Investigation of Asphalt Pavement Failure Caused by Sub- base and Subgrade Soil Properties along Kemmisse to Dessie Road

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ABSTRACT

The studies of the present work were focused on the failures of the road which connects Kemessie and Dessie towns, Amhara Region of Ethiopia. The main factors for the failures were subgrade soil properties and low quality sub-base. The faulty road regions were identified and the soil samples were collected from different regions. Various testing techniques were applied namely sieve analysis, Atterberg limits, compaction and California bearing ratio. The collected samples falling in AASHTO classification A-2-6 to A-7-6, was tested in the laboratory and found fine contents, ranging from 17.8 to 84.3%, liquid limit of 38.05 to 74.35%, plastic limit of 21.2 to 38%, plasticity index of 16.85 to 49.25%. Furthermore, the samples were tested for Maximum Dry Density and Optimum Moisture Content. The Maximum Dry Density range was found 1.33 to 1.96 Kg/m^3 and the Optimum Moisture Content range was found 12.78 to 28.6%. The California Bearing Ratio was found in the range 3 to 50.6%. Similarly, the sub - base material was tested and found Plasticity Index in the range 6.7- 18.05 and Maximum dry density in the range 1.74- 2.25 kg/m^3. The soaked specimen's California bearing ratio range was 7- 20.71%. The test results disclosed the poor standards and not maintained the standards of the Ethiopian Road Authority. Therefore, the above factors indicate poor road construction. The recommendations made in this study will be useful to the highway engineers for effective maintenance and for better road construction.

Keywords: Atterberg Limit, California Bearing Ratio, Particle Size, Proctor Test, Road Failure.

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1. INTRODUCTION

A pavement section may be generally defined as the structural material placed above a subgrade layer. In asphaltic pavement, it is typically a multi-layered system comprising the subgrade (support), sub-base, base course and surfacing. Its principal function is to receive load from the traffic and transmits it through the layers to the subgrade [17].

The subgrade is the part of the layer of natural soil upon which the pavement or sub-base is built. Subgrade soil provides support to the remainder of the pavement system. The quality of the subgrade will greatly influence the pavement design and the actual useful life of the pavement that is constructed. The importance of a good quality subgrade to the long term life of the pavement cannot be understated. As the pavement reaches design life, the subgrade will not have to be reconstructed in order to support the rehabilitated subgrade or the reconstructed pavement. In urban areas, subgrade basic engineering properties are required for design [14].

Distress is an important factor of pavement design. In the empirical methods each failure criterion should be developed separately to take care of each specific distress. Unfortunately, most of the distresses are caused by the deficiencies in construction, materials and maintenance rather than design. However, knowledge of the various types of distress is important to pavement designers. It can help to identify the causes of the distress. If distress is due to improper design, improvement in the design method can be made. Furthermore, the evaluation of pavement distress is an important part of the pavement management system by which an effective strategy can be developed for maintenance and rehabilitation [3].

Pavement distress is the major problem of the roads and occurred all over Ethiopia. One of those affected roads is the road connecting Kemmise and Dessie. The effect of pavement distress in and around these segments results in different structural failures, especially in the road structure. However; nothing has been done so far with regard to failures on the Kemmise to Dessie road segments. The distress causes mainly edge defects, depressions, corrugated cracks, alligator cracks, longitudinal cracks and large potholes.

The Kemise to Dessie trunk road network has a design life span of 20 years. Nevertheless, the damages of the pavements occurred earlier than the expected life span. Recently, the major problems faced in the road segment from Kemise to Dessie are the lower strength of pavement soil layers and poor performance of natural subgrade. These problems mainly damage the road and the pavement soil materials. Therefore, the lifespan of the road become shorter.

The present study is based on literature review, field observations, and experimental analysis of tests of samples. As part of study, investigations of the causes of pavement distresses, interpretation and evaluation of experimental data will be presented.

2. MATERIALS AND METHODS

2.1 Description of the study area

The study area undertaken was Kemmise to Desssie road section which is located in Amhara region. The length of road segment is 76km. In between Kemissie and Dessie, the road connects Harbu and Kombolcha towns and it pass through different kebeles.

The study area started from Kemissie town (1424 m above sea level) and ended at Dessie town (2470 m above sea level). The study area's altitude range is between 1400 to 2500 m above sea level, on an average. The topography of the road terrain can be classified as flat, rolling and mountainous terrain.

2.2 Details of study design and data collection

The experimental study consisted of two tasks; field work and laboratory tests. The field work includes the observation of the road environment and collection of samples from different locations within the study area. The experiments were focused on investigating the possible causes of pavement distress and the engineering properties of subgrade soil, sub base materials, and capping layer conditions. The samples were tested to measure physical properties of the soil such as materials strength, moisture content, grain size distribution, density, California Bearing Ratio (CBR) and Atterberg limits. In addition, Sieve analysis also has been performed. In this study, samples were collected from the prevalent distressed road segments. Sub-base and subgrade materials were collected from each damaged section of the road based on the layers of pavement materials. The road segment was surveyed and photograph images of the damaged road were taken. The road conditions were visually inspected and different soil samples were collected from damaged areas.

Preliminary visual survey was undertaken along the Kemmise - Dessie road segment. Field observations were performed and representative samples were transported to the laboratory for testing. The samples were tested and the results were compared with different design specifications. The initial site visit was considered on the whole portion of the road. After finishing the initial visual inspection, the conditions of the road failures along the road section were categorized. Based on the failure conditions, suitable locations were selected for the sample collection. As part of the testing, seven distressed locations were identified and samples were collected.

Table 1: Details of the affected road samples and the description of associated problems

Sample Notation	Associated Problem with the sample	Description of the problem
Sample 1	Roughness, accumulation of debris, water pond formation and vehicle's skidding on the pavement	Progressive disintegration of a pavement layer from the damaged surface due to dislodgement of aggregate particles
Sample 2	Moisture infiltration and roughness of the pavement	Transverse cracks perpendicular to the pavement's centerline (thermal cracking)
Sample 3	Pavement Roughness due to patching	Damaged pavement was repaired with the new material
Sample 4	Transversal depression on the pavement	Depressions on pavement due to non-uniform road surface
Sample 5	Distortions on the pavement	Corrugation and Shoving due to heavy traffic at a particular position on the pavement
Sample 6	Occurrence of shear on the pavement and vehicle pulling to the side of the road	Deformation of sides (rut formation) due to rain water accumulation.
Sample 7	Roughness due to bowl shaped voids and moisture infiltration	Pothole depressions occurred due to frequent vehicle passing.

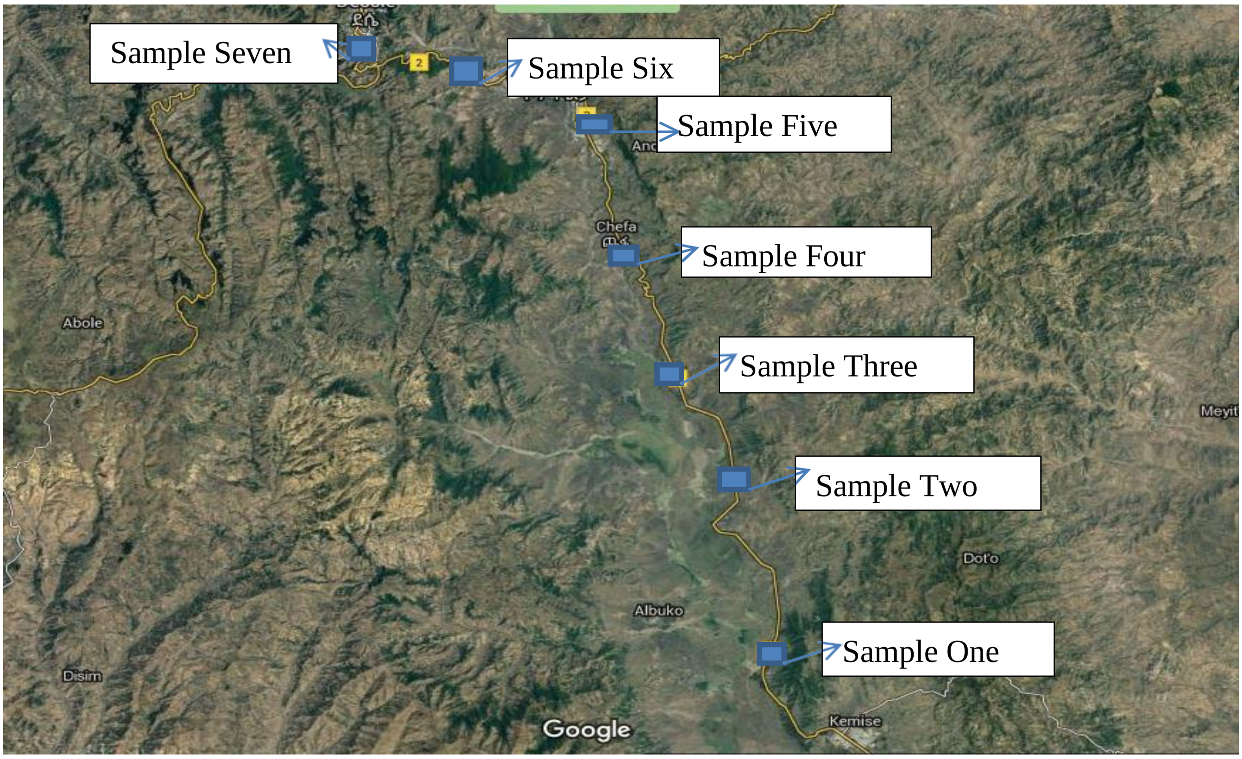

Fig. 1: Google map showing the location of damaged road pavement [20]

Fig. 2(a): Photograph image showing pavement distress of a road segment between Kemissie and Dessie; Fig.2(b): Sample -I collection from pavement dislodgement; Fig.2(c): Sample-II collection from transverse crack; Fig. 2(d): Sample-III collection from patched pavement; Fig. 2(e): Sample-IV collection from non-uniform road surface; Fig. 2(f): Sample-V collection from distorted road surface; Fig. 2(g): Sample-VI collection from sheared road surface; Fig.2(h): Sample-VII collection from potholed pavement.

2.3 Experimental procedures and sample categorization

After collection, soil samples were stored in polythene bags for not to lose moisture content. Before performing the tests, deleterious materials from samples were removed. The samples were air dried, broken down with mortar, pestled and passed through a set of sieve (i.e, from Sieve No. 10 (2.00mm) to Sieve No.200 (0.075mm) to remove large particles. Their properties were studied and determined to check their correlations among various factors proposed in the study.

All collected samples have been taken to the laboratory (Ethiopian Railways Corporation (Yapi Merkezi)) and for making the characterization. The collected samples were categorized based on soil properties. Test results were interpreted for its categorization to determine index properties, strength and maximum dry density of the failed road surface. The failures of the pavement have been identified after the comparison with standard design manuals AASHTO and ASTM. In addition to the experimental investigation of the samples, qualitative analysis was made based on site observation.

Details of the Sieve Analysis: The sieving was done by mechanical method using an automatic shaker and a set of sieves. Later, Sieve Analysis was performed in order to determine the soil particle size distribution as per standards (AASHTO T-11, 27, 88 or ASTM D 422-Method of test for soil Grain Size analysis). The collected samples were washed using BS 200, oven-dried with air and tested.

Details of Atterberg Limit Test: This test as per standards (AASHTO T-89 and T-90 or ASTM D 4318) was used to determine liquid limit, plastic limit and plasticity index, settlement characteristics of the collected samples. For the determination of liquid limit, the soil samples were passed through 425 μm sized sieve. The samples of mass 200 g were mixed with water to form a thick homogeneous paste. The paste was placed inside the grove of the Casangrade's apparatus and the number of blows required to close it were recorded.

For the plastic limit determination, the sample of mass 200 g was collected and passed through a 425μm sized sieve and then mixed with water till it became homogeneous. The homogenous paste from the plastic form turned into the ball shaped structure. Then, the ball shaped structures were allowed to roll on a plain glass plate. It is found that the rolling of the ball breaks the thread of size 3 mm in an oven at the temperature 105 ^{0}C. Thus, the plastic limit was determined.

Details of Proctor Test: This test as per standards (ASTM D 698 for standard effort and ASTM D 1557) was used to test for compaction of natural, sub-base and subgrade soil particles based on AASHTO T-180 standard. The compaction test (in terms of dry weight) is necessary to determine the bearing capacity, slope stability and to evaluate undesirable volume changes and curb undesirable settlement of structures. A mold was prepared from the sample in five layers and then was rammed by a 4.5 kg rammer.

Details of CBR Test: This test as per standard (AASHTO T-193) was used to evaluate the mechanical strength of a fill material, sub-grade and sub-base soil material. A certain amount of the sample was air-dried and mixed with suitable vapors of water. The mixture was put in the mold of CBR with five layers. Each layer was pressed at 56 blows with a 4.5 kg hammer. The compacted soil was weighed and placed under a CBR machine under the seating load. Load was recorded at various penetrations: 0.625, 1.25, 1.875, 2.54, 3.75, 5.08, 7.5, 10 and 12.5 mm.

3. RESULTS AND DISCUSSIONS

Soil subgrade and aggregate are the most important constituents of highway or pavement structure. Subgrades can be natural or stabilized on which all the other layers rest upon. Hence, the overall performance of pavement layers as a whole mainly depends on the strength of the sub-grade.

In this study, British standard, AASHTO standard method and ASTM standard tests were used for the experimental analysis. The causes of deterioration and the selection of appropriate remedial treatments needs confirmatory testing. When a road is failing, it is perhaps, quite natural to want to concentrate investigations on the failed areas. However, this is not always the best option, especially if structural failures such as cracks, ruts, potholes are occurring.

When water sinks into the failed road structures, then the properties of the pavement materials shall change considerably and this leads to trouble for identifying the main cause of the failure. The occurrences of such affected sites were shown in Figure 2. In the laboratory necessary tests were conducted to determine the right choice for subgrade, sub-base and fill materials using British, AASHTO and ASTM standards.

Table 2: Summary of test results for particle size distribution, Atterberg limits, maximum dry density, optimum moisture content and california bearing Ratio

Soil sample	Pavement layers	Particle size distribution			Atterberg limits			Modified proctor test		Soaked CBR (%)	
		Gravel (%)	Sand (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	MDD (Kg/m³)	OMC (%)	2.5 mm	5.08 mm
1	Sub-base	60.8	20.3	18.9	47.3	29.25	18.05	1.696	20.69	5.9	7.0
	Selected fill	58.3	18.9	22.8	48.95	28.45	20.5	1.787	20.33	17.4	22.3
	Natural subgrade	47.2	35	17.8	47.4	29.05	18.35	1.664	22.03	26.9	31.7
2	Sub-base	63.5	17.7	18.8	44.96	27.15	17.81	1.766	20.69	18.3	19.4
	Natural subgrade	10.4	5.3	84.3	71.05	38	33.05	1.326	28.6	3.3	3.3
3	Sub-base	78.3	12.8	8.9	34.84	25.55	9.29	2.085	10.7	47.7	60.2
	Selected fill	66.6	15.4	18	47.08	29.55	17.53	1.826	17.6	15.1	14.3
	Natural subgrade	55.5	17.4	27.1	41.09	22.9	18.19	1.72	18.88	16.5	22.1
4	Sub-base	66.8	20.2	13	40.89	30.45	10.44	1.761	18.09	25.1	26.4
	Selected fill	73.9	14.2	11.9	38.9	24.75	14.15	1.651	15.96	15.5	21.3
	Natural subgrade	13.4	5.77	80.8	74.35	25.1	49.25	1.428	24.06	3	2.5
5	Sub-base	55.4	29.7	14.9	32.3	21	11.3	1.74	9.9	15.1	17.02
	Selected fill	68.9	17.28	13.82	37.2	26	11.2	2.01	12.1	62	61
	Natural subgrade	31.1	48.6	20.3	38.05	21.2	16.85	1.96	12.78	48.82	50.58
6	Sub-base	64.82	22.97	12.21	23.6	16.9	6.7	2.25	8.5	53.4	55.8
	Selected fill	46.8	37.2	16	39.3	26	13.4	1.67	11.92	11.6	13.9
7	Sub-base	51.59	31.74	16.67	33.9	22	11.9	1.992	12.9	44	55
	Selected fill	63.15	20.25	16.6	27.6	15.8	11.8	2.16	9.4	39.19	53.2
	Natural subgrade	5.6	11.83	82.57	59.3	25.2	34.1	1.47	19.84	4.21	3.97

The tests carried out on each of the selected samples were particle size distribution, Atterberg Limits / Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI), Compaction/Optimum Moisture Content (OMC), Maximum Dry Density (MDD) and California Bearing Ratio (CBR). The results were compared with General Specification for roads and bridges [10], American Association of State Highway and Transportation Officials [2] respectively. These factors were determined in the laboratory and were tabulated in Table 2.

3.1 Sieve analysis (AASHTO T-11, 27, 88 or ASTM D 422)

The particle sizes for the samples of sub-base and selected fill are represented in Figure 3 and Figure 4 respectively. The results revealed that the clay content for sub-base samples ranged from 8.9% to 18.9%, whereas for fill samples it was from 11.9 % to 22.8 %. According to the Federal Ministry of Works and Housing (FMWH) specification [10], the clay content for samples should not exceed 35%. The nature of high clay content in the samples is the main reason for the instability of road pavement [10].These results indicate that both sub-base and fill materials in the study area are satisfying the FMWH specifications.

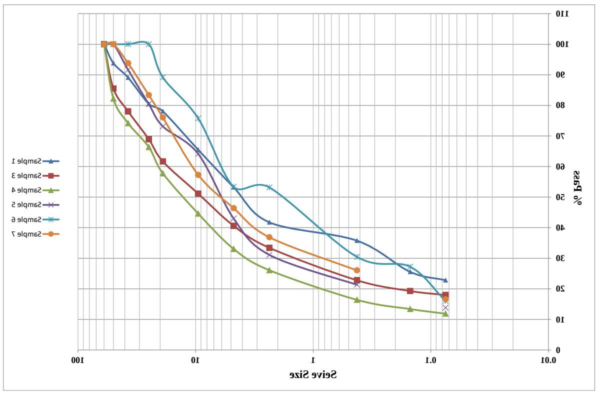

Fig.3 Graphical representation of sieve analysis for sub-base soil samples in the road segment joining Kemessie and Dessie

The particle size for the samples of subgrade materials are represented in Figure 5.The results revealed that the clay content for natural sub grade samples (sample no. 2, 4, 6 and 7) were ranged from 80.8 % to 84.3 % and were found beyond the FMWH range. Whereas, for the other samples (sample no.1,3 and 5) they were found in the range 17.8 % to 27.1 % and satisfy the FMWH range. Therefore, sample no. 2, 4, 6 and 7 are not suitable for the construction of embankments.

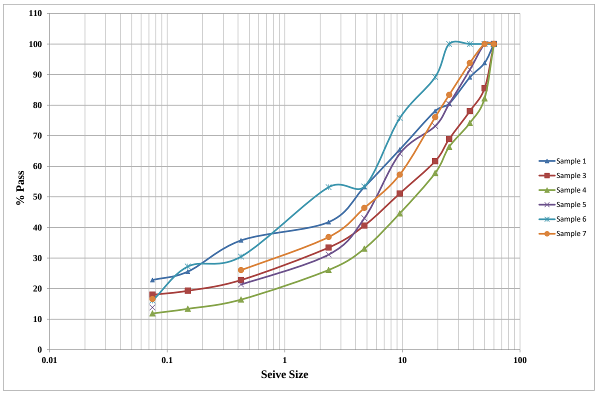

Fig.4 Graphical Representation of Sieve Analysis for selected fill material in the road segment joining Kemessie and Dessie

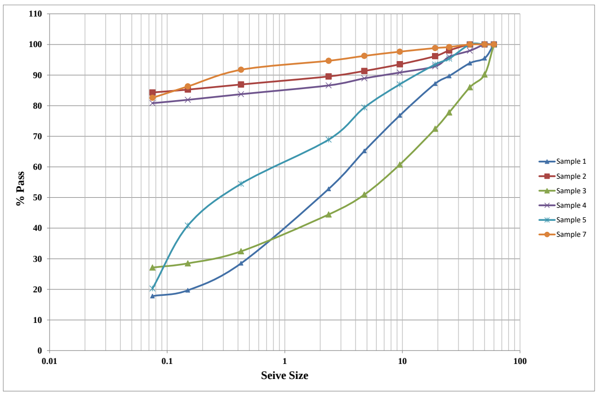

Fig.5 Graphical representation of sieve analysis for Subgrade material in the road segment joining Kemessie and Dessie

3.2 Atterberg limits (AASHTO T-89 and T -90 / ASTM D4318)

Figure 6, Figure 7 and Figure 8 illustrate LL test results for all samples in the study area. According to FMWH the maximum permissible limits for sub-base and fill materials are LL 30%. From Fig 6, it is found that LL of sub-base soils ranged from 23.6% to 47.3%. As per these results except sample no.6, the remaining are not suitable as they are deviating from the standards.

According to FMWH the maximum permissible limits for sub-base and fill materials are PL 30% and PI 13%

respectively. From the laboratory test result the PL ranged from 16.9% to 30.45% and the PI ranged from 6.7 to 18.05. According to Ethiopian Road Authority (ERA) specifications, the PI for the proposed rehabilitation project between Addis Ababa and Dessie for the sub-base materials should not exceed 15 and for fill material it is 25.Whereas, for the subgrade soil, its limit is 30. In this study, it is found that all samples met the requirement except sample no. 1 and 2.

From Fig 6, it is found that LL for fill material is ranged from 27.6% to 48.95%. As per these results except sample no.7, the remaining was not meeting the required standards.

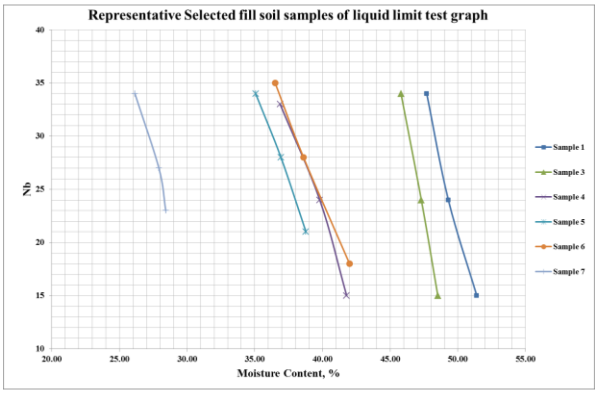

Fig.6 Graphical representation of liquid limit for selected fill material in the road segment joining Kemessie and Dessie

In the case of sub grade materials, sample no. 2, 4 and 7 do not meet the requirements of ERA. From the Fig 8, subgrade materials having LL less than 30% are considered low compressibility and plasticity. And, for the LL range from 30% to 50%, they are considered medium compressibility and plasticity. Whereas, for the LL more than 50%, the sample is considered high compressibility and plasticity [9]. From the graphical representation shown in Fig 7, sample no. 1, 3 and 5 lie in the medium range and sample no. 2, 4 and 7 lie in the high range of the chart.

As per AASHTO the soil samples no.1, 3 and 2 are considered to be good soil for the construction of highway. Since, not more than 3 % was through sieve no. 200. But, sample no. 4 to 7 are considered not appropriate (poor to fair), since the percentage pass was greater than 35% through sieve no. 200.

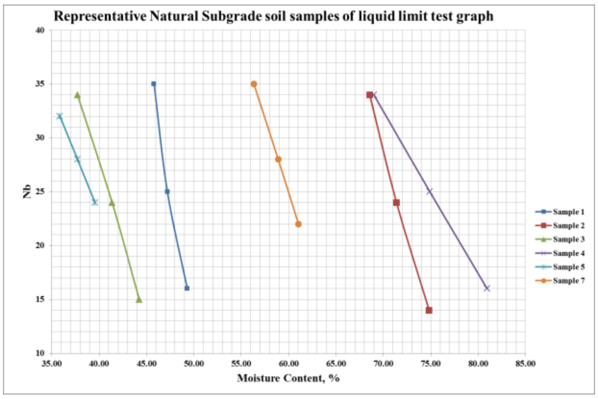

Fig.7 Graphical representation of liquid limit for subgrade material in the road segment joining Kemessie and Dessie

3.3 Maximum density and optimum moisture content(ASTM D 698 or ASTM D 1557)

According to FMWH specifications, samples of sub-base, fill and subgrade materials shall have OMC less than 18%.In the test, it was found that sub base materials with density 1.74 and 2.25 kg/m3 have OMC range 8.5% to 20.71%. From Figure 8, sample no. 1 and 2 of subbase material were not suitable, whereas sample no. 4 is the best due to minimal soil modification.

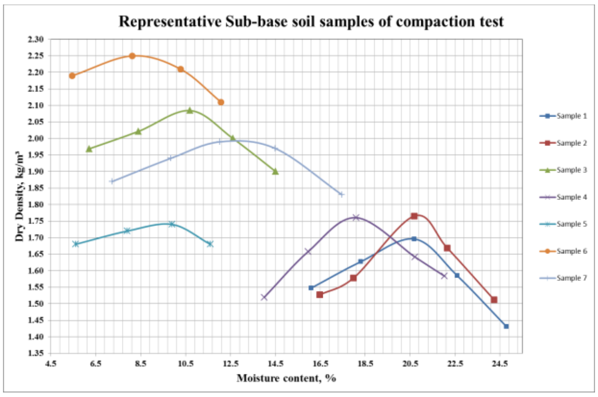

Fig.8 Graphical representation for Compaction test for sub-base material in the road segment joining Kemessie and Dessie

And for fill materials, Figure 9 illustrates that the MDD varied from 1.65 to 2.16 kg/m³ and OMC from 9.4 % to 20.33 %. Therefore, as per standards sample no. 1 was found not to be the best fill material.

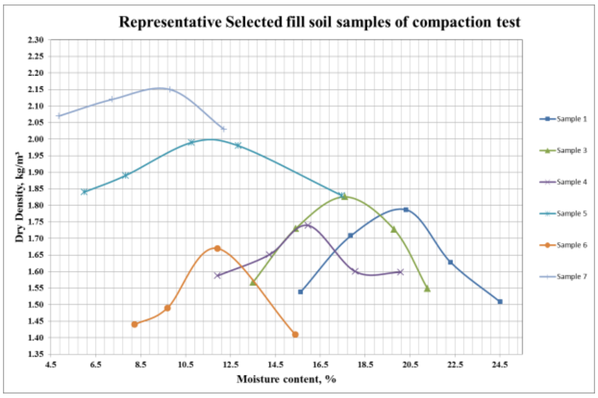

Fig. 9 Graphical representation for compaction test for selected fill material in the road segment joining Kemessie and Dessie

In the case of subgrade samples, the MDD ranged from 1.33 kg/m³ and 1.96 kg/m³ and OMC ranged from 12.78 % to 28.6%. These were shown in Figure 10. In line with FMWH specifications, sample no.1,2,4 and 7 are not the best subgrade soil materials. The natural sub-grade material sample no.3 was found to be minimal soil modification and therefore will be the best choice.

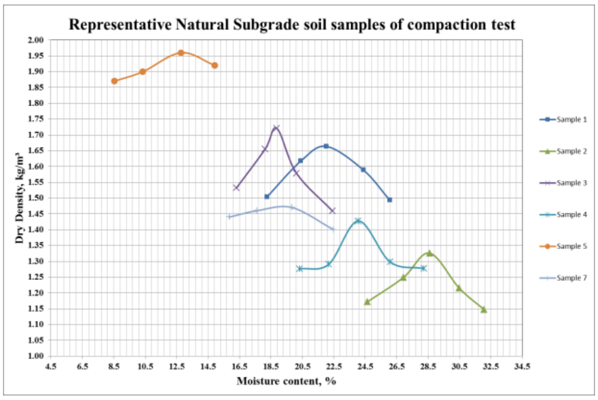

Fig.10: Graphical representation for compaction test for natural subgrade material in the road segment joining Kemessie and Dessie

3.4 California bearing ratio (ASSHTO T-193)

According to ERA, for the rehabilitation project from Addis Ababa to Dessie, the CBR should be greater than or equal to 30% for sub-base materials, greater than or equal to 15 % for fill materials and greater than or equal to 5 % for subgrade materials. To find CBR all samples are soaked for four days.

In the test, the sun-base samples resulted in the CBR in the range from 7 % to 60.2 %. Figure 11 illustrates that sub-base sample no. 1, 2, 4 and 5 are not suitable sub-base materials.

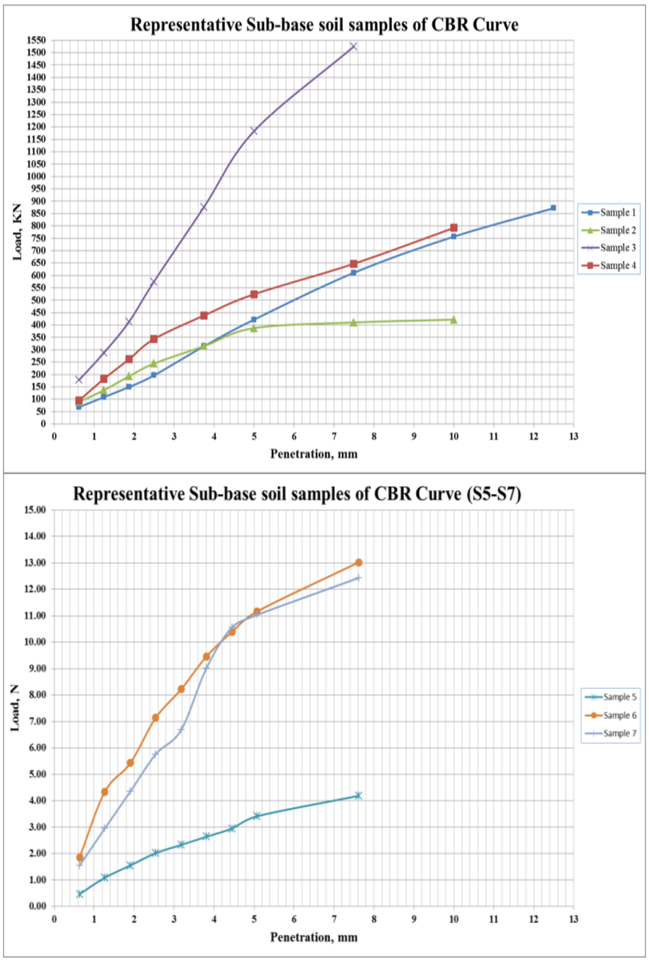

Fig.11: Graphical representation for california bearing ratio for sub-base sample in the road segment joining Kemessie and Dessie

In the case of fill soil materials CBR ranged from 11.6 % to 62 %. Figure 12 shows that the sample no. Based on these specifications, selected fill soil sample 6 are not suitable as selected fill material.

After the test, the CBR range for subgrade materials was found from 3 % to 48.82 %. Figure 13 shows that the sample no. 2, 4 and 7 are not suitable natural subgrade samples.

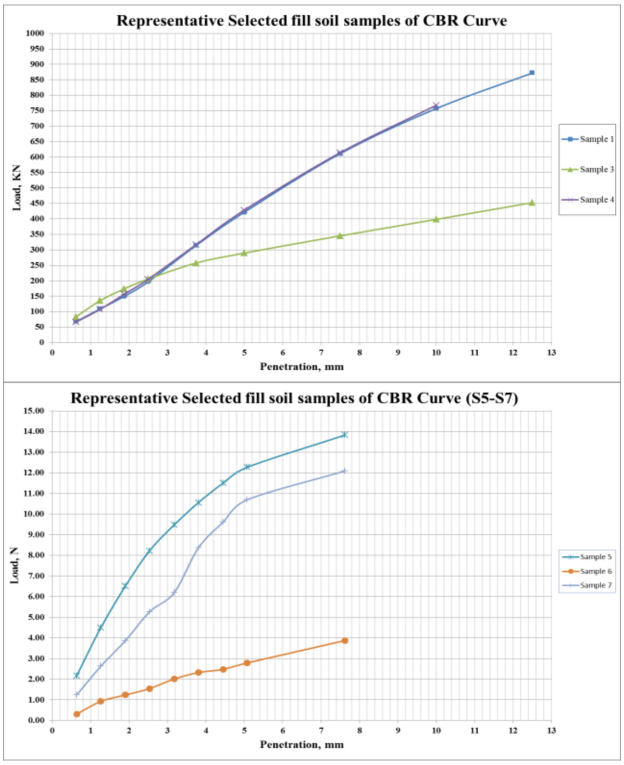

Fig. 12: Graphical representation for california bearing ratio for selected fill sample in the road segment joining Kemessie and Dessie

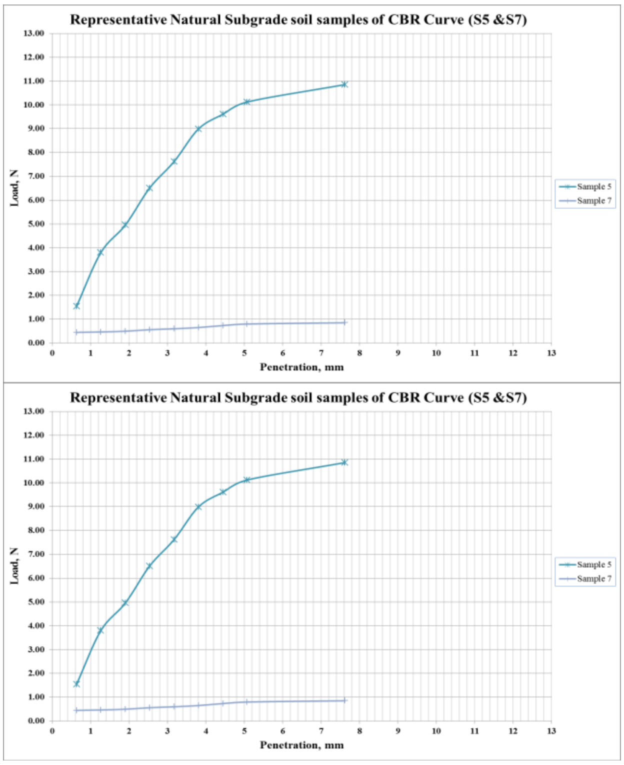

Fig.13: Graphical representation for california bearing ratio for natural subgrade sample in the road segment joining Kemessie and Dessie

4. CONCLUSION

Samples sub-base, fill and natural subgrade materials were tested for sieve analysis for grain size distribution, Atterberg limit for PI, Compaction test for finding MDD and OMC, and CBR test for knowing the strength and stability. Based on study it is concluded the following: CBR range of natural subgrade soil sample from 3%-50.58%.Sub-base samples have less clay content and their PI ranges from 6.7- 18.05, MDD from 1.74kg/m³-2.25 kg/m³ and CBR from 7%- 20.71%.Fill samples have clay content from 11.9%- 22.8%, PI from 11.2-20.5 and CBR from 13.9%- 62%.Low percentages of clayey and silt/gravel /sand contents in sub-base samples and fill samples. But, the high clayey content in the natural subgrade sample found nearly half. OMC satisfies the standard limits in almost all samples. PI and LL are high for almost all samples. The range of CBR is satisfactory for fill samples. It does meet on many samples collected from sub-base and natural subgrade materials. Overall, the sub-base sample no. 1,2,4,5 and 7 and fill sample no.6 were found to be poor samples. Similarly natural subgrade sample no.2, 4 and 7 also observed poorly.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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