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Causes and Remedial Measures of Premature Asphalt Pavement Failure: Case of a Link / Trunk Road Segments in Ethiopia

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Abstract

Premature pavement failure is one of the issues that need to be addressed to improve durability of pavements in the Ethiopian Road Sector. This study considered the case of a link and trunk road segments where some sections of the road segment are in a failed condition. The common types of the failures identified on existing road segments include rutting, shoving and fatigue cracking. To investigate this specific failure, visual assessment, desk study, field investigation by means of traffic count, axle load survey, DCP, deflection and rutting measurements were conducted and various laboratory tests were carried out on the subgrade, subbase, base course and asphalt layers by collecting samples from selected test pits. The values obtained were compared with the standard technical specifications and the design document. The test results revealed that premature asphalt pavement failures were associated with increased traffic loading, compaction problems, improper gradation and quality issues of materials used for the construction of the layers. Due consideration to the percentage of heavy vehicles during traffic projection, strict quality control and assurance, establishing reliable laboratories on site and proper compaction of the pavement layers are recommended to prevent such premature pavement failures from happening. (This article is intended to draw lessons for better practices and the results are reported anonymously to safeguard mentioning names of firms).

Key words: Premature Pavement Failure, Compaction, CBR, Atterberg limits, Gradation

1. Introduction

The road sector is one of the most important sectors in Ethiopia as it provides the infrastructure required for sustained economic growth of the country. To this end, significant budget has been allocated to the sector by the government since 1997. Accordingly, more than 525.6 billion Ethiopian Birr, over 9 billion US Dollar, has been expended through the Road Sector Development Programme (RSDP). Most of the road construction in Ethiopia is focused on link roads, upgrading of trunk/ link roads and rehabilitation of trunk roads which accounts for nearly 67% of the expenditure (ERA RSDP, 2023). In addition, the unpaved roads in Ethiopia, including trunk and link roads, are increasingly becoming asphalt surfaced (ERA, 2023).

However, reports show that part of this investment roads is being threatened by premature failure (The Reporter, 2020). 'Failure' can be defined as an unacceptable difference in performance between what is expected and what is actually realized (Smith, 2004). Thus, premature failure of a pavement is when a pavement exhibits terminal defects earlier than its design life. A pavement is said to have prematurely failed if it fails within 6-months, 2-months to a year, or 5 years after being opened to traffic (Achampong, F, Boadu, F, Agbeko, PK, Anum, 2013), (Amer-Yahia, C Miller, J and Majidzadeh, 2018); (Texas Department of Transportation, 2021). For the purpose of this study, a road with excessive terminal defects *within 5 years after opening to traffic* is considered as having failed prematurely. This is in line with road asset management models that predict a pavement does not need more than routine maintenance within the first five years after opening to traffic (Bouali, 2018).

The cost associated with premature failure of roads is significant as implied in RSDP report 2023, since additional budget is required for maintenance/re-construction of the failed roads. This would incur a loss on investment on construction, rehabilitation and upgrading related cost, which already accounts for two thirds of annual road sector expenditure in the Ethiopian context. It also increases the maintenance cost of roads which is often in scarce supply compared to demand (ERA, 2023). Furthermore, premature failure of roads increases vehicle operating costs and creates safety and comfort issues for road users and becomes a source of public complaint for road agencies.

Thus, this study aims to address this problem by identifying the causes of premature pavement failures on asphalt surfaced trunk and link roads in Ethiopia through a detailed case study.

2. Literature Review

Asphalt pavements can exhibit failure by different modes depending on traffic load, quality of the design and/or construction and environmental conditions. In this respect, (ERA, 2013) states that a few extremely defective sections are sufficient to consider a pavement as being in a poor condition instead of the average values of the whole route.

Pavement failures can manifest as structural or surface failures. Structural failures include deformation of pavement layers beneath the surfacing such as base course, subbase and/or subgrade, whereas surface failures involve problems with the (usually bituminous) wearing course (Al-Arkawazi, 2017; Wayessa, S.G, Abuye, 2019).

Structural Failures of Pavements

The most common types of structural pavement failure include rutting, settlement /depression and fatigue cracking.

- **Rutting:** is permanent deformation of the pavement along the longitudinal path following the wheel path. Rutting can be caused by improper mix design in asphalts, lack of stability, subgrade deformation, inadequate compaction, heavy traffic loading or lateral movement of a pavement due to traffic (Wada, 2016); (Tamrakar, 2019); (Sethi, K.C., Tiwari, D.S. and Baral, 2016); (Kwaku, 2016); (Chahan, S-J, Patel, A, Prajapati, B Kanojia, 2017).

  Although rutting is the most common indication of structural problems in the pavement, it can be considered surface failure if it results from initial traffic compaction on new pavements which manifests as a narrow ruts that stabilize quickly over time. However, if it is structural rutting, the rut will be wider and has a tendency to get deeper with time (ERA, 2013).

- **Fatigue (alligator) Cracking:** these are interconnected cracks creating small irregular shaped pieces of the pavement similar to an alligator's skin. These cracks can be caused by surfacing failure due to aging of binder and poor mix design or structural causes such as inadequate pavement thickness, or failure of pavement structural layers due to repeated traffic loading (Rashid, Zulufqar Bin. Gupta, 2017) (Sethi, K.C., Tiwari, D.S. and Baral, 2016); (Fitigu, Raj and Kumar, 2023); (Kwaku, 2016) (Wada, 2016).

- **Depression/Settlement:** this is obvious deformation in the pavement due to construction faults or differential movement of the pavement structure (Wada, 2016); (Sethi, K.C., Tiwari, D.S. and Baral, 2016); (Fitigu, Raj and Kumar, 2023); (Kwaku, 2016).

- **Block Cracking:** is a series of interconnected cracks in the form of rectangular shapes. This is mostly caused by shrinkage in stabilized layers but can also be caused by inadequate pavement thickness, unstable pavement layers, or aging of asphalt/ pavement (Sethi, K.C., Tiwari, D.S. and Baral, 2016) (Fitigu, Raj and Kumar, 2023); (Kwaku, 2016).

- **Longitudinal Cracking:** are cracks developed parallel to the center line of the road due to poor construction, frost heaving or joint failures, thermal or shrinkage stress or due to existing cracks on the underneath layers or even dehydration of the road due to adjacent vegetation. (Sethi, K.C., Tiwari, D.S. and Baral, 2016) (Kwaku, 2016) (Rashid, Zulufqar Bin. Gupta, 2017).

- **Transverse Cracking:** develops perpendicular to the center line of the road. It starts with thin cracks and may develop into large cracks with time. This crack is formed when the asphalt cement concrete shrinks due to temperature effect/variation (Fitigu, Raj and Kumar, 2023) (Sethi, K.C., Tiwari, D.S. and Baral, 2016) (Kwaku, 2016) (Wada, 2016) (Rashid, Zulufqar Bin. Gupta, 2017).

- **Edge Cracking:** develops at the edge of the pavement due to traffic loading, lack of proper support from the shoulder, poor drainage conditions or due to yielding of the underlying materials. (Rashid, Zulufqar Bin. Gupta, 2017); (Fitigu, Raj and Kumar, 2023) (Wada, 2016); (ERA

pavement rehabilitation and asphalt over lay design manual, 2013).

- **Pothole:** is a secondary effect that develops as water infiltrates through cracks that arises by various causes and aggravated by traffic loading (Rashid, Zulufqar Bin. Gupta, 2017) (Alaamri, R.S.N, Kattiparuthi, R.A, Koya, 2017); (Wada, 2016). Pothole can also develop due to the disintegration of pavement material, climatic condition and traffic (Rashid, Zulufqar Bin. Gupta, 2017) (Alaamri, R.S.N, Kattiparuthi, R.A, Koya, 2017); (Wada, 2016).

Surface Failures of a Pavement

The most common types of surface failures include raveling, spalling and bleeding.

- **Raveling /Fretting:** is the dislodgment of coarse or fine aggregate from the pavement surface due to poor adhesion between the mixing material, asphalt and aggregate. It can be accelerated by traffic and freezing climatic condition (Fitigu, Raj and Kumar, 2023); (Wada, 2016) (Kumar, 2014).
- **Spalling/Delamination:** occurs due to breaking of the asphalt or loss of pavement surface around cracks due to fracture under the action of traffic (Kumar, 2014).
- **Bleeding**: is the presence of excess bitumen binder/asphalt on the road surface due to high bitumen content in the mix design. Asphalt rises to the surface after construction due to traffic load and temperature (Fitigu, Raj and Kumar, 2023) (Wada, 2016).

Major Causes of Pavement Failure

The root cause of pavement failures can usually be traced back to one of more deficiencies in design, construction, pavement material, inadequate maintenance and environmental conditions as well as problematic subgrade materials.

- **Design Consideration:** includes traffic class determination that falls short in projecting the increase in heavy vehicles, overloading, inadequate subgrade strength or insufficient thickness of pavement layers (Sethi, K.C., Tiwari, D.S. and Baral, 2016) (Fitigu, Raj and Kumar, 2023) (Chamia, Gariy and Mulei, 2017). Inaccurate projection of flood discharge and subsequent inefficiency in drainage systems, increased traffic overloading due to diverted traffic could also cause premature failure (Zumrawi, 2016).
- **Construction Failure:** includes poor workmanship in production, placement, compaction, and inaccurate laboratory tests (Banda, 2018). In addition, when works do not perform according to plan and delays are encountered on site, the pavement will be subjected to secondary effects of climate which can contribute to premature failure (Otim, G and Alinative, 2016).
- **Material Failure:** using poor quality materials as pavement layers can adversely affect the performance of the road and lead to premature failure (Zumrawi, 2016); (Tamrakar, 2019) (Kate and Gebeyehu, 2017); (Chamia, Gariy and Mulei, 2017) (Geremew, Quezon and Kebede, 2016). If there is insufficient bond between the surface course and underlying course due to poor quality of materials, it can cause spalling and potholes at an early stage (Chahan, S-J, Patel, A, Prajapati, B Kanojia, 2017).
- **Failure in Maintenance:** inadequate, poor or delayed maintenance practices can affect the performance of asphalt

pavements and can cause premature failure (Banda, 2018) (Okigbo, 2018); (Al-Arkawazi, 2017).

- **Environmental Conditions:** includes climatic conditions such as increased moisture and temperature. Moisture affects the pavement performance by reducing the shear strength of the layers, while high or low temperatures affect bituminous and asphalt surfacing. (Wayessa, S.G, Abuye, 2019) (Al-Arkawazi, 2017); (Rokade, S. Agarwall, K. Shrivastava, 2012).
- **Topography:** is a major factor in terms of affecting drainage which is an important factor for pavement durability. In addition, landslides and erosion in mountainous and escarpment terrain can contribute to premature road failures (ERA drainage design manual, 2013).
- **Weak Subgrade:** these cannot support the traffic load without adequate pavement cover and can cause pavements to deform and form ruts (Al-Arkawazi, 2017); (Chukka and Chakravarthi, 2012) (Chamia, Gariy and Mulei, 2017). Problematic materials such as expansive, saline, dispersive or collapsible soils can cause premature failure if not handled correctly (Tailor, Ravin M. Shah, 2014), (Zumrawi, 2016).

3. Problem Statement

The assessment of 25 years RSDP shows that rehabilitation of trunk roads, upgrading of link and trunk roads and maintenance works consume 36% of the expenditure in the road sector (ERA, 2024). Hence, premature pavement failure has the potential to increase this cost besides to increasing vehicle operating cost and causing safety and comfort issues to road users. Although there are no studies that quantified the actual economic damage of premature pavement failures yet, previous technical studies and reported cases clearly indicated that premature failure is a notable problem , including being a source of public complaint in the country (The Reporter, 2020).

To establish the gap in the literature, previous related technical studies were reviewed including (Assefa, 2021), (Wayessa, Abuye, 2019), (Tamiru, Getu. 2018), (Banda, 2018), (Bekele et.al., 2017), (Abate, 2015). Accordingly, it was noted that the previous studies were case studies that are focused on laboratory investigation of pavement material quality. In addition, not many researches focused on premature failure but failure of roads in general.

Hence, this study focuses on investigating causes of premature asphalt pavement failure in trunk/link road segments of the federal roads of Ethiopia through detailed field measurement besides to desk study and laboratory testing. The study proposes remedial measures based on the findings.

4. Research Objectives

This study investigated the causes of premature asphalt pavement failure on trunk/ link roads in Ethiopia and recommends avoidance and remedial measures, so that similar problems can be prevented in future. The findings from the case study of selected road segments are presented with the following specific objectives:

i. To assess the modes of failure on sections of the road
ii. To identify causes of premature failure on the damaged sections of the road
iii. To propose solutions to mitigate the identified causes of premature failure

5. Methodology

This study considered the review of literature and previous works to establish study's framework. The study considered asphalt

surfaced trunk/link roads that exhibited premature failure within 5 years after being open to traffic as samples. Accordingly, sample asphalt surfaced link /trunk road segments that exhibited premature failure were chosen for the study. A preliminary site visit was conducted to verify if the roads actually exhibited signs of premature failure, such as excessive rutting or severe fatigue cracking. This was followed by a detailed desk study, subsequent field measurements, test pitting and laboratory testing.

Field work included a Visual Condition Survey (VCI), traffic count, axle load survey, Dynamic Cone Penetrometer (DCP) testing and deflection and rutting measurements. Characterization of the pavement materials including index and strength tests were conducted on the subgrade, subbase, base course and asphalt layers by collecting samples from selected test pits.

The field measurements and laboratory test results were qualitatively analyzed by comparing with ERA's standard technical specifications and the design documents. Based on this, an objective assessment was made on the root causes of the failures. The remedial actions were proposed accordingly.

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Description of Roads Under Study

The sampled road segments were located at the western part of Ethiopia, where the terrain is mostly rolling as shown in Table 1. The study area is situated at an altitude of 1,400 – 2,100m with a climate of Dega-Weyna Dega, (alpine to temperate). The maximum mean monthly temperatures in area ranges from 27^0C - 29.8^0C, and occurs from February, January and December to April respectively. The area has a maximum mean monthly rainfall ranging from 212 to 315mm falling between June & September.

Table 1 Terrain of Roads Under Study

Terrain	Link Road Segment	Trunk Road Segment 1	Trunk Road Segment 2
Rolling	69.16%	70.33%	54%
Mountainous	21.53%	26.23%	37%
Escarpment	2.69%	3.44%	9%

The selected route includes three segments, constructed by three different contractors:

- Link Road Segment 0+000-96.61km (96.61km)
- Trunk Road Segment 1 0+0000-61km (61km) and
- Trunk Road Segment 2 61+000-111+659 (50.6km).

The location map of the area is not included to keep the study anonymous. All segments are designed for traffic volume of DS4 (AADT 200-1000) and traffic class of T6 (6-10 million ESAs), with a design life of 20 years according to ERA Flexible Pavement Design Manual (2002). All studied segments have sealed shoulders with a carriage-way width of 7m. The selected route is also known for its weak expansive subgrade formation where the design considered a capping layer for mitigation (ERA, 2021).



Figure 2 Shoving of Asphalt

Site assessment and test pitting on the road was conducted during January 2021. At the time of the site investigation, the road was in its fifth year after opening to traffic. From the site assessment, it was noted that some segments of road showed excessive rutting,

shoving and bleeding. Other sections of the road were affected by landslides. However, due to scope limitation, only non-landslide related failures are covered in this study.

The field measurement considered 300m of defective sections of the road for detailed investigation as per Research Procedures Manual (2014). For sampling purposes, all test sections were labeled as shown in Table 2. Abbreviations of the roads are used in this publication for ease of reporting.

Table 2 Designations & Tested Sections

Link Road Segment (L-1)	
Selected section	km 33+346 - 33+646
Test pit	km 33+517
Trunk Road Segment 1 (T-1)	
Selected section	km 16+300 -16+600
Test pit	km 16+324
Trunk Road Segment 2 (T-2)	
Selected section	km 65+004 - 65+304
Test pit	km 65+200

6. Results and Discussion

6.1 Field Investigation

Visual Condition Survey

The Visual Condition Indices (VCI) of road segments ranged between 62 and 75% (Table 3). This means the roads had rating ranging from Good to Fair. The drainage provision was adequate based on the visual site assessment, although some siltation was recorded on the drains.

Table 3 VCI Values

Road section	VCI	Rating
L-1	75.2	Good
T-1	62.2	Fair
T-2	64.8	Fair

Traffic Analysis

A traffic count and axle load survey conducted as per ERA Flexible Pavement Design Manual (2013). The results indicated that the total traffic volume is in line with the design forecast with AADT of 862 for L-1 and 1062 for T-1 and T-2. However, axle over loading resulted due increased proportion of heavy trucks and small buses by 108% and 47% for L-1, and 137% on the T-1/ T-2 section as shown in Table 4.

Table 4 Traffic Loadings

Road section	Design Axle load ($\sum ESA10^6$)	Design Traffic class	Actual Axle load	Actual Traffic class
L-1	6.83	T6	28.13	T8
T-1 /T-2	6-10	T6	15.68	T7

Rut Depth Measurement

The major defect observed on all segments was excessive rutting based on the site assessment. The rut depths measured in the outer wheel path (OWP) and inner wheel path (IWP) as per ASTM E1703 are shown in Table 5.

ERA Manual does not explicitly categorize rut depths in terms of severity. However, the LTPP Manual for Mozambique (Phil, Paige-Green. Geddes, 2017) and South Africa's TMH 9 Manual (1992) consider a rut depth greater than 30mm as severe.

Table 5 Ruth Depth (mm), 90th Percentile

Road section	Left lane		Right lane	
	OWP	IWP	OWP	IWP
L-1	18	6	48	11
T-1	-	6	86	84
T-2	21	8	90	70

Accordingly, severe rutting was found in the OWP of the right lane on all sections. This would be expected, since the OWP is zone of moisture fluctuation. However, severe rutting was also recorded in the IWP on T-1 and T-2, which indicates additional cause/s.

Deflection Measurements

Deflections correlate with the long term performance of pavements under traffic loading (ERA pavement rehabilitation and asphalt over lay design manual, 2013). Deflections for this study were measured using a Benkelman beam, as per AASHTO T256-77 as summarized in Table 6.

Table 6 90th Percentile Deflection, mm

Road Section	Left lane		Right lane	
	OWP	IWP	OWP	IWP
L-1	0.52	0.48	0.48	0.52
T-1	0.52	0.56	0.52	0.58
T-2	0.44	0.46	0.58	0.52

According to (Jordaan, 2019), the above deflection is marginally from sound to warning condition. This extent of deflection is significant, since the pavement served not more than a quarter of its design life.

Dynamic Cone Penetrometer

Dynamic Cone Penetrometer (DCP) was used to assess the strength of subgrade as per ASTM D6951. The values obtained were converted to equivalent CBR values, as shown in Table 7, using the TRRL 1990 model for 60^0 DCP cone, Log CBR= 2.48 - 1.057 Log (mm/blow) (ERA pavement rehabilitation and asphalt over lay design manual, 2013). This is since the model applies to all soil types (Legese, 2016).

The results indicate that the respective in situ CBR values from DCP measurements fulfill the minimum CBR requirement of 4% - 5% in ERA's technical specification (ERA, 2013 and 2002). This can be due to the capping layer and/or the hardening of the expansive subgrade in the dry season. The results also showed L-1 and T-2 had strong formation underneath the subgrade.

The laboratory soaked CBR results, done as per AASHTO T-193 also showed that all subgrades fulfill the subgrade strength requirement except for T-1. This indicates the presence of unsuitable subgrade material at this section.

Field Density and Moisture Content Tests

Field density (Figure 3) and Proctor compaction tests were done on each granular layer of the pavement along with moisture contents as per AASHTO T-191, AASHTO T-180 and AASHTO T-265. The results are summarized in Table 8.



Figure 3 Field Density Testing

It was found that the subgrade of T-1 was much wetter than OMC. This pauses a serious constraint on load carrying capacity of the pavement. However, the moisture content of the sub base and base course of all segements were what would be expected (on drier side of OMC).

Table 7 Subgrade DCP Converted to CBR

Road section	DN value (mm/ blow)	CBR value (from DCP)	Equivalent Soaked CBR
L-1	11.32	23%	15%
T-1	20.63	12%	3%
T-2	7.32	37%	21%
	2.53	113%	-

The field densities compared with laboratory maximum dry densities showed that the compaction specifications were not met except for the subbase of T-1. A larger

deficiency was especially observed in the field compaction achieved for the base course of all segments.

Layer Thickness

The thickness of each pavement layer was measured in the test pits and compared with design thickness. The results revealed that all segments met the thickness requirement except for subbase of L-1, 300mm actual thickness versus the design thickness of 350mm. The asphalt layer of T-1 with actual 40mm thickness compared with the design thickness of 50mm. These deviations are beyond the tolerance limits in ERA flexible design Manual (2002).

6.2 Laboratory Results

Subgrade Classification

Based on index property tests conducted, it was noted that the subgrade material for L-1 was marginally suitable, and T-2 was good subgrade material. On the other hand, T-1 had unsuitable subgrade material as shown in Table 8.

Table 8 Subgrade Soil Classification

Section	Soil classification		Remark
L-1	A-6	Silty-clay	Ok
T-1	A-7-5	Silty-clay	Not ok
T-2	A-2-7	Gravel	Good!

The summary of all field and laboratory test results are summarized in Table 9. The results that deviate from the specification are highlighted in bold.

Table 9 Field and Laboratory Results of Subgrade, Subbase and Base Course Layers (versus ERA 2002 / 2013 Specification)

Tested as per	Property	Allowable values for subgrade		Allowable values for sub base		Allowable values for Base course		Subgrade			Sub base (Natural gravel)			Base course (Crushed rock)		
		ERA 2002	ERA 2013	ERA 2002	ERA 2013	ERA 2002	ERA 2013	L-1	T-1	T-2	L-1	T-1	T-2	L-1	T-1	T-2
Site measurement	Design thickness (mm)	√	-					-	-	-	350	350	350	200	200	200
	Actual thickness (mm)	√	-					-	-	-	300	350	350	200	200	200
AASHTO T-89/90	LL	≤60 %	≤60%		<45%			33%	***75%***	52%	***28%***	***38%***	***50%***	Non-PI	***23%***	***28%***
	PI	≤30 %	≤30%	6-12%	<12%	6%	6%	15%	***47%***	22%	***16%***	***17%***	***20%***		6%	***11%***
AASHTO T-27	Gradation	-	-			-		-	-	-	Ok	Ok~	Ok	***Not Ok***	Ok~	Ok~
	GM	-			>1.5	-		-	-	-	1.63	1.97	2.46	2.25	2.76	2.54
	Layer thickness	-	-			-										
AASHTO T-180	OMC					-		8%	***18.7%***	-	8%	11.8%	13.4%	5.25%	5.10%	6.7%
	MDD (Kg/m^3)					-		2,010	***1,620***	-	2,090	1,985	1,840	2,226	2,185	2,330
	Field moisture	±2%	±2%	±2%	±2%	±2%	-1% to +2%	10.43 %	***26.85 %***	15.09 %	6.42 %	10.01%	13.16%	2.75%	2.62%	4.59%
AASHTO T-180	Field density	95%	95%	95%/ 97%	95%/ 97%	98%	98%	-	-	-	***93.6 %***	98.54%	***91.5%***	***83.2%***	***91.8%***	***95.7%***
AASHTO T-193	CBR	4%	5%	30%	30%	100%	100%	15%	***3%***	-	***21%***	***17.5%***	34%	***104%***	***58%***	***85%***
	CBR Swell	1.5%	2%	-	-			0.5%	***7.3%***	-	0.5%	0.3	0.3	-	-	-
BS 812 part 110:1990	ACV	-	-			25-29	<25%	-	-	-	-	-	-	26%	15%	12%
AASHTO T 96-83	LAA	-		51%			<45%	-	-	-	-	-	-	33%	14%	15%
BS 812 Part 105.1	FI	-	-		<35%	<30%	<30%	-	-	-	-	-	-	14%	25%	17%

Characterization of Granular Layers

As shown in Table 9, natural gravel and crushed rock were used for sub-base and base course layers respectively in all of the studied sections.

From the results, it can be noted that good subgrade materials were used except for T-1. However, the base course and subbase layers did not meet the requirements of the standard specification at all segements. The relative in-situ densities also indicated that insufficient compaction is a recurring issue on subbase and base course layers. Thus, the above issue of material quality, coupled with the axle overloading, might have contributed to the excessive rutting and deflection that were observed during field measurements. On the other hand, terrain is not expected a contributing factor on most of the observed defects, since the test sections were mostly located on rolling terrain. In case of T-2, a steeper section is noted.

Asphalt Layer

The desk study showed that an asphalt grade of 80/100 was used at all segments. This can be assumed suitable given the moderate temperature of the area. To analyze the asphalt concrete, 95 mm diameter core samples were taken at 100m intervals from selected road segments. Stability and flow of the samples were determined from Marshal tests as per AASHTO T-245. Binder extraction tests were done as per AASHTO T-164 to determine gradation. Flakiness index of the aggregate was determined as per ASTM D-4791. The results summarized in Table 10 show that stability and flow criteria were met except for T-1. Hence, the quality of asphalt was okay for the other studied segments.

The thickness of the asphalt layers were 50mm as per the design, except for 40mm thickness of asphalt layer in T-1.

Table 10 Stability / Flow of Asphalt Layer

Station	Location	Strength analysis		Remark
		Average stability (KN)	Average flow (mm)	
L-1 (km 33+346 – 33+646)				
0+35	RHS	11	3.1	Ok!
0+50		10.9	3.23	
1+50		8.91	3.47	
1+71		8.87	3.4	
2+50		9.35	3.93	
T-1 (km 16+300 – 16+600)				
0+24.4	RHS	5	2.5	Not ok!
0+50		5.96	3.06	
1+50		7.3	2.2	
1+75.5		6.46	2.13	
2+50		5.52	2.17	
T-2 (65+004 – 65+304)				
0+10	RHS	7.58	3.4	Ok!
0+50		9.22	4.4	
1+04		9.92	2.33	
1+50		8.55	3.25	
2+50		7.81	3.17	

The gradation test done as per AASHTO T-27, as shown in Figure 3, indicated that all segeemnts fulfill the requirements.

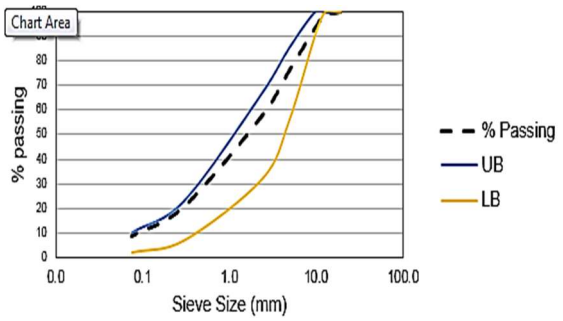


Figure 3 Gradation of Asphalt Aggregate

The results indicated that the asphalt layers had a nominal aggregate size of 12.5mm.

7. Conclusions and Recommendations

Analysis of the overall cause of failure of the road sections investigated indicated that poor material quality, construction tolerances and poor compaction played a significant role in causing premature failure of the roads.

It was also concluded that increased traffic loading made a contribution to the failures.

Rutting was the predominant mode of failure observed in all the studied segements at the time of investigation.

Based on the findings, the following measures are recommended to avoid premature failure of roads in future:

Design:

- Proper consideration of increased percentage of heavy vehicles during traffic projection.

Construction and control:

- Use good quality materials /use of appropriate technologies for marginal materials
- Strict site supervision, quality control and quality assurance on site
- Proper compaction of each pavement layer including the asphalt layer
- Ensure site laboratories are reliable and produce accurate results

Management and maintenance:

- Timely routine maintenance (clearing of ditches, early maintenance of defective sections) is essential.
- Axle load control on such major roads or increased reinforcement thereof can significantly reduce risks of premature pavement failures.

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