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The Effect of Poor Surface Drainage Structure on Pavement Performance – A Case Study

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Abstract: ***In the design and construction of highways due consideration of drainage is a necessity to keep our roads' performance satisfactory. Especially these days, due to the ever growing urbanization and extreme climatic changes, existing drainage structures are becoming incapable of accommodation the runoff that they are experiencing. In our country as well, there are a lot of problems related to drainage systems. Mizan is the major victim of this problem. Nevertheless, sufficient scientific researches that treat this issue were not conducted and thus sustainable solutions have not been given to the city's roads. This study was conducted in Mizan specifically along stadium to Telecommunication road in which the road is known for discomfort and unsafe riding surface due to over flooding and pounding of water on the surface of pavement. This research was aimed to investigate the causes of this poor surface drainage and its impact on pavement's performance. In order to attain this general objective, the researcher initially investigated the factors for the poor surface drainage such as; cross slope and amount run off and then the effects that this poor drainage impose on the structural as well as functional performances of the pavement. The process of data collection included both the primary data sources through site survey, roughness test using Roughometer III, deflection tests using Benkelman beam, questioners and secondary data sources using topographic map. From the results the road in both right and left sides didn't attain the minimum value of cross slope for adequate drainage which is 2.5% and the other factor is the actual amount of runoff is much greater than the designed one. This factor come up with high value of IRI for the right and left side of the road and also the value of mean RRD for the road is 0.95mm. From this stand point it can be concluded that drainage condition has strong relationship with the structural and functional inadequacy of pavements as well as on intensities of distresses. In order to alleviate this problem it is recommended to provide appropriate cross slope and drainage structure and also maintenance and re construction options.***

Keywords: Poor Surface, Drainage Structure, Structural and Functional Performance, Cross Slope**,** Run off.

1. Introduction

The drainage system is designed to collect storm water runoff from the roadway surface and right-of-way, convey it along and through the right-of-way, and discharge it to an adequate receiving body without causing adverse on- or off-site impacts. It is very essential to have adequate drainage in the design of highways to function properly since it affects the highway's serviceability and usable life. When the provided structures fail to accommodate the discharge the road is said to have drainage problem. The fact, known for centuries, is that as long as road structures and sub grade soil do not have excess water the road will work well. But increased water content reduces the bearing capacity of a soil, which will increase the rate of deterioration and shorten the lifetime of the road. In such cases, the road will need Rehabilitation more often than a well-drained road structure. Mainly the problem was observed on poorly working structures, such as, culverts, ditches, grass verges, poor cross fall and cracks. [1]

In the urban environment, the infiltration capacity of the soil is reduced by replacement of the natural ground cover with impervious urban concrete surfaces. Therefore surface over land flow or run off is the dominant method of disposal of excess rainwater. If this excess rain water is not properly disposed of it turns to flood. As a result of urbanization, the surface runoff water greatly increased in the town damaging the roads. The contributed runoff water thus needs to be safely disposed. [2] Now a day, many culverts, trenches and other drainage facilities lack the capacity to deal with the current frequency of extreme flows. An increase in the occurrence of extreme weather events will impose greater strain on the facilities for dewatering and drainage of roads.

2. Research Questions

- What are the major causes of poor surface drainage system?
- What extent affects structural and functional performance of pavement?
- What are the best practices for Remedial measures for these problems?

3. Study Area

The study area is Mizan which is found in south region which is located around 600 Km from Addis Ababa, Ethiopia. The average geographical location of the study area is 9°5'N latitude, 36°33'E longitudinal and 2088 m elevation. The total population of the study area around 117,077. The researcher is interested on Mizan since it's at low elevation, the road users are facings problem of over flooding and discomfort of the road.

4. Research Design

The strategy followed in this research was first started with problem identification which has been done through unstructured literature review, archival study and informal discussion with colleagues and professionals in the sector; and then the research design was formulated.

In order to attain the objectives of this study, a descriptive research was formulated based on a research design which involved both quantitative and qualitative data types were collected and analyzed to describe the condition of drainage system and to measure the pavement performance quantitatively. The qualitative data that were used to describe the pavement and drainage condition are those collected in the preliminary visit stage of the data collection. The quantitative data are those that were collected in filed measurement.

The document search was mainly intended to collect causes of poor surface drainage system and its impact on pavement performance in Mizan town. It investigates the reason for poor drainage system; assess the effect of poor drainage on structural and functional performance of pavement.

Finally, after an in-depth review of literature different tests were conducted like deflection test, roughness test and questionnaire was designed and distributed to end users and professionals to get their opinions. The data were then analyzed for cross-checking the validity and conformity of the information obtained through the overall research work. This was followed by thorough discussions in order to draw a conclusion and to forward recommendations based on the findings of the study.

4.1 Study Variables

- Independent variable:-Cross slope, Structural performance of pavement and functional performance of pavement.
- Dependent variable:-Pavement surface drainage

4.2 Non Distractive Pavement Investigation

This investigation is carried out using the following instrument: The primary data were collected through site survey using roughometer III, Benkelman beam and GPS test. Those instruments were obtained from Ethiopian roads authority (ERA).

4.3 Roughness Measurement

The measurement and analysis process is as follows:
- Measure the bump count, record events and distance.
- The data is then processed using Roughometer III software to obtain IRI.
- Check the actual roughness against permissible values.

During roughness test the roughometer III controller is installed in Nissan vehicle which provides operator feedback during the survey, accepts reference point and event inputs from the operator, and acquires Distance, Time and Roughness data.

The roughness results can provide us an objective data for true evaluation of the roughness level of the road, objectively compares and analyzes which roads are in need of remedial repair and Monitors roughness deterioration trends reviewing successive survey results spaced over several months.

4.4 Deflection Measurement using Benkelman Beam

The general procedure for using pavement deflection for structural evaluation is:
- Establish the length of pavement to be included in the structural evaluation.
- Perform a deflection survey at staggered location.
- Calculate the representative rebound deflection (RRD).
- Check if it is within the allowable range.

This test usually carried out using a Benkelman beam which is a mechanical device that measures the maximum deflection of a road pavement under the dual rear wheels of a slowly moving loaded lorry.

4.5 Method of Data Analysis and Presentation

The data gathered from the site by Roughometer III was processed by Roughometer III processing software to obtain international roughness index and the deflection reading from the dial gage was analyzed by the mathematical formula for computing representative rebound deflection. Topographic survey data was analyzed to obtain cross slope by excel sheet, the aerial photo and slope of the study area was analyzed using ArcGIS software. The data collected and analyzed through different method was presented using tables, charts, graphs, maps and field survey photos.

5. Results and Discussions

For computing the factor that affects surface drainage system and its impact on the pavement performance is very essential to use technical method to reach on valuable result. Priority is given for the technical part of the analysis because the root problem can only solved by technical computations so that the results of technical analysis are presented. Even though Questionnaire survey supplementary for the analysis of the research problem the results of them added strength to the results obtained from the root method of the analysis which is technical solution. Therefore the results of supplementary methods are presented next to the technical method.

5.1 Factors Affecting the Road Surface Drainage

The factors that were considered in a road surface drainage problem are the road cross slope and amount of runoff.

5.1.1 Cross Slope

The cross slopes of the road are measured from the surveyed points (easting, northing and elevation) using excel sheet. As the AACRA drainage manual indicates the maximum and minimum cross slope for adequate drainage is 3% and 2.5% respectively. From the surveyed data the cross slope for right and left sides of the road is expressed by percent on the pie chart below; from the total points surveyed for the right and left sides of the road as the chart indicates about 63.79% and 60.34% respectively didn’t meet the minimum requirement of cross slope for adequate drainage which is about 2.5%. But about 27.58% and 31.03% of the data for the left and right side of the road respectively satisfy the minimum requirement of cross slop for good and safe drainage system.

Cross slope is the main requirement for the road to have adequate drainage. So every road need to meet the minimum requirement which is 2.5% without exceeding maximum limit which is 3% otherwise the water sleep or pond at the surface of the road especially on the right side due to this problem it is very difficult for the road users to acquire the benefit intended from the road and sometimes traffic diverts due to over flooding of the road. These pounding of water infiltrate through cracks, potholes and different defects of pavement and weaken the pavement and decrease the life of the pavement.

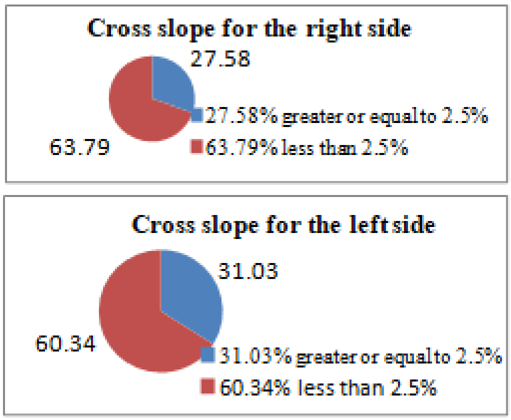

Figure 1: Cross slope for the right and left side

5.1.2 Runoff Estimation

The peak discharge was used for the design of drainage structures. So in order to identify weather the drainage structure can accommodate design runoff or not. This is accomplished by comparing the actual runoff verses the design one. Runoff is computed by the rational formula and it is a function of catchment area, coefficient of runoff and intensity.

$$Q = CIA / 360 \quad \text{......Eqn(1)}$$

Runoff coefficient (C_1) for multi-units detached is 0.40-0.60, (C_1') for asphaltic surface is in the range of 0.7-0.95,(C_2') for an improved areas is 0.10-0.30 for roof C_3 is 0.75-0.95.from this different value of runoff coefficient the weighted run off coefficient need to be calculated,

$$C_w = \frac{\sum C_i A_i}{A}$$

where,
C_w = weighted runoff coefficient
C_i , A_i = runoff coefficient and area respectively for cover type i
A = total drainage area.

Weighted runoff coefficient is computed for the study area since the areas have different type of ground cover those are roof, residential dwelling and relatively impervious land. The higher values of runoff coefficients are usually appropriate for steeply sloped areas and longer return periods because infiltration and other losses have a proportionally smaller effect on runoff in these cases. In the case of this study about 0.63km of the study road is steeply sloped, about 0.937km is flat, 0.327km is less steeply sloped and the return period that was used is 20 years which is relatively higher for drainage structure design.

a) Intensity Duration Frequency Curve

The rainfall intensity (I) is the average rainfall rate in mm/hr. for duration equal to the time of concentration for a selected return period. It is obtained by using the intensity duration frequency (IDF) curve for a given region. The IDF curve provides a summary of a site's rainfall characteristics by relating storm duration and frequency to rainfall intensity (assumed constant over the duration) [21]. The rain fall data gathered form Ethiopian Metrology Agency of Jimma station is analyzed with the aid of excel sheet to give the IDF curve. ERA Drainage design manual recommend 10-20 years of return period for urban areas so the given data for computing IDF curve is Annual Maximum Daily Rainfall data of 10 Consecutive Years, Rainfall Intensity for 30minute in order to increase the accuracy and Frequency of 20 Years Return Period.

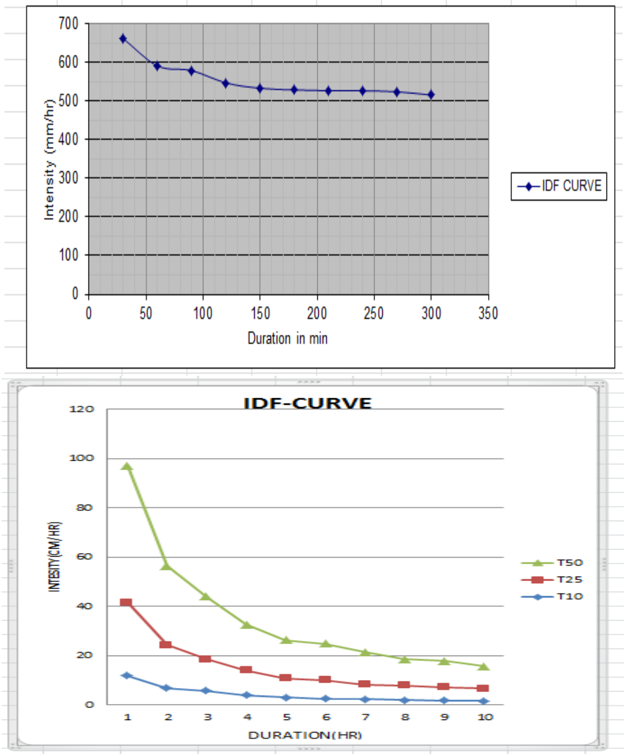

Figure 2: Intensity duration frequency curve

The time of concentration need to be calculated first in order to find rain fall intensity from the IDF curve.

$$T_C = 0.0195 K_c^{0.77} \quad \text{......Eqn(2)}$$

Where $K_c = [(L)^3 / H]^{0.5}$, L =Length of road of the section
H =Elevation difference from contour line is 1

$= ((2000)^3 / 1)^{0.5}$
=90855.13
=<u>128.22 min</u>.

By using interpolation
120……………………547.3
128.22…………………X
150……………………533.2
(120-150)/ (547.3-533.2) = (120-128.22)/ (547.3-X)
= -30(547.3-X) = 14.1 * -8.22

$= -16419 + 30X = -115.902$

$\frac{30X}{30} = \frac{16303.098}{30}$

$X=543.4$ mm/hr

For Basin 1

Have two sub basins

$Q=CIA/360$

$i=543.4$ mm/hr

$A_1= 5.64$ $C_1=0.75$

$A_1'= 42.36$ $C_1'=0.5$

$CW_1=\sum CiAi/A$

$= \frac{(5.64*0.75) + (42.36*0.5)}{48 \text{ hectare}}$

$= \frac{4.23+21.18}{48} = \frac{25.41}{48}$

$CW= 0.53$

$Q_1= \frac{CW_1*A_1*i}{360}$

$= \frac{0.53*543.4 mm/hr*48 \text{ hectare}}{360}$

$Q_1=38.4 m^3/sec$

For Basin 2

$A_2=30.82C_2=0.15$

$A_2'=13.92$ $C_2'=0.5$

$CW_2=\sum CiAi/A$

$= \frac{(30.82 * 0.15) + (13.92 * 0.5)}{44.74}$

$= \frac{4.62 + 6.96}{44.74} = \frac{11.58}{44.74} = 0.26$

$Q_2= \frac{CW_2A_2i}{360}$

$= \frac{0.26 * 543.4 * 44.74}{360}$

$Q_2= 17.56 m^3/sec$

For Basin 3

$A_3=27.26$ hectare

$C_3=0.85$

$Q_3= \frac{CW_3A_3i}{360}$

$= \frac{0.85 * 27.26 * 543.4}{360}$

$= \frac{12591.12}{360}$

$Q_3= 34.98 m^3/sec$

$Q_T = Q_1 + Q_2 + Q_3$

$= 38.4m^3/sec + 17.56m^3/sec + 34.98m^3/sec$

$Q_T = 90.94 m^3/sec$

This computed discharge is compared with the design one for the three section of the

$Q_{actual} > Q_{design}$

As the table shows above the actual amount of runoff computed by rational formula is greater than design one. Therefore the cause of poor surface drainage in other term the cause of over flooding on the test road is due to unexpected amount of runoff.

Table 1: Comparison of design and actual discharge

S. No.	Catchment area in hectare	Road length(Km)	Q_{actual} (m^3/s)	Q_{design} (m^3/s)
1	48	0+327km	38.4	22.4
2	44.74	0+630 km	16.14	14.30
3	27.26	0+937 km	41.57	30.8
		Total	90.94	67.5

5.1.3 Roughness Value (IRI)

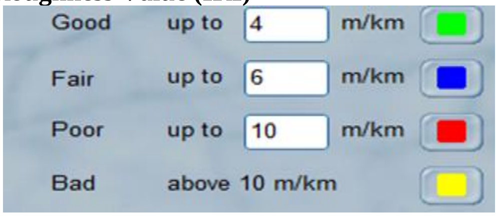

Figure 3: Map of pavement condition for the right side

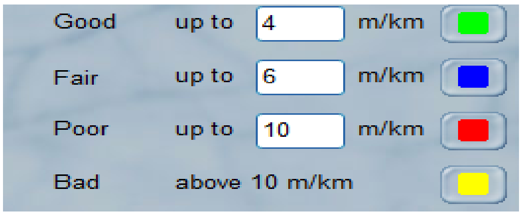

Figure 4: Map of pavement condition for the left side

5.2 Deflection Test Analysis

Deflection for this test road is done by Benkelman beam. The test was taken on staggered location of randomly and systematically selected distress free 9 points by 250m interval and the weather condition during the deflection test was sunny. The data recorded is computed by the RRD (Representative Rebound Deflection) formula.

$$RRD = (\bar{x} + 2s)C \quad \text{...............Eqn(3)}$$

The characteristic deflection "d" having been determined, it is then compared with two threshold values d1 and d2, which divide general deflection magnitudes into three ranges as follows:-

- d1 value below which pavement performance is generally good
- d2 value above which pavement performance is poor
- d1-d2 range of indecision

For roads with surfacing of asphalt concrete of more than 8 to 10 cm. d1= 60/100mmd2= 80/100mm [25].

Calculation

Step 1. The mean temperature of the pavement during deflection test was **23.88 °c** and from design data thickness of untreated aggregate base**20cm.**According to this from Temperature Adjustment Factor for Benkelman Beam Deflections graph temperature adjustment factor **(F)= 1.06** is selected.

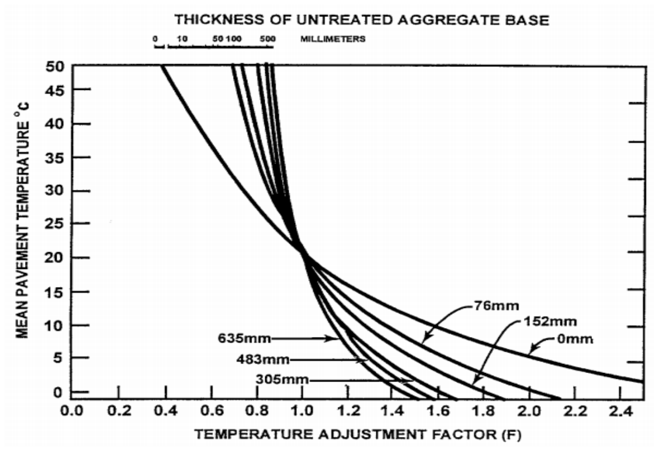

Figure 6: Temperature adjustment factor for Benkelman Beam Deflection (BBD)

Step 2: Converting the measured deflection to deflection adjusted for temperature.

Table 2: Deflection adjusted for temperature

Measured deflection (under 10 ton axle)mm (Xi)	Deflection adjusted for temperature (factor 1.06)mm (Xt)
0.4	0.42
0.66	0.70
0.58	0.61
0.5	0.53
0.44	0.46
0.54	0.57
0.56	0.59
0.70	0.74
0.66	0.70

Step 3. Calculating the arithmetic mean of individual temperature adjusted deflection measurement

X$=\Sigma X_t/n$

$= \frac{0.42+0.70+0.61+0.53+0.46+0.57+0.59+0.74+0.70}{9}$

X= 0.59

Step 4. Determine the standard deviation

$$S = \sqrt{\frac{\Sigma x^2 - x\,\Sigma x}{n-1}} \quad \text{.........Eqn (4)}$$

Where X= the arithmetic mean adjusted deflection

X_t= Individual adjusted deflection value

N= number of individual deflection test

$\sum X_t^2$= 0.18+0.49+0.37+0.28+0.21+0.32+0.34+0.55+0.49

= **3.23**

S$=\sqrt{\frac{(3.23-0.59*5.04)}{9-1}}$

$S = \sqrt{\frac{(0.26)}{8}}$

S = 0.18

Step 5. Calculating the RRD

$$RRD = (\bar{x} + 2s)C$$

Where: - C is critical adjustment factor

= (0.59+2*0.18)*1

= **0.95 mm**

Representative rebound deflection (mm) = 0.95

If the value of representative deflection for the test road is greater than 80/100 then the road is said to have poor structural pavement performance.

RRD for test road > 80/100mm indicates the road have poor structural performance.

RRD for test road < 60/100mm indicates the road have good structural performance.

According to this assessment criteria the test road have poor structural performance having **RRD=95/100mm**

As the dial gage reading shows higher value is recorded for the section of the road where the water is pounded since the water will not drain as quickly as possible it goes down and weaken the pavement layers and when the 80KN of load(for the test) is exerted it experience a deflection starting from the lower pavement layer(sub grade) and manifested on the upper layer and noticed by the dial gage, then after as this action repeatedly occurs the pavement becomes structurally inadequate to support the design traffic load in its service life, furthermore the pavement will fail structurally.

5.3 Analysis of the Questionnaires Respond

The questionnaires were designed, after identifying major causes of drainage problems and their impacts on pavement performance. The questioners were prepared from my literature review to meet the research objective.

For the purpose identifying the objective of the research consultants, contractors and end users are the main targets of the questionnaires respondent.

The questionnaires were prepared for two target groups those are professionals that are engaged in the design, construction, and maintenance of road projects and the other were the end users that are public society that are living in the research study area.

Table 3: Distribution and response of questionnaires

S.no	Status of Firms	No. of questionnaires		In percent	
		Distributed	Returned	Distributed	Returned
1	Contractor	10	7	41.7	39
2	Consultant	6	4	25	22
3	End users	8	7	33	39

5.4 Profit of Respondents

Out of 24 questionnaires send to individuals, 18 responded. 6 of the questionnaires were not answered. The response rate is 75%, which is satisfactory to conduct the analysis. For the comprehensiveness of the study, an effort was made to involve those professionals currently engaged construction project and have good experience.

Based on the result of the questionnaires survey, summarizes the profile of professionals involved in the study. Among the companies who participated in the study, 73%of them have more than 5 years' experience, which shows that companies involved in the study have vast experience in the area and implies that the information forwarded is important as required in the study. With regard to the working experience of the professional involved in the questionnaire survey, 55% of them have more than 10 year experience. This combination of experience of the participant has great value for the reliability of the information obtained from the questionnaire survey.

Table 4: Work Experiences for Professionals involved in the Questionnaires Survey

Range in year	Experience of professionals	
	In number	In percent
Less than 5 year	2	18
5-10	3	27
Greater than 10	6	55
Total	11	100

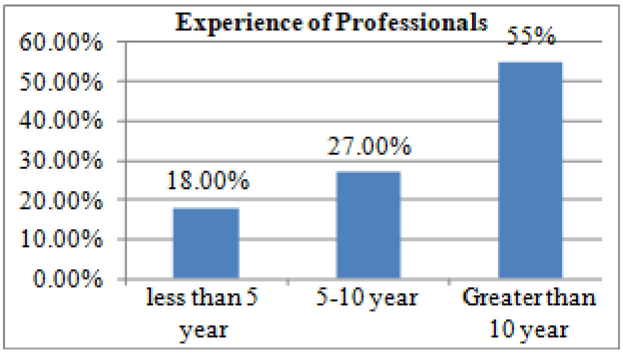

Figure 7: Percentage for the work experience of professional
(**Source:** From the questionnaire for the professionals)

About 68% of the respondents are agreed poor surface drainage system affects pavement performance to an average extent of 50%-75%. 65% of the respondents were agreed cross connection, damage root and sediments, pollutants and nutrient are very largely occurred in a drainage system in the study area. While 25% of the respondents are agreed the system design, and infiltration are largely occurred and 10% of the respondents were agreed filtration were medium occurrence. About 70% the respondents were selected poor surface flow, clogged inlets, surface settlement and puddles on the surface area were highly occurred from the major signs that are seen in the study area. And 30% of respondents were selected pavement edge raveling; preliminary cracking and pavement pumping were medium occurrence from the major signs that are seen in the study area. About 95% of respondents were agreed deflection, cracking, potholes, edge deformation, corrugation are very largely occurred as a major impact of poor drainage on the pavement performance. About 80% of respondents imply poor solid waste disposals, lack of maintenance, poor usage of the community are the major causes of over flooding. Due to this over flooding about 75% road users answered road crack, pothole, discomfort, rough surface and not functional of the road are the major impacts on the study area.

6. Conclusions and Recommendations

6.1 Conclusion

The cross slope of the test road is not sufficient to provide adequate drainage since about 63.79% for the right side and 60.34% for the left side didn't attain the minimum requirement for adequate drainage which is 2.5% and also the amount of actual run off is much greater by 23.44m^3/sec from the design amount of run off for the total segment of the test road. According to the survey made for this thesis purpose, even some of the existing surface drains are not properly functioning.

The results of the nondestructive structural evaluation based on deflection revealed that the pavement have a mean RRD value of 0.95mm which is much greater than the very bad limit which is 0.80 mm. The structural evaluation made on the road confirms that the pavement is not structurally adequate to serve the intended purpose.

The result of roughness evaluation for right and left side is 5.9m/km and 6.1m/km respectively. The mean IRI values fall in the range of poor functional performance especially for the left side since left side of the road has high number of distresses which trap water and weaken the pavement performance which leads to failure of the road before it reaches its intended service life.

Large deflection, high IRI values and consequently higher distress has significant impact on the pavement functional and structural conditions. This indicates that the visually observed surface defects are aggravated by inadequacies in the surface drainage system. One can deduce from this relationship that the functional and structural failure of the pavement is highly associated with the presence of water.

The deflection and roughness measurement results on test road clearly indicates that this road is experiencing poor performance which mean that it have functional and structural inadequacy to support the existing traffic loading.

6.2 Recommendation

- More emphasis is needed to be given for the design; construction and provision of exact size and shape of drainage structure rather than to seat as a symbol. Ethiopia roads authority provides drainage structure traditionally without considering specific runoff, coefficient of runoff and catchment area for each respective road section projects. Therefore every responsible office in the design and construction of roads must focus in the provision of sufficient cross slope and adequate drainage structure which can accommodate the maximum amount of runoff for the entire design life to overcome over flooding of pavement.
- Regular annual evaluation of drainage systems is an important part of maintaining and managing road. The required periodic and routine maintenance need to be done before its adverse impact is manifested on the pavement.
- The appropriate maintenance and rehabilitation measure for the test road is structural and functional upgrading using complete reconstruction and rehabilitation. Hence, the traditional maintenance techniques being undertaken by the Ethiopia roads authority year after year, like

patching and thin overlays provide a solution for the time being rather than to find and resolve the root problem. There is still no proper material and construction quality control for the road maintenance and rehabilitation works. As a result, repeated and premature failures are observed. Therefore, the pavement design and construction practice must be modified in such a way to improve the structural and functional adequacy of pavement.

- Ethiopia Roads Authority road asset management stream is not well organized, not fully equipped with performance measuring instrument and qualified professional in operating and analyzing, interpreting the output in order to evaluate serviceability of pavement. Therefore Ethiopia Roads Authority need to have their own equipment and qualified technician in order to manage the asset.
- Hence, it is advisable to develop a continuous system of data collection for deflection measures, roughness results, type and extent of distresses, evaluation of drainage structures and maintenance and construction records on the test road for a longer period of time. Such strategic data collection and analysis could certainly enable to develop clear functional relationship among this evaluation parameters and its respective rehabilitation technique.
- No detail material test of the existing pavement structure is carried out under this research. Hence, it is also advisable to perform some destructive tests such as DCP test, CBR, material grade and drainage coefficient's to check further the structural and functional capacity of the pavement with their respective measures.
- The analysis and findings of this research could only be considered as a preliminary assessment that may serve as a spring board to further carry out detailed assessment within the Jimma road network.

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