CHAPTER 3 - PAVED ROAD CRACKING AND RUT DEPTH ANALYSIS

3.1 INTRODUCTION

A considerable amount of public money is spent on pavement maintenance every year, as pavements deteriorate over time due to traffic loading and climatic factors. For efficient use of maintenance resources, it is necessary to estimate the future condition or serviceability level of the different pavement sections in a specific network. Such an estimate is only possible if the pavement engineer or planner has reliable predictive models available. Moreover, distress prediction models are essential technological tools in the analysis of alternative pavement design strategies.

This chapter presents the results of analysis performed on data collected on pavement cracking and rutting, with the objective of developing empirical prediction models for these two types of distress manifestations. Quantitative information on pavement cracking and rutting is obtained from condition surveys, which are mechanistic measurements of distress. It should be clear that the prediction models developed can be only used for estimating pavement distress in a way compatible with the measurement system used in the field.

3.2 ANALYSIS OF PAVEMENT CRACKING

The approach for studying pavement cracking was to monitor the percent area cracked at selected test locations on existing roads. Detailed information developed to characterize each test location included traffic loads and volumes, pavement structural number, Benkelman beam and Dynaflect deflections.

The cracking variable used in this analysis is defined as the percent of the pavement's total area which shows Class 2 to 4 cracks or potholes. Class 1 cracks, which have widths of less than 1 mm and are normally called hairline cracks, were not included in the percent calculation because they are not readily identifiable in the field, and their measurement depends, to a great extent, on the observer's judgement and weather conditions. Additionally, hairline cracks can result from poor rolling of asphalt mixtures during construction and, in this case, their prediction as a function of pavement strength and traffic loadings is meaningless.

Another reason for not including hairline cracks in the computation of the cracking variable is that this type of cracking would hardly ever warrant any pavement maintenance response. Moreover, Class 1 cracks were not included in the cracking term used to estimate serviceability at the AASHO Road Test (HRB, 1962). Therefore, it seems appropriate to quantify a cracking variable as previously defined.

Very few of the surface treatment sections exhibited cracks. Consequently, test sections with this type of surfacing were not included in the analysis of pavement cracking.

3.2.1 *Approach for Cracking Analysis*

Observation of the data indicated that it may take a pavement several years to show the first crack, but after the initial cracks appear, the deterioration process is relatively fast. Therefore, it was considered necessary to develop two types of models: one to predict when cracks first appear and the other to predict how fast cracks progress in a specified pavement. The analyses corresponding to these models are called, respectively, crack initiation and crack progression analysis.

The need for these two types of models was identified by Finn (1973) who stated that, to be helpful to the highway engineer, the output variable of cracking as predicted from research should include not only some estimate of initial cracking, but also the rate of progression of cracking with time.

3.2.2 *Crack Initiation*

The dependent variable used in this part of the analysis is the number of equivalent axles supported by the pavement to first crack. The inference space is governed by the ranges of the dependent and independent variables which are listed in Table 3.1. As the objective of this part of the study was to predict when cracks first appear, only test sections which showed their first crack during the

TABLE 3.1 - MEAN, STANDARD DEVIATION AND RANGE OF THE VARIABLES USED IN THE CRACK PROGRESSION ANALYSIS

DESCRIPTION	MEAN	STANDARD DEVIATION	RANGE	
			MINIMUM	MAXIMUM
Number of Sections	19	-	-	-
- As constructed	12	-	-	-
- Overlayed	7	-	-	-
Age During Observation Period (Years)	5.3	3.5	1.2	15.8
Benkelman Beam Deflection (0.01 mm)	58.7	21.6	34.0	102.0
Dynaflect Deflection (Sensor 1) (0.001 in.)	0.817	0.288	0.400	1.460
Surface Curvature Index (0.001 in.)	0.277	0.104	0.120	0.460
Base Curvature Index (0.001 in.)	0.108	0.042	0.050	0.200
Structural Number	3.49	0.86	1.90	4.30
Corrected Structural Number	5.30	8.60	3.70	6.70
Log_{10} Cumulative Equivalent Axles	5.49	0.61	4.30	6.28
Subgrade CBR	33.6	14.4	13.0	64.0

study period were used. The correlation matrix of variables included in the analysis is given in Table 3.2.

A number of functional relationships were investigated through regression analysis. The model found to best fit the data is:

$$LN = 1.205 + 5.96 \log SNC \qquad (3.1)$$

where

LN = logarithm to the base 10 of the number of equivalent axles to first crack;
SNC = corrected structural number; and
log = logarithm to base 10.

Equation 3.1 has a correlation coefficient squared of 0.52, a standard error for residuals of 0.44, and is based on a sample size of 19. Other statistical results pertaining to this equation are given in Table 3.3. The approximate 95 percent confidence interval is:

$$CI = LN \pm 0.95 \text{ or } 0.11N \text{ to } 8.9N$$

As described in Chapter 2, several groups of independent variables were used in the analysis. However, no acceptable regression equation could be developed with independent variables other than corrected structural number. It is expected that test sections which have not shown any cracking - and therefore not included in this analysis - will enhance the inference space for future analyses. This may make it possible to obtain reasonable models for the other combinations of independent variables.

3.2.3 *Crack Progression*

Two different dependent variables were used in this part of the analysis:

TABLE 3.2 - CORRELATION MATRIX OF VARIABLES INCLUDED IN THE CRACK INITIATION ANALYSIS

Variable	SNC	B	D	AGE	LN
SNC	1.00	-.64	-.65	.18	.72
B		1.00	.78	-.24	-.26
D			1.00	-.27	-.26
AGE				1.00	.44
LN					1.00

TABLE 3.3 - REGRESSION ANALYSIS RESULTS FOR EQUATION 3.1

a) Analysis of Variance

	Degrees of Freedom	Sum of Square	Mean Square	F Ratio
Regression	1	3.474	3.474	18.29
Residual	17	3.229	0.190	-

b) Regression Equation

Parameter	Estimate	Standard Error	F-Value
Intercept	1.205	-	-
LSNC	5.963	1.394	18.29

Correlation coefficient squared : 0.518

Standard error for residuals : 0.436

a) the percentage area cracked at a specified pavement age; and

b) the age when the percent of area cracked reaches a specified value.

Models developed for the first dependent variable are useful, for example, when the engineer wants to predict the cracking condition of a pavement t years from now, if no maintenance is applied to the pavement. The resulting numbers could indicate the need to request additional funds for certain projects in the road network.

An example of application of models developed for the second dependent variable is the estimation of the time at which a pavement cracking condition will reach a limiting value, at which rehabilitation is necessary. Limiting values for this condition depend on a number of factors, including the highway function, resources available and local practice. Limiting values suggested by diferent researchers fall in a wide range of 5 to 35 percent, the average approaching 15 percent (Queiroz,1981a, p. 119).

The inference space in the crack progression analysis is governed by the ranges of the dependent and independent variables which are listed in Table 3.4. The correlation matrix of a select subset of variables included in the analysis is given in Table 3.5.

A number of functional relationships were investigated in order to develop models to predict the amount of pavement cracking. The three models which to best fit the data are:

1. <u>Independent variables include Benkelman beam deflections</u>

$$CR = -18.53 + 0.0456\ B \times LN + 0.00501\ B \times AGE \times LN \tag{3.2}$$

R squared : 0.644

Standard error : 12.616

CI = CR ± 25.28

TABLE 3.4 - MEAN, STANDARD DEVIATION AND RANGE OF THE VARIABLES USED IN THE CRACK PROGRESSION ANALYSIS

DESCRIPTION	MEAN	STANDARD DEVIATION	RANGE	
			MINIMUM	MAXIMUM
Number of Sections	28	-	-	-
- As Constructed	18	-	-	-
- Overlayed	10	-	-	-
Age During Observation Period (Years)	7.63	4.82	1.2	20.7
Benkelman Beam Deflection (0.01 mm)	63.8	27.0	34.0	132.0
Dynaflect Deflection (Sensor 1) (0.001 in.)	0.780	0.236	0.40	1.46
Surface Curvature Index (0.001 in.)	0.269	0.094	0.11	0.46
Base Curvature Index (0.001 in.)	0.108	0.034	0.05	0.20
Structural Number	3.76	0.91	1.90	6.50
Corrected Structural Number	5.55	0.79	3.70	7.50
Log_{10} Cumulative Equivalent Axles	5.75	0.64	4.30	7.27
Subgrade CBR	33.2	12.8	13.0	64.0
Percentage of Area Cracked	12.50	20.86	0.00	83.75

TABLE 3.5 - CORRELATION MATRIX OF VARIABLES INCLUDED IN THE CRACK PROGRESSION ANALYSIS

Variable	SNC	CBR	B	D	AGE	LN	CR
SNC	1.00	-.02	-.41	-.42	.35	.62	.04
CBR		1.00	-.13	-.11	-.30	-.31	-.18
B			1.00	.67	-.06	.01	.55
D				1.00	-.12	.16	.34
AGE					1.00	.49	.47
LN						1.00	.38
CR							1.00

Definition of symbols:

SNC = corrected structural number;
CBR = subgrade CBR;
B = mean Benkelman beam deflection (0.01 mm);
D = mean Dynaflect deflection (0.001 in.);
AGE = pavement age in years;
LN = $\log_{10}$ cumulative equivalent axles;
CR = percentage area cracked (%).

2. Independent variables include Dynaflect deflections

$$CR = -14.10 + 2.84\ D \times LN + 0.395\ D \times AGE \times LN \qquad (3.3)$$

R squared	:	0.439
Standard error	:	15.843

$CI = CR \pm 31.74$

3. Independent variables include corrected structural number

$$CR = -57.7 + 53.5\ LN/SNC + 0.313\ AGE \times LN \qquad (3.4)$$

R squared	:	0.345
Standard error	:	17.120

$CI = CR \pm 34.31$

where

CR = percentage area cracked;
B = mean Benkelman deflection (0.01 mm);
LN = logarithm to the base 10 of the number of cumulative equivalent axles;
AGE = pavement age since construction or overlay (years);
D = mean Dynaflect deflection (0.001 in.);
SNC = corrected structural number; and
CI = approximate 95 percent confidence interval.

Detailed regression results pertaining to Equation 3.2 to 3.4 are given in Tables 3.6 to 3.8, respectively. Stability of the regression coefficients was examined through ridge analysis. The corresponding ridge traces showed that the three equations developed have very high stability. It was not possible to obtain acceptable regression equations (in terms of statistical significance and stability of coefficients) involving other groups of independent variables.

TABLE 3.6 - REGRESSION ANALYSIS RESULTS FOR EQUATION 3.2

a) Analysis of Variance

	Degree of Freedom	Sum of Squares	Mean Square	F Ratio
Regression	2	21031	10515.7	66.07
Residual	73	11613	159.2	-

b) Regression Equation

Parameter	Estimate	Standard Error	F-Value
Intercept	-18.530	-	-
B x LN	4.564×10^{-2}	1.089×10^{-2}	17.55
B x AGE X LN	5.011×10^{-3}	7.226×10^{-4}	48.08

Multiple correlation coefficient squared : 0.644

Standard error for residuals : 12.616

TABLE 3.7 - REGRESSION ANALYSIS RESULTS FOR EQUATION 3.3

a) Analysis of Variance

	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Regression	2	14328	7164.2	28.54
Residual	73	18322	251.0	-

b) Regression Equation

Parameter	Estimate	Standard Error	F-Value
Intercept	-14.105	-	-
D x LN	2.843	1.278	4.95
D x AGE x LN	0.3948	0.0684	33.28

Multiple correlation coefficient squared : 0.439

Standard error for residuals : 15.843