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Investigation of the Causes of Severe Asphalt Damagedon Road Pavement in Addis Ababa - Jimma Road

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Abstract— The research study was conducted in Addis Ababa – Jimma Road Upgrading Project with a total road length 355 km. Detailed Investigation was carried out from km 265 to km 281, and more attention was given to several damaged sections between for km 265 to km 281. In this study, a sampling of pavement materials from the road was collected for laboratory tests, and I carried out in-situ DCP test on five testing pits along the road on layers of Subbase and Subgrade. These samplings have been done on all layers from each pit. From the test result, I confirmed that the subgrade is so weak based on strength parameter.I identify subbase strength tests along the study area which I revealed that the subbase has an excellent material and its class is based on ERA design manual. Therefore,it has no problem to the pavement structural thickness to accommodate the current traffic.I also investigate the pattern of shear failures from km 275+000 to km 281+600 which are very similar failure type to the one in km 265+000 to km 271+340. Therefore, the shear failure is caused by the under design. Whereas, the failure comes exactly from weak subgrade with higher PI value and the subgrade is made up of black cotton in which eventually weaken the overall performance of the pavement structure. The investigationwas also carried out in the drainage facility along the study area, especially from km 265+500 to km 281+600 has been found a side water from uphill to the side of the road which eventually saturates the subbase and makes pavement structure so weak.Based on the actual moisture determination of the sub base from km 265+500 to km 281+600 would reveal that the sub base is saturated with water, but the subgrade has critical change with the laboratory optimum moisture content due to the nature of the materials mainly expansive which not drain the water easily.Based on the findings of this investigation, it is recommended the following proposed remedial measures should be taken into account: a) There are some isolated potholes and cracks which cannot be caused by the quality of the materials but it came from poor workmanship, and therefore it is better to patch all the potholes and defect areas to cut and west the contaminated materials and cut to fill based on the recommended thickness and quality of materials, b) The damaged part of the road basically needs reconstruction based on my recommendation, soil stabilization is the best solution because the main problem is the weakness of the subgrade soil which is a black cotton type of soil,c) Under this study I observed that the failed section is starting from km 265+000 to the end of km 285+600; however, from the point of quality of the materials used for the sub-base has been done by according to ERA standard compacted layer by layer not greater than 200mm.

Index Terms— Direct Compression Test, Subbase, Subgrade, ERA standard, Jimma road, Plasticity Index, Moisture Content.

1 INTRODUCTION

The Addis Abeba - Jimma road rehabilitation project is located in the Oromia and Southern Nations and Nationalities Peoples Regions in the western part of Ethiopia. In this study failure of roads constructed on expansive soils of Central Ethiopia, with particular emphasis on the Addis Ababa - Jimma road is investigated. Italians, in 1930 G.C, initially constructed the road. Since 1998G.C the road is under rehabilitation. In the year 2000 the Contractor started construction of wearing course, and after three months the Consultant's personnel have found cracks in some portions of the newly constructed road. In the following months the cracks aggravated and additional cracks were also seen.

The road is being constructed by the joint venture DRAGADOS J&P. The original contract price ETB 405,973,872.12 and variation ETB 243,603,432.01 revised contract price is ETB 649,577,304.13. The contract was signed in December 2000, and the project totally completed and finished in January 2006.

The Supervision Consultant on the project is a Joint Venture of DIWI-TYPSA. The design was carried out using the Ethiopian Design Manuals 2001. The project route is classified as a Class I Trunk Road, and the design traffic flow determines that Design Standard DS4 should be adopted for the full length of the project.

The road when completed will enhance development in the vicinity of the project. Besides accelerating economic development, the road upgrading will assist the administrative and social coverage in the region and reduce the operating cost of vehicles as well as the regional maintenance costs.

The Addis Ababa -Jimma Road Rehabilitation Project consists of the upgrading of 355 Km of existing Asphalt surfaced road to upgrading and overlaying the existing surfaced roads. In rural areas, the road will have a 7-meter carriageway width and 1.5-meter shoulders on both sides. Urban areas and some villages will include parking lanes and footpaths on both sides of the carriageway together with a positive drainage system. The design includes improvement in the geometric condition, drainage provisions, and structures along the route. The project road traverses flat, rolling and mountainous terrains. The rolling terrain dominates the area. The majority of the area is strewn with boulders and vegetation is classified as scrub land throughout.

Early in the contract, the highly deformed condition of the existing road, particularly between km 10+600 and km 58 backward towards Addis and forwards towards km 68 was brought to the supervisor's attention. The extensive presence of black cotton soil, although alluded to in the designer's was also identified as a significant problem for which and in December 2000, Dr. Frank Netted berg was appointed to undertake a detailed investigation into the causes of the cracking and propose recommendations to counteract the effects of the black cotton soil. The final report was submitted in April 2001. But the other part which is the most severely damaged sections of the road between Sokoru and Asandaboo was not covered in the investigation of Dr, FrankNettedberg [7].

In the United States alone, expansive clays have been estimated to produce at least two billion dollars of damage annually, however, in our country, there is no tangible document. Additionally, long highway routes in Ethiopia have no particular detour and various areas subject to free flood actions [3,6]. The minor influences are the presence of moisture due to poor drainage, broken drains, transpiration (drying effect) and so on. Therefore, clay soils need to be improved to make them suitable types of construction. Soils can often be economically improved by the use of admixtures [7], [12]. The length of road between Km 268 to Km 285 is known as the "Gilgel Gibe realignment ." In which this detail investigation has been carried out in the failed AC 1 section.

The objectives of this research study were to investigate causes of severe asphalt concrete road pavement defects in Addis Ababa - Jimma road and its proposed remedial measures.This research work was to answer the following questions:What are the main causes of this failure?What kinds of failures exist?What solutions could be provided to reduce damages due to this problem?

2RESEARCH METHODOLOGY

2.1 General

Site Investigation was carried out from km 268 to km 285+600 and more attention given to more damaged section for km 265+000-281+500, and in this study, we carried out in-situ tests and laboratory tests for five testing pits from the road on each layer (AC, Base Course, Subbase, and Subgrade).
The latest traffic count was performed previously and presented under this report, which has been done from ERA,
In this section, all test results were presented in tables and charts to aquick understanding of the properties of the materials used along with the project specification and the latest traffic count data analysis were discussed at the end of this chapter.
The scope of this detail investigation for failed section of the road is to clearly existent the findings, observations and the corresponding engineering assessment cause of cracking and breaking up of pavements are the main issues. Therefore, in this research primarily identify the problems and propose better solutions that use for minimizing the maintenance cost and support the economic growth of our country.This road section suffers a pavement failure as clearly shown during the condition survey. The sub base is entirely saturated with water and loses its strength and changes its grading as well.

2.2 Pavement Condition Survey

Before the beginning of the detailed field investigation activity, the condition of the road has been assessed and identified.The pavement condition survey was carried out in the study section of road to identify areas showing pavement defects and to assess causes of defects and decide whether a severely damaged road section is to be scarified and reconstructed.The most common types of pavement distress with associated information have been measured and recorded at a small interval of the road.Those modes of distress which are controlled largely by the strength of the subgrade soils and thickness and quality of the pavement structures have been recorded, these were potholes, deformation, and cracking. Those modes of distress which are controlled largely by the strength of the subgrade soils and thickness and quality of the pavement structures have been recorded; these were potholes, Deformation, and Cracking.

Potholes are a wet weather deterioration formed under traffic action. Free water on the surface accumulates in depressions, and the passage of a vehicle tire stirs up the water causing fine materials to pass into suspension. Water, with the suspended fine material, is also forced out of the depression. Under the action of many wheel passages and sufficient water, this is a rapidly accelerating phenomenon. Although shallow, and few in numbers, potholes were observed along the study area mainly from km 265 to km 281.

Deformation is a permanent distress on the road section, which develops when the surface or pavement materials like saturated sub base have inadequate shear strength under traffic loading and prevailing moisture conditions. Deformation was measured at critical locations using a 3-meter steel straight edge in mm. Deformation, although variation in theextent of severity, has been observed all over the study area.

There are different types of cracks resulting from the distress of the pavement surfaces. The major repeated crack types observed in the study area is crocodile cracks in the deformed section. Crocodile cracks: these are interconnected cracks forming a series of small cracks. When confined to the bituminous surfacing, it is usually the final stage of cracking due to thermal stresses. It is the result of excessive deflection of the surface over unstable subgrade or lower courses of pavement.

2.3Test Pits and Sampling

Test pits according to my research proposal staggered left and right of the road, particularly around the failed spots; all the layers are logged and measured, and representative samples were taken for laboratory test and in- situ moisture content, AASHTO soil classification, gradation, and Atterberg Limits, Procter and CBR.The test pitting and sampling furnished not only laboratory indication of the character of the sub-grade, but also the thickness and character of the overlying materials of the sub-base, the base course, and AC1. All laboratory test results are attached here and described each pavement materials in the subsequent headlines.

2.4 Natural Moisture Content (NMC)

The results in Table: 2 shows the natural moisture content done on each pavement structure using a speedy moisture determination apparatus.
As per ERA standard technical specification 2002 and section 5107(a) and 5209(b) show the maximum tolerated moisture content deviated from laboratory determined optimum moisture content for sub base and base course respectively, in which thesubgrade has higher moisture.

2.5Measurement of Thickness

The design thickness of the study area based on the supervision consultant recommendation is as follows:

Table 2.1 Thickness of Road Layers

No.	Layer	Thickness
1	Asphalt	50mm
2	Base Course	200mm
3	Subbase	300mm
4	Capping layer	200mm

- Asphalt concrete plant mix, compacted depth 5cm
- Crushed aggregate base course grading, compacted depth 20cm
- Special sub base grade, compacted depth 30cm
- Gravel capping layer, compacted depth 20cm

2.6Laboratory Test

2.6.1 General

To confirm the quality of each pavement material used to the following laboratory test types, and by conducting laboratory tests after proper sampling and preparations of materials from the road with by the AASHTO test procedure.
Sampling was executed after performing Procter test and in-situ moisture measurement. Test pits were commonly dug to a depth of up to a maximum of 2.0 m starting from the road surface.

Table 2.2. Laboratory Test Types

Lab Test Type	Subgrade	Subbase	Base Course	Bitumen
Classification Test AASHTO T-88	√		√	√
PI AASHTO T-89/90	√	√	√	√
CBR AASHTO T-193	√	√	√	√
Gradation AASHTO-11/27		√	√	√
Free Swell Test AASHTO A7-5	√	√	√	
Extraction of Bitumen Content				√

2.6.2 Subgrade

The subgrade is the under the most layer of a pavement and as such is one of the main concerns of a pavement design. Many pavement failures could be traced to insufficient consideration given to the natural subgrade material, especially in the case of problematic soils, the identification of which is of paramount importance and half the solution towards the mitigation measures.
The pavement subgrade material was investigated using test pitting to a depth of 90-200 cm from the top surface, for laboratory analysis. The result of the analysis is used to identify problematic soils along the study road stretch, classify the whole road stretch into uniform sections of identical subgrade strength.
Due to thehomogeneity of the subgrade to a vast extent, representative soil samples were taken from test pits staggered and dug to the left and right edges of the road at highly destroyed stations of the study area 5-point CBR, PI and soil classification test. Samples were collected from the full depth of the test pits where soil profiles exhibit nearly uniform soil horizons.

Furthermore, more samples were collected from pits that show different typical layers and soil characteristics.
Sampling was executed after performing Procter test and in-situ moisture measurement. Test pits were commonly dug to a depth of up to a maximum of 2.0 m starting from the road surface.
The Sub-grade CBR test was conducted on samples taken from the sub-grade material in the study area to investigate its bearing capacity to supplement the classification tests carried out.
The Free Swell Test was conducted to determine the swelling percentage and to determine the level of the expansive soil.

2.6.3 Subbase

All the tests done for the subgrade described above are also carried out on the subbase of the failed pavement. The laboratory classification test on the pavement subbase material was carried out according to AASHTO to evaluate the soil class category of the material and the PI range.
Samples of the subbase material of the pavement were taken at an interval of approximately 4 km along the whole study stretch at a variable left and right of the carriageway and subjected to laboratory CBR test. This was done near to failed spots so that the existing pavement would be destroyed, much to dig out a sufficient amount of material that is needed for CBR test and other quality tests.

2.6.4 Base Coarse

The tests done in the subbase as described above are also carried out on the base course of the failed pavement. The laboratory classification test on the pavement base course material was carried out according to AASHTO T-88 to evaluate the soil class category of the material and the PI range in which it is found.
Samples from the failed section, base course material were taken at the damaged section along the road stretch at alternating left and right of the carriage way and subjected to laboratory tests for PI and Grading and 4km interval for strength parameters such as CBR.

2.6.5 Asphalt Concrete (AC)

During the investigation, we took samples of AC by cutting 0.5 from 0.5m AC slab from the road, and the following tests have been conducted in the ERA Jimma district.
Extraction tests which determine the grading of aggregates and bitumen content in the asphalt concrete in accordance to AASHTO T-164 and T-27.
The results of the laboratory test conducted on the samples (Refer to Table 16) indicate that most of the road section consists of bad to fair AC materials mixture based on extraction test i.e. grading and Bitumen contents.

3 RESULTS AND DISCUSSION

3.1General

In this section, I analyzed all the actual test data and the actual field condition. It is very clear that before testing any pavement structure, the impacts of the geography, geology, temperature, and rainfall has to be checked and during site survey, there must be a routine tests that have to be conducted in the laboratory; however, during my study all of the previous test results in the document full fill all the contractual specification requirements, thus our focus lies to the actual test result which were carried out in the ERA Jimma district laboratory for this study.

3.2Interpretation of Test Results

The actual moisture content determinations for each pavement structure were determined and found to be far from the optimum moisture content (OMC) for subbase and subgrade, but for thebasecourse, it is near to optimum moisture content thus this has a high effect on the performance of the pavement structure.

3.2.1Moisture Content (MC)

Table 3.1 NMC vs. OMC for each pavement structure

Chainage	NMC vs. OMC		
	(Base Coarse) %	(Sub Base) %	(Sub Grade) %
LHS Km 268+000	11.0 vs. 4.4	12.0 vs. 4.8	21.82 vs. 15.37
RHS Km 271+600	12.0 vs. 4.6	12.0 vs. 5.1	28.3 vs. 23.28
LHS Km 274+200	12.0 vs. 4.6	13.5 vs. 5.1	22.41 vs. 14.9
LHS Km 277+500	12.0 vs. 4.5	14.0 vs. 5.2	21.35 vs. 13.9
RHS Km 277+600	11.0 vs. 4.5	13.0 vs. 4.7	30.73 vs. 16.4

As per ERA standard technical specification 2002, and section 5107 (a) and 5209 (b), shows the maximum tolerated moisture content deviated from laboratory determined optimum moisture content for sub base and base course, respectively. The subgradehas higher moisture as shown in Table 3.1 above and this moisture has a bigger contribution to the failure of the pavement.

3.2.2Section Layer Thickness

Table 3.2-A:NMC vs OMC

Chainage	Thickness			
	Bituminous (mm)		Base Coarse (mm)	
	Design	Actual	Design	Actual
LHS Km 268+000	50	50	200	160
RHS Km 271+600	50	50	200	162
LHS Km 274+200	50	50	200	165
LHS Km 277+500	50	50	200	160
RHS Km 281+600	50	50	200	160

Table 3.2-B:NMC vs OMC

Chainage	Thickness			
	Subbase(mm)		Capping Layer(mm)	
	Design	Actual	Design	Actual
LHS Km 268+000	300	200	200	200
RHS Km 271+600	300	200	200	200
LHS Km 274+200	300	200	200	200
LHS Km 277+500	300	200	200	200
RHS Km 281+600	300	200	200	200

During theinvestigation, the actual thickness of some of the sections is not as per the design requirements, refer to Table 3.2. Based on this data,there is aneedfor a deepinvestigation, according to the ERA design manual.The investigation should be done levels only at random points which might be more than 40m intervals. In addition to this according to the ERA design manual that the tolerance of each pavement, given in the contract that makes the thickness lower value; however, for the section from km 268+000 to km 282+600, the average thickness we found was 163mm which is still below the project specification and design.

As per AASHTO Classification, about 100 % of the material is composed of mostly clayey soils (A-7-5) this indicates that all of the sub-grade material lies in the range of fair to poor regarding strength and other engineering properties for road construction.

3.2.3Subgrade Investigation

Table 3.3Distribution of PI (Subgrade)

Plastic Limit and Plasticity Index of Subgrade Soils			
Chainage	LL	PL	PI
Km 268+000 LHS	53.89	31.69	22.2
Km 271+600 RHS	52.57	29.96	22.2
Km 274+200 LHS	50.86	29.02	21.84
Km 277+500 LHS	50.08	31.00	19.08
Km 281+600 RHS	51.41	31.74	19.67

It can be seen from Table 3.3 shows that the PI distribution along the study area is not satisfactory and there is no much change in test results from the previous test data.

Table 3.4CBR Distribution(Subgrade)

Chainage	Swell after 4 Days	Height of Specimen	% of Swell	% CBR
Km 268+000 LHS	7.7	116.43	6.61	2.04
Km 271+600 RHS	12.52	116.43	10.75	2.1
Km 274+200 LHS	4.72	116.43	4.05	3.06
Km 277+500 LHS	7.52	116.43	6.46	2.14
Km 281+600 RHS	12.21	116.43	10.49	2.23

The results of the laboratory test conducted on all the samplesindicatethat the soil samples are below the minimum ERA standard.
The distribution of the subgrade laboratory CBR along the road stretch is tabulated in the following Table 3.4.

From the tabulated data, it can be seen that the subgrade material in the failed section of the study area has an average CBR of 3% and average PI of 21.08% as shown in Table 3.3 and Table 3.4 respectively.

Table 3.5Free Swell Distribution (Subgrade)

Chainage	Sample No.	Volume of Soil with Distilled Water	Volume of Soil with Kerosene	Free Swell Index (%)
Km 268+000 LHS	1	14.50	10	45.00
Km 271+600 RHS	2	18.00	12	50.00
Km 274+200	3	14.00	10	40.00

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LHS				
Km 277+500 LHS	4	14.00	10	40.00
Km 281+600 RHS	5	20.00	13	53.85

According to the result shown in Table 3.5, the average Free Swell is less that 50%.
Soil to Free Swell of 50% is considered expansive in the medium classification by (IS).

3.2.4Subbase Investigation

Table 3.6PI Distribution (Subbase)

Plastic Limit and Plasticity Index of Subgrade Soils			
Chainage	LL	PL	PI
Km 268+000 LHS	26	16	10
Km 271+600 RHS	23	17	6
Km 274+200 LHS	23	17	6
Km 277+500 LHS	30	20	10
Km 281+600 RHS	25	15	10

From the Table 3.6, most of the material has a PI of in between 5-15%, which is designated as plastic soils. The PI distribution increases along the road length from the beginning at km 269+540 up to the end of the study area at km 282+600.

Table 3.7CBR Distribution(Subbase)

Chainage	Swell after 4 Days	Height of Specimen	% of Swell	% CBR
Km 268+000 LHS	0.34	116.43	0.3	59.4
Km 271+600 RHS	0.76	116.43	0 .65	84.6
Km 274+200 LHS	1.30	116.43	1.17	62.8
Km 277+500 LHS	2.3	116.43	1.97	13.6
Km 281+600 RHS	1.68	116.43	1.44	5.7

Subbase test results of the laboratory test conducted on the samples indicate that most of the road section consists of good sub-base material having an average CBR of 39.22% in the stretch of km 268+000-282+600 (Refer to Table 3.7). This is assumed to have resulted due to saturation of the subbase material with the underlying especially in those places where the pavement shows serious deformation and distress. There are some stretches where a higher value of subbase CBR was found from km 268 to km 285+600 having an average CBR of 39.22% which is very good quality of the required design CBR.

3.2.5Base Course Investigation

Samples from the failed section, base course material were taken at the damaged section along the road stretch at alternating left and right of the carriage way and subjected to laboratory tests for PI and Grading and 4km interval for strength parameters such as CBR.

Table 3.8PI Distribution (Base Coarse)

Plastic Limit and Plasticity Index of Subgrade Soils			
Chainage	LL	PL	PI
Km 268+000 LHS	34	23	11
Km 271+600 RHS	39	25	14
Km 274+200 LHS	33	22	11
Km 277+500 LHS	26	20	6
Km 281+600 RHS	32	19	13

It can be seen from Table 3.8 that the PI of higher than 6% (6-15%) is observed on the base course material in the study area (Refer to Table 3.8). The average PI of the study area is 11% this test is indicated; the material quality is below the ERA minimum standard.

Table 3.9Summary of test result for base course

Chainage	Sample No.	PI	FI	CBR	Ave. % Swell	Ave. ACV %
LHS Km 268+000	1	11	20.6	130	0.05	13
RHS Km 271+600	2	14	20.2	110	0.08	12
LHS Km 274+200	3	11	25.9	125	0.07	10
LHS Km 277+500	4	6	24.5	130	0.03	12
RHS Km 281+600	5	13	22.6	128	0.06	12

The results of the laboratory test conducted on the samples indicate that most of the tests such as CBR, PI, FI and Grading on the base course material have good results based on project specification. But its PI value shown in the Table 3.9 would be so critical to any volume change which occurs due to excessive moisture would give a premature failure in AC.

3.2.6Asphalt Concrete (AC) Investigation

Table 3.10-A:Bitumen Content of AC Test Result

Quantitative Extraction of Bitumen			
Before Test		**Sample**	
		1	**2**
Mass of Bowl + Filler (g)	A	6259	6263
Mass of Bowl +	B	7638.5	7650

Sample + Filter (g)			
Mass of Sample	A-B=C	1377	1391
After Test			
Mass of Bowl + Sample + Filter (g)	D	7575.5	7581
Mass of filter from extracted solution (g)	E	4.1	4.6
Mass of aggregate after extraction (g)	D-A=F	1314	1322
Mass of total aggregate + filter (g)	F+E=G	1318.1	1326.6
Mass of bitumen (g)	C-G=H	58.9	64.4
Bitumen Content (%)	H/C	4.28	4.63

Table 4.10-B:Bitumen Content of AC Test Result

Quantitative Extraction of Bitumen			
Before Test	**Sample**		
	3	**4**	**5**
Mass of Bowl + Filler (g)	6263	6263	6264
Mass of Bowl + Sample + Filter (g)	7676	7694	7671
Mass of Sample	1413	1431	1407
After Test			
Mass of Bowl + Sample + Filter (g)	7620.5	7627	7606
Mass of filter from extracted solution (g)	2.5	8.7	6
Mass of aggregate after extraction (g)	1357.5	1364.5	1342
Mass of total aggregate + filter (g)	1360	1373.2	1348
Mass of bitumen (g)	53	57.8	59
Bitumen Content (%)	3.75	4.04	4.19

From the Table 3.10, the average bitumen content of the study area has shown as 3.1 % below the dry side of the mixture which is smaller than the specification required (4.3%-4.9%).
The average bitumen content differs from the lower limit of 4%, and which is clearly shown the AC lacked some bitumen in the mix but based on its service year it is feasible.

4 CONCLUSION

This research investigated evaluation on failed area of the road section. The following was concluded from the conducted research:

- During the site investigation using visual inspection, it was found out that in the damaged area there is a drainage problem which directly goes the water to the road during the rainy season. And because the soil is an expansive soil, then the road
- Detail Investigation was carried out from km 265+000 to km 282+600 and more attention given to more damaged section. In this study, asampling of pavement materials from the road was collected for laboratory tests. From the test result, I confirm that the sub-grade is so weak based on strength parameter.
- On subgrade strength tests along the study area revealed that the subgrade has a weak soil black cotton material and its class based on ERA design manual.The rest of the test results on subgrade have got a CBR of less than 3%, and under this report, we also checked the subgrade strength has unsatisfactory, which classified under S5. Therefore, it has ahigh problem with the pavement structural thickness to accommodate the current traffic.
- An investigationwas carried out in the drainage facility along the study area, especially from km 271+200 to km 282+600 has been found a side water from uphill to the side of the road which eventually saturates the sub-base and makes the pavement structure so weak.
- Based on the actual moisture content determination of the subbase materials in the research area, it revealed that the subbase is saturated with water, but the subgrade has no change to the laboratory optimum moisture content due to the nature of the materials mainly sandy which drains the water easily.
- The failure comes exactly from weak subgrade with higher PI value, and the subgrade is made up of black cotton in which eventually weaken the overall performance of the pavement structure.

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