

TABLE 3.8 - REGRESSION ANALYSIS RESULTS FOR EQUATION 3.4

a) Analysis of Variance

	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Regression	2	11254	5626.9	18.20
Residual	73	21397	293.1	

b) Regression Equation

Parameter	Estimate	Standard Error	F-Value
Intercept	-57.66	-	-
LN/SNC	53.47	16.96	9.94
AGE x LN	0.3126	0.0610	26.23

Multiple correlation coefficient squared : 0.345

Standard error for residuals : 17.120

As mentioned previously, an effort was also made to develop equations to predict the age when the percent of area cracked reaches a specified value. Only one statistically acceptable model could be derived from this part of the analysis:

$$\begin{aligned} \text{AGE} = & 11.46 - 0.0974 B + 0.1454 CR & (3.5) \\ & + 2.51 \times 10^5 CR / (RLA \times B) \end{aligned}$$

R squared : 0.418

Standard error : 3.751

CI = AGE \pm 7.51

where

RLA = rate of load applications, *i.e.*, average number of equivalent axles per year;

AGE = number of years since construction or overlay it will take a pavement to have a percent area cracked CR;

B = Benkelman beam deflection (0.01 mm); and

CI = approximate 95 percent confidence interval.

Detailed statistical results for Equation 3.5 are listed in Table 3.9.

3.3 INTERPRETATION OF CRACKING MODELS

3.3.1 Crack Initiation

Equation 3.1 predicts the number of equivalent 80 kN single axle loads to first crack, as a function of corrected structural number. The equation is graphically shown in Figure 3.1, along with the data points obtained from 19 test sections which first cracked during the study period.

As in other parts of the analysis conducted in this investigation, an effort was made to develop crack initiation models involving different groups of independent variables. However, no

TABLE 3.9 - REGRESSION ANALYSIS RESULTS FOR EQUATION 3.5

a) Analysis of Variance

	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Regression	3	728.76	242.92	17.27
Residual	72	1012.94	14.07	-

b) Regression Equation

Parameter	Estimate	Standard Error	F-Value
Intercept	11.457	-	-
B	-9.74×10^{-2}	2.01×10^{-2}	23.38
CR	14.54×10^{-2}	2.62×10^{-2}	30.89
CR/(RLA x B)	2.51×10^{-5}	9.62×10^4	6.83

Multiple correlation coefficient squared : 0.4184

Standard error for residuals : 3.7508

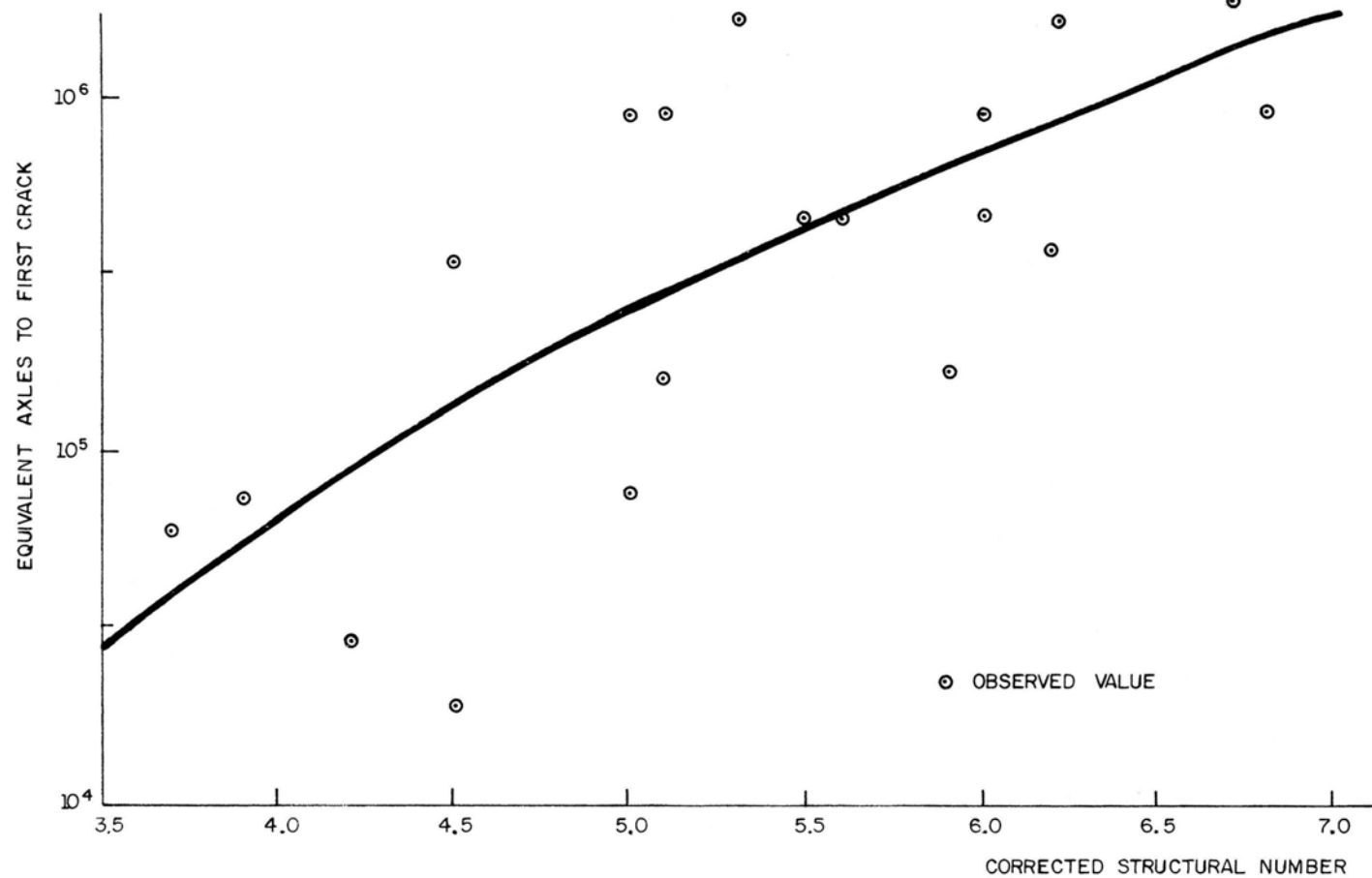


FIGURE 3.1 - NUMBER OF EQUIVALENT AXLES TO FIRST CRACK FOR ASPHALTIC CONCRETE PAVEMENTS, AS A FUNCTION OF CORRECTED STRUCTURAL NUMBER (EQUATION 5.1).

structural variable, other than corrected structural number, was able to explain the phenomenon of crack initiation in pavements. This fact could, to some extent be anticipated from inspection of the correlation matrix shown in Table 3.2, where very low correlation between deflection and cumulative number of equivalent axles (or age) to first crack is presented.

A number of test sections, including most of the surface treatment sections, did not show any sign of cracking during the study period. Therefore, these sections were not used in the crack initiation (nor crack progression) analysis. As data collection in the field is anticipated to continue, it is expected that crack initiation models, in terms of other structural variables, can be developed in future analysis. Then, the data base may be significantly augmented.

3.3.2. *Crack Progression*

Three models to predict the amount of cracking have been developed in terms of pavement age and traffic and one of the following: Benkelman beam deflection, Dynaflect deflection, or corrected structural number. Simultaneous inclusion of two structural variables into the equation, e.g., Dynaflect deflection and structural number, did not improve the equation significantly. In fact, this simultaneous inclusion caused high instability of the regression coefficients, as verified in the ridge analysis.

Equations 3.2 to 3.4 are relatively similar in form. Equation 3.2 is graphically shown in Figure 3.2, which demonstrates the effect of Benkelman beam deflection on the estimated amount of cracking over time. The figure was constructed assuming an average of 50,000 equivalent axle load applications per year.

It is clear that empirical models should be used at the bounds of the inference space only with extreme caution. It is evident, from Figure 3.2, that Equation 3.2 does not give accurate predictions at very low pavement ages and very high deflections. However, the equation does give suitable prediction accuracy in those applications where it is most needed; the region corresponding to the average limiting criterion of 15 percent cracking (as discussed

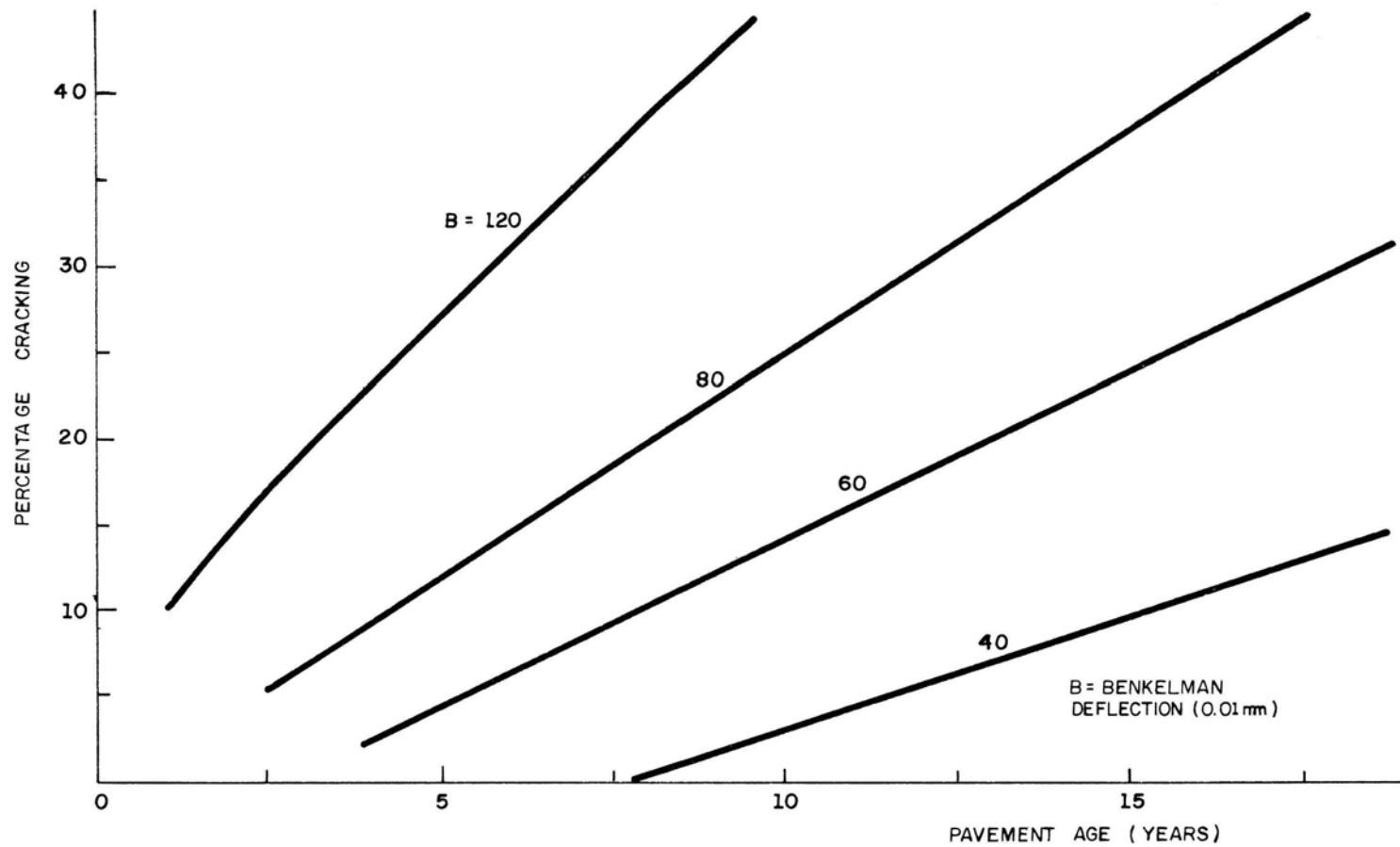


FIGURE 3.2- EXAMPLE OF PAVEMENT CRACKING ESTIMATED FROM EQUATION 3.2.

earlier) is close to the mean cracking value of 12.50 percent encountered in the inference space (see Table 3.4).

A model has also been developed to predict the age when the percent of area cracked reaches a specified value, *i.e.*, Equation 3.5. This equation is illustrated in two different examples presented in Figures 3.3 and 3.4. Figure 3.3 shows the influence of Benkelman beam deflection on the number of years it takes a pavement to develop different cracking levels. The figure was constructed assuming an average of 50,000 equivalent axle load applications per year.

The number of years it takes a pavement to develop 15 percent cracking, which is the cracking level corresponding to an average limiting criterion, is graphically shown in Figure 3.4, for different levels of the rate of load applications, as a function of Benkelman beam deflections. As expected, the age decreases as deflection or loading rate increases.

Because of the vicinity of the inference space bounds, Equation 3.5 does not give accurate predictions at very high deflections and very low cracking levels. However, the model is considered to have very good accuracy at the important level of 15 percent cracking, which is close to the mean of 12.50 percent cracking of the inference space.

3.4 EFFECT OF SLURRY SEAL

The cracking variable previously defined, CR, was the dependent variable studied to evaluate the effect of slurry sealing on pavement cracking. Class 4 cracks and potholes were, in general, patched before slurry seal applications. Therefore, they are not included in the slurry seal effect analysis.

Plots of the data were examined and the following observations made:

- 1) After a slurry seal there always existed a period of time when no cracks reappeared.
- 2) The length of time before the first appearance of crack was related to the amount of cracking on the subsection when it was sealed.

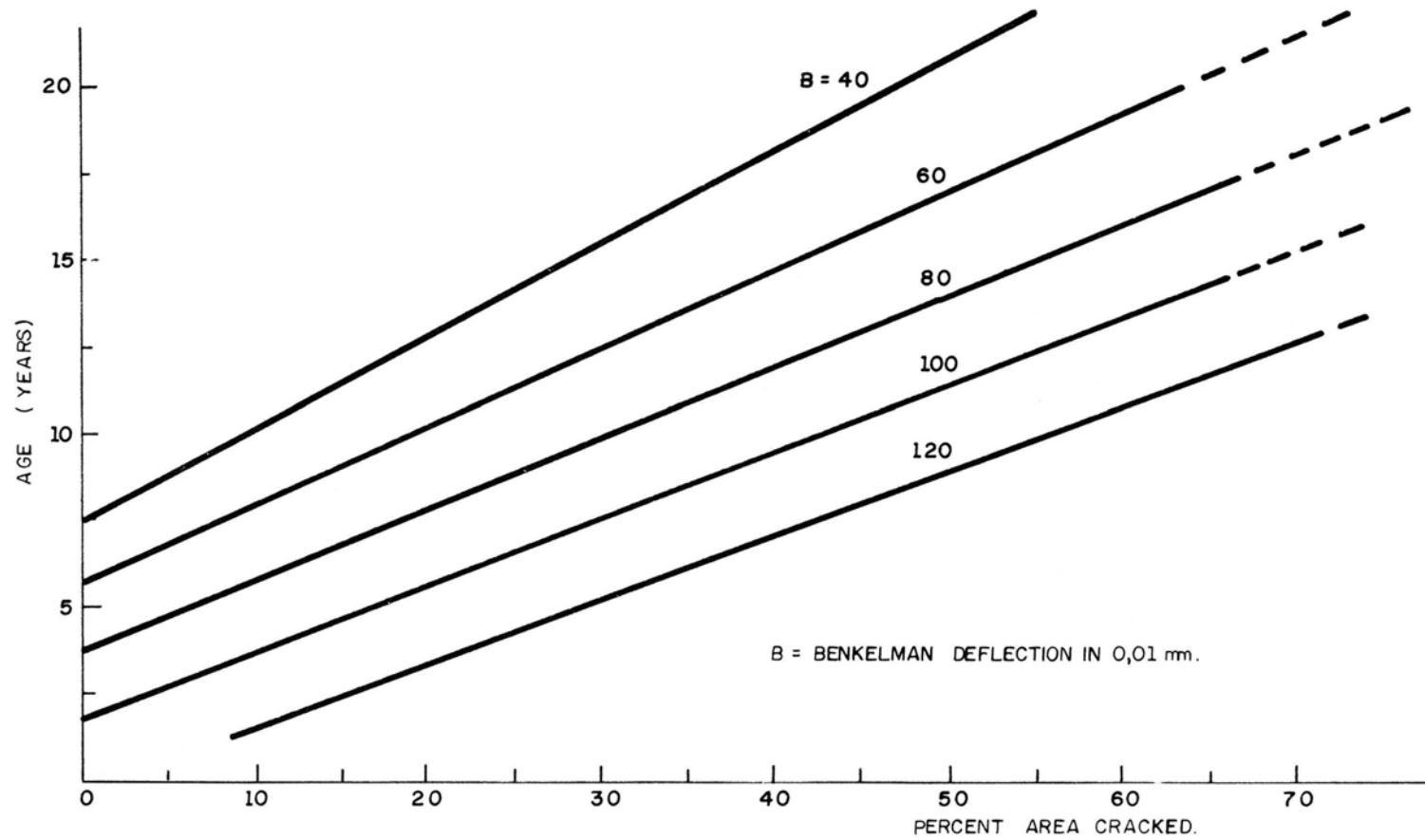


FIGURE 3.3 - EXAMPLE OF AGES TO DIFFERENT LEVELS OF CRACKING PREDICTED BY EQUATION 3.5.

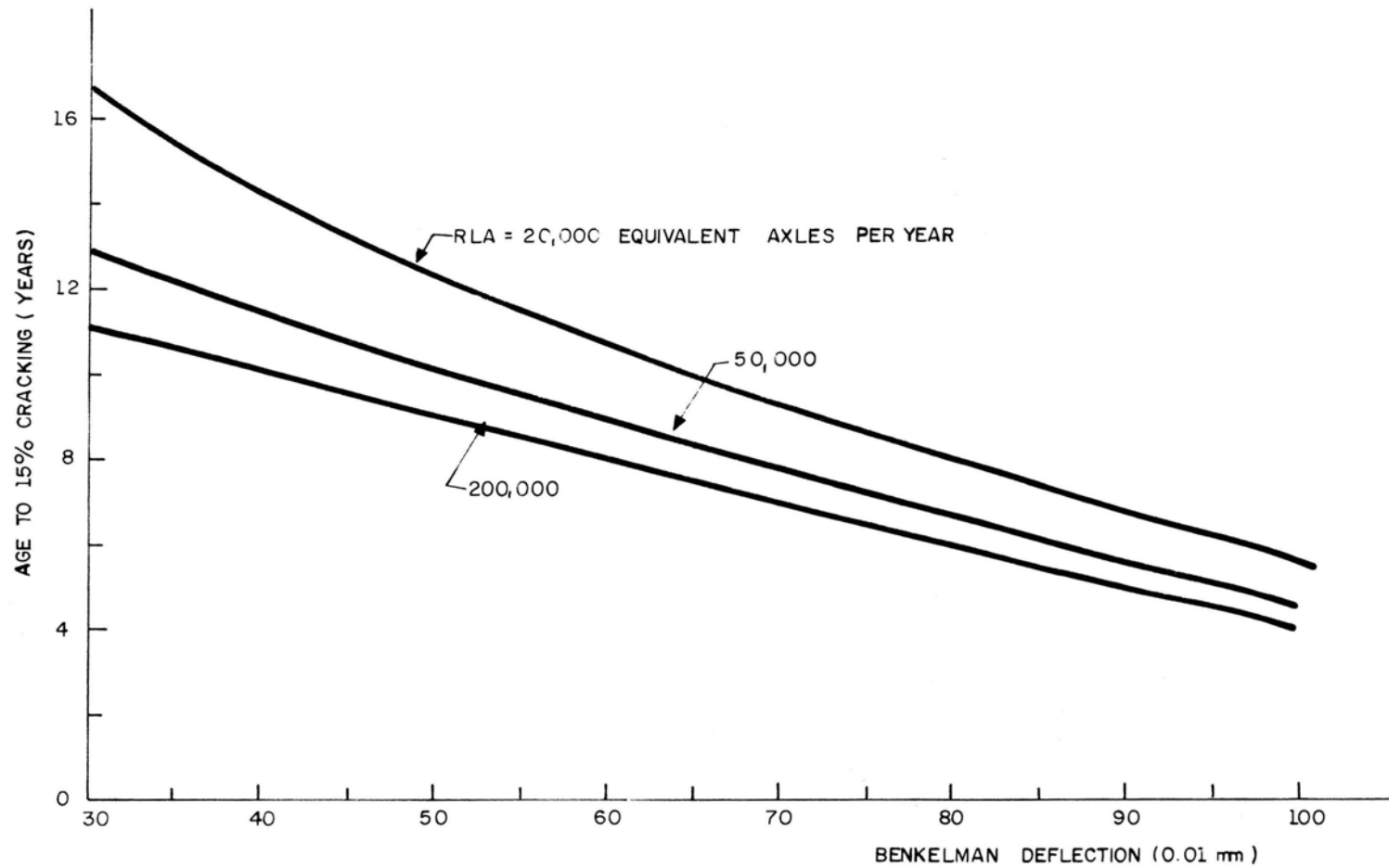


FIGURE 3.4 - PAVEMENT AGE AT 15 PERCENT CRACKING AS PREDICTED BY EQUATION 3.5.

The effects of grade, overlay, base type, number of equivalent axles per year, structural number, and CBR of the subgrade were investigated and found to be nonsignificant at $\alpha = 0.1$. The development of more realistic models to predict the effect of slurry sealing on pavement cracking will require data collection over longer time periods and further analysis.

The model found to best describe the progression of cracking after a slurry seal was applied is:

$$CR = T (0.219 B + 1.43 CR_0) \quad (3.6)$$

R squared : 0,770

Standard error for residuals : 0,130

where

CR = percentage area cracked;

B = Benkelman beam deflection (0.01 mm);

CR_0 = the last observed value of CR before slurry sealing;

$T = 0$ if $A_0 - (A_s + 10/CR_0) \leq 0$,

$T = A_0 - (A_s + 10/CR_0)$ otherwise;

A_0 = pavement age when it is being observed;

A_s = pavement age when it is slurry sealed ($A_0 > A_s$).

The t-values in Equation 3.6 are 2.80 and 6.34 for B and CR_0 respectively.

The equation shows that once cracks appear after slurry sealing, their rate of increase is relatively high.

3.5 RUT DEPTH STUDY

The objective of this part of the study was to develop models to predict rut depth as a function of age and structural and

traffic variables. The mean, standard deviation and range of variables studied is presented in Table 3.10. The observed rut depths on the test sections were very low (maximum of 7.4 mm).

Haas and Hudson (1978) indicated that the major possible effects of excessive rutting on the road user are:

1. hydroplaning;
2. loss of vehicle control; and
3. freezing of ponded water resulting in icy conditions.

Of course, the last effect is not a factor of importance for Brazilian conditions. There are no absolute limiting values to avoid the foregoing safety hazards, nor can researchers and practicing engineers generally agree as to a limiting criterion for maximum allowable rut depth, as discussed by Queiroz (1981).

Although the limiting criterion for pavement rut depth varies among authors, it falls within the range of 10 to 25 mm. As mentioned earlier, rutting was found to be very slight in the study area, with an average of 2.5 mm. This means that rut depth probably will not act as a trigger to initiate maintenance on the pavements studied in this investigation.

Empirical models apply to the inference space governed by the observed variables. Thus, any rut depth prediction model developed from the data currently available will apply for rut depths below 7.4 mm, as shown in Table 3.10. However, as previously demonstrated, it is important to predict rut depths of at least 10 mm, in order that the prediction models find practical application. Therefore, no attempt has been made in this investigation to develop equations to predict pavement rutting.

3.6 SUMMARY AND CONCLUSIONS

Models were developed to predict asphaltic concrete pavement cracking. Two separate analyses were carried out to yield crack initiation and crack progression models. The resulting regression equations are useful to predict:

TABLE 3.10 - MEAN, STANDARD DEVIATION AND RANGE OF VARIABLES STUDIED TO EVALUATE RUT DEPTH

Variable	Mean	Standard Deviation	Minimum	Maximum
Number of sections	45	-	-	-
Age (years)	7.71	4.80	1.5	20.5
Benkelman beam deflection (mm)	0.78	0.43	0.17	2.13
Corrected structural number	5.00	0.88	3.40	7.50
Log ₁₀ cumulative equivalent axles	5.56	0.74	3.20	7.23
Rut depth (mm)	2.53	0.90	0.40	7.40

1. the number of cumulative equivalent 80 kN single axle loads to first crack, as a function of corrected structural number;
2. the degree of cracking as a function of Benkelman beam deflection, traffic, and age;
3. the degree of cracking as a function of Dynaflect deflection, traffic, and age;
4. the degree of cracking as a function of corrected structural number, traffic, and age;
5. the pavement age at a specified percentage cracking as a function of Benkelman beam deflection, rate of axle load applications, and the degree of cracking, and
6. the effect of slurry sealing on pavement cracking.

The models developed are acceptable with respect to the traditional statistical criteria of levels of significance, and have highly stable regression coefficients, as evaluated through ridge analysis.

Rutting was found to be very slight in the study area. This means that rut depth probably will not act as a trigger to initiate maintenance on the pavements studied in this investigation. Any rut depth prediction model derived from the data base currently available would not apply to the range of interest in practical applications. Thus, no equation was developed to predict rut depth.