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Prediction of Longitudinal Cracking of Asphalt Pavements

Ripunjoy Gogoi

Abstract: ***Longitudinal cracking is one of the major structural distresses of asphalt pavement. These cracks appear on the pavement along the direction of moving traffic. This study makes an attempt to predict the extent of longitudinal cracking based on three parameters which are: asphalt binder content, traffic load repetitions and asphalt stiffness modulus. For the study, the data has been used from Long Term Pavement Performance (LTPP) database. Linear Least Square (LLS) regression method is employed to model the observed trends between the longitudinal cracking and the three parameters. The results of the analyses has shown that longitudinal cracking vary linearly with respect to each parameter. It is observed that (i) longitudinal cracking decreases linearly with increase in percentage asphalt binder content in asphalt concrete (ii) longitudinal cracking increases linearly with increasing traffic load repetitions and (iii) longitudinal cracking decreases linearly with increase in stiffness modulus of asphalt concrete.***

Index Terms: ***asphalt pavements, longitudinal cracking, asphalt content, asphalt stiffness modulus, traffic load repetitions***

I. INTRODUCTION

Longitudinal cracking is one of the major distresses of asphalt pavement. It is also referred as top down fatigue cracking. The cracks appear both along the wheel and non wheel paths. The crack initiates at the surface and propagates downward with increasing load repetitions. Such cracks appear as a line on the pavement, along the direction parallel to the movement of traffic as shown in the Figure 1. The cracks often propagate downward to the full depth of the asphalt layer.

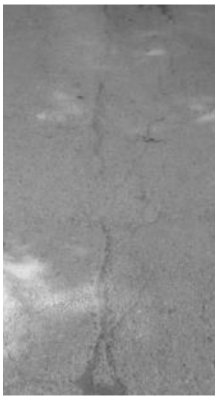

Fig. 1. Typical longitudinal cracking observed on an asphalt pavement

As per the study conducted by Gerritsen et al.[1] in Netherlands, the most likely reasons of longitudinal cracking were: low asphalt binder content and improper compactions. A study by Dauzats and Rampal [2] revealed that longitudinal cracking is triggered by thermal stresses generated at asphalt surface layers. Based on study done by Wambura et al [3], it was reported that severe oxidation and hardening of the top asphalt layers lead to longitudinal cracking. The results were obtained by performing tests on pavement cores. Matsuno and Nishizawa [4] performed a mechanistic study to find the possible causes of longitudinal cracking. The authors conducted the study by using finite element method. In the work, two different asphalt pavements cross sections were used. The results of the study reported that traffic load causes high tensile strain which result in longitudinal cracking. Meyers et al. [5] reported that radial truck tire causes longitudinal cracking in asphalt pavement. A study done by Uhlmeyer etal. [6] showed that pavement thickness might impact the initiation and propagation of longitudinal cracking. However, it seems there are no models developed from the distress data information to predict the propagation of longitudinal cracking of asphalt pavement. Thus this work makes an attempt to develop longitudinal cracking prediction models by finding the possible relationship between the longitudinal cracking and different factors such as traffic load repetitions, asphalt binder content and stiffness modulus of asphalt concrete. For the study, data has been used from long term pavement performance (LTPP) database [7].

The objective of the present study is presented in Section II. A brief overview of the LTPP database is discussed in Section III. In Section IV, the analyses of the current study are discussed. The results are also discussed in the same section. Conclusions are discussed in the last section.

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II. OBJECTIVES OF THE CURRENT STUDY

In this work, three parameters are considered to study the propagation of longitudinal cracking. These parameters are: (a) traffic load repetitions (b) asphalt binder content and (c) stiffness modulus of asphalt concrete. The objectives of the current study are as follows:

1. To study the possible relationship between longitudinal cracking and traffic load repetitions.
2. To study the possible relationship between longitudinal cracking and asphalt binder content.
3. To study the possible relationship between longitudinal cracking and stiffness modulus of asphalt concrete.

To study the above objectives, data has been used from LTPP.

III. LONG TERM PAVEMENT PERFORMANCE DATABASE

For the proposed study, long term pavement performance (LTPP) database is used. The data is available in two categories, (1) General Pavement Studies (GPS) and (2) Specific Pavement Studies (SPS). GPS has data information of existing pavements that were built prior to the incorporation of LTPP program, where as in SPS, data are available for pavements that are specifically designed or changed as per requirement of various studies made under LTPP research schemes. Hence time to time various new pavements are built under SPS program. There are approximately 2500 pavement sections in this database for which every year various pavement information are collected and stored. When a pavement is initially included in the LTPP program for data collection, the pavement is identified by a number called construction number (CN). Thus, a CN value of 'one' is used initially but as the pavements are subsequently maintained or rehabilitated then the CN value is increased by one. Each LTPP pavement test section is of 152 meters in length and 3.6 meters in width and the distress data are available at mainly at an interval of 15.2 meters along the longitudinal direction. These locations are termed as profile location (PL) in LTPP. In the current study, data from both SPS and GPS are used.

IV. METHODOLOGY

This section discusses the analysis undertaken to predict the longitudinal cracking of asphalt pavement with respect to the three parameters, which are: (1) asphalt binder content (2) traffic load repetitions and (3) stiffness modulus of asphalt concrete. Regression analysis is employed to model the observed trends. The ordinary least square (OLS) regression method is adopted. In this method, the best fit model is obtained by minimizing the sum of squares of the residuals. Residuals are offsets of the observed data from the predicted regression line. Based on the regression analysis statistics, the best fit regression equation is accepted as the final model. Data are extracted from various modules of LTPP database. Later, graphs are plotted between longitudinal cracking and individual parameters. If any trend is observed between the longitudinal cracking and the parameter, then regression analysis is performed to model the relationship between the dependent and independent parameters.

A. Longitudinal cracking and bitumen binder content

A total of 86 data points are extracted from LTPP data for the present study. The extracted data contains information on the extent of longitudinal cracking of different pavement sections spread across various states of USA. The percentage of asphalt binder content used in the construction of the same pavement sections are also extracted from the LTPP data. Figure 2 shows the distribution of percentage binder content used in the construction of the considered asphalt pavement sections. The amount of binder content used in the construction of pavement sections varies from 4% to 10%. However, it can be seen that major portion of the pavements are constructed with asphalt binder content of around 8% (refer to Fig. 2). In this current analysis, the data is grouped in the category of asphalt binder content. The groups are 4 to 5%, 5 to 6%, 6 to 7%, 7 to 8% and 8 to 9%. For each of these groups, the average longitudinal cracking of the pavement sections is observed. Figure 3 shows the plot between the average longitudinal cracking and percentage binder content. From the figure it can be seen that with increasing binder content, the level of longitudinal cracking is decreasing. The decreasing trend can be attributed to the fact that with increasing binder content, the stiffness of the asphalt concrete mix decreases. The decrease in stiffness of the asphalt binder improves the elastic properties of the pavement. Binder with insufficient elasticity results in crack when subjected to repeated traffic load repetitions. Hence, the reduction in stiffness of binder content results in decrease in longitudinal cracking. To model this trend, the least square regression analysis has been employed.

The final model is,

$$y = 468.42 - 51.12 \times x \qquad (1)$$

Where,

x is the percentage asphalt binder content and y is the longitudinal cracking in meter.

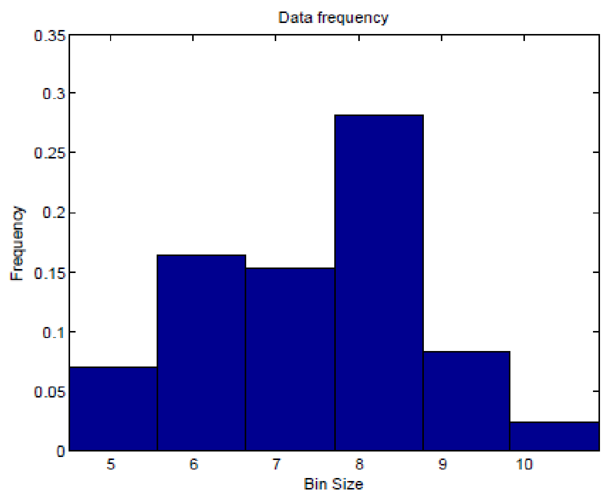

Fig.2. Frequency distribution of percentage binder content used in the LTPP asphalt pavement sections

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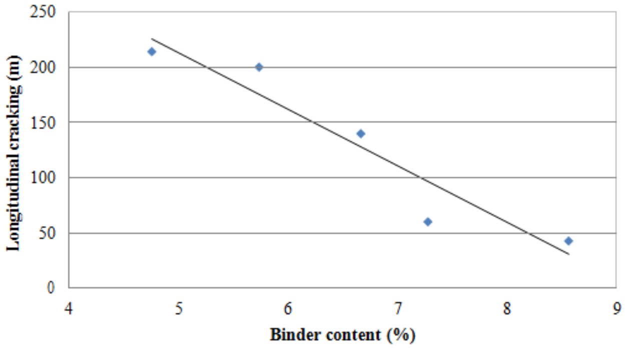

Fig.3. Plot showing the average values of binder content and longitudinal cracking

The result of the analysis is shown in Table 1.

The confidence interval used in analysis is 95%. The t-stat and the p-value of the estimates suggest that the values of the parameter estimates are statistically significant at 5% level of significance. The R2 (a value of 0.902) and F-statistic suggest that there is a strong linear relation between longitudinal cracking and binder content.

Table 1: Summary of regression analysis to model extent of longitudinal cracking with respect to binder content

B. Longitudinal cracking and Equivalent Standard Axle Load (ESAL)

A total of 49 data points are found relevant for the study and extracted from LTPP data. The data contains information on the extent of longitudinal cracking and the amount of traffic load repetitions that the pavement has undergone. The traffic load repetitions information in LTPP is available as Equivalent Standard Axle Load (ESAL). Fig 4 shows the data distribution of the ESAL in the units of million standard axles (msa). Again, for this particular analysis, the traffic data is grouped into 5 different categories. The groups are: less than 300 msa, 300 to 350 msa, 350 to 400 msa, 400 to 450 msa and greater than 450 msa. The average longitudinal cracking of the pavement sections in each group is observed. Fig 5 shows the plot between the average longitudinal cracking and ESAL in msa. From the figure, it is seen that with increasing traffic load repetitions, the amount of longitudinal cracking tends to increase. The increase in cracking can be attributed to the accumulation of tensile strain on the top of the asphalt surface due to repeated traffic loads. This strain initiates cracks on the surface which later propagates downward with increasing load repetitions. To model this trend with mathematical equation, the least square regression analysis is employed.

The regression model is,

$$y = 0.24 \times m - 20.31 \qquad (2)$$

Where,

m is the traffic load repetition and y is the longitudinal cracking in meter.

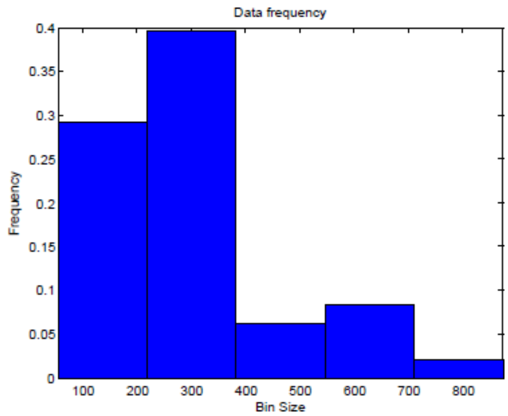

Fig.3. ESAL (msa) data distribution of the studied LTPP pavement sections

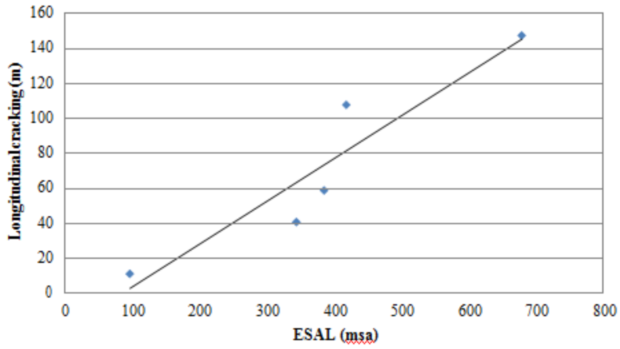

Fig. 5: Plot showing the variation of average longitudinal cracking with respect to average ESAL (msa)

The result of the analysis is shown in Table 2. The confidence interval used in analysis is 95%. The t-stat and the p-value of the estimate suggest that the estimate of slope is statistically significant at 5% level of significance. The R2 (0.873) and F-statistic suggest that there is a strong linear relation between longitudinal cracking and ESAL.

Table 2. Summary of regression analysis to model extent of longitudinal cracking with respect to ESAL (msa)

	Coefficients	t Stat	P-value
Intercept	-20.312399	-0.8898453	0.4391014
X Variable 1	0.2447893	4.5599506	0.0197734

C. Longitudinal cracking and stiffness modulus of asphalt concrete

A total of 50 data points are available in LTPP database with information of longitudinal cracking and stiffness modulus value of the pavements. Fig 6 shows the data distribution of the stiffness modulus values used in the LTPP pavements. Similar to the previous analyses, the data is grouped based on stiffness modulus of the pavement. The different groups of stiffness modulus are: less than 4 × 106 psi, 4 × 106 to 4.5 × 106 psi, 4.5 × 106 to 5 × 106 psi, 5 × 106 to 5.5 × 106 psi and 5.5 × 106 to 6 × 106 psi. The average longitudinal cracking of the pavement sections for each of the group is calculated.

Fig 7 shows the plot between the average longitudinal cracking and average stiffness modulus. From the figure, it is seen that with increasing stiffness value, the amount of longitudinal cracking increases. The increase in cracking can be attributed to the accumulation of top tensile strain on the asphalt surface. The increase in stiffness modulus values increases strain in asphalt layer because stiffness reduces the ductility property of the pavement. The ductility property enables the pavement to return to its original profile after the traffic load has passed. The generated strain initiates cracks on the pavement along the longitudinal direction of travel. The observed trend is modeled using the regression method.

The regression model is,

$$y = 76.83 + 3.90 \times 10^{-5} \times s \qquad (3)$$

Where,

s is the stiffness modulus of asphalt concrete and y is the longitudinal cracking in meter.

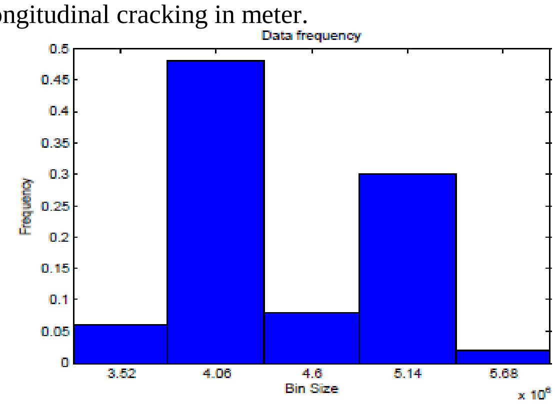

Fig. 6. The data distribution of asphalt stiffness modulus used in studied LTPP pavement sections

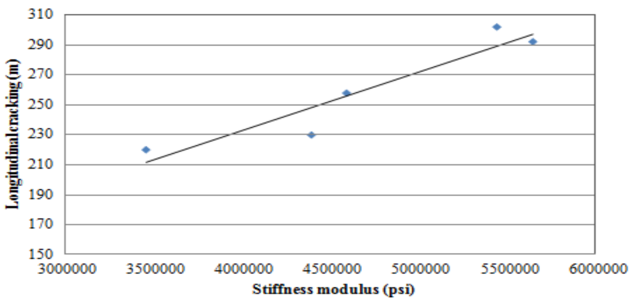

Fig. 7. Plot showing the variation of average longitudinal cracking with respect to average stiffness modulus of asphalt concrete (psi)

The result of the analysis is shown in Table 3. The confidence interval used in analysis is 95%. The *t*-stat and the *p*-value of the estimate suggest that the estimate of slope is statistically significant at 5% level of significance. The R^2 (0.88) and F-statistic suggest that there is a strong linear relation between longitudinal cracking and stiffness modulus.

Table 3. Summary of regression analysis to model extent of longitudinal cracking with respect to asphalt stiffness modulus (psi)

	Coefficients	t Stat	P-value
Intercept	76.83853166	2.0200084	0.1366551
X Variable 1	3.90941E-05	4.8949242	0.0163135

V. CONCLUSION

In this work, the propagation of longitudinal cracking of asphalt pavements with respect to three parameters, which are: (1) asphalt binder content (2) equivalent standard axle load (traffic load repetitions) and (3) asphalt stiffness modulus have been studied. For the study, data was used from LTPP database. Each parameter was individually considered to predict the propagation of longitudinal cracking. Trends were observed which are all linear. To model the trends, OLS regression method was employed. These models were discussed and presented in this paper. The results from the regression analysis were presented for the models. From the analysis, it seems that (1) longitudinal cracking decreases linearly with increasing asphalt binder content in the asphalt concrete, (2) longitudinal cracking increases linearly with respect to increasing traffic load repetition and (3) longitudinal cracking increases linearly with increasing stiffness modulus of asphalt concrete.

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Ripunjoy Gogoi is working as an Assistant Professor in the Department of Civil Engineering, Amity School of Engineering and Technology, Amity University Madhya Pradesh, Gwalior. He has done his PhD in Civil Engineering from Indian Institute of Technology Kanpur. He received his Master of Engineering degree from BITS Pilani, Rajasthan. He has his B.E. degree in Civil Engineering from Assam Engineering College, Gauhati University. His areas of interests are: pavement maintenance, pavement material, design and evaluation of pavements etc. He has published his research works in many national and international journals.