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Effects of Sub-Grade and Sub-Base Materials Quality on Flexible Pavement: A Case Study

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ABSTRACT

Flexible pavements are composed of asphaltic layer, base course; sub base materials which laid over a well compacted and strong sub grade foundation soil. Basic engineering properties of Sub grade materials are required for design and Coarse grained soils serves as good for supporting pavements whereas fine grained soils, particularly clayey soils pose problem to pavement. Jimma town is a big trade center and coffee production areas of in Ethiopia but, the current existing condition most parts of the road are deteriorated. The objective of this research was to investigate effects of subgrade and sub-base materials quality on flexible pavement.

The distress is categorized by level of severity according to Ethiopian Roads Authority (ERA) standard specification to get 4-stations high deterioration of block crack, 6-stations medium deterioration of Alligator crack and 5-stations low deterioration of edge crack of the studied stretch along Ajip to Gebrel church of 10 km in Jimma town. The samples taken randomly from the deteriorated area of the subgrade and sub-base materials of 15 stations and laboratory tests conducted and also the results were discussed, compared with the ERA, AASHTO and ASTM.

The tests result NMC>OMC indicated that excess water in the subgrade and sub-base materials according to AASHTO D-180 specification, compaction of subgrade and sub-base layers are below the minimum requirement (MDD>97% laboratory density) of AASHTO, poor strength (CBR<1.76gm/cc) of AASHTO T-193 and ERA specification, sieve analysis for gradation out of the upper and lower limit of AASHTO T-27 for the subgrade and sub-base materials. These can be causes of pavement deterioration on flexible pavement. But, the Atterberg's limit test results satisfy the standard specification of ASTM D-4318.

From this research recommended that the designer and contractor should be follow the minimum requirement set by standard specification regarding the engineering properties of materials, the side ditch must be constructed so as to prevent infiltration of water to the under lining strata, seal coats shall be applied to prevent infiltration of water through cracked surfaces to subgrade layer of the pavement.

Keyword: *Deterioration, Distress, Moisture Content, Pavement, Sub-base and Subgrade.*

1. INTRODUCTION

Asphalt pavements designed and constructed properly for the roads deliver a smooth, quiet, and durable solution. The success of any asphalt pavement is depending on the construction materials being designed for its environment, construction methodology and drainage and workmanship. The main structural function of pavement are to support the wheel loads applied to the carriage way and ultimately distribute to the subgrade layer. The major problem of flexible pavements were not being designed and constructed to sufficiently long lasting and cost effective. It reflects problems like early cracking, rutting and moisture damage.

This research was conducted on Jimma city. This is a big trade center in south western part of Ethiopia where people from different direction comes to the city for business exchange. Besides these Jimma Zone is one of the country's coffee production areas. Hence this coffee product is mostly packed and loaded to the center of country from warehouses found in Jimma town. Pavement deterioration mostly occurs in poor (unsuitable) construction of the subgrade and sub-base materials. This permanent deterioration in a well-designed pavement is fairly load distributed between the pavement layers of materials.

In Ethiopia, Road deterioration could be in the form of cracks, potholes, surface deformation, and surface defects which makes unsafe the road network and unsuitable to the road users. For the effect of result to loss of lives, properties and human injuries through accidents, retardation of the rate of economic growth and development in affected areas, environmental pollution and degradation, impedance of human movement and the flow of economic activities and numerous cases of armed rob by attacks along affected area. These effects need to investigate on effects of subgrade and sub base materials quality on flexible pavement: A case study along Ajip to Gebrel of Jimma town.

2. STUDY AREA

The research was conducted at Jimma Zone of Oromia region in Ethiopia. This located in 346 km from south west of capital city of Ethiopia (Addis Ababa). It has latitude and longitude of 7^0 40'N to 7^0 45'N, 36^0 50E to 36^0 45'N and total population about 220, 573. Investigations were carried out along Ajip to Gebrel Church of Jimma town which is 10 km and more attention to the deteriorated stations of the study stretch of existing road.

Average elevation of the studied area is 1,700m above mean sea level and the topography is flat and rolling. The climate of the area is moderate temperature and rainfall. The mean annual temperature of the area is 18^0C. The mean annual rainfall ranges 800 to 1200mm. The major dominate rocks are naturally light in color and highly susceptible to physical and chemical weathering and the major dominant types of soils of the town are clay soil.

Drainage is one of the major problems in Jimma city. In some sections of the road shallow earth ditches are available. On the other hand there is no drainage structure which facilitates flow of water alongside of road. Most of observed drainage structures are currently under poor condition both structurally and functionally. The city has natural flood problem which have negative impact on existing pavement.

3. RESEARCH DESIGN

The study was analyzed in relation to theoretical propositions. The overall approach was six stages process: Identified the types of distress of studied stretch, categorized by level of severity (high, medium and low), necessary sample extracted by using random sampling method of the distress stations and conducted in the laboratory and the laboratory test results are compared with the standard specification and finally conclusions and recommendations have been made based on the findings.

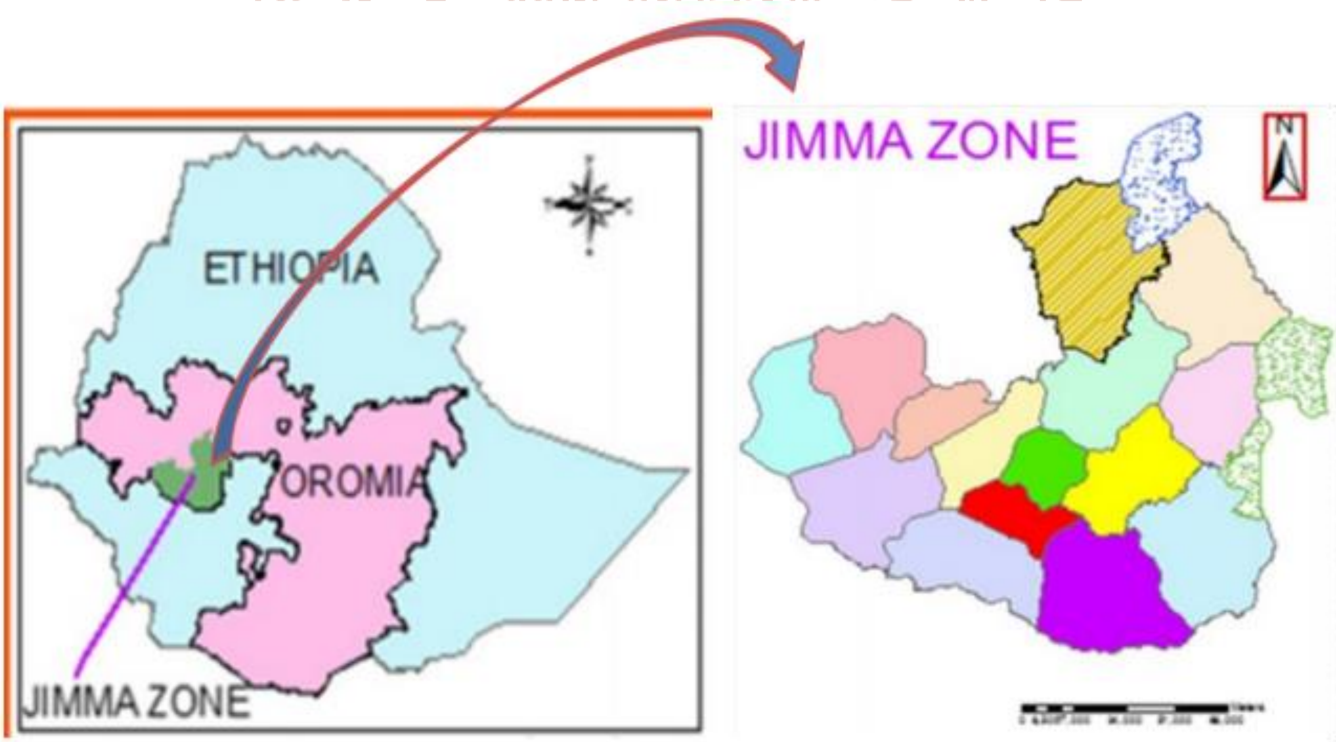


Fig 1: Location of Jimma zone

3.1 Study Procedure

- To identify the distress along study stretch (block cracking, alligator cracking and edge cracking).
- To categorize according to ERA standard specification of 4-stations high deteriorations of block cracking, 6-stations medium deterioration of alligator cracking and 5-Stations low deterioration of edge cracking.
- The Samples extracted by random sampling method of the distress stations.
- The laboratory tests conducted (Natural moisture content, Atterberg's limit, Compaction, Sieve analysis and California bearing ratio).
- The results are discussed compared with standard specification of ERA, AASHTO and ASTM.
- Conclusions would be developed and recommended appropriate remedial measure towards sustainable solution.

3.2 Sample size and Data collection process

In order to generate data for the general and specific objective, field survey and laboratory test were carried out on distress stations. The researcher first identified the distress and categorized by level of severity (high, medium and low deterioration). Collect the primary data of samples were taken from subgrade and sub-base materials of the deteriorated flexible pavement along Ajip to Gebrel church of Jimma town in Ethiopia.

Fig 2: Sample extracted photos captured date 08/04/2017@3:00p.m

Quantitative and qualitative data utilized based on the necessarily input parameters for analysis and compare with ERA, AASHTO and ASTM specification manuals. Data collection process included but not limited to: reviewing letter for correspondence reports, design documents, field visual inspection and inventory, identified the type of distress (edge cracking, block cracking and alligator cracking), categorized by level of severity (5-low deteriorated stations of edge cracking, 4-high deteriorated stations of block cracking and 6-medium deteriorated stations of alligator cracking) by ERA (2002), samples extracted from the deteriorated area.

Field observation was necessary to begin by site visit was taken on the whole portion of roads and at the same time identifies the type of distresses of studied stretch (Ajip to Gebrel church).Then, categorized by level of severity by ERA manual, samples were taken from the studied stretch for distress stations of subgrade and sub base materials for laboratory test a total length of 10km. 15 samples extracted for subgrade and sub base layer of the distress stations, 200kgs from high deterioration, 400kgsfrom medium deterioration and 300kgs from low deterioration were collected samples were tested in the laboratory.

By random sampling technique was used by Samples extracted from the deteriorated area of sub-base and subgrade materials to make it sure as the engineering parameters had certain characteristics as applied for this study.

3.3 Laboratory test

Sample extracted and laboratory performed are Atterbegs limit (for comparison and determination of liquid limit and plastic limit), Grain size analysis (distribution of particle size analysis), compaction test (for determination of maximum dry density and optimum moisture contents), California Bearing ratio (CBR) test (for Determine of shear strength of materials), Natural moisture content (percentage of water by dry soil). The tests are performed according to AASHTO, ERA and ASTM specification.

3.3.1 Grain size Analysis Test

Fig 3: Apparatuses for grain size analysis test

Purpose: To determine the grain size distribution curve of soil samples and is useful for soil fraction larger than 75µm.

Apparatus: Series of standard sieves (for gravel fraction 4.75-75mm aperture size, and for sand fraction 0.075-2mm aperture size), Lid (cover), Pan (receiver), sieve shaker, Balance sensitive to 0.1g, Soft wire brush, Sample splitter, Mortar, and rubber-covered pestle for breaking up aggregates of soil particles, Oven.

3.3.2 Compaction Test

Fig 4: Apparatuses for compaction test

Purpose: To get the maximum dry density (MDD) for the soil and optimum moisture content (OMC).

Apparatus: mold, compaction with full accessories (hummer 2.5kg) and Oven dry machine

3.3.3 Atterberg's limit test

Fig 5: Apparatuses for atterberg's limit test

Purpose: To measure the plasticity and shrinkage nature of the soil.

Apparatus: Grooving tools, Casagrande, tools and spatula.

3.3.4 Natural moisture content test

Fig 6: Apparatuses for natural moisture content test

Purpose: The amount of water exists in a given subgrade and sub-base materials mass.

Apparatus: Sampling trey, weight balance and Oven dry machine

3.3.5 California Bearing Ratio (CBR)

Purpose: To determine the shear strength of subgrade and sub-base materials.

Apparatus: Mold, a separate base plate, an extension collar and a spacer disc.

Fig 7: Apparatuses for CBR test

4. RESULTS AND DISCUSSIONS

These study sections were observed 4-stations block crack of high deterioration (more severe), 6-stations alligator crack of medium deterioration (severe) and 5-stations edge crack of low deterioration (low severe).Level of severity (damage) is classified by ERA manual, depend upon length, depth and width of the crack. These measured by using Tape meter.

Table 1: Distress details along the study stretch

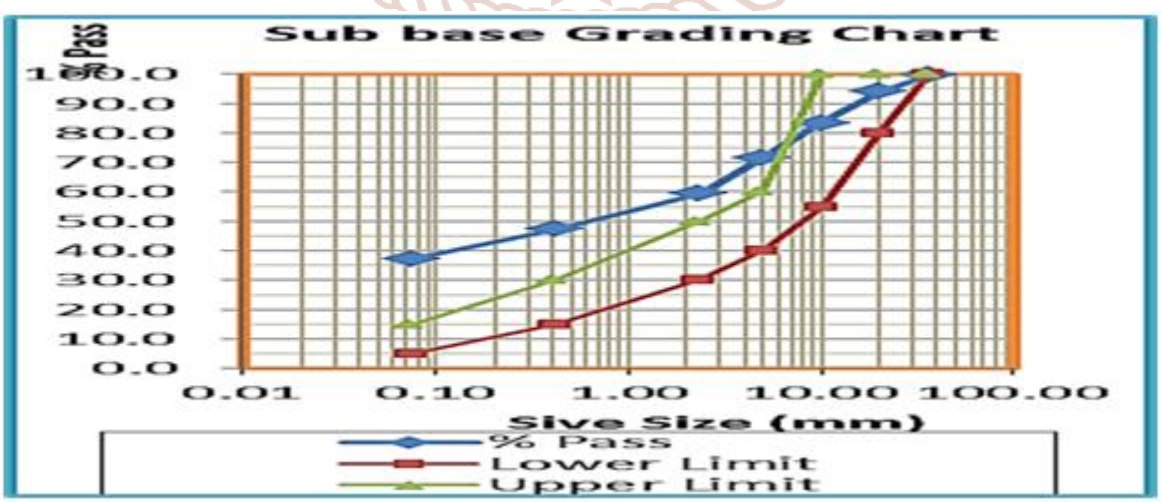
Section	Stn	Location (GPS)	Distress Types	Level of Damage (Severity) ERA 2002	Distress Direction
Section -1 (0-2km)	0+020	N=0567853 E=0969637 Z=1218	Alligator crock	Medium deterioration (Severity)	Left side
	0+920	N=0567852 E=0969639 Z=1219	Block crack	High deterioration (More sever)	Center
	1+840	N=0567856 E=0969638 Z=1217	Edge crack	Low deterioration (Low severe)	Right side
Section -2 (2-4km)	2+160	N=0566782 E=0968827 Z=1219	Edge crack	Low deterioration (Low severe)	Left side
	3+160	N=0566784 E=0968829 Z=1218	Alligator crack	Medium deterioration (Severe)	Both side
	3+740	N=0566781 E=0968827 Z=1217	Block crack	High deterioration (more severe)	Center
Section -3 (4-6 km)	4+240	N=0566785 E=0968827 Z=1218	Alligator crack	Medium deterioration (Severe)	Both
	4+300	N=0566787 E=0968826 Z=1219	Edge crack	Low deterioration (Low severe)	Right side
	5+500	N=0566789 E=0968827 Z=1220	Alligator crack	Medium deterioration (Severe)	Both

Section -4 (6-8km)	6+720	N=0567851 E=0969637 Z=1221	Block crack	High deterioration (more Severe)	Center
	7+740	N=0567853 E=0969638 Z=1220	Alligator crack	Medium deterioration (Severe)	Both side
	7+820	N=0567854 E=0967636 Z=1219	Edge crack	Low deterioration (Low severe)	Left side
Section 5 (8-10km)	9+140	N=0568119 E=0968834 Z=1220	Edge crack	High deterioration	Left side
	9+420	N=0568121 E=0968830 Z=1221	Block crock	High deterioration (More severe)	Center
	9+720	N=0568122 E=0968632 Z=1222	Alligator crack	Medium deterioration (Severe)	Both

Table 2: Categorized by level of severity along the study stretch

Type of distress (cracking)	Level of Deterioration(severity) for degree of distress	Measure the distress pavement			
		Average Length (m)	Average Diameter (width) of Distress (cm)	Average Depth of distress (cm)	ERA Standard specification of severity(standard)
Block cracking	High	0.78	52	50	(Length x Width) >(50cm x50cm)
Alligator cracking	Medium	18	28.67	50	>15cm Diameter of distress
Edge cracking	Low	17.41	34.84	50	>17cm width of distress

Grain size Analysis: At the whole stretch of the road of sub base and subgrade materials were used performed on laboratory test and the results showed for the samples have been tested were out of Minimum and maximum range limit of AASHTO T-27 standard specification. Which implies those have been constructed was not uniformly graded at all. The detail results are attached in appendix A.



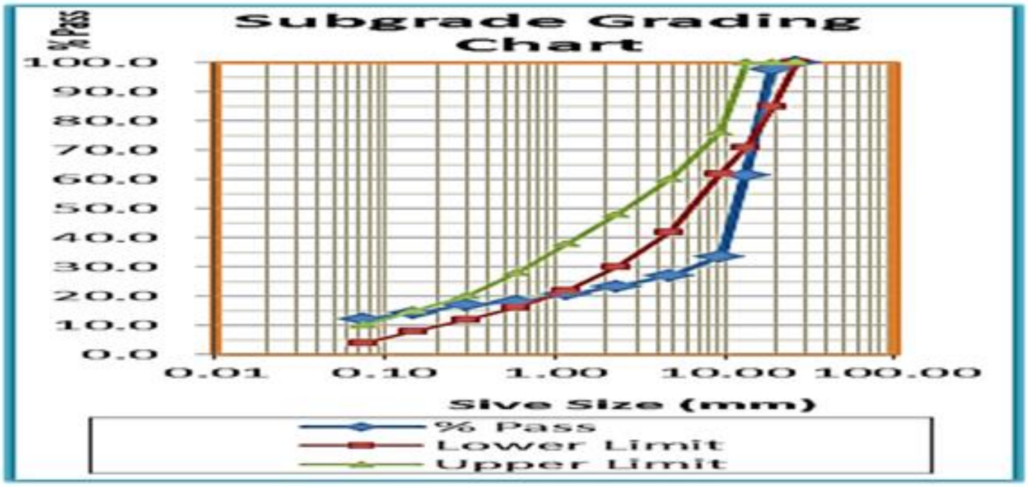


Fig 8: Laboratory test result for the grain size analysis of sub base

Figure 8 depicts that laboratory test result for the grain size analysis of sub base At all sample stations it is out of minimum and maximum limit of AASHTO T-11 Standard specification (the material passing 0.075mm sieve size by sieve analysis method) which implies not uniformly graded (poor graded). It was observed that the gradation of the sub-grade and the sub-base materials was not within the recommended range (out of the range).

Atterberg's limit

Table 3: Atterberg's limit test results

Level of damage (severe)	Station	Sub-grade materials			Sub-base materials		
		Liquid limit (LL)	Plastic limit (PL)	Plasticity Index (PI)	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)
High deterioration (More severe)	0+920	67.15	32.41	34.74	38.16	27.12	11.04
	3+740	62.14	34.82	27.32	43.14	28.46	14.68
	6+720	60.70	32.82	27.89	42.78	29.16	13.62
	9+420	68.84	35.07	33.77	39.15	29.68	9.47
	Average	64.71	37.78	30.93	40.81	28.61	12.20
Medium deterioration (Severe)	0+020	55.09	28.74	26.35	34.08	25.63	8.45
	3+160	57.63	29.84	27.79	33.71	26.18	7.53
	4+240	53.95	30.16	23.79	30.89	24.73	6.16
	5+500	51.81	31.09	20.72	32.92	26.19	6.73
	7+740	52.07	30.74	21.33	35.01	25.82	9.19
	9+720	55.71	31.88	23.83	31.93	27.01	4.92
	Average	54.38	30.41	23.97	33.09	25.93	7.16
Low deterioration (Low severe)	1+840	51.71	28.55	23.16	24.88	22.35	2.53
	2+160	50.89	25.92	24.97	28.16	23.81	4.35
	4+300	50.14	26.67	23.47	30.43	20.98	9.45
	7+820	50.65	28.16	22.49	30.11	21.65	8.45
	9+140	50.12	27.05	23.07	27.81	21.87	5.94
	Average	50.70	27.27	23.43	28.27	22.13	6.14
Total Average		56.59	31.82	24.77	33.85	25.89	7.96

The Laboratory test results, it could be seen that the sub-grade and sub-base materials average liquid limits are 56.59 and 33.85 and average plasticity Index 24.77 and 7.96 respectively. The sub-base LL and PI of the ASTM D 4318 specified value are LL $\leq$ 45% and PI$\leq$ 12% and sub-grade LL$\leq$80% and PI $\leq$ 55% in general the average value of PI for sub-base and sub-grade with is the recommended specification. Both sub-base and sub-grade materials are satisfy the requirement.

Natural moisture content

Table 4: Natural moisture content test results

Level of Damage (severe)	Station	Natural moisture content (%)	
		Sub-grade layers	Sub base layer
High deterioration (More severe)	0+920	39.32	18.67
	3+740	38.67	14.91
	6+720	33.71	17.74
	9+420	34.45	15.65
	Average	36.76	15.08
Medium deterioration (Severe)	0+020	20.34	15.72
	3+160	20.15	13.11
	4+240	38.82	10.01
	5+500	39.43	13.98
	7+740	38.97	12.34
	9+720	39.65	12.58
	Average	32.44	32.27
Low deterioration (Low severe)	1+840	27.52	28.42
	2+160	27.94	28.81
	4+300	26.98	27.93
	7+820	27.05	28.77
	9+140	28.74	27.63
	Average	27.64	28.31
Total Average		32.28	25.22

The average natural moisture content (NMC) test of subgrade and sub base materials obtained from the laboratory more deterioration, medium deterioration and less deterioration are36.76%, 32.44%, 27.64% and 15.08%, 32.27%, 28.31% respectively and optimum moisture content (OMC) of AASHTO D-180standard specification of the subgrade and the sub base materials are 30.05%, 12.06%, 11.08% and 14.44%, 30.44%, 26.06% respectively. MC>OMC.

Compaction (Moisture – density relation)

The relation between maximum dry densities MDD Vs Optimum moisture content (OMC) of the selected stretch.

Table 5: Compaction test results

Level of Damage (severe)	Station	Sub grade layers		Sub base Layers	
		OMC (%)	MDD (g/cc)	OMC (%)	MDD (g/cc)
High deterioration (More severe)	0+920	35.12	1.27	14.52	1.72
	3+740	34.86	1.29	14.11	1.84
	6+720	32.80	1.31	14.46	1.65
	9+420	37.24	1.28	14.67	1.82
	Average	35.01	1.29	14.44	1.76
Medium deterioration (Severe)	0+020	30.92	1.32	11.90	1.73
	3+160	31.46	1.36	12.80	1.79
	4+240	30.76	1.29	11.97	1.86
	5+500	31.01	1.25	12.56	1.52
	7+740	29.82	1.26	11.46	1.51
	9+720	28.68	1.30	11.62	1.82
	Average	30.44	1.30	12.06	1.71
Low deterioration (Low severe)	1+840	26.31	1.31	8.13	1.96
	2+160	25.45	1.26	7.14	1.98
	4+300	24.97	1.22	6.98	1.92

	7+820	26.42	1.32	6.50	1.97
	9+140	27.15	1.35	5.02	1.93
	Average	26.06	1.29	6.75	1.95
Total Average =		30.50	1.29	11.08	1.81

The sub-grade soil samples were subjected to the determination of maximum dry density (MDD) and optimum moisture content (OMC) in the Laboratory. The Laboratory test result reveals that the range of maximum dry density of the sub-grade and sub base materials lies in the range of 1.22g/cc - 1.36 g/cc and1.51g/cc - 1.98g/cc and optimum

Moisture content (OMC) lies in between 24.97% to 37.24% and 5.02%-14.67%. But, AASHTO D-180 standard specification of the subgrade and sub base materials are MDD≥1.76g/cc and MDD 2g/cc respectively. So, the subgrade and the sub base laboratory results under the specification.

California Bearing Ratio

California Bearing Ratio (CBR) is a measure of shearing resistance of the material under controlled density and moisture conditions. The test consisted of causing a cylindrical plunger of 50mm diameter to penetrate a pavement component material at 1.25mm/minute. The loads for 2.54mm and 5.08mm were recorded. This load is expressed as a percentage of standard load value at a respective deformation level to obtain CBR value.

Table 6: Three point California bearing ratio (CBR) test results

Level of Damage) High	Station	Sub-grade layers						Sub-base layer					
		2.54mm			5.08mm			2.54mm			5.08mm		
		No. of blows			No. of blows			No. of blows			No. of blows		
		10	30	65	10	30	65	10	30	65	10	30	65
deterioration (More severe)	0+920	3.6	4.2	4.2	3.2	4.1	4.3	13.2	18.1	19.2	6.0	9.6	10.4
	3+740	3.4	3.5	4.1	3.6	4.2	3.9	13.9	18.3	29.4	6.1	10.1	9.8
	6+720	3.2	3.4	4.3	3.1	3.8	4.2	14.5	17.9	18.6	9.4	11.6	7.9
	9+420	3.9	3.2	4.2	3.3	3.7	4.8	14.1	18.2	19.0	8.2	10.7	12.6
	Average	3.5	3.6	4.2	3.3	4.0	4.1	13.9	18.1	21.5	7.7	10.0	10.2
Medium deterioration (Severe)	0+020	3.2	4.1	4.5	3.1	3.8	4.2	4.8	8.3	20.2	6.5	16.2	12.5
	3+160	3.1	3.3	4.9	3.3	3.7	4.8	3.2	8.6	28.7	6.4	17.6	11.2
	4+240	3.5	3.6	4.7	3.2	4.1	4.3	6.2	8.5	29.2	6.3	15.2	14.6
	5+500	3.6	3.7	4.9	3.6	4.2	3.9	3.7	8.9	28.4	6.8	14.6	15.3
	7+740	3.4	3.6	4.8	3.3	3.7	4.2	6.6	8.2	21.6	6.2	18.2	13.9
	9+720	4.2	4.2	4.7	3.6	4.9	4.2	6.8	8.7	28.6	6.3	10.7	12.1
	Average	3.6	3.8	4.6	2.9	3.7	4.1	4.4	8.5	26.1	6.4	15.4	13.3
Low deterioration (Low severe)	1+840	3.6	4.4	4.7	3.4	4.5	4.6	7.1	7.1	10.1	6.6	18.2	10.2
	2+160	4.6	4.1	4.8	3.2	3.7	3.9	7.9	10.6	19.8	6.5	19.6	14.5
	4+300	4.2	4.2	4.9	2.6	3.6	3.6	6.3	7.4	29.6	6.9	17.5	19.3
	7+820	2.9	3.4	4.8	4.1	3.9	3.7	6.5	9.8	20.4	6.8	20.6	16.4
	9+140	3.8	4.2	4.9	3.5	3.5	4.7	7.8	6.2	21.3	6.7	18.3	20.4
	Average	4.2	3.3	4.8	2.6	3.8	4.2	7.1	9.6	22.2	6.7	18.8	16.1
Total Average		3.9	4.1	4.5	3.5	3.9	4.3	7.4	8.7	23.3	6	14	13.2

The average CBR test values of high, medium and low deterioration (sever) of sub base results are 21.5, 26.1 and 22.24 respectively .But, AASHTO T-193 specification for the standard minimum requirement for sub base indicate as 30% (CRR≥30%) table and also the average value of subgrade soil laboratory test results were 4.2,4.6 and 4.82 at High ,Medium and Low Deterioration .But, ERA specification for the standard minimum requirement for sub base indicate as 5% (CRR≥5%).From the point of view the CBR value of laboratory test of sub base and subgrade materials are under the specification

5. CONCLUSIONS

After identify the distress and categorized the level of severity sample extracted and conducted laboratory tests. The following conclusions are drawn:-

- The subgrade and the sub base materials are poor graded because of weak compaction, high void and moisture fluctuation. Since this moisture fluctuation can be affected or washed out of the fine ingredient and the materials can't interlock each other.
- NMC greater than OMC because of excess air and water in the sub grade and sub base materials it tends to keep particle apart.
- The sub grade and sub base layers of the studied stretch should not compact well and not achieve at least a relative density of 95%.
- The subgrade and the sub base materials are poor strength or unsuitable for road construction as a result the sub base materials can't carry the base course because low CBR value from the standard specification.
- The measure causes of deterioration can be excess water, poor materials, lack of proper drainage, lack of drainage, lack of routine and timely maintained, seepage and infiltration of water in to pavement layers, poor compaction (poor method of compaction). These can be cause of deteriorations.
- But, The Atterberg's limit tests of the sub-base and subgrade materials were observed in the laboratory satisfy the standard specification.

6. RECOMMENDATION

Based on the above conclusion the following recommendations are drawn:

- The sub base and the subgrade materials should be properly selected properly compacted at least a relative density of 95% of MDD achieved by heavy compaction and adequate shoulder constructed unless too much money invested for maintenance.
- Asphalt surface adequate surface or subsurface drain, run out and protection should be provided. Seal coats shall be applied to prevent infiltration and seepage of water through cracked surfaces to different layers of the pavement.
- The possible recommended remedial measure of edge cracking type deformations are elimination of excess moisture by building shoulder and providing proper drainage with good materials important to enhance both serviceability and structural capacity levels.
- The subgrade and the sub base layers of materials are Poor strength (CBR) this is not suitable for road construction. So, either removed unsuitable materials and replace suitable materials or maintenance and rehabilitation alternative.
- The voids beneath of the pavement should be filled with high soften under sealing asphalt to prevent the intrusion of water in to the subgrade and sub base.
- The problem of the subgrade drainage, the attention must be given to ground water pumping, seepage and water infiltration that needs in depth geochemical investigation.

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