CHAPTER 2 - PAVED ROAD ROUGHNESS ANALYSIS

2.1 INTRODUCTION

Since the AASHO Road Test, where the concept of pavement serviceability was developed by Carey and Irick (1960), increasing importance has been given to user-related pavement evaluation. This type of evaluation is concerned primarily with the overall function of the pavement, that is, how well it serves traffic or the riding public.

The serviceability of a pavement is largely a function of its roughness (Haas and Hudson, 1978), and several models can be found in the literature to estimate serviceability as a function of roughness (HRB, 1964; Walker and Hudson, 1973). Moreover, it has been demonstrated that roughness is the principal measurement of pavement condition directly related to vehicle operating costs (Hide *et al.*, 1975; Wyatt *et al.*, 1979). Consequently, a major effort is devoted in this study to develop (1) pavement roughness prediction models and (2) a procedure through which the roughness standard used can be transferred among different regions or countries, based on rod and level measurements of roadway profiles. The latter subject is discussed by Queiroz (1981a, 1981b). This chapter presents an empirical analysis of roughness data collected in order to develop roughness predictive models for asphaltic pavements.

2.2 ROUGHNESS PREDICTION MODELS

Roughness was expected to be a function of pavement structural variables, traffic loads and volumes, and environment. The pavement test sections in our study were located in a relatively narrow geographic area. There was very little variation in the environmental parameters, rainfall and temperature, and consequently these factors were not considered in the analysis. However, the implicit influence of the environment over time was considered since the pavement age was included and found to significantly affect roughness.

Traffic loads and volumes were combined to give the number of cumulative equivalent 80 kN axles. Seven groups of variables describing pavement strength were included in the analysis. These variables are: (a) pavement structural variables, consisting of the structural number, structural number corrected for the subgrade resistance; and subgrade, sub-base and base CBR; (b) Benkelman beam deflection; (c) Dynaflect deflection and curvature indexes; (d) a combination of (a) and (b); (e) a combination of (a) and (c); (f) a combination of (b) and (c); and (g) a combination of (a), (b), and (c).

The inference space for this analysis is governed by the ranges of the dependent and independent variables which are listed in Table 2.1. The definition of symbols used in this part of the study is given in Table 2.2. Table 2.3 shows the correlation matrix of variables included in the analysis.

The roughness prediction models which best fits the data are presented next, according to the group of independent variables used.

1. <u>Equation including structural number</u>

$$LQI = 1.487 - 0.1383\ RH + 0.00795\ AGE + 0.0224\ (LN/SNC)^2 \qquad (2.1)$$

R squared : 0.259

Standard error for residuals : 0.135

where

LQI = decimal logarithm of quarter-car index, i. e., $\log_{10}$ QI*;

RH = state of rehabilitation indicator:
= 0 as constructed,
= 1 overlayed;

AGE = number of years since construction or overlay;

LN = logarithm to the base 10 of the number (N) of cumulative equivalent axles; and

SNC = structural number corrected for the subgrade strength.

TABLE 2.1 - SUMMARY STATISTICS OF VARIABLES USED IN THE ANALYSIS OF ROUGHNESS DATA

Variable	Mean	Standard Deviation	Minimum	Maximum
QI*	39.0	15.2	18.0	95.0
SN	2.8	1.0	1.0	6.5
SNC	4.6	1.1	1.8	7.5
LN	5.5	0.7	2.7	7.2
B (0.01 mm)	64.5	24.3	32.0	128.0
D (0.001 in.)	0.91	0.28	0.40	1.56
SCI (0.001 in.)	0.33	0.13	0.11	0.77
BCI (0.001 in.)	0.12	0.04	0.05	0.20
AGE (years)	7.1	4.6	1.1	20.3
P (%)	0.08	0.50	0.00	4.60

NOTE: Variable symbols are defined in Table 2.2.

TABLE 2.2 - DEFINITION OF SYMBOLS USED IN THE ANALYSIS OF ROUGHNESS DATA

Symbol	Variable
QI*	Roughness measured with a Maysmeter and converted into quarter-car index through a calibration equation (counts/km).
SN	Pavement structural number.
SNC	Structural number corrected for the subgrade resistance.
LN	Logarithm to the base 10 of the number of 80 KN cumulative equivalent axles.
B	Benkelman beam mean deflection (0.01mm).
D, SCI, BCI	Dynaflect maximum deflection, surface curvature index, and base curvature index (0.001 in.).
AGE	Surface age since construction or overlay (years).
P	Percent area of the pavement which received repairs in the form of deep patches (%).
ST	Surface type dummy variable: ST = 0 asphaltic concrete; ST = 1 double surface treatment.
RH	State of rehabilitation dummy variable: RH = 0 as constructed; RH = 1 overlayed.

TABLE 2.3 - CORRELATION MATRIX OF VARIABLES USED IN THE ANALYSIS OF ROUGHNESS DATA

Variable	QI*	SN	SNC	LN	B	D	AGE	P
QI*	1.00	-.32	-.32	.00	.48	.28	.24	.26
SN		1.00	.97	.29	-.17	-.36	.05	-.06
SNC			1.00	.28	-.14	-.32	-.01	-.07
LN				1.00	-.03	-.06	.44	.05
B					1.00	.60	.03	.33
D						1.00	-.01	.12
AGE							1.00	.15
P								1.00

NOTE: Variable symbols are defined in Table 2.2.

Detailed statistical results pertaining to Equation 2.1 are given in Table 2.4. The ridge trace, in Figure 2.1, shows the high stability of the regression coefficients (Chatterjee and Price, 1977). Included in this figure is the coefficient for ST, a surface type indicator variable, which was subsequently deleted. This coefficient value is very close to zero, as can be observed in Figure 2.1, and is not significant even at the 25 percent level, as demonstrated by its F-value.

Assuming normality of residuals, an approximation to the 95 percent confidence interval about the mean roughness predicted by Equation 2.1 is:

$$CI = LQI \pm 0.27 \text{ or } 0.54QI^* \text{ to } 1.86\ QI^*$$

As an example, if the roughness value estimated from Equation 2.1 is 60, the corresponding 95 percent confidence interval lies between QI* values of 32 and 112 counts/km.

2. Equation including Benkelman beam deflection

$$QI^* = 21.8 - 7.52\ RH + 5.16\ ST + 0.515\ AGE + 7.22 \times 10^{-5}(B \times LN)^2 \quad (2.2)$$

R squared : 0.484

Standard error for residuals : 10.584

where

QI* = quarter-car index (counts/km);

ST = surface type dummy variable:

= 0 asphaltic concrete;

= 1 surface treatment; and

B = Benkelman beam deflection (0.01 mm).

Other symbols were defined previously. Detailed statistical results for Equation 2.2 are given in Table 2.5. All regression coefficients

TABLE 2.4 - REGRESSION ANALYSIS RESULTS FOR EQUATION 2.1

a) Analysis of Variance

	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Regression	3	0.4687	0.1562	8.63
Residual	74	1.3399	0.0181	

b) Regression Equation

Parameter	Estimate	Standard Error	F-Value
Intercept	1.47842		
RH	-0.13827	0.04726	8.56
$(LN/SNC)^2$	0.02244	0.01222	3.37
AGE	0.00795	0.00347	5.24

R squared : 0.259
Standard error for residuals: 0.135

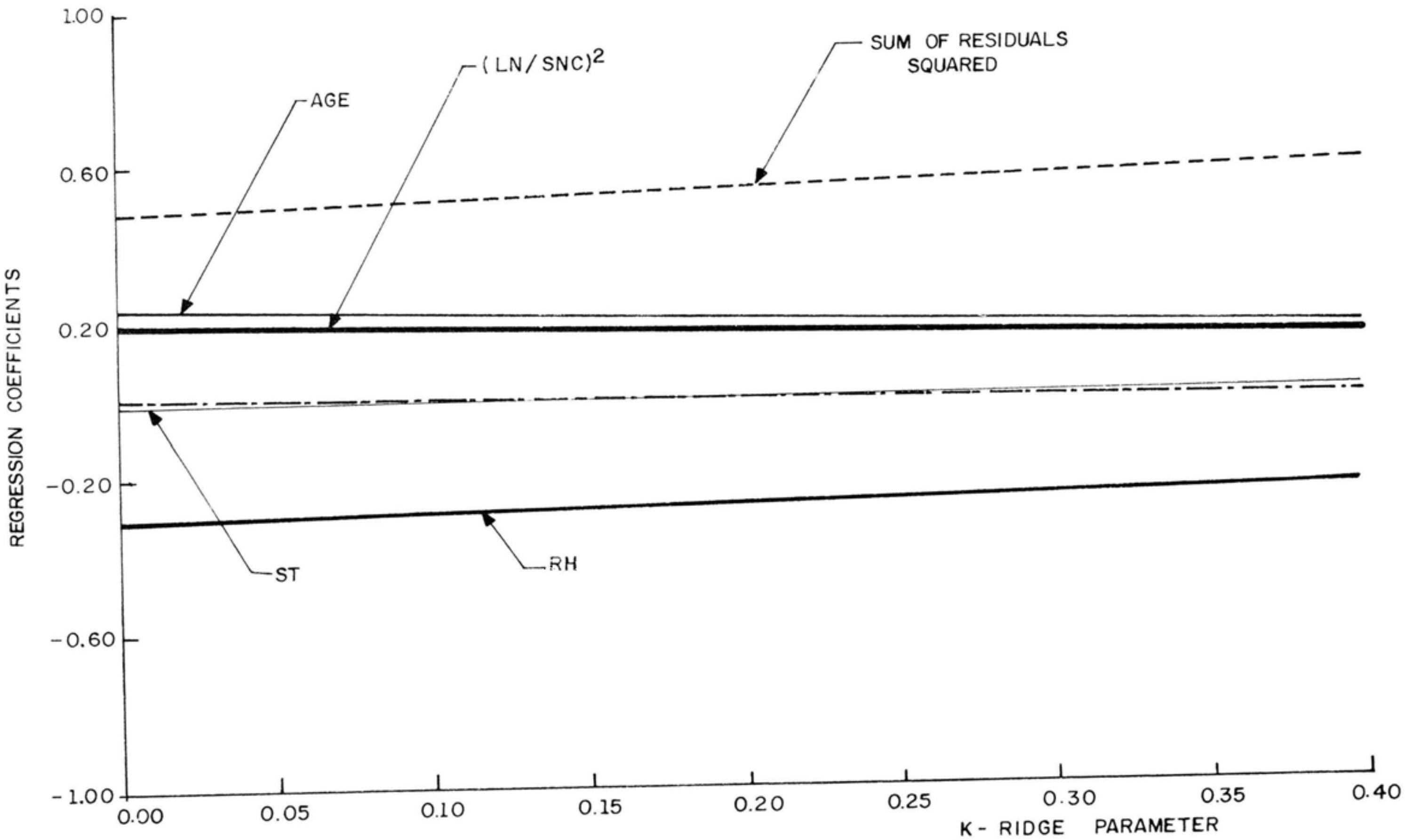

FIGURE 2.1- RIDGE TRACE FOR EQUATION 2.1.