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Assess the Impacts of Environmental Factors (Temperature and Moisture) on the Performance of Flexible Pavement: A Case of Tarcha-OMO River Highway

Kebede Haile Folla[1], Gutema Wakjira Gemeda[1], Garuma Negasa Takuma[2]

[1]Highway Engineering, Civil and Environmental Engineering, Jimma University, Jimma, Ethiopia

[2]Water Resources and Hydraulic Engineering, Engineering and Technology, Wollega University, Nekemte, Ethiopia

Email address:

kebetewabech@gmail.com (Kebede Haile Folla), gute88wakjira@gmail.com (Gutema Wakjira Gemeda), garuma3negasa@gmail.com (Garuma Negasa Takuma)

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Abstract: The structural behavior of pavements can be affected by seasonal variation in environmental factors such as temperature and moisture content. In Ethiopia the design, construction and maintenance process of roads mostly give attention to structural thickness of pavement layers, on which the designers and authoring focus on expected future traffic. However, it is critical to admit in practical the variation of pavement material properties due to seasonal environmental changes, especially the temperature and moisture. This study focused on assessment of the impacts of environmental factors (temperature and moisture) on performance of flexible pavement in generally and particularly on Tarcha-Omo River highway, hence doing this study, the objectives were: to investigate the impact of temperature on the performance of selected highway, analyze the impact of moisture on the performance of pavement through laboratory based investigation and to examine the efficiency of the drainage system in removing excess water from the pavement structure of selected highway by collecting all primary data from the project site and secondary from, standard specification, Ethiopian roads authority, Omo River-Tarcha road upgrading project. An assessment was done by using both field observation and laboratory tests to characterize materials toward the factors. The field observation was made to investigate the condition of drainage system in removing water from pavement and surrounding. The sample of base course, sub base and sub grade were collected from three different sampling stations and laboratory tests were conducted and finally compared with standards to check the moisture sensitivity of materials. NMC, Compaction, Particle size distribution, CBR and Atterberg's Limit were tests conducted.. The assessment showed that temperature and moisture has considerable impact on performance of flexible pavement and the pavement failed due to moisture variation on pavement base, sub base and subgrade, due to, inadequate drainage facility, lack of effective protection work and excessive water in the sub grade in first section and temperature in second section of study. Therefore Standard of construction and design should be improved. More research should be carried out on the engineering geo-techniques of study road.

Keywords: Environmental Effect, Flexible Pavement, Moisture Variation, Temperature

1. Introduction

1.1. Background

The road network is an important element of the national infrastructure and its construction, operation, and maintenance constitute a large part of the national annual budget. The road network in Ethiopia provides the dominant mode of freight and passenger transport and thus plays a vital role in the economy of the country. The network comprises a huge national asset that requires adherence to appropriate standards for design, construction and maintenance in order to provide a high level of service. As the length of the road network is increasing, appropriate choice of methods to preserve this investment becomes increasingly important [4].

"According to [7, 10, 12, 14], seasonal variations are difficult problem in the design of pavement structures particularly in flexible pavement". Generally speaking, there are two sources of climatic variations that reduce the life of the pavement structure: the soil moisture and the ambient temperature. The former causes a reduction in the subgrade strength, whereas the latter results in a decrease in the asphalt-layer stiffness and associated strength. The combination of both clearly affects the overall pavement deterioration, and this has economic impacts including both maintenance and rehabilitation costs along with user costs.

Environmental changes have a direct impact on the structural capacity of the pavement, and consequently its performance. While the subgrade soil and the unbound materials are sensitive to moisture variation, the Asphalt Concrete (AC) layers are more sensitive to temperature variations. Quantifying the effect of these two environmental factors, moisture and temperature, is necessary for incorporation in the pavement design process [5].

"According to [3, 7, 15, 18] Temperature of the asphalt concrete (AC) and water content in the base layer and the subgrade are the most critical factors that influence flexible pavement performance". A change in the pavement temperature directly affects the stiffness of the asphalt-bound layers, which alters the stress state throughout the pavement. This change in stress state can, in turn, affect the stiffness of the underlying unbound layers since they usually exhibit stress dependence. The structural capacity of the entire pavement system is thus affected by changes in pavement temperature. Likewise, moisture induced change in the base and subgrade may cause increased strains in the AC layer [19] Mechanistic-empirical pavement design methods for flexible pavements are based on the assumption that the pavement life is inversely proportional to the magnitude of the traffic-induced pavement strains. These strains vary with the stiffness of the asphalt layer and underlying base layer and subgrade. The stiffness of the asphalt layer varies with temperature and the stiffness of the unbound base layer and subgrade varies with water content. Because these relationships are nonlinear, the additional pavement life consumed at higher than-average temperatures or water contents is not offset by savings at lower than-average temperatures or water contents. Since the variation in temperature and water content can take place at different times, the effects cannot simply be considered separately and the results superimposed [11] and it also suggested that the combined effects of temperature and water content variations should be accounted for in the estimation of pavement life, particularly in moderate to warm climates where. Hence, environmental factors are the major constraints in the pavement life after it has been constructed. These factors mostly determine the service life of the road pavement structure constructed. The purpose of this study is to evaluate the impact of environmental factors on the performance of pavement structure through field observation and laboratory tests, to come with recommendations for the problems.

1.2. Objective of the Study

The main objective of this study is to assess the impact of environmental factors (Temperature and moisture) on performance of pavement structures.

Figure 1. *Location map of the selected highway.*

2. Research Methodology

2.1. Study Area Description

The selected highway segment Tarcha–Omo River is section of link road described in Ethio road map as B52 that connects Dawuro zone with its neighboring zones and regions. This road has been upgraded to asphalt few years and some kilometers are up today under construction. The road is found in south Nations Nationalities and Peoples Regional state Dawuro zone. It has economic value in integrating Dawuro Zone with neighbor Zones, Regional offices and also with central government. It is the back bone in integrating south east Zones with Dawuro zone for trade and other economic activities. Dawuro Zone is located in 7°00'00"N latitude and 37°09'60" E. The length of highway segment selected for this study was 50 km from Tarcha Town - Omo River. The study was conducted in section of selected highway section that crosses Loma and Mareka districts in Dawuro Zone of Southern Nations, nationalities and Peoples Regional State (SNNPRS) Ethiopia. Figure 1 shows the location of selected highway for study. The section of study section lies between 6°54'29.96" to 6°55'16.78" N and 37°13'49.11" to 37°14'18.05" E. The study area was sectioned in to two. The first section is from Tarcha Town to Yalo Municipality and the second section extends from Yalo municipality to Gibe-III (Halala Kela). The section of study area lies between 2286 and 2565 msl a total annual rainfall range from 1355.40 to 2565.50 mm with mean monthly temperature varying from 11.7 to 23.5°C for the first study section and 21.56 to 33.12°C for the second. The location of the study is shown in figure 1.

Figure 2. *Site observation (photo: by Kebede Haile, 21th May, 2021).*

Figure 3. *Sample extraction and preparation (photo: by Mengistu Bayu, 11th Jun, 2021).*

2.2. Data Collection

The data were collected from primary and secondary sources. The primary data was collected through field visit on the selected highway segment in order to identify the deteriorated places and condition of drainage system; Road condition survey has carried out to determine the present state and condition of the selected study road sections. All the primary data were collected from the area having different weather conditions through the route of the road. while the secondary data collected were, standards used during the construction of the road, weather records from metrology agency and the design of the road previously used for the construction of the road. Both field observation and laboratory works for extracted sample were used before analysis. Some part of data collection is shown in figure 2 and figure 3.

2.3. Methods of Data Processing and Analysis

Data processing has conducted through different laboratory tests to determine the variation in stiffness due to the environmental factors in order to compare with the material property during construction and also adequacy of underlain material to serve as;

1) Subgrade;
2) Sub base and
3) Base course material based on project specification and Ethiopian Roads Authority (ERA) standard specifications.

The laboratory tests on representative samples extracted from the site were conducted to characterize materials in relation with environmental factors to compare the test results with the standard specification and the material property during construction as well as with the existing condition of the pavement. Mean time laboratory test was conducted to determine the Mr values of the materials of representative sample. Hence the Mr value has high relation with the environmental factor (moisture).

After collection of all core information through site observation and laboratory the results are analyzed by using excel spread sheet and Microsoft word in the forms of table, graphs and equations. The laboratory tests conducted were Natural Moisture content (NMC), Atterberg limit, proctor, gradation and CBR. NMC is conducted to determine the Natural water content of the material through which the amount of water for the CBR is determined. Liquid limit and plastic limit were conducted to determine the index properties of sampled materials from each station. That is, important to determine the moisture sensitivity of materials. The modified proctor test which is used in the laboratory to show the relationship of moisture content and density of materials (compacted mass of materials in a unit volume through a range of moisture contents) was conducted for each sample from different stations. The gradation test was conducted to determine the degree of inhabitance of different size of materials. Samples collected from deteriorated place the CBR tests were carried out and comparisons were made between the CBR value of existing document and current CBR values. CBR values changed to resilient modulus by using Equation (1) and (2) used as empirical formula.

$$Mr(Mpa) = 1.7(CBR)^{1.2} \quad (1)$$

For base course and sub base granular materials.

$$Mr(Mpa) = 10.342(CBR) \quad (2)$$

for Sub grade soil.

The data collected from repetitive observation, and secondary document analysis was analyzed to meet the specific objectives. Statistical Microsoft Excel 2007 software was employed to analyze the data. The analyzed data were presented using tables, graphs and charts. Using laboratory results the engineering properties of soil materials were determined as per specifications, and then classified as AASHTO Classifications. Defects on the pavement due to environmental factors were analyzed from the results measured in the field and careful observation taken at different section of the road section during different time. The side drainage effectiveness in removing excess water from the road was analyzed from visual observation. Based on field observation made, the adequacy of the drainage was analyzed.

2.4. Laboratory Tests

To determine the engineering properties of materials and the relation of results with environmental factors, base course, sub base and sub grade were sampled from three representative stations and different tests have conducted. The basic test such as sieve analysis, Atterberg limit, natural moisture content, compaction, Atterberg limit, and CBR of materials are investigated separately to know the properties of materials as per the relevant code of standard and examine the result in relation with environmental factor (moisture).

2.4.1. Compaction Test (Method: AASHTO -180)

This test is to obtain relationship between compacted dry density and soil moisture content, using manual compaction effect. The test is used to provide a guide for specification on field compaction. A modified version of the test was developed to allow the application of greater compaction effort (and achieve greater density), compacting the soil of the same height in five approximately equal layers using a 4.5kg hammer falling through 457mm height (modified or heavy compaction test). Material or soil compaction tests were performed using disturbed soil sample. The tests were done in the laboratory according to AASHTO T-180 (Modified Proctor Test) is used for base course, sub-base and subgrade materials. The sample was first air dried and sieved (usually through the 4.75-mm (No.4) sieve or 19 mm sieve), mixed thoroughly with water and then compacted in 5 layers. The mass of the compacted sample is measured (W), and a small sample taken to measure the corresponding moisture content (w). More water ware then added to the soil, and the procedure repeated until the dry density obtained decreases. The experiment was conducted to examine the moisture sensitivity of materials due to variation in moisture content because of environmental factor (moisture) in addition to obtaining compacted dry density and moisture content relation to achieve the maximum dry density at which the materials gains its high strength at certain compaction efforts.

At Natural moisture content higher than the OMC, the air and water in the soil mass tend to keep particles apart and prevent compaction. The dry density at higher moisture contents than OMC, decreases and the total voids decrease. The density moisture relationship is shown in figure 4.

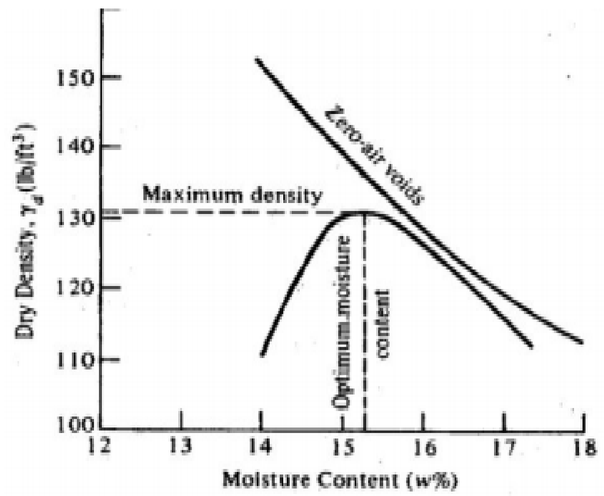

Figure 4. *Density moisture relationships.*

2.4.2. California Bearing Ratio Test (CBR)

The strength of subgrade, sub-base and base course materials are expressed in terms of their California bearing ratio (CBR) values. The CBR value is a requirement is design for pavement materials of natural gravel or crushed rock the purpose of pavement construction. The CBR is a measure of shearing resistance of the material under controlled density and moisture conditions the test consists of causing a cylindrical plunger of 50 mm diameter to penetrate pavement component materials at 1.25 mm/minute. The Loads for 2.54 mm and 5.08 mm are recorded. This load is express as percentage of standard load value at respective deformation level to obtain CBR value. The test procedure is based on, American society for testing and materials, AASHTO T193. The CBR Value for a pavement material depends upon its density, molding moisture content and moisture content after soaking. The points CBR was conducted for base course, sub base and subgrade soil in the laboratory and design CBR value considered at 95% of MDD. The California bearing ratio (CBR) was used to evaluating the suitability of materials used base course, sub base and subgrade layers. Three point CBR test is made for all of the samples of different layers base course, sub-base and subgrade materials. Materials strength is classified according to the CBR values which determine the suitability of each type of materials for its respective layer with attention to environmental factors. The 4 days (96hr) soaked CBR tests were performed on the material samples to determine the sampled material shear strengths and predict the Mr values which determines the stiffness of material. The CBR number is obtained as the ratio of the unit load (in KN/m^2) required to effect a certain depth of penetration of the penetration piston in to a compacted specimen of material at some water content and density to the standard unit load. The results from the laboratory tests combined with the relevant pavement condition survey provide an evaluation of pavement performance in relation to environmental factors. Hence the Value of Mr is estimated from the calculation by using the formula described in equation (1) and (2) for base course and subgrade soil respectively.

And the amount of water to be added for CBR in order to get the maximum shear strength is given in Equation (3)

$$\text{Water to be Added} = \frac{\text{OMC}-\text{NMC}}{\text{NMC}+100} * 6000 \quad (3)$$

2.4.3. Determining the Temperature of AC Layer

It has been widely accepted that temperature mainly impacts the asphalt layer, where increase in temperature can reduce the stiffness of asphalt materials, which in turn limit the stress strain response of the pavement and reduce the ability of pavement structures to distribute loads from moving traffic [2]. The common empirical formula developed by AASHTO (1993) which was described in Equation (4) was used to determine the Modulus of asphalt layer with respective to representative temperature value. The values determined by using formula

$$\text{E1(t)} = 15000 - 7900 \times \log(t) \quad (4)$$

3. Results and Discussion

3.1. Impact of Temperature on the Performance of Pavement Structures of Selected Highway Segment

A relationship between temperature and the elastic modulus of the asphalt mixtures of the motorways calculated using Equation (2), after determination of asphalt temperature by using Equation (1) and the results of the respective modulus of resilient of asphalt with its respective temperature in accordance to variation in temperature with in season for sections has illustrated in Tables 1 and 2. It was observed that along the selected highway segment (50 km) there is different temperature from place to place. The maximum temperature ranges for first section of road is 20.76 to 23.46°C. The temperature near to Omo River (Gibe–III Dam), second section is 21.56 to 33.12°C and decrease approach to Waka town. And from the result it shows that, the less temperature in the first section, the highest is the modulus of elasticity of the asphalt and the higher is temperature in the second section, the less is modulus of elasticity of asphalt layer. This implies temperature has impact on AC layer of flexible pavement, which can also affect the stress resistance of beneath layers. Tables 1 and 2 shows the elastic modulus of AC with respective asphalt temperature for section one and section two respectively.

Table 1. *Elastic modulus of AC with respective asphalt temperature for section one.*

Month	Minimum Temperature (°C)	Maximum temperature (°C)	Monthly rainfall (mm)	T_{asp} (°C)	E (MPa)
January	12.49	22.94	45.12	12.04	6.46
February	12.84	23.46	59.69	12.48	6.34
March	12.54	23.01	137.61	12.10	6.44
April	12.41	22.58	177.27	11.94	6.50
May	12.19	21.94	198.44	11.67	6.57
June	12.23	21.37	184.18	11.72	6.56
July	11.76	20.76	237.48	11.13	6.73
August	11.74	21.12	256.96	11.10	6.74
September	11.83	20.91	177.01	11.22	6.51
October	12.07	21.76	116.52	11.52	6.62
November	12.26	22.32	76.22	11.76	6.55
December	12.29	22.54	53.08	11.80	6.54

Table 2. *Elastic modulus of AC with respective asphalt temperature for section two.*

Month	Minimum Temperature (°C)	Maximum temperature (°C)	Monthly rainfall (mm)	T_{asp} (°C)	E (MPa)
January	17.56	33.00	0.00	37.68	2.55
February	16.88	32.07	0.00	36.52	2.66
March	21.00	33.12	32.00	37.83	2.54
April	19.56	31.00	53.56	35.18	2.78
May	18.21	29.45	89.11	33.24	3.00
June	18.06	27.00	91.33	30.18	3.32
July	17.89	27.11	98.53	30.32	3.30
August	13.13	21.56	133.32	23.38	4.20
September	13.89	23.43	101.76	25.72	3.86
October	14.11	25.00	77.89	27.68	3.61
November	14.76	25.87	0.00	28.77	3.50
December	19.41	31.89	0.00	36.30	2.68

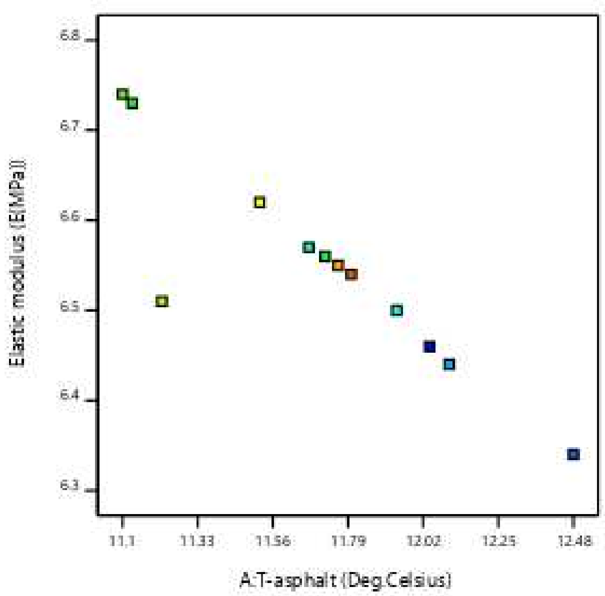

Figure 5. *Moduli versus temperature for section one (design expert software output).*

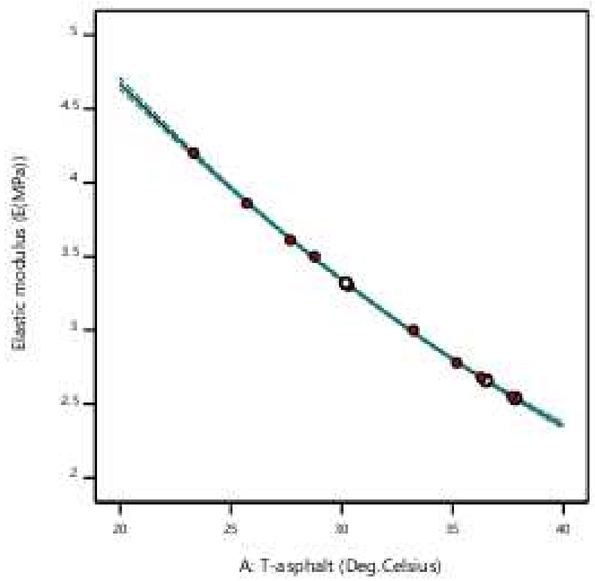

Figure 6. *Moduli versus temperature for section Two (design expert software output).*

From the results described on Figures 5 and 6, at low temperatures the elastic modulus values increase and at high temperatures the elastic modulus values decrease. This finding is consistent with the rheological properties and viscosity, whereby the asphalt mixture is easily influenced by changes in temperature. Figures 5 and 6 shows the relationship between the pavement temperature and elastic modulus (E) for both sections.

Based on the empirical equation of AASHTO (1993), and the relation conducted by using design Expert, Figures 5 and 6, both parameters show a good agreement, where R^2 is 0.9999 for second section and 0.9995 for the first one, equal to one (ideal conditions). At low temperatures the elastic modulus values increase and at high temperatures the elastic modulus values decrease. This implies that change in the pavement temperature directly affects the stiffness of the asphalt-bound layers, which alters the stress state throughout the pavement. This change in stress state can, in turn, affect the stiffness of the underlying unbound layers since they usually exhibit stress dependence.

3.2. Impacts of Moisture Variation on Performance of Pavement

3.2.1. Natural Moisture Content (NMC)

For the samples collected from three representative stations NMC was determined. This NMC value determines the amount of water to be added to determine the CBR Value at which the material can attain its strength. It also indicates that during the time of field compaction, how much water could be showered or ripped to release its moisture in order to attain its maximum dry density. In a sense the value of NMC should be less than OMC.

The NMC and corresponding amount of water to be added and comparison of existing OMC and NMC for three samples are summarized in Table 3. The NMC is greater than OMC, this resulted with the amount of water to add for Compaction in order to get the maximum dry density as well as the strength of material that is expressed in terms of CBR Value is not needed or in small amount. This implies that the amount of moisture in the area is high and due to the entrance of water to the pavement structure, and the source of this water could be, high rainfall in the area, infiltration from the surrounding s through poor side ditch construction, poor disposal of ground water near the pavement structure and lack of treatment.

The percentage of distress on the selected highway segment within 50 km are analyzed and summarized in Figure 7. It implies in such climatic areas, the contractor, during construction and maintenance time, shall consider the condition of compaction under which the OMC that results with maximum dry density, the amount of water because the area is moist and the pavement structure gains its moisture from the natural environment at post construction and also it is essential to provide well designed and paved shoulder, excellent surface and sub-surface drainage system to control the entry of excess water from the surroundings to pavement structure and remove the excess water from pavement structure.

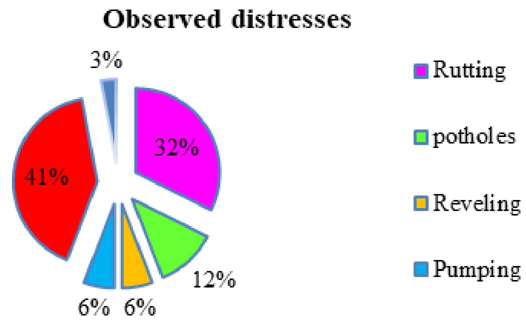

Figure 7. *Observed distresses in percent for selected highway section.*

Table 3. *Comparison b/n existing and calculated NMC and water to be added.*

Station	Material	OMC (%)	NMC (%)	Water to be added (ml)	Existing OMC (%)	Existing NMC (%)
	BC	8.50	13.67	-273.00	10.95	3.39
89+320	SB	18.38	23.50	-248.75	8.20	2.93
	SG	16.13	19.70	-178.95	20.50	5.59
	BC	9.00	5.12	223.00	8.20	2.90
104+540	SB	10.70	17.10	-327.93	14.00	7.60
	SG	12.51	30.06	-809.63	19.75	6.13
	BC	5.83	5.45	21.54	9.33	3.42
124+000	SB	8.40	14.40	-314.68	12.50	4.70
	SG	11.92	18.22	-319.75	21.82	5.34

3.2.2. CBR and Mr

The 4 days (96hr) soaked CBR tests were performed on samples to determine the materials strengths. The CBR number is obtained as the ratio of the unit load (in KN/m^2) required to effect a certain depth of penetration of the penetration piston in to a compacted specimen of material at some water content and density to the standard unit load. Meanwhile the Value of Mr which determines the stiffness of material is estimated from the calculation by using the formula described in Equation 2.1 and 2.2 as per [1] for base course and sub base granular materials and sub grade respectively.

From the result, at OMC, the samples were attained both MDD and CBR respectively. CBR values were increased gradually prior to its maximum level at OMC. Samples with highest NMC above the OMC level showed a dramatic decline of CBR value and resulted with decreased Mr.

The values of OMC, NMC, MDD, and CBR of sampled materials from each station are illustrated in Table 4. The NMC value exception to base course materials from station 104+540 and 124+000, are greater than OMC and could cause decline in CBR values. This implies the increased value of moisture could resulted in declined value of CBR as well as Mr.

Table 4. *OMC, NMC, MDD and CBR of sampled materials (laboratory result for each station where the samples extracted).*

Station	Material	OMC (%)	NMC (%)	MDD (%)	CBR (%)					
					2.00 mm			5.08 mm		
					No of blows			No of blows		
					10	30	65	10	30	65
	BC	8.50	13.67	2.28	47.10	51.90	62.80	46.70	53.90	99.60
89+320	SB	18.38	23.50	1.69	6.40	11.10	16.10	6.40	11.70	13.80
	SG	16.13	19.70	1.82	4.80	9.70	13.00	5.40	10.80	12.90
	BC	9.00	5.12	2.34	34.60	56.60	128.8	39.40	70.50	126.00
104+540	SB	10.9	17.1	2.09	15.90	23.80	22.50	19.10	24.50	23.40
	SG	12.51	30.06	1.71	4.80	6.50	4.90	6.50	6.50	5.40
	BC	5.83	5.45	2.39	36.10	51.90	103.70	37.30	61.20	101.60
124+000	SB	8.4	14.4	2.09	19.10	27.00	41.80	29.00	41.50	59.60
	SG	11.92	18.22	2.04	11.20	13.00	9.70	11.80	12.90	8.60

(a). Base Course

Tables 5, 6 and 7 shows the Californian bearing ratio values and the estimated Mr values of base course collected from three different places and took the average values of each. The sample was collected in range of existing laboratory result from previous result to compare with current test result with the specification under ERA for the project and variation could be due to variation of moisture in the project area. The comparison was taken after determination of resilient modulus from the conducted CBR laboratory result. From the results, the CBR and Mr Values of the materials dramatically decreased. The results show the specimens having high values of NMC than OMC has less value of CBR and Mr. This implies that, as the amount of moisture in base course of material increases the material in response could has decreased value of shear strength and stiffness which is expressed in terms of Mr to resist the load from heavy traffic. Hence the pavement has exposed to distresses described on Figure 7. Therefore approaches could be employed to control or reduce moisture problems are: Prevent moisture from entering the pavement system, use materials that are insensitive to the effects of moisture, incorporate design features to minimize moisture damage, quickly remove moisture that enters the pavement system and use of open graded materials as in order to remove excess moisture from pavement structure. The CBR and Mr values of base course material from sampled station are shown in Tables 5, 6 and 7.

Table 5. *CBR values and the estimated Mr values of base course from station 89+320.*

Station 89+320						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	6.22	9.33	47.10	46.7	46.9	172.13
30	6.84	10.78	51.9	53.9	52.9	198.82
65	8.30	19.91	62.8	99.6	81.2	332.6
Average					60.3	234.52

Table 6. *CBR values and the estimated Mr values of base course from station 104+540.*

Station 104+540						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	4.56	7.88	34.6	39.4	37.0	129.45
30	7.47	14.10	56.6	70.5	63.5	247.81
65	17.01	25.20	128.8	126.0	127.4	571.12
Average					76.0	316.12

Table 7. *CBR values and the estimated Mr values of base course from station 124+000.*

Station 124+000						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	4.77	7.47	36.1	37.3	36.7	128.4
30	6.84	12.24	51.9	61.2	56.5	215.31
65	13.69	20.33	103.7	101.6	102.7	440.71
Average					65.3	261.47

The existing CBR values and predicted Mr Values of the material are given in Tables 8, 9 and 10 respectively.

Table 8. *The existing CBR values and Mr Values of base course, station 89+320.*

Station 89+320						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	7.22	11.61	48.2	46.7	47.45	174.56
30	9.96	19.29	75.4	96.4	85.9	355.83
65	816.59	23.64	125.7	118.2	121.95	541.84
Average					85.1	357.41

Table 9. *The existing CBR values and Mr Values of base course, station 104+540.*

Station 104+540						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	6.33	12.45	39.56	46.7	43.13	155.66
30	8.6	20.42	68.77	96.4	82.56	339.41
65	18.23	26.77	133.56	1244.66	129.11	580.23
Average					84.95	358.44

Table 10. *The existing CBR values and Mr Values of base course, station 124+000.*

Station 124+000						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	5.33	8.12	43.55	45.67	44.61	162.10
30	7.2	13.45	58.76	76.54	67.65	267.16
65	12.66	21.65	111.53	108.21	109.87	478.10
Average					74.05	302.45

Comparing the results and the existing Value shows that, the Mr value of the material could decreased due to the moisture variation.

(b). Sub Base

Tables 11, 12 and 13 shows the Californian bearing ratio values of sub base materials which was collected from three different places. From the laboratory results of CBR and predicted Mr Value of sampled materials and their existing values respectively, the Mr value decreased.

Table 11. *CBR values and the estimated Mr values of Sub base, station 89+320.*

Station 89+320						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	0.85	1.27	6.4	6.4	6.4	15.67
30	1.48	2.33	11.10	11.7	11..4	31.56
65	2.12	2.76	16.10	13.8	14.9	43.64
Average					10.9	30.29

Table 12. *CBR values and the estimated Mr values of sub base, station 104+540.*

Station 104+540						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	2.12	3.82	15.90	19.10	17.50	52.78
30	3.18	4.88	23.80	24.50	24.10	77.60
65	2.97	4.66	22.50	23.40	22.90	73.00
Average					21.50	67.80

Table 13. *CBR values and the estimated Mr values of Sub base from station 124+000.*

Station 124+000						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	2.54	5.94	19.10	29.80	24.40	78.66
30	3.60	8.27	27.00	41.50	34.20	118.00
65	5.51	11.87	41.80	60.00	50.70	188.83
Average					36.40	128.50

The existing laboratory result of the sub base material is described in Tables 14, 15 and 16.

Table 14. *The existing CBR values and Mr Values of Sub base, station 89+320.*

Station 89+320						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	2.54	5.94	19.10	29.80	24.45	78.77
30	3.60	8.27	27.00	41.50	34.25	118.04
65	5.51	11.87	59.60	41.80	50.7	189
Average					36.47	128.61

Table 15. *The existing CBR values and Mr Values of Sub base, station 104+540.*

Station 104+540						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	2.43	3.64	18.35	28.54	223.45	74.91
30	3.58	5.65	38.78	26.91	32.85	112.26
65	3.35	6.32	47.86	39.64	43.75	158.35
Average					33.35	115.17

Table 16. *The existing CBR values and Mr Values of Sub base, station 124+000.*

Station 124+000						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	2.84	6.14	20.10	31.20	25.65	83.44
30	4.66	8.64	32.00	39.55	35.78	124.38
65	5.62	12.34	61.87	49.54	49.54	183.82
Average					37.00	130.56

(c). Sub Grade

In comparing the results with existing values of Mr which was determined from CBR, shows the Mr value of the sub grade soil is decreasing in each sampled station in comparison with the existing result.

Therefore increase in the moisture content, past the optimum conditions can be detrimental to fine-grained subgrade soils. If the pavement design fails to account for changes in the Mr value due to moisture fluctuations, it could lead to a decrease in the service life of a pavement. Hence the selected highway section for this study could be exposed to different distress as illustrated in Figure 7. The variation in moisture content in the sub grade soil of study highway segment could be high rainfall in the area, infiltration from the surroundings through poor side ditch construction, poor disposal of ground water near the pavement structure. And the considerable measurements shall be taken for proper maintenance and reconstruction of the pavement by blocking or reducing the entrances of water which causes the excess moisture to the sub grade soil which in turn reduces the stiffness of sub grade materials, such as use materials that are insensitive to the effects of moisture means of preventing moisture-accelerated damage is to use moisture insensitive or non-erodible and non-expansive materials that are less affected by the detrimental effects of moisture, Incorporate design features to minimize moisture damage an effective means for minimizing surface infiltration is to provide adequate cross-slopes and longitudinal slopes to drain water from the pavement surface quickly, provision of paved shoulder with appropriate slopes, well designed and effective side ditch. In general, the less time the water is allowed to stay on the pavement surface, shoulder or side ditch, the less moisture can infiltrate through joints and cracks. Tables 17, 18 and 19, show the CBR values of sub grade from the sample stations.

Table 17. *The CBR values and estimated Mr Values of Sub grade, station 89+320.*

Station 89+320						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	0.64	1.07	4.80	5.40	5.10	52.71
30	1.29	2.14	9.70	10.8	10.20	106.00
65	1.71	2.57	13.00	12.90	12.90	133.90
Average					9.40	97.54

Table 18. *The CBR values and estimated Mr Values of Sub grade, station 104+540.*

Station 104+540						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	0.64	1.29	4.80	6.50	5.60	58.27
30	0.86	1.29	6.50	6.50	6.50	66.95
65	0.64	1.07	4.90	5.40	5.10	53.00
Average					5.70	59.40

Table 19. *The CBR values and estimated Mr Values of Sub grade, station 124+000.*

Station 124+000						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.50	2.36	11.20	11.80	11.50	119.28
30	1.71	2.57	13.00	12.90	12.90	133.90
65	1.29	1.71	9.74	8.60	9.20	94.87
Average					11.20	116.02

Tables 20, 21 and 22 shows the existing laboratory result of CBR and the predicted Mr value.

Table 20. *The existing CBR values and Mr Values of Sub grade, station 89+320.*

Station 89+320						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54 mm	5.08 mm	2.54 mm	5.08 mm		
10	1.71	3.64	12.80	18.30	15.55	160.82
30	2.57	4.93	19.50	24.70	22.10	228.56
65	3.64	5.57	28.00	27.60	27.80	287.51
Average					21.82	225.63

Table 21. *The existing CBR values and Mr Values of Sub grade, station 104+540.*

Station 104+540						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	0.87	1.43	9.54	18.30	13.92	143.96
30	1.20	1.76	12.98	24.70	18.84	194.84
65	1.43	2.05	24.55	19.67	22.11	228.66
Average					18.29	189.20

Table 22. *The existing CBR values and Mr Values of Sub grade, station 124+000.*

Station 124+000						
	Load (KN)		**CBR (%)**		**Ave. CBR (%)**	**Mr (Mpa)**
Blows	2.54	5.08	2.54	5.08		
10	1.62	2.88	12.8	13.43	13.12	135.64
30	1.88	2.76	14.65	15.67	15.16	156.78
65	1.39	1.86	17.65	11.665	14.65	151.51
Average					14.31	147.98

3.3. Efficiency of the Drainage System in Removing the Excess Water from the Pavement Structure

Drainage quality is an important parameter which affects the highway pavement performance. The excessive water content in the pavement base, sub-base, and sub-grade soils can cause early distress and lead to a structural or functional failure of pavement.

Figure 8. *Ponding sides of U-ditch at Gessa Town (photo: by Mengistu Bayu, 19th May, 2021).*

From field observation made, along the selected highway segment for this study, there is no effective side drainage constructed. Even though the road has been constructed five years ago, the construction of side drain is not completed. In other hand, the drainage structures constructed are also not effective in removing the excess water from the pavement structure. In addition to this, as observed from field, in some places the constructed drainage structure is not properly managed and the construction procedure is not scientifically followed, see Figure 8: the backfilling work not done, due to this the surface water is directly enter to the pavement structure easily. This is abundant in Gessa town after construction of the pavement and U- ditch last three year.

Meantime, it was observed defects on drainage structures on the selected road: obstructions, silting, ponding in drains and on shoulders, drain lining is damaged, defect at drain outfall, silting or debris blocking on culverts, erosion of culvert bed at outlet, minor headwall damage. The condition of silting and obstruction is shown in figure 9.

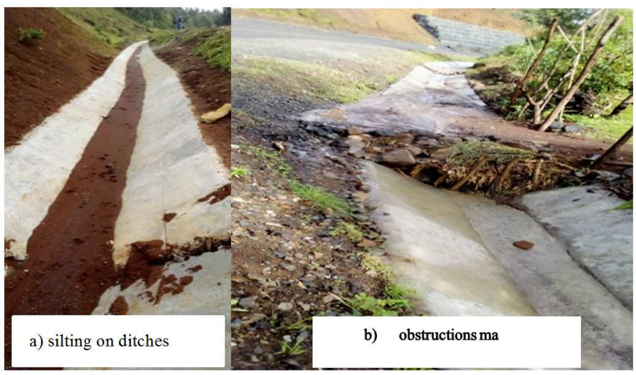

Figure 9. *Different Obstructions on side ditch (photo: by Mengistu Bayu, 21th May, 2021).*

Generally different types of damages on the selected highway segment have observed during the study could be due to in adequacy of side ditches in removing water from the surface of pavement from surroundings.

These are deformation, pumping, pothole and washing of the road pavement. The deformation observed was about 10 to 18 cm in all sampled places. Washing of the pavement shoulder also observed due to improper slope provided and this caused the edge break on different stations of the study segment. Figures 10 and 11 shows different damages occurred to roads in the study area as it was observed in the field investigation.

Figure 10. *Observed problems on shoulder (photo: by Abebe Bura, 24th May, 2021).*

Figure 11. *Distresses on selected segment (photo: by Mengistu Bayu, 28th May, 2021).*

4. Conclusion and Recommendation

4.1. Conclusion

Based on the results obtained in the field observation and Laboratory investigation, the following conclusions have been drawn.

1) Revelling and Block cracking is the observed distress on selected highway segment where the temperature is high near to Give-III (section two of study highway).
2) The NMC of base course, sub base and sub grade materials sampled from station 89+320 is greater than OMC. That is 13.67%, 23.5% and 19.7% for base course, sub base and sub grade respectively whereas OMC from the result are 8.5%, 18.38% and 16.13%. The NMC of materials sampled from station 104+540 are; 5.12%, 17.1% and 30.06% for base course, sub base and sub grade and their respective OMC values are; 9%, 10.70% and 12.51%. The NMC and OMC of Materials from station 124+000 has determined and the values are; 5.45%, 14.40% and 18.22% and 5.83%, 8.40% and 11.92%. Form these, almost the values of OMC<NMC. This implies that the moisture content of pavement materials varies after construction due to fluctuation in moisture in the study area.
3) The Mr Values of materials sampled from each station is less than compared with the Mr values of determined from CBR during the construction of the road five years ago. The Mr values various in each layer in each station in decreasing order. Mr Value for base course from each station varies 357.40 Mpa to 234.52 Mpa, 358.44 Mpa to 316.12 Mpa and 302.45 Mpa to 261.47 Mpa for station 89+320, 104+540 and 124+000. For sub base it varies 128.61 Mpa to 30.29Mpa, 115.17 Mpa to 67.80 Mpa and 130.50 Mpa to 128.50 Mpa for station 89+320, 104+540 and 124+000 respectively. The result of Mr for sub grade soil varies 225.63 Mpa to 97.54 Mpa, 189.20 Mpa to 59.40 Mpa and 147.98 Mpa to 116.02 Mpa from station 89+320, 104+540 and 124+000. The decreasing values of Mr values indicates that, the Mr which is the measure of stiffness of base course, sub base and sub grade Material varies with moisture content fluctuations. One of the reasons for reduced resilient modulus with increased moisture content is lubricating effect of water, causing lower inter-particle forces. Hence the environmental factor (moisture) is major constraint in pavement life after it has been constructed. Therefore decrease in Mr could lead to increased deflection of pavement which results in shortening of the service life of the pavement.
4) It was determined 35 distresses in different places as described in Figure 7. The observed distresses are Edge Cracking 41%, Rutting 32%, Potholes 12%, Pumping 6%, Revelling 6% and 3% of block cracking. This indicates the majority of extents of the distress were edge breaking. This is due to lack of support of the shoulder/non- sealed shoulder, excessive moisture, hence the shoulder is washed by water from surface. 32% of rutting has observed. The type of rutting observed was wide rutting. This indicates failure of sub grade materials. The observed pothole was 12% and it is observed in flat terrain. Revelling was observed station near to Gibe-III or Gebeta Lahager Halala Kela cluster where the temperature is high. Pumping is observed more between waka and Gessa Towns where the annual rain fall goes more than 2000 ml and extremely high from March-August. This indicates that the rain fall has considerable effect on pavement unbounded and sub grade material. Due to high rain fall in the area, there might be change in ground water level and cause deflection on sub grade layer of soil.
5) The sub grade soils sampled from three representatives are grouped in A-2-7 as per AASHTO soil classification rating as to good as sub grade material.
6) The quality of drainage quality is poor as observed water is logged at side drains. Pavement drainage is most beneficial when excessive moisture can be rapidly removed from the structure, ideally within 2 hours and preferably within 24 hours; however, the benefits derived from a subsurface drainage system will vary depending on pavement type, annual rainfall, subgrade conditions, geometric design, and design of the overall pavement system.
7) Dry density, Atterberg's limit and Mr are sensitive to

moisture content of sub grade material at compaction and the field moisture content certain year after construction due to heavy rain fall, poor drainage, and sub-surface water level.

4.2. Recommendations

It is better in the future design and construction of flexible pavement, the pavement layer thickness should be considerably increased or boulder base and sub base with less fine materials should be used in cases of highways in areas where the yearly rain fall >2000 mm and surrounded by agriculture lands to reduce the higher distress caused by variations in water content during the highway service life after construction and the thickness of AC layer should be considered where the temperature is high.

Provide the subgrade soil with a minimum diameter of grain size with corresponding to 10 % finer (weight) in the distribution to overcome flow of water through them that can cause adverse effects on the strength properties of subgrade soil and boulder materials for effective removal of sub surface water carefully with considerable slope.

Attention should be given to construction of side and cross drainage structures after preparation of sub grade layer prior to starting the overlaying pavement layers.

Excess moisture should be eliminated, and the shoulders rebuilt with good materials.

For Future Researchers

Further study should be carried out on the other factors that cause variation of moisture or saturation in a subgrade soil.

Further study should be carried out on the depth of ground water and its fluctuation at different season.

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