed pavement), the gradation results are completely out of the ERA specification range. This indicates that the base course at this station was poorly graded. Also, from 18+300-18+400 station (poor pavement condition), the gradation results are partially in the range of ERA specification. This implies that the base course at this station was poorly graded. Similarly, from 9+200-9+300 station (poor pavement condition) the gradation results of base course material are fully into the range of ERA specification and consequently, the materials were well graded. The base course material shall be of such nature that can be compacted readily to form a firm, stable base layer. And also a placed layer must have a mass mechanical interlocking stability sufficient to resist loads imposed during the design life of a pavement. Well-graded base course materials are dense and more compact than poorly graded. As a result; they are more resistant to rutting, alligator cracking, and pothole. Therefore, from 38+900-39+000 station (failed pavement), poorly graded base course can be a cause for the occurrence of Pothole and raveling. Similarly, rutting, pothole, and alligator cracking observed from 18+300-18+400 station (poor pavement condition) was also due to base course gradation.

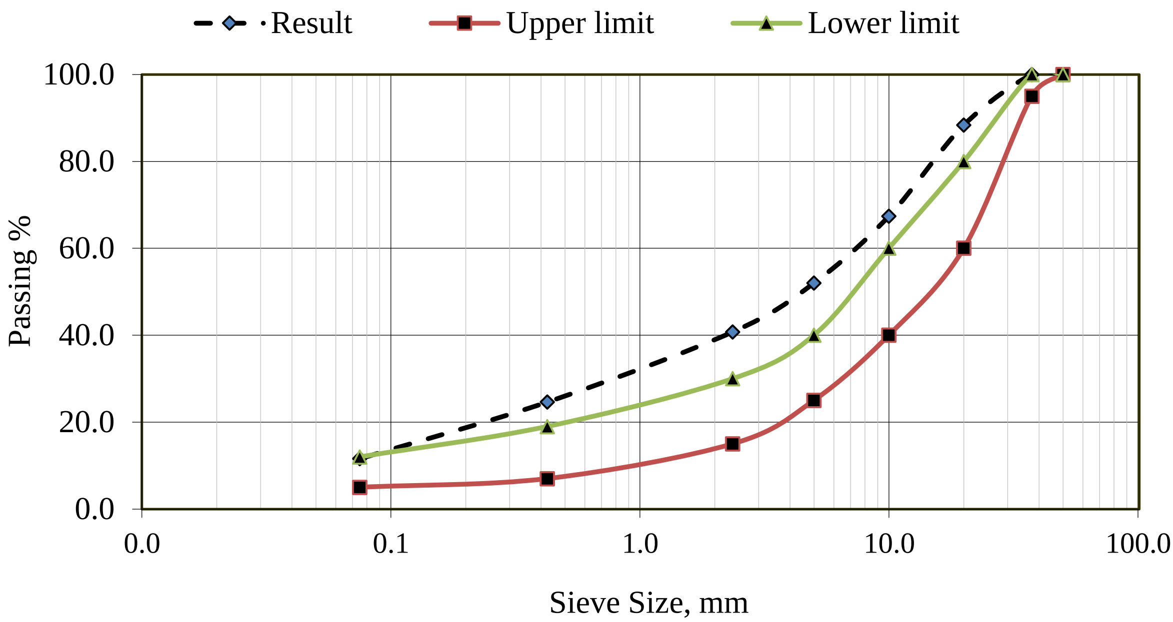

Figure 5 Gradation of existing base course material from 38+900-39+000

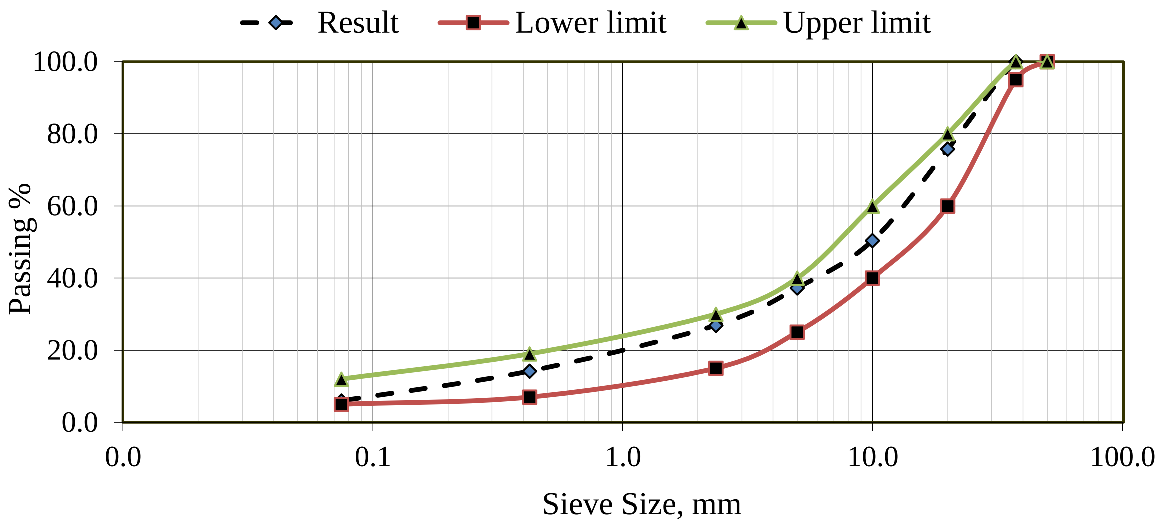

Figure 6 Gradation of existing base course material from 9+200-9+300

3.6.4 Grain size analysis of existing sub-base course

In the whole stretch of the road, the brown granular material was used as a sub-base material. For all samples tested gradation results are within the minimum and maximum range limit of the ERA specification except sample at station (9+200-9+300). The gradation result of sub-base material from the 9+200-9+300 station indicated that the pavement is poor which may be due to the material was not dense and durable. For this reason, they were not able to resist traffic loads and rutting occurred. Therefore, poorly graded sub-base materials can be responsible for the manifestation of rutting on the road sections. Figure 7 and 8 show the grain size analysis result and comparison of sample sub-base material gradation with the ERA manual specification.

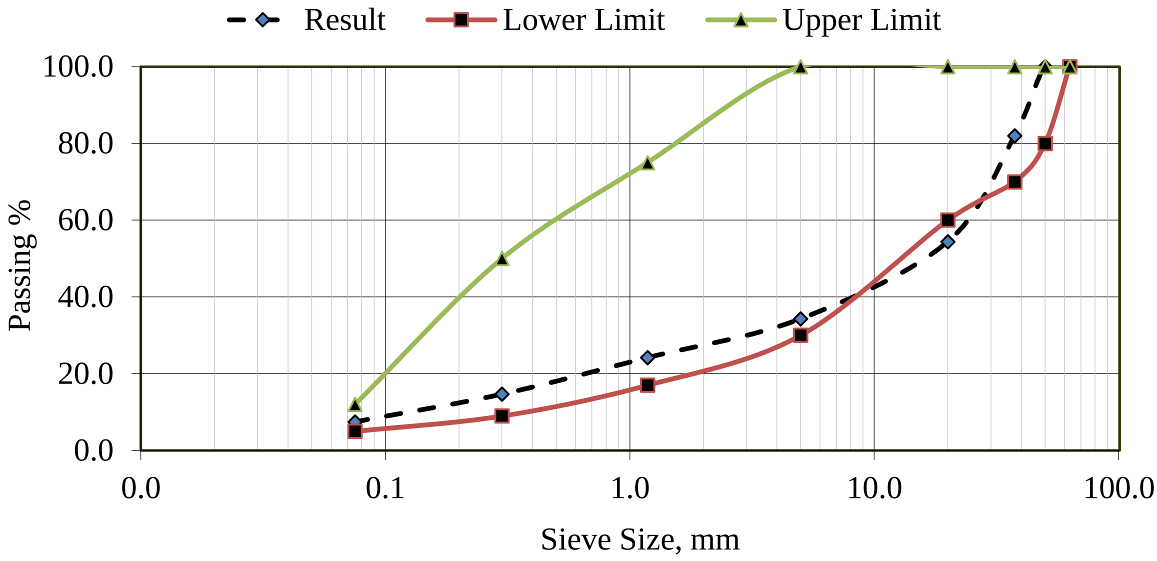

Figure 7 Gradation of existing sub-base material from 9+200-9+300

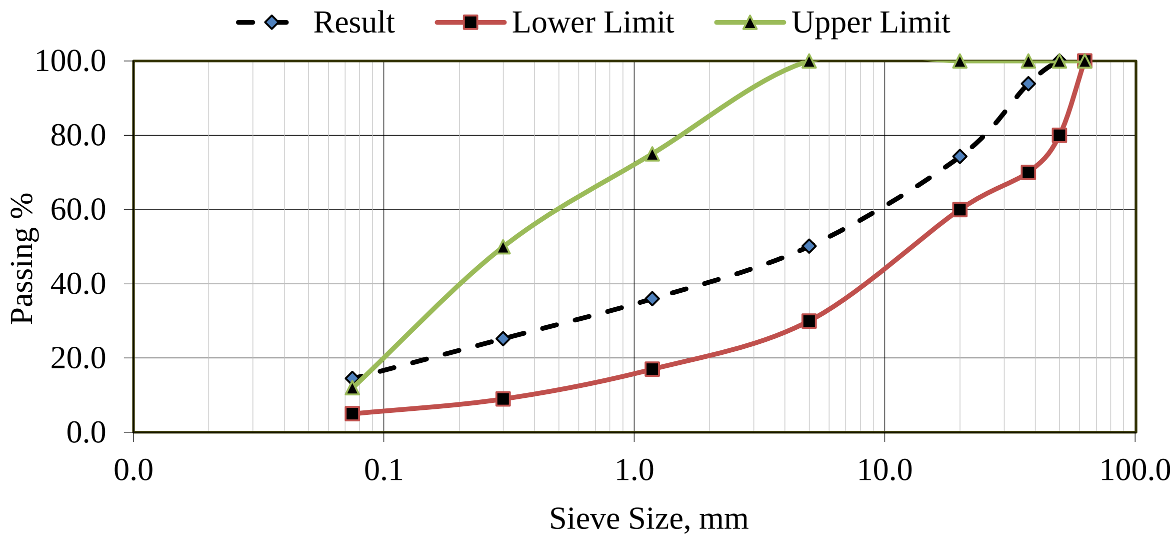

Figure 8 Gradation of existing sub-base material from 18+300-18+400

3.6.5 Compaction analysis of existing pavement materials

This laboratory test was performed to determine the relationship between the moisture content and the dry density of soil in a specified compaction effort. The results of the maximum dry density (MDD) and the optimum moisture content (OMC) are given in Table 17. The existing base course optimum moisture content varies from 6.4% to 8.8% and that of maximum dry density varies from 2.21 g/cm^3 to 2.38 g/cm^3. The existing sub-base material optimum moisture content ranges from 9.3% to 17.2% and that of maximum dry density varies from 1.92 g/cm^3 to 2.06 g/cm^3. The existing sub-grade optimum moisture content varies from 24.8% to 31.6% and that of maximum dry density varies from 1.49 g/cm^3 to 1.545 g/cm^3.

Table 17 Compaction results of existing pavement materials.

S/N	Station	PCR	Base course		Sub-base		Sub-grade	
			OMC	MDD	OMC	MDD	OMC	MDD
1	38+900-39+000	Failed	8	2.28	9.3	2.06	24.8	1.545
2	18+300-18+400	Poor	8.6	2.21	14.4	1.92	27.8	1.545
3	9+200-9+300	Poor	6.4	2.38	14.2	1.97	31.6	1.49
4	5+400-5+500	Normal	8.8	2.37	17.2	1.89	27.8	1.54

3.6.6 California bearing ratio analysis of existing pavement materials

Table 18 shows four days' soaked CBR values of base course, sub-base, and subgrade soils. The minimum requirement of the ERA specification for crushed stone road base constructed with proper care with GB1 materials should have CBR values above 100%. All results of existing base course materials have CBR greater than 100%. Hence, the strength of existing base course materials satisfies the standard specification of ERA. According to ERA manual 2013, the minimum soaked Californian Bearing Ratio (CBR) of sub-base material shall be 30% when determined by the requirements of AASHTO T-193 and shall be determined at a density of 95% of the maximum dry density when determined by the requirements of AASHTO T-180 method D. The CBR value of sub-base from 18+300 to 18+400 (poor pavement) is 21.8%. Thus, the result of sub-base material at this selected station does not meet the minimum requirements of ERA. However, the other stations have CBR greater than 30% (44%, 33.5%, and 34%). The CBR result of existing sub-grade soil is greater than 5% for all segments. According to the ERA specification, these samples indicate it is good sub materials, and suitable borrow fill materials. However, from 38+900-39+000 station (failed pavement) and 9+200-9+300 (poor pavement), the results of swell are 4.34 % and 2.3% respectively which are an indication of expansive soil. Hence, it is possible to conclude that pavement failure observed at 9+200-9+300 and 38+900- 39+000 are due to the expansive properties of sub-grade material.

Table 18 CBR and Swell results of existing pavement materials

S/N	Station	PCR	Base course (%)		Sub-base (%)		Sub-grade (%)	
			CBR	Swell	CBR	Swell	CBR	Swell
1	38+900-39+000	Failed	108	0.04	44	0.95	5.3	4.34
2	18+300-18+400	Poor	130	0.07	21.8	1.78	20	1.46
3	9+200-9+300	Poor	152	0.07	33.5	0.68	7.4	2.3
4	5+400-5+500	Normal	118	0.06	34	0.89	14	1.07

3.6.7 Surfacing course material analysis

The asphalt concrete sample was taken from two places of poor sections of the road (18+300-18+400 and 9+200-9+300). The bitumen was obtained from the sampled asphalt concrete through the extraction process in the laboratory. The average bitumen contents at 9+200-9+300 and 18+300 -18+400 are 3.7% and 3.9%, respectively which are smaller than the required specification of 5%. The average bitumen content of 3.8% clearly shows the AC lacked some bitumen in the mix. Using too little bitumen in HMA causes Raveling and Weathering, Alligator cracking, Edge crack and Pothole. For this reason, alligator cracking, raveling, and a pothole formed on poor pavement condition (18+300-18+400) were due to low bitumen content. The average grading of the surfacing course is shown in Figure 9 and 10. Surface course material shall be dense, can be compacted, mechanically interlocking stability sufficiently to resist loads imposed during the design life of a pavement. A well-graded surface course exhibits all these behaviors. If the surface course material is not dense and not interlocked, the surface course is unable to resist traffic loading. This poor gradation of asphalt mix causes cracking, raveling, and rutting. Also occasionally potholes can occur. The grain size analysis of the existing asphalt concrete satisfied ERA standard specification which shows it is well graded. Therefore, gradation of the existing surface course material does not affect the occurrence of Rutting, alligator cracking, pothole and raveling observed on the poor condition pavement (18+300-18+400 station). In the same manner, the gradation of this material cannot be a cause of the formation of rutting on the poor condition of pavement (9+200-9+300 station).

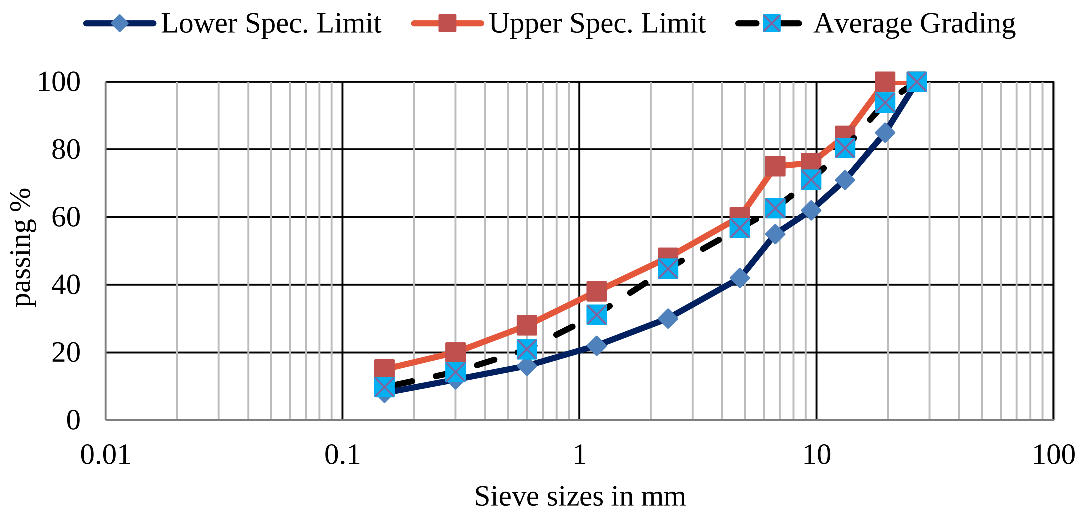

Figure 9 Gradation of existing surfacing course from 18+300-18+400

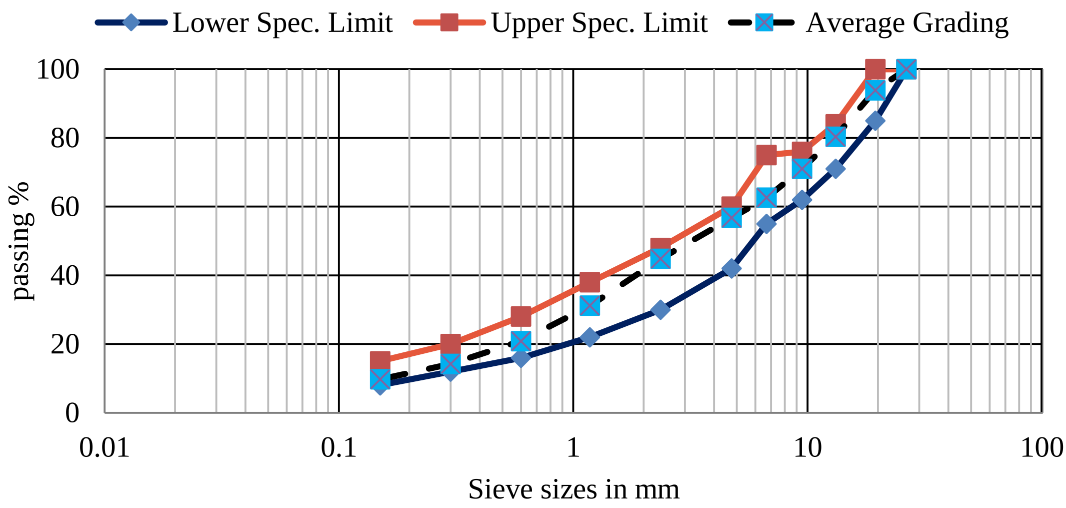

Figure 10 Gradation of existing surfacing course from 9+200-9+30

3.6.8 Los Angeles abrasion analysis of existing base course and sub-base materials

The base course and sub-base materials LAA results are shown in Table 19. The LAA result of existing base course material varies from 8.15% to 9.2%. The Los Angeles Abrasion value by AASHTO T-96 shall not exceed 45 at 500 revolutions. Hence, the result of the LAA of base course material satisfies the standard specification and is not a cause for the occurrence of distress. The LAA result of the sub-base varies from 8.8% to 28.9%. The Los Angeles abrasion value by AASHTO T-96 shall not exceed 51%. Therefore, the results of sub-base material meet the standard specification of ERA. Los Angeles abrasion of Sub-base and base course material means they need to be resistant to any loads imposed during construction (loads during compaction) and design life of a pavement (traffic loads). The low numerical value of LAA of means the material is tougher and more resistant to abrasion. So, base course aggregate material and sub-base shall resist distress like rutting. Since the result of the LAA of base course material and sub-base material meets the standard specification of ERA, rutting created on the road section was not due to the lack of toughness of the sub-base and base course materials.

Table 19 LAA of existing base course and sub-base

S/N	Station	PCR	LAA in %	
			Base course	Sub-base
1	38+900-39+000	Failed	8.15	20.8
2	18+300-18+400	Poor	8.79	28.9
3	9+200-9+300	Poor	9.2	8.8
4	5+400-5+500	Normal	8.75	18.8

3.6.9 Strength analysis of existing of base course material

The flakiness index, ACV, and TFV results of existing base course material are shown in Table 20 respectively. The flakiness index of base course material varies from 8.4% to 19.46%. According to ERA standard specification the flakiness index of base course material by BS 812, Part 105, or ASTM D 3398 shall not exceed 30%. Hence, all flakiness index test results of the base course satisfied the specification. According to Era specification, the Aggregate Crushing Value (ACV) should be less than 25. The Ten percent fine values (TFV) are greater than 110KN, which meets the requirement of the ERA standard specification. The shape of the base course aggregate is important to resist loads applied on it and consequently rutting. The shape of aggregate needs to be cubic, not flaky because cubic aggregates can pack more, low void ratio, and have more compact material. Therefore, the shape of the base course cannot be a cause for observed rutting of the poor pavement condition. In addition, base course aggregate materials should resist crushing when traffic loads are applied to them. When base course aggregate is crushed, rutting, polishing off a pavement and alligator cracking can occur on the pavement surface. Generally, alligator cracking and rutting observed on the poor pavement condition (18+300-18+400 station) and rutting on poor pavement condition (9+200-9+300 station) were not from the problem of strength of base course aggregate.

Table 20 Strength analysis of existing of base course material

S/N	Station	PCR	Flakiness (%)	ACV (%)	TFV (kN)
1	38+900-39+000	Failed	8.44	15.77	126
2	18+300-18+400	Poor	8.59	17.81	116
3	9+200-9+300	Poor	19.78	13.45	111
4	5+400-5+500	Normal	19.46	14.15	114

3.7 Traffic Analysis

The Bako to Nekemte road upgrading project was completed and opened for traffic in 2013. The traffic analysis of this road section was done by comparing predicted traffic volume and existing traffic volume starting from 2013 to 2019. A historical traffic count on the road section was obtained from ERA Road Asset management and Directorate while forecasted traffic volume was taken from the report of Saba Engineering consultants. The adjusted AADT using traffic growth rates at the openings of project road (2011) was taken from ERA, which was done by SABA Engineering consultants during the feasibility study. The estimated and actual AADT value is 5575 and 8725 respectively. The actual traffic volume exceeded the forecast by 56.5% from 2013 to 2019. Hence, it is possible to conclude that the cause of the failure of the road can be due to traffic volume.

3.8 Drainage condition

Based on field observation on Bako to Nekemte road segment poor drainage condition has been observed along the segment. For example, at the exit of Bako town to Nekemte, the water has eroded the shoulder and edge of a pavement. Due to this reason, the pavement has shown edge cracking. This shows the road has lacked side drainage. Also, an overflow of food was observed from 50+400-50+500 which caused the deterioration surface of the road. This also implies that the pavement lacked a sufficient side drainage system. Therefore, it is possible to say that the cause of the failure of Bako to Nekemte road can be the absence of insufficient provision of a side drainage.

3.9 Observed Cause of Pavement Failures

From field observation and laboratory test result factors that created pavement failures on the road segments are low quality materials, Poor construction techniques, unproper mix design, over traffic loading, and improper drainage system. Failing to consider these factors in design and construction resulted in distress soon after construction.

3.9.1 Pavement distress due to Pavement material characteristics

Based on the laboratory result of CBR of the sub-base, gradation of sub-base material, and base course, these materials have no desirable characteristics and then played a role in the formation of distress on the study road. One of the desirable characteristics of pavement material is Dense graded. The gradation test result of samples of base course from station 38+900-39+000 and 18+300-18+400 is out of the upper limit and lower limit of ERA specification. In addition to this, the gradation result of sub-base material taken from stations 9+200 - 9+300 does not satisfy ERA specifications. The CBR result of samples of sub-base from 18+300-18+400 is 21.8% less than 30% which is a minimum standard requirement. Therefore, the constructed base course and sub-base layer were not dense-graded for good compaction. When the gradation of pavement material requirement is not achieved, distress like alligator cracks, rutting, depression, and potholes can be formed. Therefore, alligator cracks, rutting, potholes, and edge cracks observed on the road segment are due to the poor quality of the base course and sub-base materials.

3.9.2 Pavement distress due to poor mix design

Not only material characteristics but also the mix-design of asphalt and aggregate of the pavement caused different distresses. From the laboratory test result, low asphalt content is obtained, which is 3.8% less than 5% which is standard. Low asphalt content in the mix of Asphalt and aggregate can bring some common distress as alligator cracks and raveling. Besides, some induced distresses as potholes and edge cracks can occur. Therefore, alligator cracking, raveling, and pothole created from 18+300-18+400 stations can be due to poor mix design, particularly low asphalt content. The poor gradation of surface course is the other poor mix design that can cause distress like rutting and raveling. But, since the gradation test result of the surface course fulfilled ERA specification, raveling and rutting observed on the road section cannot be due to poor mix design.

3.9.3 Pavement distress due to Poor construction design

Poor construction design can be the poor treatment of sub-grade soils. From laboratory results subgrade soils of the study area at 38+900-39+000 and 9+200-9+300 stations found poor subgrade soils according to AASTHO classification. And also swell test resulted 2.3%, 4.34% respectively for 9+200-9+300 and 38+900-39+000. According to ERA specification, the swell % of sub-grade soil must be ≤ 2%. In addition to this, ERA suggests that subgrade soils that have swelled % ≥25% shall have to be excavated and replaced by suitable materials having a swell percentage not more than 2% based on standerd requirement. But, the sub-grade soil was not treated accordingly. Therefore, pavement distress observed from 38+900-39+000 station (raveling and pothole) and 9+200-9+300 station (Rutting) was due to the poor construction design of subgrade soils.

3.9.4 Pavement distresses due to Traffic Loading

From the result of traffic analysis, the existing traffic volume starting from the opening of the road 2013 up to 2019 exceeded designed traffic volume for the same year by 56.5%. When a pavement carries a traffic load greater than forecasted volume failures like alligator cracks and deformation (rutting, corrugation, depression) can be formed. Therefore, it is possible to conclude that pavement distresses: Alligator cracks, rutting, depression, and corrugation observed on the road segment was due to traffic loading.

3.9.5 Pavement Distress Due to Improper Drainage Provision

As can be seen from field observation the road has no proper or sufficient side drainage system. At a place where there is no provision of side drainage on the road, edge cracking failure was observed. And also insufficient drainage system on the road segment allowed over the flow of water from the side of the road to the center of the carriageway. This has caused alligator cracking, pothole, and raveling distress. For this reason, the absence of proper drainage provision on the road segment caused distress like edge cracks, alligator cracks, potholes, and raveling.

3.10 Remedial Measures for distress

In section one (0+000-8+600), the shoulder deteriorated and was highly damaged by edge cracking, due to the absence of side drainage. The remedial measure for this distress is by providing sufficient side drainage structures like a ditch. And also at stations 4+800 - 4+900, the pavement is affected by high severity rutting and the condition of the pavement is very poor. On section 4 (32+900-54+500) the pavement failed at two stations (33+900-34+00 and 38+900-39+000). So, the solution for this failure is the demolition of existing pavement layers and the reconstruction of new pavement layers.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Based on the finding of the study, the following conclusions are drawn. The pavement condition survey along the study road segment shows the different failure types. These are Alligator cracking, Edge cracking, Potholes, rutting, Weathering and Raveling, Corrugation, and Depression. From these, rutting types of distress are major dominating types of distress along the stretch. This occurrence of distresses show a lack of routine and periodic maintenance of the road section. The result of PCR for the selected four pavement sections show out of 159 sample units inspected: 1.89% are excellent, 8.18% very good, 20.13% good, 31.45% fair, 18.87 % poor, 18.24% very poor and 1.26% failed. The weighted PCI of the section 0+000-8+600, 8+600-16+400, 16+400-32+900, and 32+900-54+500 is 55.42%, 50.58%, 44.98% and 39.05% respectively. The average PCI value of the selected four pavement sections is 47%. This value shows that the pavement condition of the road segment (81km) is under fair surface condition. From this, it is possible to conclude that this road segment needs routine maintenance as a treatment option.

The gradation analysis of the existing base course and sub-base material shows the constructed materials are not dense-graded and are out of the upper and lower limit of ERA specification. In addition, CBR result existing sub-base material in poor condition (9+200-9+300) is 21.8%, which is less than the minimum standard requirement (30%). So, pavement failures created on the road segment are due to poor characteristics of the Base course and Sub-base material. And also the Bitumen content of the surface course is 3.8% < standard (5%). Therefore, the cause of pavement failure on the study road is due to poor mix design, particularly low asphalt content. The result of the laboratory tests on sub-grade soil show that the soil is classified according to AASHTO as, A-7-5 (13), A-7-6 (30), and A-7-5(14) which are fair to poor subgrade soil. The types of significant constituents of the materials are silty soils and clayey soils. The sub-grade soil, which was classified as A-7-6(30) is very poor sub-grade soil. The result of the swell % test shows an average of 2.7 % for distress pavement and 1.06% for none distress pavement. This indicates that the subgrade soil at distress pavements is very poor. Therefore, poor construction design or untreated poor sub-grade soils has a significant effect on the occurrence of pavement failures on the road segment. The pavement was designed by assuming 5575 AADT starts from 2013 to 2019. But actual/ existing AADT for the same year is 8725. The designed traffic volume is increased by 51.24% within seven years service of the road. Therefore, the pavement was carrying traffic volume beyond its capacity and this indicates that the failure of the road segment is due to high traffic loading. From field observation, the road from Bako to Nekemte had poor drainage systems like the absence of a side drainage system and insufficient capacity of existing drainage. This implies that failures observed are due to improper drainage provision. For observed pavement failure along the road section remedial measure should be taken, like routine maintenance and reconstruction of pavement at failed conditions (poor subgrade soils). The channels of high severity rutting should be filled with the hot-asphalt mix. And also small areas of alligator crack should be fixed with a patch or area repair. This is important to avoid the development of potholes. Highly damaged areas by edge cracking need reconstruction and the provision of a sufficient side drainage system is essential to prevent further deterioration of the edge of a pavement. The pavement areas, which suffered by raveling, should be repaired with a wearing course or an overlay.

4.2 Recommendations

Based on the findings of the study, the following recommendation is drawn.

Future road design & construction should avoid sub-grade with a high swell or should incorporate a proper treatment method of expansive sub-grade by excavation and replacement to a depth where the moisture variation is minimal. Pavement areas affected by raveling failure should be scarified and reconstructed. And also failed section of pavement should be reconstructed. The sections with various sizes of potholes should be patched with good quality asphalt. Adequate longitudinal drainage, cross drainages, and other drainage facilities should be provided to control the drainage problem. Seal coats shall be applied to cracked surfaces to prevent infiltration of water and then the formation of other distresses. The road segment should be maintained (routine maintenance) by the responsible organ specifically the Nekemte ERA district to prevent further failure of pavement and to extend the service life of the pavement. The consultants and contractors should keep the minimum standard requirement set by ERA regarding the quality of pavement materials for road construction like gradation and method of construction to prevent the pavement from failure. Designers of pavement for traffic load should give attention to generating traffic and diverting traffic in addition to normal traffic when they estimate traffic load to overcome traffic forecasting error which can be the cause of failure of a road. The level of groundwater table and the condition of drainage should be studied before beginning maintenance of a road in the future. For future research, it is recommended that a detailed in-depth investigation can be carried out on a related project by including compliance of existing compaction of pavement materials by ERA Standard Specifications to avoid future failure.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] Zumrawi, M. M. E. (2016). Investigating causes of pavement deterioration in Khartoum State. Int J Civ Eng Technol, 7(2), 203–214. https://doi.org/10.5281/zenodo.1110059

[2] Geremew, A., Quezon, E. T., & Kebede, G. (2016). Influence Of Subsurface Courses Materials On Pavement Performance: A Case Study in Yebu-Agaro Road. International Journal of Scientific & Engineering Research, 7(10), 1252–1260.

[3] Jemal, A., Agon, E. C., & Geremew, A. (2019). Utilization of crushed stone dust as A stabilizer for sub grade soil: A case study in Jimma town. Annals of the Faculty of Engineering Hunedoara, 17(4), 55–64.

[4] Geremew, A. (2018). Experimental Performance Studies on the Improved Expansive Subgrade Soil Formation by Using Mechanical Stabilization with Natural Gravel Around Jimma Quarry Sites. American Journal of Civil Engineering, 6(5), 154. https://doi.org/10.11648/j.ajce.20180605.13

[5] Kõrbe Kaare, K., Kuhi, K., & Koppel, O. (2012). Tire and pavement wear interaction monitoring for road performance indicators. Estonian Journal of Engineering, 18(4), 324. https://doi.org/10.3176/eng.2012.4.04

[6] Fentaw, M., Alemayehu, E., & Geremew, A. (2021). Experimental Study of Stabilization of Expansive Soil Using the Mixture of Marble Dust, Rice Husk Ash And Cement for Sub-Grade Road Construction: A Case Study of Woldia Town. Journal of Civil Engineering, Science and Technology, 12(2), 141–159. https://doi.org/10.33736/jcest.3977.2021

[7] N C, O. (2020). Causes of Failure of Flexible Pavement (a Case Study of Awka-Ugwuoba Section of the Old Enugu-Onitsha Expressway).

[8] Emmanuel, U. O., Ogbonnaya, I., & Uche, U. B. (2021). An investigation into the cause of road failure along Sagamu-Papalanto highway southwestern Nigeria. Geoenvironmental Disasters, 8(1), 3. https://doi.org/10.1186/s40677-020-00174-8

[9] Ekwulo, E. O., & Eme, D. B. (2009). Fatigue and rutting strain analysis of flexible pavements designed using CBR methods. African Journal of Environmental Science and Technology, 3(12). https://doi.org/10.5897/AJEST09.018

[10] Ragnoli, A., De Blasiis, M., & Di Benedetto, A. (2018). Pavement Distress Detection Methods: A Review. Infrastructures, 3(4), 58. https://doi.org/10.3390/infrastructures3040058

[11] Adeke, P. T., Atoo, A. A., & Orga, S. G. (2019). Assessment of pavement condition index: a case of flexible road pavements on the university of agriculture Makurdi Campus. Nigerian Journal of Technology, 38(1), 15. https://doi.org/10.4314/njt.v38i1.3

[12] Qiao, Y., Dawson, A. R., Parry, T., Flintsch, G., & Wang, W. (2020). Flexible Pavements and Climate Change: A Comprehensive Review and Implications. Sustainability, 12(3), 1057. https://doi.org/10.3390/su12031057

[13] Llopis-Castelló, D., García-Segura, T., Montalbán-Domingo, L., Sanz-Benlloch, A., & Pellicer, E. (2020). Influence

of Pavement Structure, Traffic, and Weather on Urban Flexible Pavement Deterioration. Sustainability, 12(22), 9717. https://doi.org/10.3390/su12229717
[14] Abubakar, M., Belel, Z., & Abba, H. (2012). Road Pavement Failure Induced by Poor Soil Properties Along Gombi-Biu Highway, Nigeria. Journal of Engineering and Applied Science.
[15] PLC, S. E. (2006). Review of Feasibility Study, Review of EIA, Preparation of Resettlement Action Plan & Review of Detailed Engineering Design and Tender Documents, Gedo-Nekemte Road Upgrading Project Review of Environmental Impact Assessment Report.