TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-90/473-3F		

4. Title and Subtitle	5. Report Date
A Microcomputer Based Procedure for Load-Zoning Determination on Low-Volume Roads	November 1989
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
B. Lanka Santha, Weishih Yang, and Robert L. Lytton	Research Report 473-3F
9. Performing Organization Name and Address	10. Work Unit No.
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	11. Contract or Grant No. Study No. 2-18-87-473
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	Final - September 1986 August 1989
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.
Research Study Title: Investigation of the Effects of Raising Legal Load Limits to 80,000 lbs. on Farm-to-Market Roads

16. Abstract

A computerized procedure, LOADRATE Version 2.0, for the strucutal evaluation of light pavement structures has been developed by the Texas Transportation Institute. This report describes the improved version of the LOADRATE program, its User's Guide, and its applications with case studies. The LOADRATE program is a nondestructive procedure which uses data obtained from the Falling Weight Deflectometer (FWD) or the Dynaflect to evaluate the pavement condition.

The new version of LOADRATE program uses a simple mechanistic procedure to calculate the rut depth for a given number of 18 kip equivalent single axle load passes and vice versa. It is able to handle sandy subgrades by adding a nonlinear "modulus" versus "deviator stress" relationship in the data base for the sandy subgrades. The LOADRATE 2.0 can be used to predict the remaining life of pavement sections, and it also provides estimates for allowable axle loads for test sections. In addition, a capability of making temperature and moisture corrections for the base course modulus is also added to the program. Case studies are provided to demonstrate the use of the LOADRATE procedure for structural evaluation and load-zoning of light pavements.

17. Key Words	18. Distribution Statement
Load-Zoning, Low-Volume Roads, NDT Rut Depth Prediction, Temperature and Moisture Correction of Base Moduli	No restrictions. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	106	

Form DOT F 1700.7 (8-69)

A MICROCOMPUTER BASED PROCEDURE FOR LOAD-ZONING DETERMINATION ON LOW-VOLUME ROADS

by

B. LANKA SANTHA, WEISHIH YANG, and ROBERT L. LYTTON

Research Report 473-3F

Investigation of the Effects of Raising Legal
Load Limits to 80,000 lbs on Farm-to-Market Roads

Research Study 2-18-87-473

Conducted for

Texas State Department of Highways and Public Transportation

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

by the

Texas Transportation Institute
The Texas A&M University System
College Station, Texas

November 1989

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

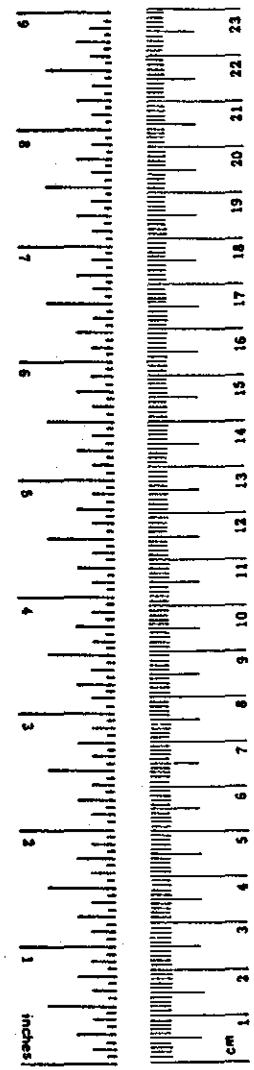
VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac

MASS (weight)

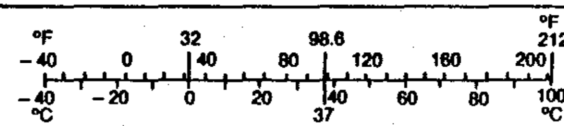
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

ABSTRACT

A computerized procedure, LOADRATE Version 2.0, for the structural evaluation of light pavement structures has been developed by the Texas Transportation Institute. This report describes the improved version of the LOADRATE program, its User's Guide, and its applications with case studies. The LOADRATE program is a nondestructive procedure which uses data obtained from the Falling Weight Deflectometer (FWD) or the Dynaflect to evaluate the pavement condition.

The new version of LOADRATE program uses a simple mechanistic procedure to calculate the rut depth for a given number of 18 kip equivalent single axle load passes and vice versa. It is able to handle sandy subgrades by adding a nonlinear "modulus" versus "deviator stress" relationship in the data base for the sandy subgrades. The LOADRATE 2.0 can be used to predict the remaining life of pavement sections, and it also provides estimates for allowable axle loads for test sections. In addition, a capability of making temperature and moisture corrections for the base course modulus is also added to the program. Case studies are provided to demonstrate the use of the LOADRATE procedure for structural evaluation and load-zoning of light pavements.

SUMMARY

As a result of increasing traffic volumes and heavier trucks, the low volume roads have gained much attention from various highway agencies. The Texas State Department of Highway and Public Transportation is looking for a fast and efficient way to evaluate the structural adequacy of any light pavement structures, especially for the purpose of load-zoning. An efficient nondestructive testing procedure is needed to determine the damage to pavements by its traffic.

The objective of this study is to develop a swift, accurate, efficient, and practicable procedure using nondestructive testing methods, which if possible, can be correlated with the Texas Triaxial Test results, to determine the structural characteristics of farm-to-market roads. This procedure will (a) evaluate the effects of the increase in the legal load limit to 80,000 lbs. (GVW) in terms of the reduction in design life as well as structural adequacy and (b) present a basis for the computation of the requirements for pavement strengthening so that load restrictions can be removed.

A computerized procedure for the evaluation of light pavements, LOADRATE Version 2.0, has been developed by the Texas Transportation Institute (TTI). This report describes the improved version of the LOADRATE program and its applications with case studies.

The new version of LOADRATE program uses a simple mechanistic procedure to calculate the rut depth for a given number of passes of a wheel load or a multiple-axled vehicle and vice versa. It can be used to predict the remaining life of pavement sections and provides a direct measure of pavement condition. In addition, a capability of making temperature and moisture corrections for the base course modulus is also added to the program. It allows the user to evaluate the effect of seasonal variations of the base course moduli on the life of the pavement, if required. Other significant improvements of the new version of LOADRATE are the incorporation of a nonlinear modulus versus deviator stress relationship for sandy subgrades and the reconstruction of the database used in the program. The nonlinear elastic properties of the base course and the subgrade can be better determined from these improvements. Input/Output have been improved. The LOADRATE program is a nondestructive procedure which uses data obtained from the Dynaflect or the Falling Weight Deflectometer (FWD) to evaluate the pavement condition. Case studies were used to demonstrate the use of the new LOADRATE program.

IMPLEMENTATION STATEMENT

The report describes the development of a microcomputer based program to determine the load-zoning for low volume roads. The computer program named LOADRATE Version 2.0 uses results obtained from the Falling Weight Deflectometer or the Dynaflect to calculate the remaining life for a given rut depth. The allowable axle loads for single, tandem, and triple axles are reported at the end of the analysis. The LOADRATE Version 2.0 is ready for use in the structural evaluation of farm-to-market roads at the project level.

DISCLAIMER

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I
INTRODUCTION

Most of the pavements in the United States are light pavement structures which are commonly referred to as rural roads or low volume roads. In the State of Texas, these roads are farm-to-market (FM) roads, most of which are basically two-layer pavement systems which consist of a granular base layer covered with a thin asphalt surface treatment laid over in-situ or improved subgrade. The surface treatment acts as a wearing course as well as a waterproofing course. As a result of heavier trucks and higher traffic volumes, these roads have gained much attention from various highway agencies. At this point, there is a decisive need for a fast and efficient way to evaluate the structural integrity of these light pavement structures, especially for the purpose of load-zoning. The agencies responsible must be able to evaluate the structural adequacy of any light pavement structure when considering load-zoning. Therefore, an efficient, nondestructive testing procedure is required to determine the traffic damage to pavements.

The objective of this study is to develop a swift, accurate, efficient, and practicable procedure using nondestructive testing methods, which if possible can be correlated with the Texas Triaxial Test results, to determine the structural characteristics of farm-to-market roads. This procedure will (a) evaluate the effects of the increase in the legal load limit to 80,000 lbs. (GVW) in terms of the reduction in design life as well as structural adequacy and (b) present a basis for the computation of the requirements for pavement strengthening so that load restrictions can be removed.

A mechanistic modelling approach has been developed for this purpose. It involves a computerized procedure to analyze data obtained from the Dynaflect or the Falling Weight Deflectometer (FWD). With other information (e.g., traffic data, base course thickness, and subgrade material type) of pavement sections, the remaining-life, the number of passes to achieve a specified rut depth, and the elastic moduli of the base course and subgrade can be determined. The remaining life determination is based on a rut depth accumulation which is the criterion of acceptability. Rut depths are caused by the accumulating pavement deformation under repeated load applications. Each time a load passes, the pavement rebounds less than it was deflected under load. With repeated loading and unloading sequences, each layer accumulates a significant amount of permanent deformation. Rutting in the wheel path is not only uncomfortable to motorists, but also can cause hydroplaning of vehicles under wet conditions.

This report describes improvements of a computerized procedure, LOADRATE Version 2.0, for evaluating light pavements and demonstrates its applications with case studies. The flow chart of the LOADRATE program is given in Figure 1.

The LOADRATE program was developed by TTI (1,2) to use the deflection basin obtained from either the Falling Weight Deflectometer (FWD) or the Dynaflect to determine the nonlinear elastic properties of the base course and the subgrade (3). The LOADRATE program has been further revised to improve its capabilities and accuracy. In the new version of LOADRATE, the rut-depth calculation is achieved using a new approach developed by Yapa and Lytton (4). The capability of making temperature and moisture corrections for the base course modulus is also added to the program (5). The temperature and moisture correction capability allows the user to evaluate seasonal variations of the base course, if required. Finally, a significant improvement of the new version of LOADRATE is the incorporation of a 5^{th} curve to the ILLI-PAVE (6,7) subgrade model and the reconstruction of the database used in the program. The nonlinear elastic properties of the base course and the subgrade can be better determined from these improvements. In addition to the above theoretical improvements, the new LOADRATE program also provides better outputs. It calculates the remaining life in years to cause a given rut depth. It also provides several graphic capabilities such as plots of base moduli, subgrade moduli, number of passes and remaining life for all pavement sections.

The LOADRATE program has been custom-built into a system for the Texas Department of Highways and Public Transportation. Dynaflect data analysis is made possible by the correlation between the readings of the two devices. The LOADRATE program development is based on FWD specifications and a FWD load level of 10,956 lbs; therefore, the new version will usually yield better results from analyzing FWD data than from Dynaflect data.

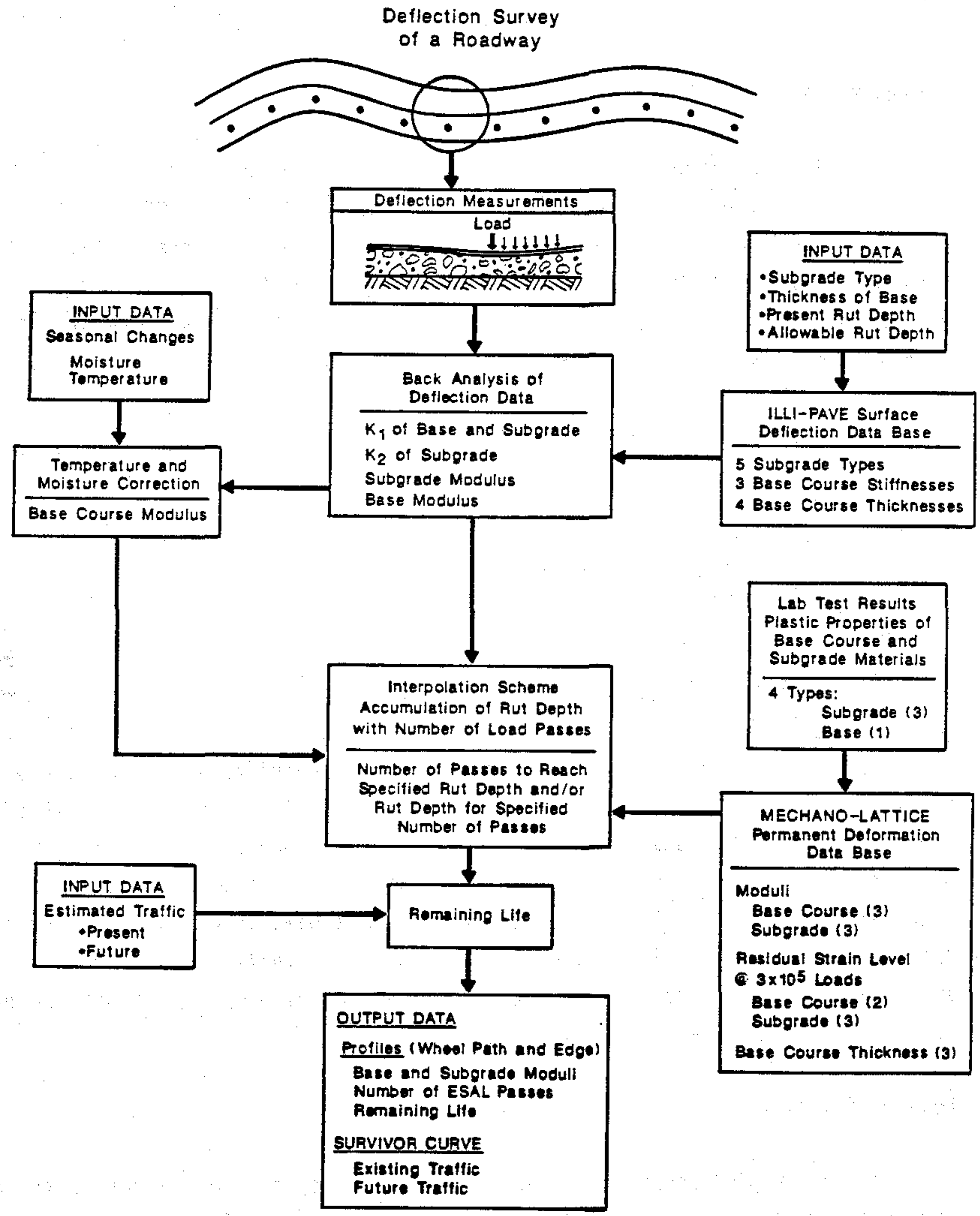


Figure 1. Flow Chart of the LOADRATE Program.

CHAPTER II
LOADRATE PROGRAM

Pavement Material Properties

The thin surface course of the pavement does not contribute much in terms of pavement rigidity. An assumed modulus of 30,000 psi was used in the analysis for surface courses of 1-inch thickness or less. This assumption is reasonable although the actual value of the surface course modulus has virtually no influence on the results. The elastic modulus of the base course material is expressed as

$$E = k_1 \theta^{k_2} \qquad (1)$$

where

θ = the bulk stress, or the sum of the principal stresses,

K_1 = modulus coefficient and

K_2 = modulus exponent, assumed to be 0.33 (1).

The subgrade properties are described by five curves shown in Figure 2. These five nonlinear relationships represent very soft, soft, medium, stiff and very stiff subgrades. The fifth curve, for a sandy subgrade, was developed because of the need to represent these stiff subgrades. A description of the development of the fifth curve will be discussed later in this paper. The other four curves have been successfully used in the ILLI-PAVE (6, 7). A summary of the pavement material properties used in the analyses with ILLI-PAVE is given in Table 1.

Load Deflection Model

The load-deflection relationship of layered systems was investigated by Burmister (8, 9) in the 1940's. He adapted Boussinesq's (1885) theory of distribution of stresses in an elastic half-space under the compressive action of a rigid body to include a layered system. Subsequently, many computerized

Table 1. Material Properties Used in ILLI-PAVE Runs.

			Subgrade				
Property	Surface Course	Base Course	Very Stiff	Stiff	Medium	Soft	Very Soft
Unit Weight (pcf)	145.00	135.00	110.00	125.00	120.00	115.00	110.00
Lateral Pressure Coefficient at Rest	0.87	0.60	0.82	0.82	0.82	0.82	0.82
Poisson's Ratio		0.38	0.45	0.45	0.45	0.45	0.45
Unconfined Compressive Strength (psi)			32.80	32.80	22.85	12.90	6.21
Deviator Stress (psi)							
Upper Limit			32.80	32.80	22.85	12.90	6.21
Lower Limit			2.00	2.00	2.00	2.00	2.00
Deviator Stress at Break Point (psi)			6.20	6.20	6.20	6.20	6.20
Initial Elastic Modulus (ksi)			24.00	12.34	7.68	3.02	1.00
Elastic Modulus at Failure (ksi)			9.392	7.605	4.716	1.827	1.00
Constant Elastic Modulus (psi)	30,000						
Friction Angle (degrees)		40.0	30.0	0.0	0.0	0.0	0.0
Cohesion (psi)		0.0	0.0	16.4	11.425	6.45	3.105

systems of closed form solution were developed. These solutions assume linearly elastic material properties.

Numerical approaches such as the finite element method are more versatile and are able to simulate both linearly and nonlinearly elastic materials. In the analysis, the body under consideration is divided into a set of elements which are connected at their nodal points. From the material property assumed, that is, the force-displacement relationship, the stiffness at each nodal point is specified. By expressing the nodal force in terms of displacements and stiffnesses, the equilibrium equations for each nodal point can then be solved to obtain the displacements. The stress and strains in each element can then be computed.

ILLI-PAVE (6,7), a finite element program, was used in the LOADRATE to model the load-deflection relationship. ILLI-PAVE models an asymmetrical solid of revolution and allows for linear as well as nonlinear stress-dependent elastic moduli for granular and fine-grained soil. This program has been shown to be adequate in predicting the flexible pavement response to load by comparing the results of computer modeling and field test data (10).

Rut Depth Prediction Model

In original LOADRATE program (1, 2), the number of passes of a given wheel load (P) to cause a given rut-depth (R) can be calculated by the following equation:

$$N = \frac{R}{(\Delta - A \times P/\text{Multiplier})} \qquad (2)$$

where the multiplier is the ratio of the slope of the unloading path to that of the initial slope of the load deflection curve. The multiplier is described by the following equation:

$$\text{Multiplier} = 1 + 1.2 \times 10^{5}[9000\ A / (1-9000\ B)]^{-0.65} \qquad (3)$$

A and B are the coefficients determined by the load deflection equation. The multiplier was based on observed field data.

The new version of LOADRATE program uses a simple mechanistic procedure (4, 11) to calculate the rut depth and number of passes. There are a number of models to relate the plastic strain accumulation with the number of load repetitions. Yapa et al.(4) gives a detailed description of these models. The rut-depth model in the latest version of LOADRATE uses a relationship given by the following equation:

$$\epsilon_p = a N^b \tag{4}$$

where

ϵ_p = total residual strain at the end of N cycles and

a, b = material constants.

Equation 4 can be expanded to get a linear relation in a log-log plot between the accumulated permanent strain and the number of load applications (12, 13). It changes to

$$\log \epsilon_p = \log a + b \log N \tag{5}$$

Yapa (4) used the data obtained from a series of laboratory tests and published literature to develop atypical values for the material constants "a" and "b" for various types of soils. The unified soil classification is used to categorize the soil types for this purpose. The subgrade materials are divided into three groups. They include heavy clay (CH-clay), light or silty clay and clayey silt (CL-ML) and clayey silt or uniform sand (SC-SM). All the granular materials used for the base course were considered as one group. The average "b" values for CH-clay, CL-ML group, SC-SM group and base course material were 0.236, 0.162, 0.142 and 0.125 respectively. A curve fitting technique was used to describe the behavior of the "a" values with respect to the resilient modulus for the above mentioned four groups of materials. Table 2 shows the "a" and "b" values for these soil groups in the rut-depth model. A total of 162 Mechano-lattice (14, 15, 16) runs were made in order to build the data base. The required inputs for these runs were the elastic moduli of both the base course and subgrade, the accumulated residual strain of both the base course and the subgrade, and the thickness of the base layer. The input parameters were varied over a wide range (Table 3), and this enables the database to cover all possible types of low volume roads. For each computer run, the depression caused in the wheel path by 300,000 load repetitions of a 9,000 lb single wheel load was obtained. This value represents the rut depth. In the new LOADRATE program, the rut-depth value for a particular road is predicted using a multidimensional polynomial interpolation routine (17) with a data base developed by the Mechano-lattice runs.

Temperature and Moisture Correction Model

The latest version of the LOADRATE program is able to correct the base modulus for temperature and moisture variation. The theoretical procedure was described by Chandra et al.(5). Basically, the procedure has two models, namely, thermal and moisture models. The thermal model requires as input material type, modulus, coefficient of thermal expansion, and Possion's ratio at the reference temperature of the base course material. The moisture model requires reference suction values in psi. Each model computes the change of modulus due to temperature and suction changes separately. Addition of the two modulus changes gives the net modulus change.

The Thermal Model

The thermal model is based on the micro-mechanical approach which treats the granular materials as elastic spheres in contact subjected to temperature changes. In this model, the soil particles are assumed to be confined in all directions. An increase in temperature will cause an increase in the contact forces between particles, and this leads to an increase of the stiffness of soil. As stated earlier, the resilient modulus and bulk stress relationship for granular materials is given in Equation 1. The change of modulus (ΔE) with respect to a change of bulk stress ($\Delta\theta$) is obtained by taking the derivative of Equation 1, which is

$$\Delta E = K_1 K_2 \, \theta^{k_2 - 1} \, \Delta\theta \qquad (6)$$

Table 2. Rutting Parameters for Pavement Materials.

Material	Rutting Parameter Intercept a x 10⁴	Rutting Parameter Slope b
Base Course	174 $M_R^{-0.57}$	0.125
Subgrade		
Heavy Clay (CH-clay)	933 $M_R^{-2.84}$	0.236
Clayey Silt/Silty Clay (CL-ML)	10 $M_R^{-0.73}$	0.162
Clayey/Silty Sand (SC-SM)	750 $M_R^{-1.62}$	0.142

* M_R - Resilient Modulus (in ksi)

Table 3. Input Parameters for Mechano-Lattice Runs.

Parameter	Unit	Level 1	Level 2	Level 3
Resilient Modulus	psi			
- Base Course		100,000	70,000	40,000
- Subgrade		25,000	15,000	5,000
Accumulated Residual Strain	in/in			
- Base Course		0.0075	0.0025	
- Subgrade		0.0100	0.0060	0.0020
Base Thickness	in	18.0	12.0	6.0

It is clear that an increase in temperature will cause an increase in the stiffness which will depend on the initial level of confining pressure and on the material properties. Chandra et al. (5) derived the hydrostatic pressure (P) due to a change of temperature (ΔT) as:

$$P = (X / \sqrt{2}\,\omega + (1 - X) / 4\omega)\ (0.333\ \alpha_v\ \Delta T)^{3/2} \qquad (7)$$

where

X = fraction of close-packed spheres

α_v = cubical thermal coefficient which is approximately three times the linear thermal coefficient α

$\omega = \dfrac{3\,(1 - \nu^2)}{4\,E}$ is a property of the material, and

ν = Poisson's ratio

If an initial bulk stress is θ, the change of bulk stress ($\Delta\theta_T$) due to a temperature change is given by the hydrostatic pressure (P) in Equation 7.

Moisture Model

The moisture model is also based on the micro-mechanical approach which represents the load-deformation behavior of a partially saturated soil utilizing thermodynamics laws. The model consists of equal spheres in contact, surrounded by an air-water mixture, and each considered as a different phase. Both phases are modeled as homogeneous, isotopic, linear elastic materials.

Chandra et al. (5) derived a relationship for the change in the mean principal stress, $\Delta\theta_s$, which is

$$\Delta\theta_s = C_w\ (\Delta P_w) \qquad (8)$$

Where

ΔP_w = change in mean principal stress of the water phase, which is equivalent to a change in suction.

Thus,

$$\Delta\theta_s = -\Delta\ (\text{Suction})\ (V_w/V_T) \tag{9}$$

V_w = Volume of water and

V_T = Total volume.

Using Equations 7 and 9, Equation 6 can be rewritten as

$$\Delta E = K_1\ K_2\ \theta^{k_2 - 1}\ (\Delta\theta_T + \Delta\theta_S)$$

The temperature and moisture correction capability enables the user to represent the seasonal variations of the base moduli. As a result of this, the performance of a pavement under changing climatic conditions can also be analyzed.

Reconstruction of Data Base

The data base that is used to determine the nonlinear elastic properties of the base course and the subgrade in the earlier version of the LOADRATE program was based on the ILLI-PAVE subgrade model (first 4 curves in Figure 2). The ILLI-PAVE subgrade model basically represents a clay or silt subgrade. It was found that the earlier LOADRATE program performed poorly when the subgrade consisted of sandy material (6). It underpredicts the sandy subgrade moduli; therefore, as a remedial measure, it was decided to develop a different curve for the sandy subgrades that is similar to the ILLI-PAVE subgrade model.

The ILLI-PAVE subgrade model is based on the results of a series of laboratory tests (18, 19). Specimens tested for those models were done with no lateral confining pressure (e.g. $\sigma_3 = 0$). Plots of resilient modulus

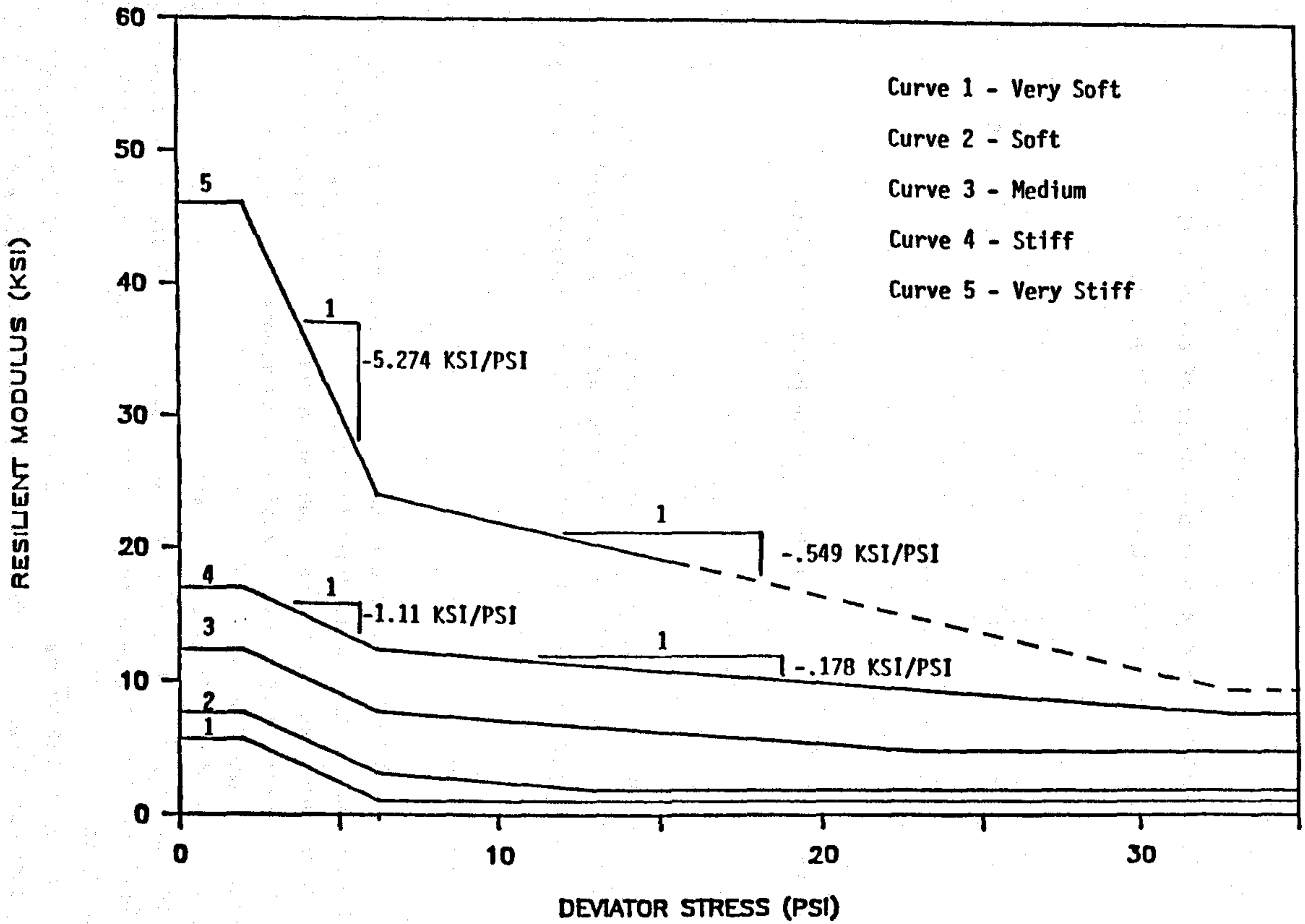


Figure 2. Subgrade Soil Material Models.

versus repeated deviator stress were used to develop these four curves. The point where a substantial change occurred in the slope of the resilient modulus and deviator stress relation was called the "break point" deviator stress. Two linear regression analyses were conducted using the data for deviator stresses either side of the break point deviator stress. It was possible to find the point of intersection using the two regression lines. The resilient modulus and deviator stress corresponding to the intersection point and the slopes of the two regression lines were recorded.

Thompson and Robnett (19) studied the effects of the resilient modulus at the break point (E_{Ri}) and the slope of the regression line below the break point deviator stress (M_1) on the surface deflections of flexible pavements. It was found that the E_{Ri} effects were most pronounced and primarily controlled the surface deflection. Variations of M_1 were fairly insensitive to surface deflections except for very low E_{Ri} values. The data used to develop the fifth curve for the sandy subgrades were obtained from a separate TTI research project (11). In that project, triaxial tests were carried out as a part of the effort to develop a new rut-depth model. During the triaxial testing, several steps were taken to ensure that the laboratory test procedure will closely simulate the actual field conditions. The subgrade material chosen for this study is a red-brown silty sand with a liquid limit of 19. A number of samples were obtained from an in-service low-volume road using 3 in. Shelby tubes. Density and moisture content used for triaxial tests were 110 pcf and 14.0% respectively. The percentage of soil passing through a 200 sieve was 11.5. The tests were carried out at confining pressures of 1, 4 and 8 psi for 4 deviator stress levels ranging from 2 to 11.8 psi. The complete set of test data is shown in Table 4. The confining and deviator stress levels applied to the samples were chosen from the results of a series of CHEVDEF elastic layered program runs simulating a standard 9,000 lb load on typical low-volume road.

A haversine load pulse with a load/unload period of 0.1 sec. and a rest period of 0.9 sec was used to apply the deviator load. This was applied by a Material Testing System (MTS) servo-controlled machine. The deformations were measured by LVDT's mounted between the top and the bottom platens. Graphite powder was used between Teflon papers at the platens to reduce the errors due

Table 4. Triaxial Test Data for Sandy Subgrade.

Location	Sample	Confining Pressure (psi)	Deviator Stress (psi)	Resilient Modulus (ksi)
District 8	S1	1	2.2	32.75
FM 1983		1	5.2	22.21
# 7, 9, 10		1	8.1	17.43
		1	11.7	18.40
		4	2.2	49.80
		4	5.3	24.98
		4	8.1	21.08
		4	11.9	18.98
		8	2.2	52.57
		8	5.2	28.66
		8	8.1	24.14
		8	11.8	22.60
	S3	1	2.1	35.93
		1	5.3	22.90
		1	8.1	19.34
		1	11.6	16.30
		4	2.1	48.13
		4	5.2	29.74
		4	8.2	25.39
		4	11.8	21.92
		8	2.0	52.68
		8	5.2	46.31
		8	8.2	31.00
		8	11.8	26.87

to end effects. The fifth curve developed from these data is shown in Figure 3. This curve was developed by doing two linear regression analyses for the data less than and greater than the "break point" deviator stress. These two straight lines were used to construct the new curve for the subgrade model, according to the method used to develop the ILLI-PAVE subgrade model(19). It is very interesting to find that the "break point" deviator stress of the new curve is 6.2 psi, which is exactly the same as for all other ILLI-PAVE subgrade curves. Figure 3 shows the new curve and the data points highlighting the three confining pressures. It was observed that confining pressure had an effect on the resilient behavior of the soils used for the test. The new subgrade model used to develop the data base is shown in Figure 2. These five nonlinear elastic moduli curves represent the very soft, soft, medium, stiff and very stiff subgrades. A summary of the pavement material properties used in the analyses with ILLI-PAVE is given in Table 1.

A new set of ILLI-PAVE runs and regressions were carried out to regenerate the data base which is used to determine the nonlinear elastic properties of the base course and subgrade. To obtain enough load-deflection data to cover a wide spectrum of light pavement structures with different materials, 60 ILLI-PAVE runs were made. These simulations included a combination of the above mentioned five subgrade types and three base course materials with K_1 values at 10,000, 100,000 and 200,000. In addition, four different base course thicknesses were used (1-inch, 6-inch, 12-inch and 18-inch). For all the above combinations, a FWD loading of 100 psi was used, and the corresponding load was 10,956 lbs. The regression analyses and correlations of the various parameters were performed according to the procedure used to develop the database in the original version of the LOADRATE (1).

Calculation of The Remaining Life and Allowable Axle Loads

The calculation of the remaining life requires the following as input, the number of passes (ESALs) to cause a predetermined rut depth and traffic information. The number of passes of an 18 kip single axle load (ESAL) to cause a predetermined rut depth can be calculated using the rut depth prediction model. The predetermined rut depth, i.e., the allowable rut depth, is a user provided criterion at which the pavement requires a major

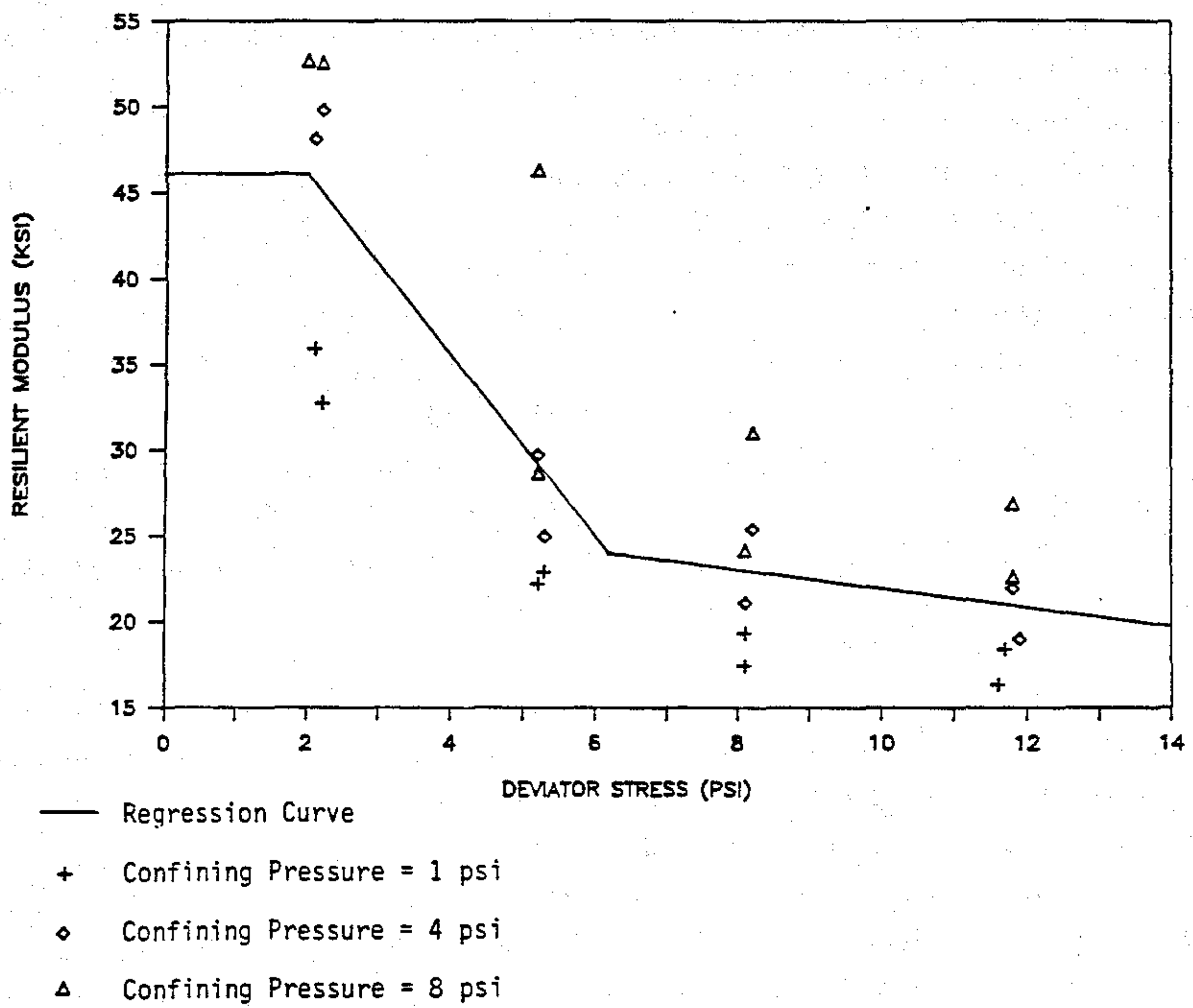


Figure 3. Nonlinear Modulus Versus Deviator Stress Curve for Sandy Subgrade.

rehabilitation work. To determine the remaining life of the test sections in years, the traffic information is also needed. The user is required to input the first year ESAL passes and traffic growth rate. Two options are implemented in the program for traffic data input. The first option allows user to input the number of first-year ESAL passes and the percent growth rate. The second option asks for first-year average daily traffic (ADT), twentieth-year ADT, and the number of twenty-year total ESAL passes. In the second option the first year ESAL passes and the growth rate are calculated using the input data.

The calculated remaining life of the test sections and the AASHTO axle load equivalency factors (20) are used to estimate the allowable axle load limits. First, the cumulative percent of the test sections versus remaining life is determined. The remaining life of the 100% cumulative sections is compared to a predetermined number. In Texas a minimum of 10 years is used for the FM systems. If the remaining life of 100% cumulative sections is less than 10 years, the allowable axle loads limits are adjusted using AASHTO axle load equivalency factors. The adjusted allowable axle loads is to insure a minimum of ten years remaining life for the whole test sections. At the final stage, a comparison will be made between the calculated allowable axle loads and the legal load limits to determine the allowable axle load. The legal load limits in Texas are 18,000 lbs for single axle, 34,000 lbs for tandem axles, and 46,000 lbs for triple axles. If the calculated axle loads exceed the legal loads, the legal loads will be reported.

Program Limitations

The main objective of Study 473 was to investigate the effect of load-zoning on light pavement structures which in general have only a thin surface treatment layer. Thus the LOADRATE program was developed for a two-layer system which consists of a base and the subgrade. The failure criterion used in the LOADRATE program is based on the allowable rut depth; fatigue cracking in the surface layer is not considered. As a result, the LOADRATE program has limitations:

1. It can only be used for FM roads with a surface treatment layer; it cannot be used for asphalt concrete surface pavements;

2. It can only be used to predict rutting failure; it cannot be used to predict cracking failure.

CHAPTER III
CASE STUDIES

The following case studies demonstrate various applications of the latest version of the LOADRATE program in the structural evaluation of light pavements.

Case Study 1

Farm-to-Market road 3225 is located in Henderson County, Texas. A 15-inch thick crushed limestone base was laid on sandy clay and topped with a 1-inch thick emulsion asphalt treatment layer. The Texas triaxial classification for the subgrade was 5.0. The existing load limit is 58,420 lbs gross vehicle weight (GVW). There is a gravel pit close to this road. Due to the load limit on this road, trucks loaded with gravel must follow a longer path to reach the main road. Presently an average of 25 gravel trucks are moving along the alternative route daily. An increase of the load limit to 80,000 lbs will allow these trucks to use FM 3225. Thus there is a request to increase the load limit in FM 3225. As a result of this request, the Texas State Department of Highways and Public Transportation (TSDHPT) officials decided to study the possibility of raising the load limits of FM 3225. The calculation of the expected additional traffic data was provided by the TSDHPT and is given in Table 5. According to the information obtained from TSDHPT officials, there was some rain in the pavement area about 1 to 4 weeks prior to the date of testing. The existing traffic information of the road was not available; therefore, an annual ESAL of 18,592 with a 5% growth rate was assumed for the purpose of this demonstration (Table 5). To meet the SDHPT requirements, the allowable rut depth value was taken as 0.5 inch, and there was no existing rut depth as the surface course was new. All of this information was used to run the LOADRATE program.

In April 1989, a set of FWD tests was carried out on FM 3225 for a 2.5 mile section. The testing consisted of 23 FWD readings in the outer wheel path and another 23 FWD readings between edge of the road and outer wheel path. A cross section of the test road is given in Figure 4. The distance between test points was 0.1 mile. During the test, the air temperature was about 80°F.

Table 5. Traffic Data for FM 3225 Road.

Traffic Data analysis for FM 3225, Henderson County

Estimated Vehicles/Day: 25 Date of Estimation: 11/23/88

Distribution of Truck Traffic:

(Vehicles/day)		18-Kip Equivalent AASHTO 86(SN = 2, Pt = 2.0)	Daily 18-Kip Equivalent
2-axle Dumps:	5	3.18	15.9
3-axle Dumps:	5	2.66	13.3
3-S2 Dumps:	17	3.73	63.41
			92.61

Above traffic estimates are based on data provided by the Gravel Supplier for the last 3 months (August, September, October of 1988)

Traffic Estimates assuming no growth:

Yearly 18-Kip Equivalent: 33,802.65

10-Year 18-Kip Equivalent: 338,026.5

20-Year 18-Kip Equivalent: 676,053

Removal of load restrictions will increase the gravel business by 10%. This raises the 18-Kip Equivalent as follows:

Yearly 18-Kip Equivalent: 37,182.91

10-Year 18-Kip Equivalent: 371,829.1

20-Year Kip Equivalent: 743,658.3

Assuming a uniform 5% increase/year in business the following traffic levels are expected:

Yearly 18-Kip equivalent: 37,182.91

10-Year 18-Kip Equivalent: 467,761.0

20-Year 18-Kip Equivalent: 1,229,267

Existing traffic on this road was taken as 50% of the above figures. This will give an existing yearly 18-Kip Equivalent of 18,592.

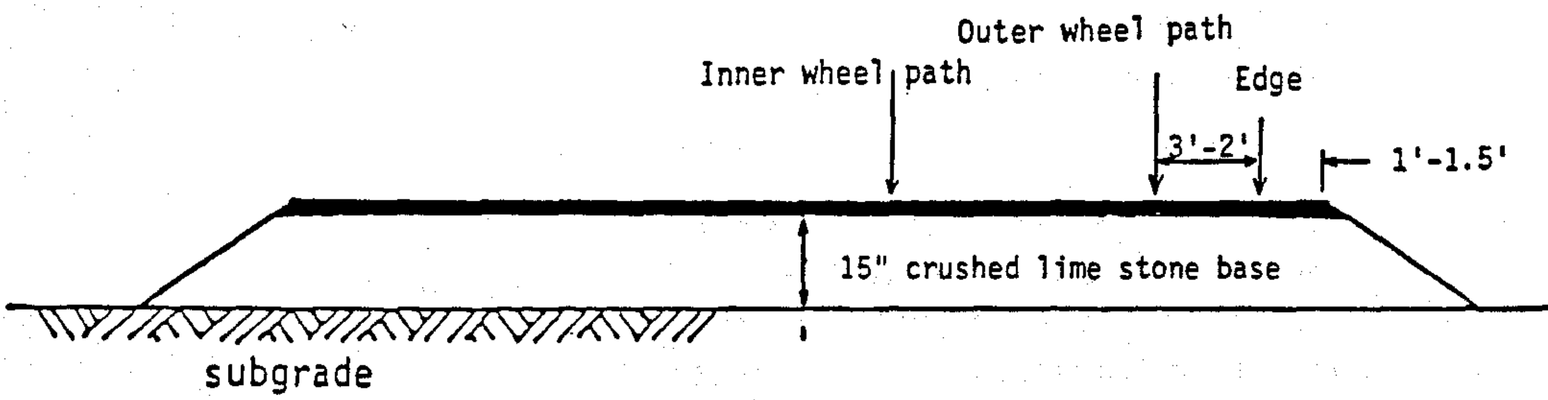


Figure 4. Cross Section of the Test Road Indicating Outer Wheel Path and Edge Positions (FWD Testing Points).

The FWD readings taken for a load level close to 10,956 lbs were used for the LOADRATE analysis. The analysis were made in 4 steps. The first analysis was made with the data taken in the outer wheel path with existing traffic data. The results of this LOADRATE run is shown in Table 6. The second analysis was made of the outer wheel path data with future traffic and the output file is given in Table 7. Results obtained from these two LOADRATE runs were used to compare the performance of the pavement in two traffic conditions.

The third LOADRATE analysis was made using FWD data taken at the edge of the road with existing traffic data. Results obtained from this analysis (Table 8) were used to compare the structural capabilities of the pavement in the outer wheel path and at the edge. As a final step, LOADRATE was used to demonstrate a temperature and moisture correction for the base moduli in the outer wheel path. For this purpose, the future condition (corrected condition) was assumed to be a fairly dry climate which represents a base course temperature of 95°F and suction value in the base course of -90 psi. The base course temperature and the suction value on the day of the FWD tests were 75°F and -40 psi, respectively.

Results

The results obtained from the LOADRATE analysis in the outer wheel path for existing traffic data are plotted in Figures 5 and 6. The subgrade modulus in Figure 5 varies within a close range when compared to the variation of the base moduli. Figure 6 shows the variation of the number of ESAL passes to cause a 0.5-inch rut depth. This number of passes is directly related to the modulus values of base and subgrade. It can be seen in these two figures that the higher the modulus values, the higher the number of passes and vice versa. Figure 6 shows that the first 0.8 mile of the tested pavement section can carry a higher number of passes compared to stations number 0.9 to 1.2 and 1.7 to 2.2.

Figure 7 illustrates the variation of the remaining life in the outer wheel path for existing and future traffic. From the two curves, it is clear that there is a minimum of 6.5 years of life reduction in all of the test sections due to the additional traffic. In some sections, this value is as

Table 6. Results of LOADRATE Analysis of the FWD Data Taken in the Outer Wheel Path With Existing Traffic.

TEXAS TRANSPORTATION INSTITUTE
LOAD RATING OF LIGHT PAVEMENT

JOB : fwd Testing(OWP)   (INPUT FILE a:f3225a.lrd)

DISTRICT: 0   COUNTY:Bender.   ROAD:10108 fm3225
ALLOWABLE RDT(INS): .5   RECORDED RDT(INS): 0

TRUCK NO. 1
AXLE NUMBER   SINGLE WHEEL/ESWL(LBS)
1   9000

ANNUAL TRAFFIC GROWTH RATE: .05   # OF YEARS: 10   FIRST YEAR TRAFFIC: 18592
TOTAL NUMBER OF PASSES DURING ABOVE PERIOD: 233848

DATE:4-25-89   FALLING WEIGHT DEFLECTOMETER

SEC #	BASE (IN)	D1 (MILS)	D7 (MILS)	FWD LOAD (LBS)	E1-BASE (PSI)	E2-SUBG (PSI)	* NO. OF PASSES	* REMAINING LIFE (YEARS)
0.0	15.0	39.90	1.77	10584	35357	9117	395093	14.8
0.1	15.0	35.42	1.53	11040	53529	11364	624657	20.2
0.2	15.0	32.91	1.73	11328	70569	10336	632379	20.4
0.3	15.0	36.09	1.53	11072	51030	11682	627737	20.3
0.4	15.0	37.89	1.73	11032	46229	9902	446626	16.2
0.5	15.0	28.33	1.61	11048	87063	10436	863672	21.0
0.6	15.0	40.48	1.41	10648	34270	11964	578970	19.2
0.7	15.0	31.14	1.09	11312	61642	15895	776165	23.1
0.8	15.0	39.39	1.37	10688	37385	11642	581068	19.3
0.9	15.0	41.55	2.17	11032	33684	7928	350894	13.6
1.0	15.0	41.00	2.89	10912	25188	6287	281085	11.5
1.1	15.0	37.58	1.81	11168	48233	9072	418612	15.3
1.2	15.0	84.98	2.45	10688	9555	6839	286230	11.7
1.3	15.0	38.21	1.25	11056	40941	13507	647850	20.7
1.4	15.0	33.81	1.85	11440	67741	9276	459234	16.5
1.5	15.0	43.74	2.01	10768	28590	8393	355715	13.8
1.6	15.0	29.10	1.37	11536	92670	12615	745707	22.6
1.7	15.0	42.53	2.61	10688	24102	6782	295516	12.0
1.8	15.0	61.10	1.53	11160	14675	10857	483601	17.1
1.9	15.0	40.25	1.97	10672	34504	8559	374035	14.3
2.0	15.0	34.75	2.01	11064	53449	8071	389147	14.7
2.1	15.0	50.03	3.05	10544	13525	6173	271495	11.2
2.2	15.0	36.60	1.65	10840	47677	9632	438994	16.0

* NUMBER OF PASSES AND REMAINING LIFE FOR SPECIFIED RUT DEPTH OF .5 in

Remaining Life(yrs)	Cumulative % Sections
1	100.0
2	100.0
3	100.0
4	100.0
5	100.0
6	100.0
7	100.0
8	100.0
9	100.0
10	100.0
11	100.0
12	82.6
13	82.6
14	73.9
15	60.9
16	52.2
17	43.5
18	39.1
19	39.1
20	30.4
21	8.7
22	8.7
23	4.3

Table 7. Results of LOADRATE Analysis of the FWD Data Taken in the Outer Wheel Path With Future Traffic.

TEXAS TRANSPORTATION INSTITUTE
LOAD RATING OF LIGHT PAVEMENT

JOB : fwd Testing(OWP)   (INPUT FILE a:f3225af.lrd)

DISTRICT: 0   COUNTY:Hender.   ROAD:10108 fm3225
ALLOWABLE RUT(INS): .5   RECORDED RUT(INS): 0

TRUCK NO. 1
AXLE NUMBER   SINGLE WHEEL/ESWL(LBS)
1   9000

ANNUAL TRAFFIC GROWTH RATE: .05   # OF YEARS: 10   FIRST YEAR TRAFFIC: 55775
TOTAL NUMBER OF PASSES DURING ABOVE PERIOD: 701532

DATE:4-25-89   FALLING WEIGHT DEFLECTOMETER

SEC #	BASE (IN)	D1 (MILS)	D7 (MILS)	FWD LOAD (LBS)	E1-BASE (PSI)	E2-SUBG (PSI)	* NO. OF PASSES	* REMAINING LIFE (YEARS)
0.0	15.0	39.90	1.77	10584	35357	9117	395093	6.2
0.1	15.0	35.42	1.53	11040	53529	11364	624557	9.1
0.2	15.0	32.91	1.73	11328	70569	10336	632379	9.2
0.3	15.0	36.09	1.53	11072	51030	11682	627737	9.2
0.4	15.0	37.89	1.73	11032	45229	9902	446626	6.9
0.5	15.0	29.33	1.61	11048	87063	10436	663072	9.6
0.6	15.0	40.48	1.41	10648	34270	11964	578970	8.6
0.7	15.0	31.14	1.09	11312	61642	15895	776165	10.8
0.8	15.0	39.39	1.37	10688	37395	11642	581866	8.6
0.9	15.0	41.55	2.17	11032	33684	7928	350894	5.6
1.0	15.0	41.00	2.89	10912	25188	6287	281065	4.6
1.1	15.0	37.58	1.81	11168	48233	9072	418612	6.5
1.2	15.0	84.98	2.45	10688	9555	6539	286230	4.7
1.3	15.0	38.21	1.25	11056	40941	13507	647850	9.4
1.4	15.0	33.81	1.85	11440	67741	9276	459234	7.1
1.5	15.0	43.74	2.01	10768	28590	8393	355715	5.7
1.6	15.0	29.10	1.37	11536	92670	12615	745707	10.5
1.7	15.0	42.53	2.61	10688	24102	6782	295516	4.8
1.8	15.0	61.10	1.53	11160	14675	10857	483601	7.4
1.9	15.0	40.25	1.97	10672	34504	8559	374035	5.9
2.0	15.0	34.75	2.01	11064	53449	8071	389147	6.1
2.1	15.0	50.03	3.05	10544	13525	6173	271495	4.5
2.2	15.0	36.60	1.65	10840	47677	9632	438994	6.8

* NUMBER OF PASSES AND REMAINING LIFE FOR SPECIFIED RUT DEPTH OF .5 in

Remaining Life(yrs)	Cumulative % Sections
1	100.0
2	100.0
3	100.0
4	100.0
5	82.6
6	69.6
7	47.8
8	39.1
9	30.4
10	8.7

Table 8. Results of LOADRATE Analysis of the FWD Data Taken at the Edge With Existing Traffic.

TEXAS TRANSPORTATION INSTITUTE
LOAD RATING OF LIGHT PAVEMENT

JOB : FWD TESTING (EDGE)   (INPUT FILE a:f3225b.lrd)

DISTRICT: 8   COUNTY:Hend.   ROAD:10801 fm3225S
ALLOWABLE RUT(INS): .5   RECORDED RUT(INS): 0

TRUCK NO. 1
AXLE NUMBER   SINGLE WHEEL/ESWL(LBS)
1   9000

ANNUAL TRAFFIC GROWTH RATE: .05   # OF YEARS: 10   FIRST YEAR TRAFFIC: 18592
TOTAL NUMBER OF PASSES DURING ABOVE PERIOD: 233848

DATE:4-25-89   FALLING WEIGHT DEFLECTOMETER

SEC #	BASE (IN)	D1 (MILS)	D7 (MILS)	FWD LOAD (LBS)	E1-BASE (PSI)	E2-SUBG (PSI)	# NO. OF PASSES	# REMAINING LIFE (YEARS)
0.0	15.0	64.24	1.37	10328	11647	10618	478650	17.0
0.1	15.0	72.57	1.89	10232	10743	8820	349105	13.6
0.2	15.0	76.49	2.33	10216	9653	7188	302373	12.2
0.3	15.0	52.89	2.05	10640	17079	8268	331920	13.1
0.4	15.0	54.50	2.05	10584	14983	7831	319960	12.7
0.5	15.0	69.11	1.57	10048	11342	10319	469889	16.7
0.6	15.0	55.68	1.61	10800	16796	10733	478841	17.0
0.7	15.0	76.89	1.33	10464	12427	12584	529794	18.2
0.8	15.0	61.53	1.97	10480	11430	8537	340793	13.3
0.9	15.0	55.92	2.93	10520	9629	5918	267080	11.1
1.0	15.0	61.61	1.85	10336	11215	9042	355418	13.7
1.1	15.0	61.34	2.93	10528	8866	6002	267338	11.1
1.2	15.0	59.96	1.65	10560	13129	10171	463398	16.6
1.3	15.0	51.13	1.65	10832	20843	9627	370665	14.2
1.4	15.0	61.22	2.21	10176	10006	7673	316335	12.6
1.5	15.0	58.78	1.61	10592	13868	9960	381854	14.5
1.6	15.0	56.62	2.73	10496	10644	6466	280868	11.5
1.7	15.0	55.17	1.73	10512	15758	9524	368266	14.1
1.8	15.0	60.35	2.21	10120	9746	7359	307319	12.3
1.9	15.0	56.19	2.37	10488	11557	6785	290286	11.8
2.0	15.0	74.88	3.30	10064	8202	5648	266818	11.1
2.1	15.0	74.61	1.97	10048	10303	8268	333318	13.1
2.2	15.0	58.82	2.41	10160	9465	6887	293608	11.9

NUMBER OF PASSES AND REMAINING LIFE FOR SPECIFIED RUT DEPTH OF .5 in

Remaining Life(yrs)	Cumulative % Sections
1	100.0
2	100.0
3	100.0
4	100.0
5	100.0
6	100.0
7	100.0
8	100.0
9	100.0
10	100.0
11	100.0
12	73.9
13	56.5
14	34.8
15	21.7
16	21.7
17	4.3
18	4.3

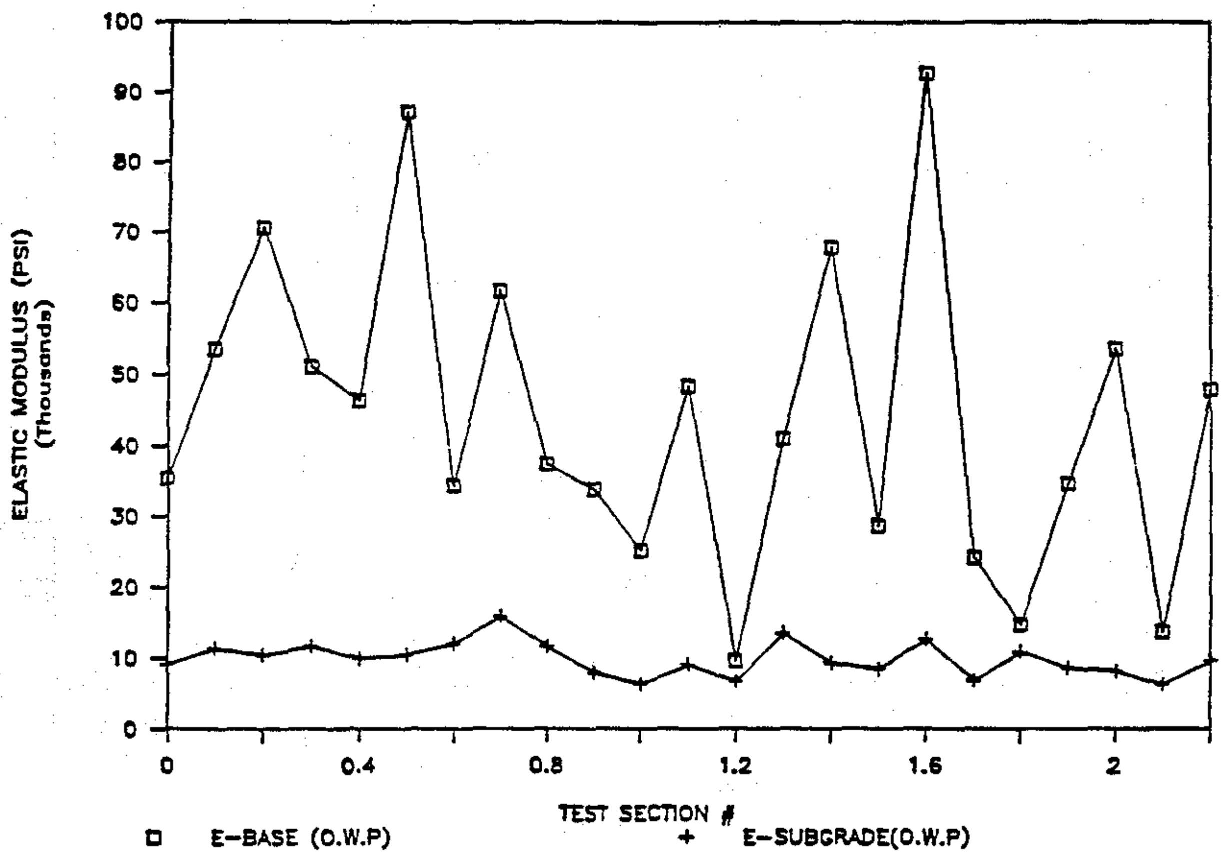


Figure 5. Subgrade and Base Moduli Variation in Outer Wheel Path.

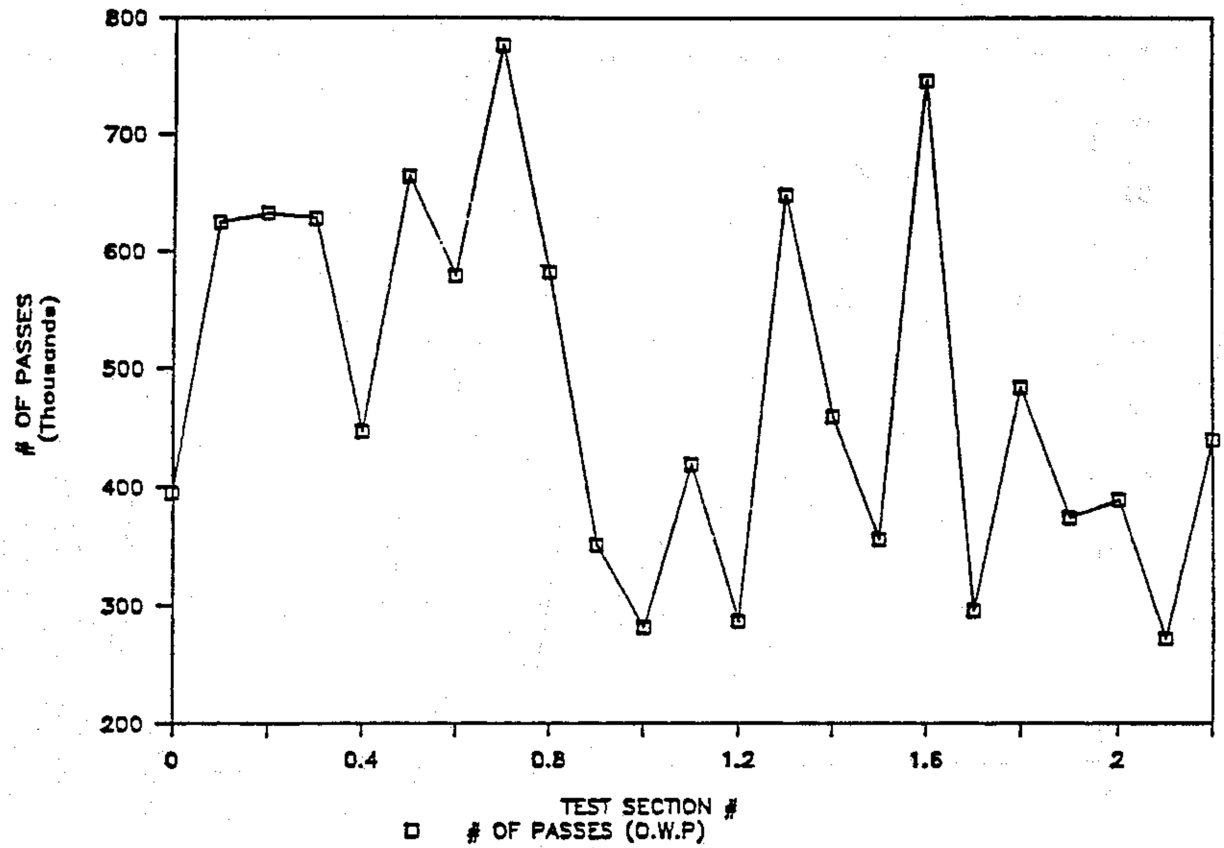


Figure 6. Variation of Number of ESAL Passes to Cause 0.5 Inch Rut-Depth Along the Project Length.

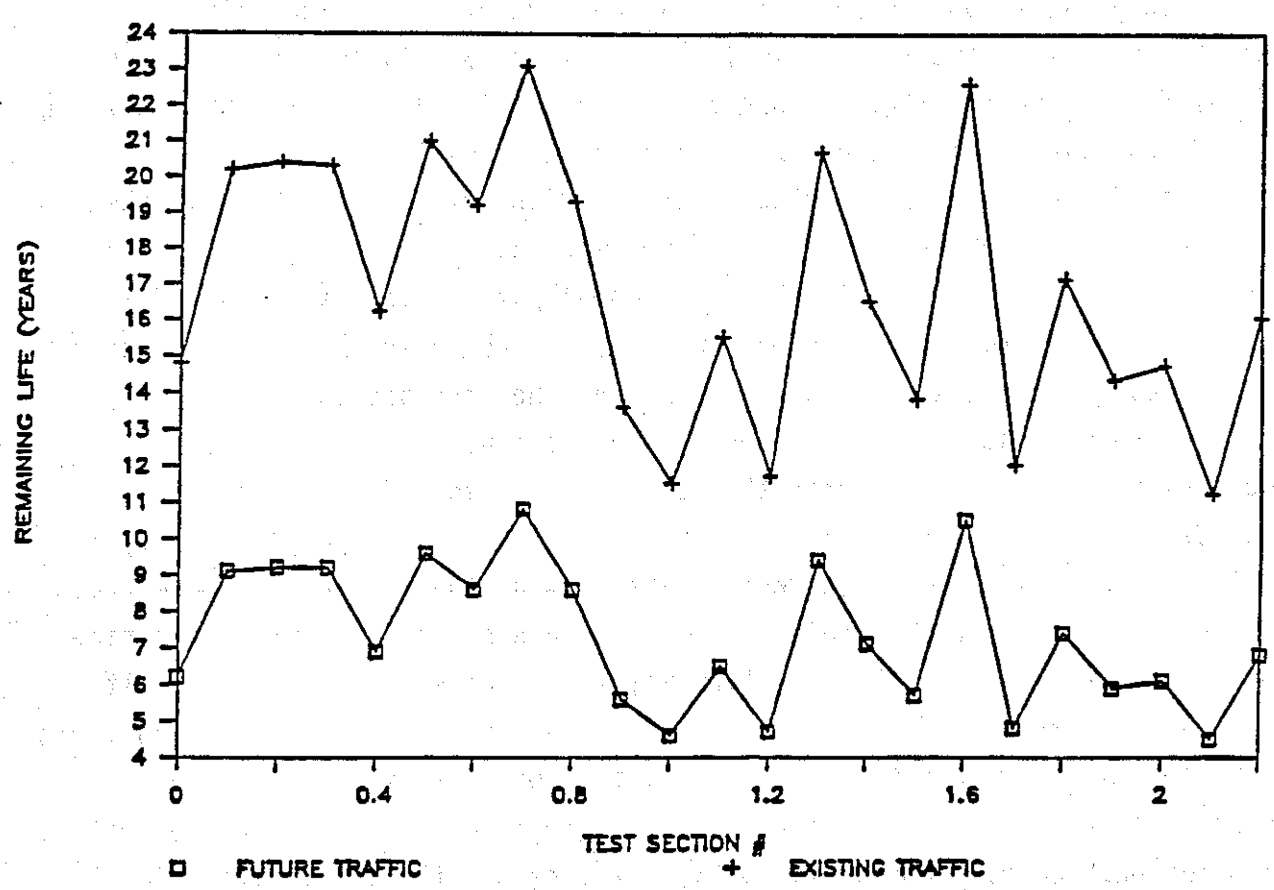


Figure 7. Variation of Remaining Life in the Outer Wheel Path Along the Test Pavement (for Existing and Future Traffic).

high as 12 years. This same information can be presented in another way, as in Figure 8. The two curves in this figure represent the two conditions described earlier. The curve for the existing traffic shows that all the sections tested have a remaining life of at least 11 years while the future traffic curve has only 4 years. Also, it can be seen that 50% of the sections tested have a remaining life of 16 years under the existing traffic, but only 6 years with future traffic. These results explain the effects of an increase in load limit in this road. Based on these analyses, Texas SDHPT may decide whether they can afford to lose the additional years of service life, considering that if the load limit is increased to 80,000 lbs, the pavement will need major rehabilitation work by the end of 6 years. Under the existing traffic conditions, it will not need major repair for 16 years.

The LOADRATE program results obtained by analyzing the FWD data taken at the edge of the pavement show the pavement structure at the edge is weaker than the pavement structure in the outer wheel path. Figures 9, 10 and 11 illustrate this situation. The base modulus in the outer wheel path is higher than the base modulus at the edge for most of the test sections (Figure 9). Figure 10 shows that the subgrade moduli in the inner wheel path are not always higher than those beneath the edge. The effect of weak base and subgrade at the edge results in a lower life span at the edge (Figure 11) if the traffic passes close to the edge. There is a tendency to have more truck traffic on the edge under conditions such as passing and meeting approaching traffic. Repetition of this situation may easily cause edge failures. It is important to take this factor into account when considering raising load limit to 80,000 lbs. The results obtained from the temperature and moisture corrections indicate that an increase of temperature and suction values will raise the base course modulus (Table 9). Therefore, it is reasonable to accept some variation of pavement performance under different climatic conditions. The pavement performance for corrected base moduli can also be analyzed by the LOADRATE program.

Case Study 2

The objective of this case study was to investigate the variations of base moduli in transverse direction on farm-to-market roads. It will enable engineers to identify the change of structural stability in different

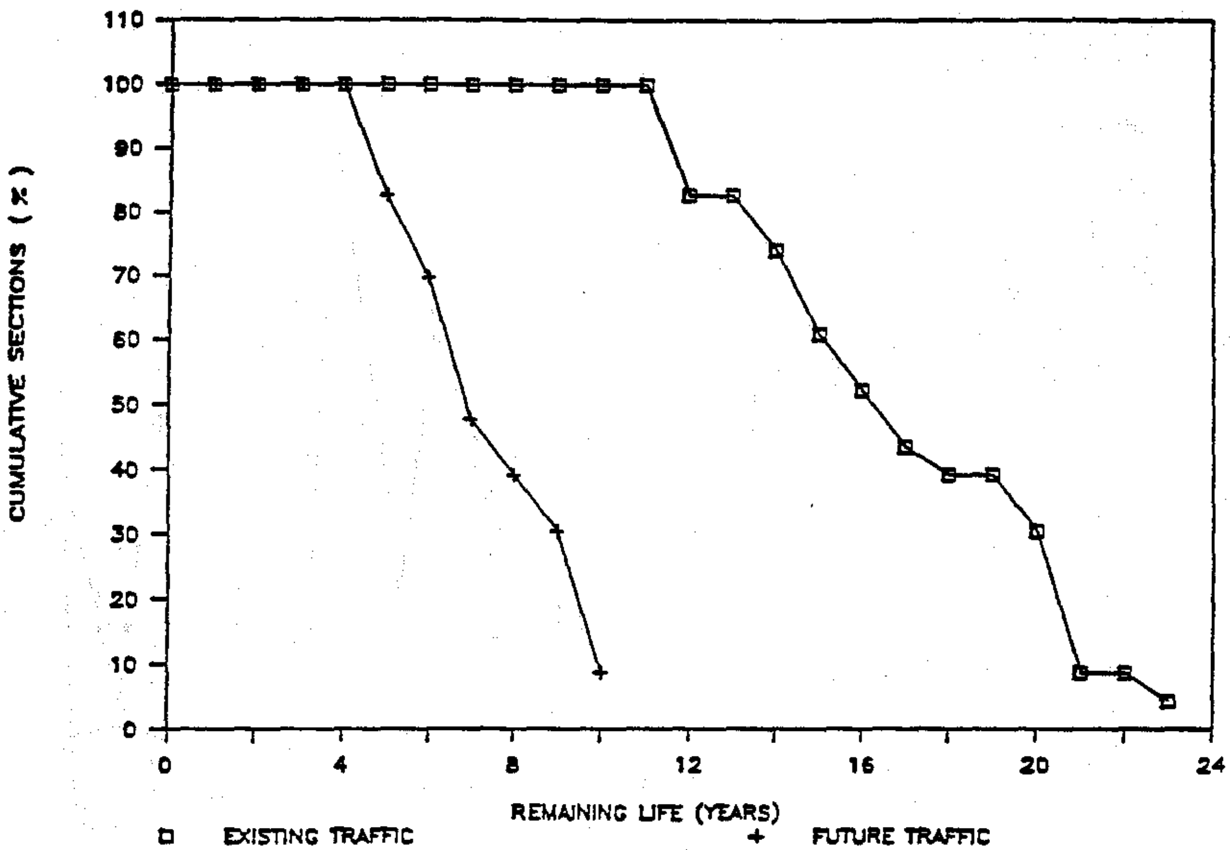


Figure 8. Remaining Life of the Cumulative Sections (in Percent) in the Outer Wheel Path (for Existing and Future Traffic).

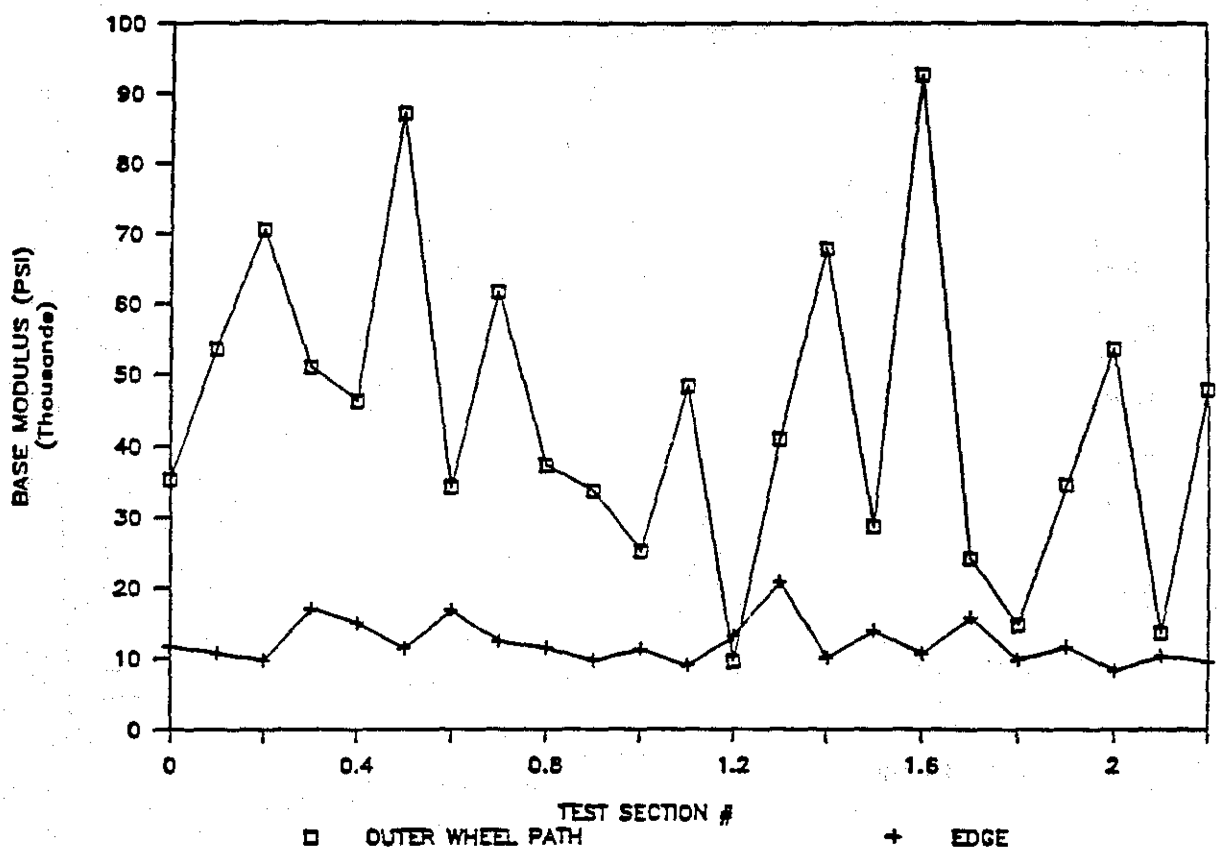


Figure 9. Variation of Base Moduli in Outer Wheel Path and Edge Along the Project Length.

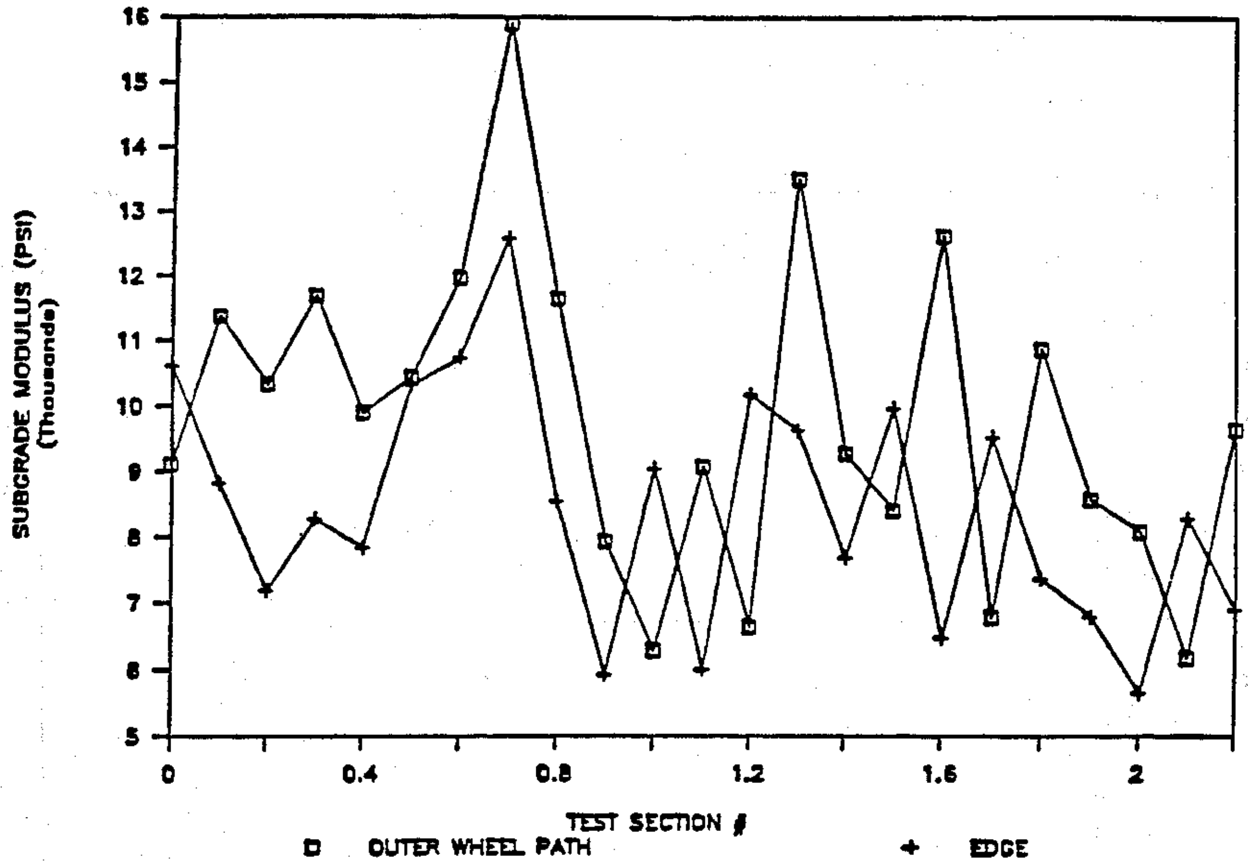


Figure 10. Variation of Subgrade Moduli in Outer Wheel Path and Edge Along the Project Length.

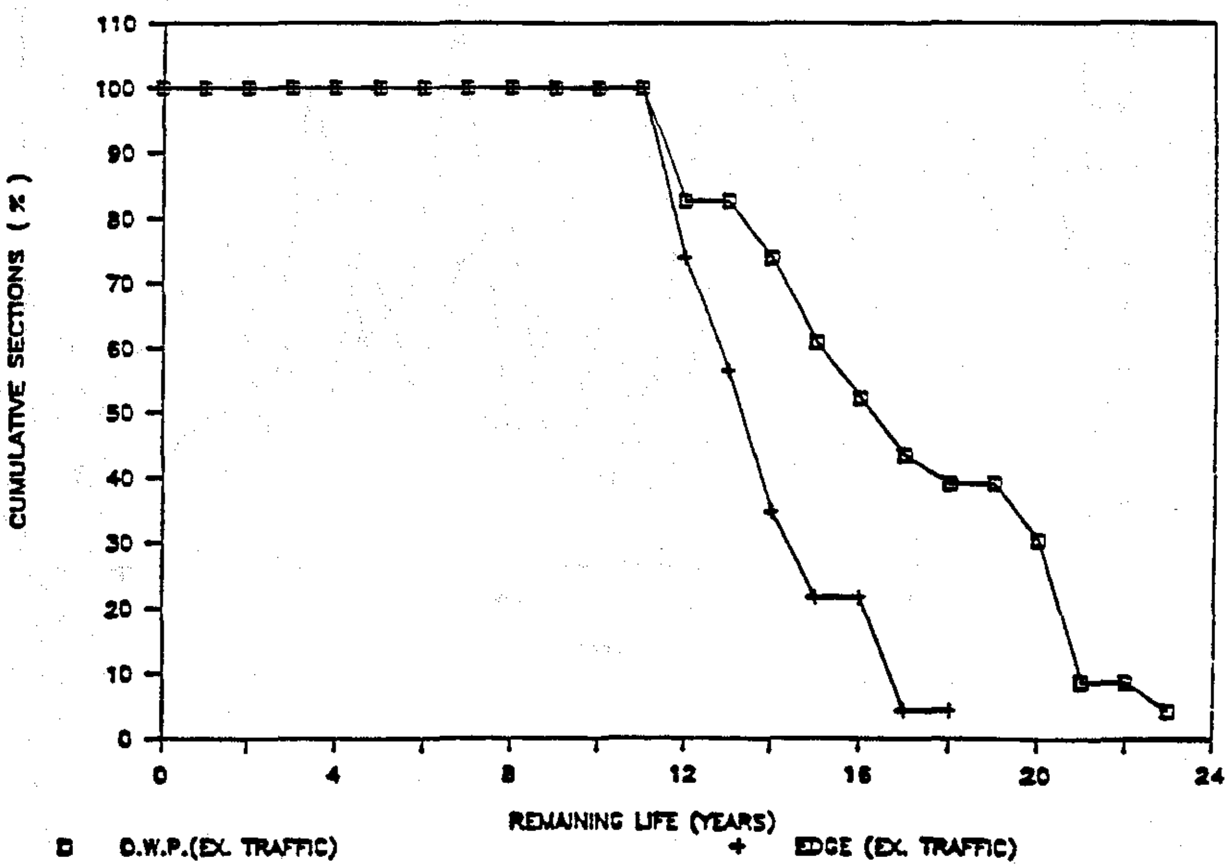


Figure 11. Remaining Life of the Cumulative Sections (in Percent) for Existing Traffic in the Outer Wheel Path and Edge.

Table 9. Results of temperature and moisture correction for base moduli at outer wheel path.

TEMPERATURE CORRECTION DATA

INPUT CONDITIONS:		WANTED CONDITIONS:	
TEMPERATURE =	75.0 deg. F	TEMPERATURE =	95.0 deg. F
SUCTION =	-40.0 psi	SUCTION =	-90.0 psi

SEC #	INPUT MODULUS (psi)	WANTED CONDITION MODULUS (psi)	MODULUS CHANGE DUE TO TEMPER. (psi)	MODULUS CHANGE DUE TO SUCTION (psi)
0.0	35357.5	38668.8	1618.3	1692.9
0.1	53529.1	57179.9	1784.3	1866.5
0.2	70568.6	75932.2	2621.4	2742.2
0.3	51029.8	54361.8	1628.5	1703.5
0.4	46229.0	49917.3	1802.6	1885.7
0.5	87062.5	94122.3	3450.3	3609.4
0.6	34270.2	36493.4	1086.5	1136.6
0.7	61642.3	64538.7	1415.6	1480.8
0.8	37384.7	39895.9	1227.4	1283.9
0.9	33684.2	37268.1	1751.6	1832.3
1.0	25187.7	29259.9	1990.2	2082.0
1.1	48233.1	52513.8	2092.1	2188.6
1.2	9554.5	10752.6	585.5	612.5
1.3	40941.3	43177.5	1092.9	1143.3
1.4	67740.8	73578.8	2853.2	2984.7
1.5	28590.3	31429.1	1387.4	1451.4
1.6	92670.5	98217.8	2711.2	2836.2
1.7	24102.4	27567.0	1693.3	1771.3
1.8	14674.9	15557.4	431.3	451.2
1.9	34504.3	37993.3	1705.2	1783.8
2.0	53448.9	59386.0	2901.7	3035.4
2.1	13525.5	15702.6	1064.0	1113.1
2.2	47677.0	51786.5	2008.5	2101.0

positions of the pavements, and it will also permit engineers to compare the effects of different shoulder types to the structural stability of the traffic lane pavement.

Effect of Shoulder

Once a new pavement is constructed, it is going to function properly as far as the design criteria are satisfied. The deterioration of quality of one or more important components in the pavement structure, such as surface layer, base, subgrade, etc., is going to weaken the pavement structure and the ultimate result will be a failure in the pavement. The deterioration of quality of these components can be due to various reasons, such as overloaded vehicles, poor drainage, etc.

Shoulders provide lateral support to the traffic lanes. Strong lateral supports help to maintain efficient functioning of pavement. If the lateral supports are weak, pavement edge starts deterioration with the load applications. The degree of lateral support has been found to depend on factors such as quality of construction of pavement beneath the road shoulder and moisture content of shoulder material. If the quality of shoulder pavement construction is considerably lower than that of traffic lanes, it could not provide a good lateral support. On the other hand if shoulder material is wet, it will lose its strength; so will the lateral support. In sharp bends, there is an additional horizontal force acting on the pavement due to the centrifugal action of the vehicle. Therefore, to compensate this horizontal force, sharp bends need stronger outside lateral support for traffic lane pavement than straight road sections.

If the drainage system is poor, the moisture content in the subgrade, the shoulder, and the edge of traffic lane pavement will increase despite the fact the shoulders are paved. If the shoulders are unsealed, moisture entry through permeable shoulder material may weaken the pavement structure. These weak materials at the edge of the pavement are not able to carry the anticipated load.

Procedure

Sets of FWD testing were conducted in Districts 11 and 17. In District

11, testing was done in five pavement sections, whereas in District 17, testing was done in four pavement sections. These test sections were selected according to the information obtained from Texas State Department of Highways District Offices. These test sections were selected from different straight pavement sections which did not show any visible cracks. Out of these nine test sections three test sections had hot mix asphalt concrete surface layers. Therefore, these pavement sections were not considered as typical FM roads, and were not included in the analysis. FWD testing was carried out on each test point along the inner wheel path, outer wheel path, and edge of the pavement (Figure 4). In each test site, two holes were punched using Dynamic Cone Penetrometer.

The base thicknesses of test sections were estimated using the information obtained from State Department of Highways District Offices and the data obtained from Dynamic Cone Penetrometer testing. The subgrade type of each test site was recorded and checked with soil maps. The general information on test sections is given in Table 10. The modulus values of the base course at each test point was back-calculated using the LOADRATE Program.

Results

The results of all five test sections without paved shoulders showed low base moduli along the edge of the pavement and also lighter base moduli in inner wheel path than outer wheel path (Figure 12 to Figure 16). Therefore it is reasonable to conclude that the pavements without paved shoulders tend to have weak edges.

There was only one test section with paved shoulders among the six test sections. The results of this test (Figure 17) showed fairly high base moduli along the edge when compared to moduli in the wheel paths. Thus, a paved shoulder helps the traffic lane pavement to maintain its intergrity. Since it is very difficult to find surface treated FM roads with paved shoulders, the effects of paved shoulders on traffic lane pavement is difficult to evaluate.

Table 10. General Information of Test Sections in Case Study 2

Test Section	District	Temperature °F	Drainage Condition	Base Thickness	Subgrade	Base
FM 2223	17	68	Good	8"	Clay	Limestone
FM 1179	17	68	Good	6"	Clay	Limestone
FM 2776	17	68	Good	10"	Clay	Limestone
SH 7	11	85	Good	10"	Silty-Sand	Iron Ore Gravel
FM 2864	11	85	Good	10"	Sandy Clay	Iron Ore Gravel
LP 224	11	85	Good	10"	Sandy Clay	Iron Ore Gravel

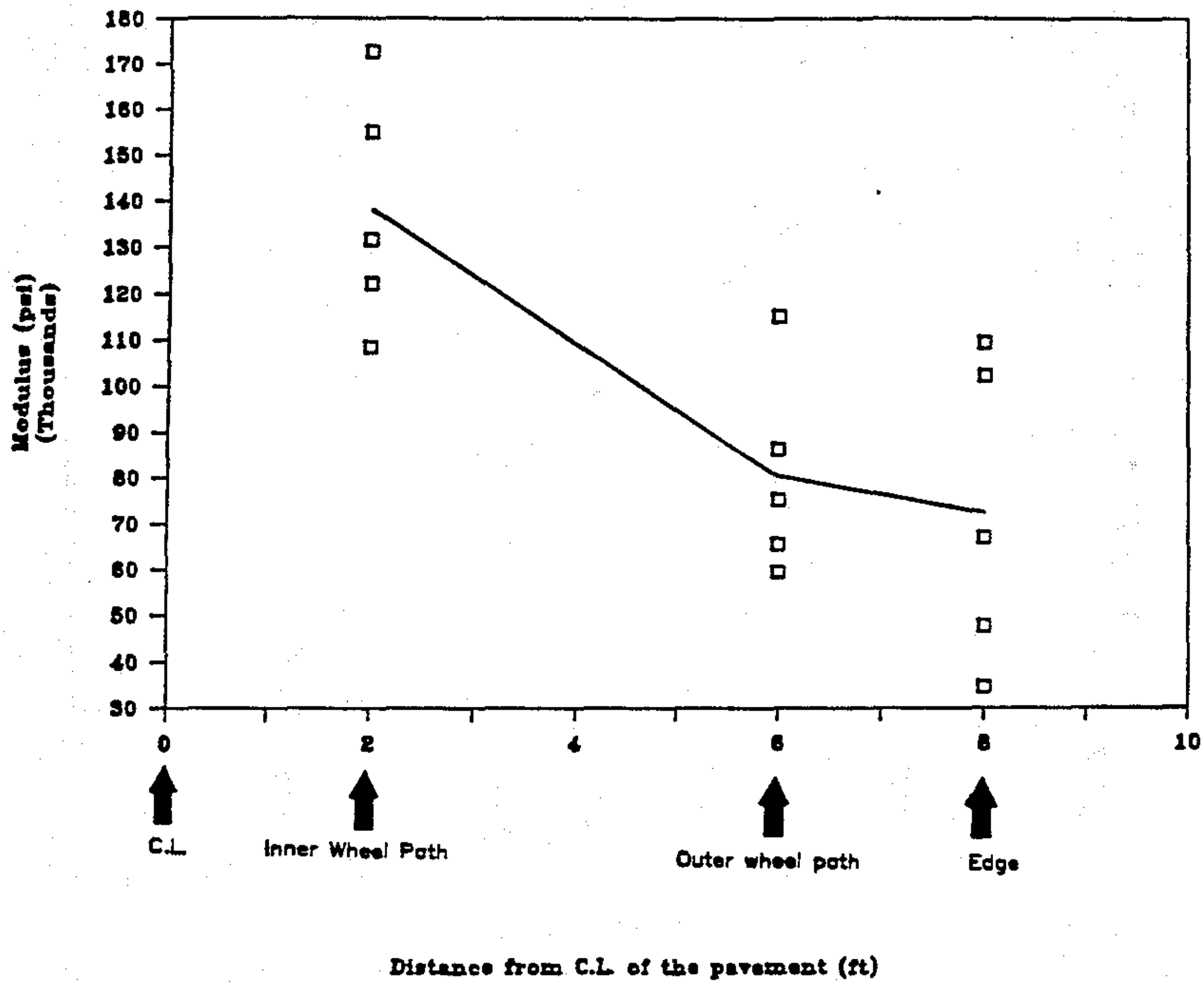


Figure 12. Variation of Base Modulus in FM 2776 Test Section.

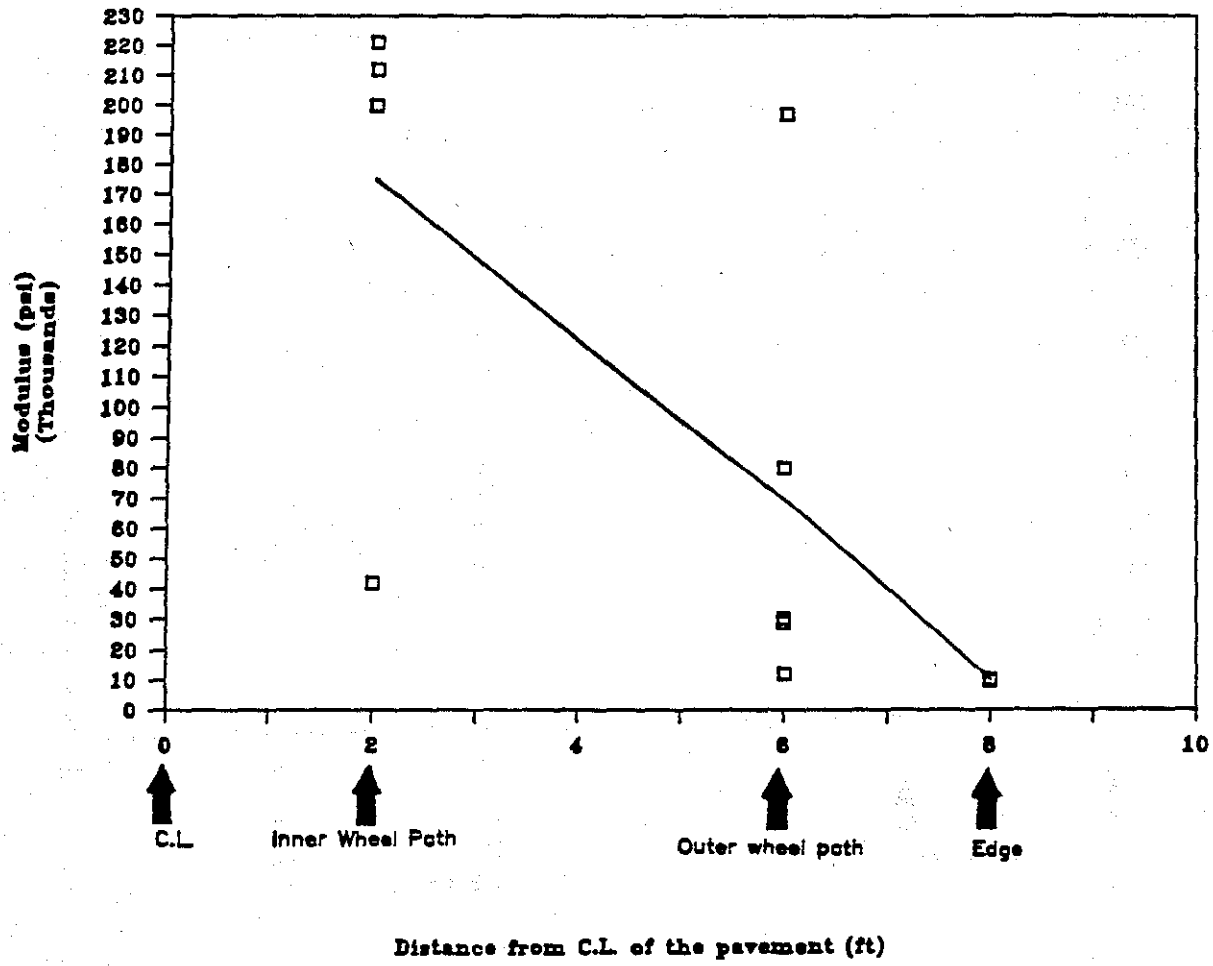


Figure 13. Variation of Base Modulus in FM 2223 Test Section.

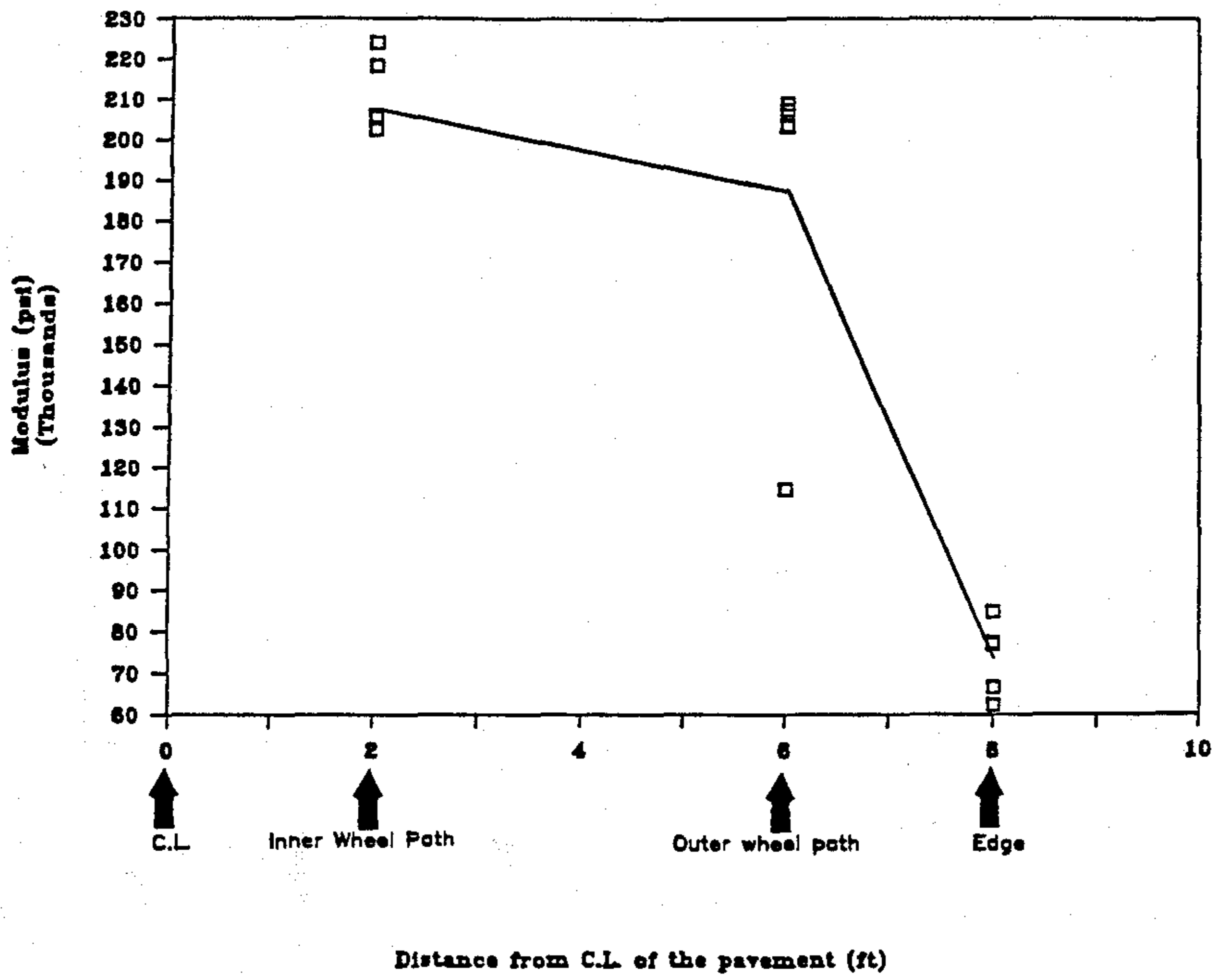


Figure 14. Variation of Base Modulus in FM 1179 Test Section.

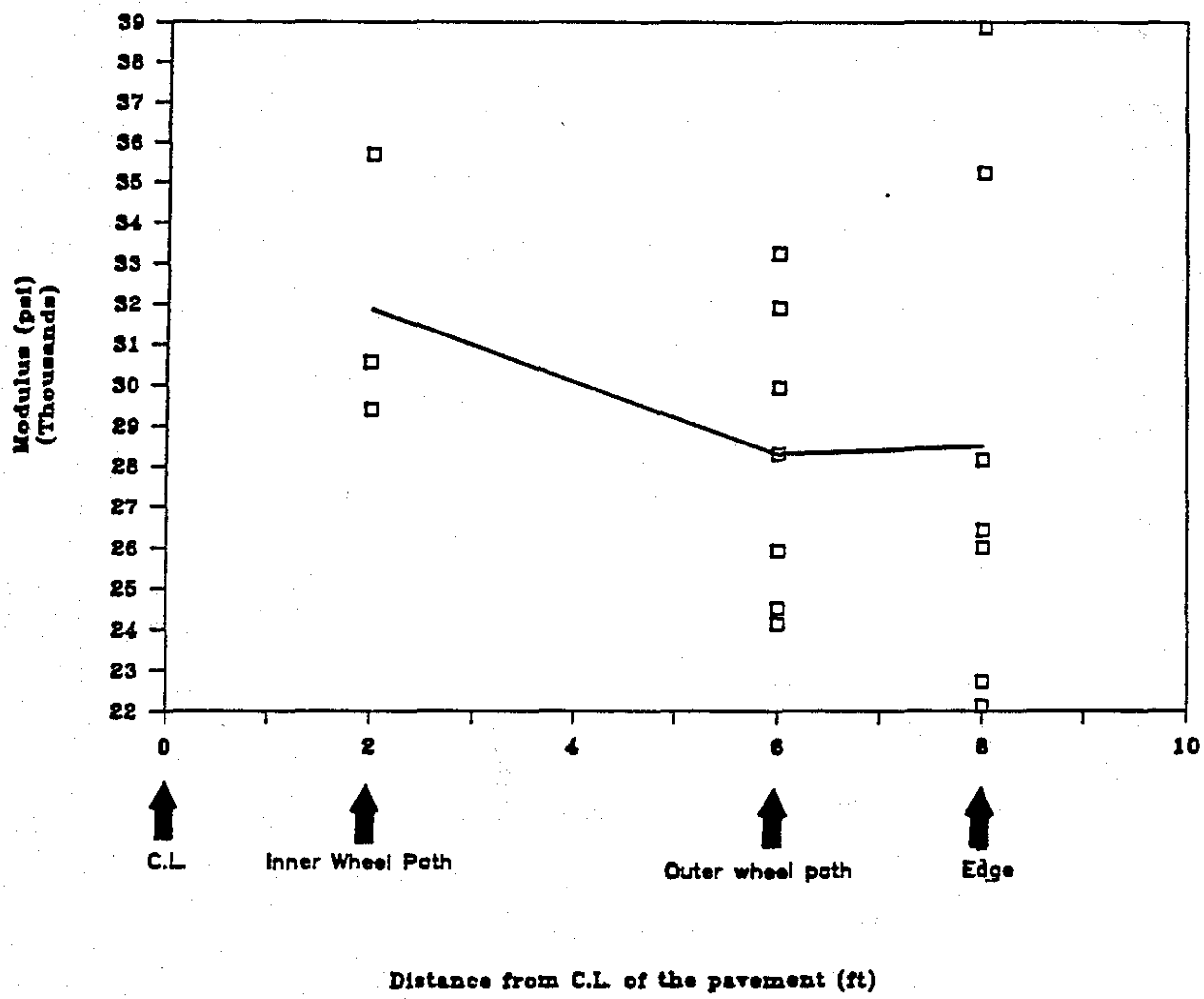


Figure 15. Variation of Base Modulus in FM 2864 Test Section.

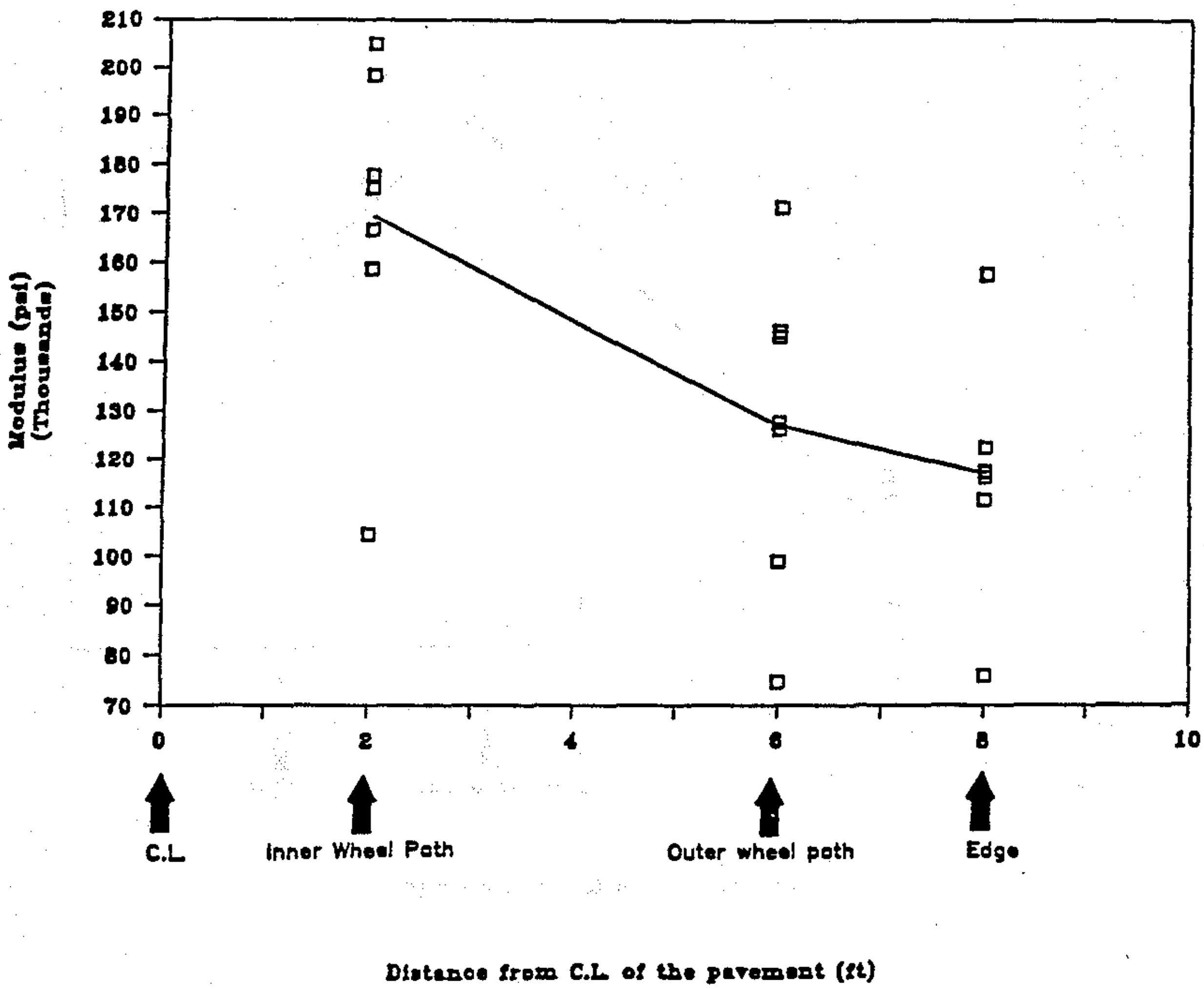


Figure 16. Variation of Base Modulus in SH 7 Test Section.

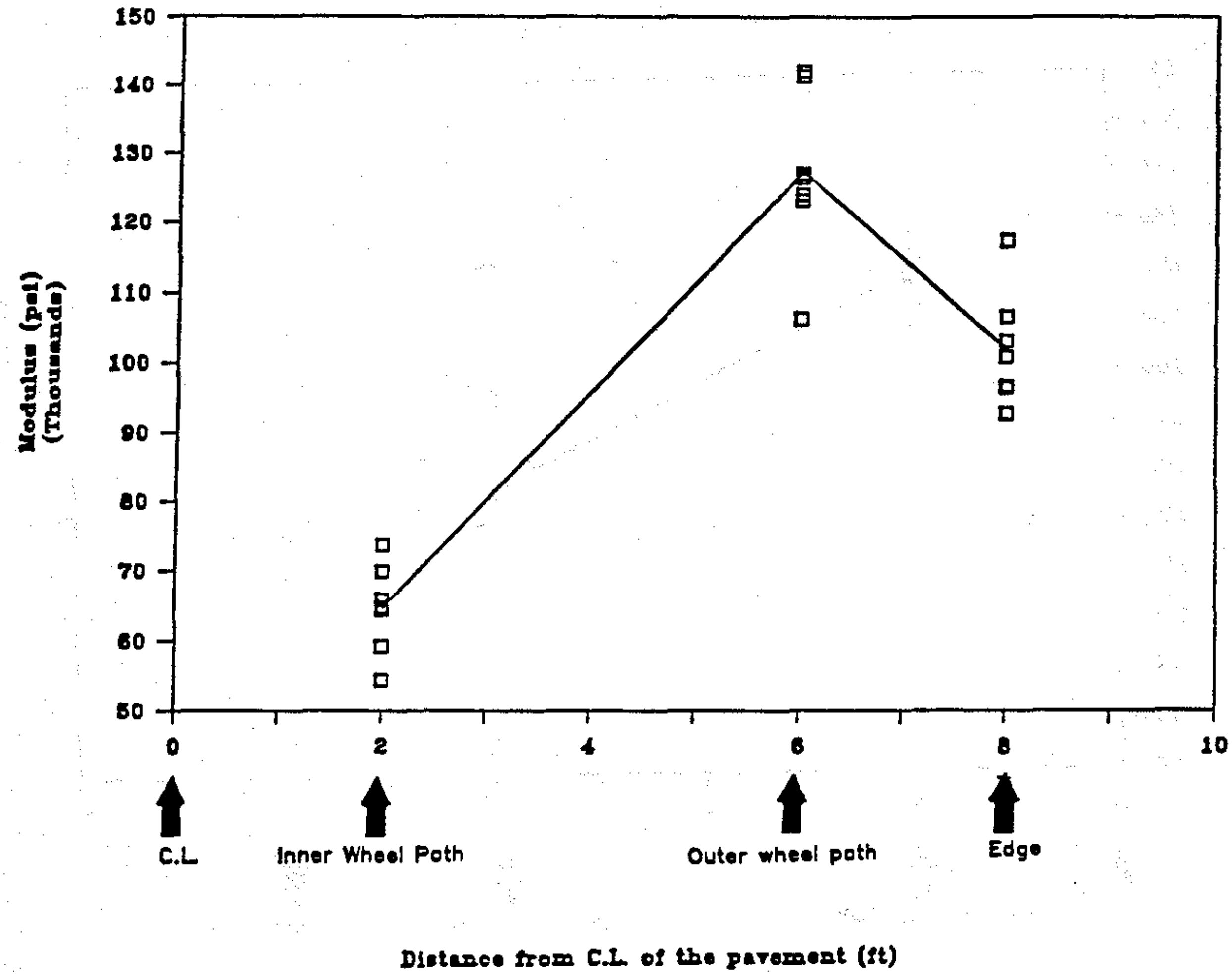


Figure 17. Variation of Base Modulus in LOOP 224 Test Section.

CHAPTER IV
CONCLUSIONS AND RECOMMENDATIONS

A computer program, LOADRATE Version 2.0, has been improved considerably. The program employs a new rut-depth prediction model. It is able to make temperature and moisture corrections for the base modulus. The LOADRATE program analyzes the Falling Weight Deflectometer or the Dynaflect data to calculate the remaining life for a given rut depth. The allowable axle loads for single, tandem, and triple axles are reported at the end of the analysis. The LOADRATE program has been tested with several case studies and is ready for use in the structural evaluation of farm-to-market roads at the project level.

The following conclusions can be drawn form this study:

1. The new rut depth prediction approach has been implemented into the new version of the LOADRATE program. It can provide a better rut-depth prediction.
2. The new LOADRATE program has the capability to make the adjustments in base modulus for different temperature and moisture conditions.
3. A new nonlinear modulus versus deviator stress curve has been added to the subgrade model in the LOADRATE program to represent the sandy subgrades.
4. The new version of the LOADRATE program can be used to determine the remaining life of FM roads by analyzing either FWD or Dynaflect data. The results of the analysis (i.e., the allowable axle loads for single, tandem, and triple axles) can be used to determine the load limits for the FM roads.
5. From the case studies, it can be noted that the strength of the pavement at the edge is weaker than the strength of the pavement in the outer wheel path. A paved shoulder not only prevents water penetration into the road bed, but also provides some lateral support to maintain pavement strength.

The following recommendations were made for further studies:

1. Temperature and moisture corrections should be extended to the subgrade in order to study the complete seasonal variations in the pavement.
2. Test sections should be established on farm-to-market roads around the state to monitor the traffic and rutting. The data collected can be used to calibrate the LOADRATE program.
3. The AASHTO damage factors for single, tandem, and triple axles should be revised based on the rutting failure on farm-to-market roads.

REFERENCES

1. K. M. Chua and R. L. Lytton. Load Rating of Light Pavement Structures. In Transportation Research Record 1043, Transportation Research Board, National Research Council, Washington, D.C., 1984, pp. 89-101.

2. K. M. Chua and R. L. Lytton. Structural Evaluation and Load-Zoning Consideration of Light Pavements. Presented at the Transportation Research Board 66th Annual Meeting, Washington, D.C., Jan. 1987.

3. K. M. Chua. Evaluation of Moduli Back-Calculation Programs for Low-Volume Roads. Presented at 1st International Symposium on Nondestructive Testing of Pavements and Back-Calculation of Moduli, Baltimore, Maryland, June 1988.

4. K. A. S. Yapa, K. M. Chua and R. L. Lytton. A Simplified Mechanistic Rut Depth Prediction Procedure for Low-Volume Roads. Presented at the Transportation Research Board 68th Annual Meeting, Washington, D.C., Jan. 1989.

5. Djan Chandra, K. M. Chua and R. L. Lytton. Effect of Temperature and Moisture on the Response of Granular Base Course Material in Thin Pavements. Presented at the Transportation Research Board 68th Annual Meeting, Washington, D.C., Jan. 1989.

6. J. L. Figueroa and M. R. Thompson. Simplified Structural Analysis of Flexible Pavements for Secondary Roads Based on ILLI-PAVE. In Transportation Research Record 776, Transportation Research Board, National Research Council, Washington, D.C., 1980, pp. 5-10.

7. ILLI-PAVE User's Manual. Transportation Facilities Group. Department of Civil Engineering. University of Illinois at Urbana-Champaign, May, 1982.

8. D.M. Burmister. The General Theory of Stresser and Displacement in Layered Systems and Application to the Design of Airport Runways, Proceedings, HRB, Vol. 23, 1943, pp. 126-148.

9. D.M. Burmister. The General Theory of Stresses and Displacements in Layered Systems. Journal of Applied Physics, Vol. 16, 1945, pp. 84-94, pp. 126-127, pp. 296-302.

10. M.L. Taylor, Characterization of Flexible Pavements by Nondestructive Testing. Civil Engineering Department, University of Illinois at Urbana-Champaign, Ph.D. dissertation 1978.

11. K. A. S. Yapa. A Simplified Mechanistic Rut Depth Prediction Procedure for Low-Volume Roads. M. S. Thesis, Texas A & M University, Dec., 1988.

12. C. L. Monismith, N. Ogawa and C. R. Freeme. Pavement Deformation Characteristics of Subgrade Soils Due to Repeated Loading. In Transportation Research Record 537, Transportation Research Board, National Research Council, Washington, DC, 1974, pp. 1-17.

REFERENCES (Continued)

13. H. A. Loffti, C. W. Schwartz and M. W. Witzack. Compaction Specification for the Control of Subgrade Rutting. Presented at Transportation Research Board 67th Annual Meeting, Washington, D.C., Jan. 1988.

14. W. O. Yandell. Mechano-Lattice Prediction of Pavement Performance. Proc., 4th Conference on Asphaltic Pavements for Southern Africa, Capetown, 1984, pp. 201-215.

15. W.O. Yandell. New Method of Simulating Layered Systems of Unbound Granular Material. In Transportation Research Record 1022, Transportation Research Board, National Research Council, Washington, D.C., 1985, pp. 91-98.

16. W.O. Yandell. Measurement and Prediction of Forward Movement and Rutting in Pavements Under Repetitive Wheel Loads. In Transportation Research Record 888, Transportation Research Board, National Research Council, Washington, D.C., 1982, pp. 77-84.

17. W. H. Press, B. P. Flannery, S. A. Tenkolsky and W. T. Vetterling. Numerical Recipes: The Art of Scientific Computing. Cambridge University Press, Cambridge, 1987, pp. 77-101.

18. M. R. Thompson and Q. L. Robnett. Final Report-Resilient Properties of Subgrade Soils. Transportation Engineering Series No 14, Civil Engineering Studies, Illinois Cooperative Highway and Transportation Series No 160, University of Illinois at Urbana-Champaign, Urbana, IL., June, 1976.

19. M. R. Thompson and Q. L. Robnett. Resilient Properties of Subgrade Soil. Transportation Engineering Journal, Jan. 1979, pp. 71-89.

20. AASHTO Guide for Design of Pavement Structures, 1986.

APPENDIX A

LOADRATE USER'S MANUAL

LOADRATE USER'S MANUAL
VERSION 2.0, AUGUST 1989

A. General

The LOADRATE program is provided for use as a tool for performing structural evaluation of farm-to-market roads at project level. This is a research program which must be used with reasonable good input data and is not intended to replace good engineering judgement. The LOADRATE program has been custom-built into a system for the Texas Department of Highway and Public Transportation (SDHPT). It can be used to analyzes data collected by Falling Weight Deflectometer (FWD) and Dynaflect. A preprocessor software named LDATA has been developed to convert the raw FWD data to INPUT data file. The LOADRATE program was developed for light pavement structures based upon rutting failure criterion. To ensure the accuracy of the results, it should be used only for thin surface treatments pavements (e.g., one to one-and-half inch). The FWD load should be applied around 11,000 lbs.

B. Hardware Requirements

The preprocessor program LDATA is complied using Microsoft FORTRAN VERSION 4.1. The LOADRATE program is complied using QUICK BASIC 3.0. It requires an IBM compatible machine with DOS 3.0 or higher. The program is provided on a 5 1/4-in. disk. A detailed report is written to the disk which can be used for hard copy if a printer is available. This report can be viewed on the screen using the "TYPE" command or it can be printed on the printer using the "PRINT" command. However, a printer is required to generate the graphic outputs. There are seven files on the disk:

1. INSTALL.BAT
2. LDATA.EXE
3. LOADRATE.EXE
4. EXAMPLE.FWD

5. EXAMPLE.LRD
6. EXAMPLE.OUT
7. BRUN40.EXE

To install the program, you have to change the disk drive to the disk drive containing the distribution disk (A or B), and type "Install Name of the disk drive containing the program disk Name of the drive to be installed" (example: "Install A C"). It will create a subdirectory LOADRATE in drive C and copy all the files to that directory. To run the preprocessor, just change to the LOADRATE directory, and type LDATA. To run the LOADRATE analysis, type LOADRATE. You will now be directed through the program to its completion. If you do not have a hard disk, do not run the INSTALL program. Just change to the drive having the distribution disk and type LDATA or LOADRATE.

C. INPUT DATA FILE

The program LDATA converts the FWD raw data to a format that is compatible with the LOADRATE program. It extracts the following variables from FWD file: district number, county number, highway prefix and number, mile-post position of the test station, and loads and deflection readings for prespecified drops. For SDHPT, in general, FWD data are collected either with two replicate drops or four drops at different load levels. This LDATA program is written to handle the FWD data files available with the Texas Dynatest FWDS. To run the LDATA program, just change to the "LOADRATE" subdirectory and type "LDATA," and press return, and follow the request to its completion.

1. Name of the directory and FWD file name: example a:FM2818.fwd
2. Name of the directory and File name for output file: example a:FM2818.lrd
3. Job Title: Up to 72 characters
4. Allowable rut depth (inch): example = 0.5 (Note 1)
5. Existing rut depth (inch): example = 0 (Note 2)

Note 1: Rut depth is the measurement of serviceability; at this specified rut depth, pavement needs some kinds of improvement.

Note 2: If there is no rut depth at present, enter zero.

6. Traffic Input Data:

There are four options available. (Figure A1)

Option 1: Using current annual traffic (in ESAL), annual traffic growth rate and number of years. (Note 3)

Note 3: Option 1 is required to input first year traffic in ESALS and percent annual traffic growth rate. It will estimate the remaining life in years for each test location and allowable axle loads for test pavement.

Selection of Option 1 leads to the following inputs:

1. Current annual traffic in 18 kip ESALs. example: 18000
2. Annual percent traffic growth rate. example: 5
3. Total analysis period in years. example: 10

Option 2: Using first and 20th-year average daily traffic (ADT) and total 20-year traffic in 18 kip ESALs. (Note 4)

Note 4: This option also allows to calculate the remaining life of each test location and allowable axle loads for the test pavement. The percent annual traffic growth rate is calculated from the information of first-year and 20th-year average daily traffic (ADT). It requires the total number of ESAL passes in 20 years.

Selection of Option 2 leads to the following inputs:

1. First-year ADT. example: 1100
2. 20th-year ADT. example: 2100
3. 20-year traffic in ESALs. example: 420000

Option 3: 10-year projected ESAL : example 210000 (Note 5)

Note 5: In this option the analysis is done for the total amount of 10-year traffic. The only input required for this option is the total ESAL passes in 10 years.

Option 4: 20-year projected ESAL : example: 420000 (Note 6)

Note 6: In this option the analysis is done for the total amount of 20-year traffic. Required input is the total number of ESAL passes in 20 years.

INPUT OF TRAFFIC DATA

The options 1 and 2 allow to find the remaining life of the pavement in years

(1) USING CURRENT ANNUAL TRAFFIC (IN ESAL), TRAFFIC GROWTH RATE AND NUMBER OF YEARS
(2) USING 1st AND 20th YEAR ADT AND TOTAL NUMBER OF ESAL PASSES IN 20 YEARS
(3) 10-YEAR PROJECTED ESAL
(4) 20-YEAR PROJECTED ESAL

ENTER YOUR OPTION

Figure A1. Options to Input Traffic Data in LDATA Program.

7. Thickness of the base course (inch) : example: 10
8. Deflection bowls to be analyzed: Two options are available (Figure A2):

Option 1: All the deflection bowls at each test location.

Option 2: Only one deflection bowl from each test point.

SELECTION OF DEFLECTION BOWLS FOR ANALYSIS

(1) All the deflection bowls
(2) Only one deflection bowl from each

ENTER YOUR OPTION

Figure A2. Selection of Deflection Bowls for LOADRATE Analysis.

9. Format of the FWD data file : example = 0 (Version 9.0).

Once the process is completed, it will create an output file for LOADRATE analysis. At the final stage of the LDATA process, it will ask whether you want to process another FWD data file or Exit the program. Just enter "Y" to process another FWD data file or enter "N" to exit the program.

D. Running the LOADRATE PROGRAM

To run the LOADRATE program, just change to the LOADRATE subdirectory, and type LOADRATE. The main program menu should appear on the screen, as shown in Figure A3.

```
LOADRATE - STRUCTURAL ANALYSIS OF LIGHT PAVEMENT

                  MAIN MENU

          SELECT THE OPERATION DESIRED;

(1)  Structural analysis of pavements
     (moduli, # or passes, rut depth, remaining life and
     allowable axle load calculations, and analysis of
     temperature and moisture effects on base material)
(2)  Temperature correction of base modulus only
(3)  Rut depth calculation only
(4)  Exit program


ENTER SELECTION AND <RET> : ?
```

Figure A3. Main Menu in LOADRATE Program.

Main Program Menu Options

The main program Menu allows the selection of any of the four available options. Select your option and type the number followed by <RETURN> to execute that routine.

Option 1 in Main Menu: Structural analysis of pavements

This option allows the user to execute a complete analysis of a pavement. The analysis uses input files that have been converted from FWD files using LDATA.EXE program, or it can also process files that have been custom-made using a text editor or similar program. The Dynaflect data can be prepared using a text editor.

Option 2: Temperature correction for base modulus

Select this option to obtain base modulus value at different temperature and suction values.

Option 3: Rut-Depth calculation

This option allows the user to calculate the rut depth and number of passes to achieve a given rut depth for pavements with known material properties.

Option 4 : Exit program

Running the options in Main Menu

After selecting option 1 from the menu, the user is asked to enter the input file name (this can be the file created by LDATA program or a file create by a text editor or similar program), example a:FM2818.lrd). The LOADRATE program will read and display the input data on the screen. Then the user is requested to select the option for hard copy.

MENU 2

No hard copies - 0
Hard copies of input and output - 1
Hard copy of output only - 2

If hard copies are requested, it is important to have the printer on.

MENU 3 (Figure A4)

Option 1. Require subgrade material classification to determine approximate rutting potentials. This option allows user to give subgrade material type to determine approximate rutting potentials.

Option 2. Require laboratory data on residual deformation behavior of base and subgrade. This option require results of laboratory testing of base and subgrade.

```
INPUT DATA OPTIONS FOR RUT DEPTH CALCULATIONS:

(1)  Require subgrade material
     classification to determine approximate
     rutting potentials.

(2)  Require laboratory data on residual deforma-
     tion behavior of base and subgrade.

OPTION:  1=SOIL CLASS, 2=LAB DATA?
```

Figure A4. Option to Input Base and Subgrade Material Properties.

Select your option and press <RETURN>. Selection of option 1 the program will display a screen to select subgrade material type (Figure A5). Select your option which represents the subgrade material type and press <RETURN>. Selection of option 2 provide the facility to enter laboratory data for base and subgrade material (Figure A6). The material constants are "a" and "b".

```
Subgrade Material Type:

(1)  Heavy Clay - (CH)

(2)  Light/Silty Clay, Clayey Silt - (CL-ML)

(3)  Clayey/Silty/Uniform Sand - (SC-SM)

 ENTER SELECTION & <RET>
```

Figure A5. Option to Select Subgrade Material Type.

```
            Laboratory Data Input:

            Log a - Intercept of the Straight Line Fit on a
                    Log-Log Plot of Accumulated Residual Strain
                    vs. Number of Load Repetitions

            b     - Slope of the Straight Line Fit


Log a - Base Course Material? 0.4
b     - Base Course Material? 0.125
Log a - Subgrade Material? 0.236

b     - Subgrade Material? 0.236
```

Figure A6. Option to Input Base and Subgrade Laboratory Data.

The program displays the values of log "a" and "b" and ask user to confirm these values (Figure A7). If the user wants to correct these values, type 1 and press <RETURN>. This will allow the user to reenter the values of log "a" and "b". If values entered are correct, just press <RETURN>. Now the interpolation scheme starts to execute; it takes 20 to 60 seconds to run depending on the disk access speed and the length of the input file. When program has successfully executed, depending on hard copy option, it will start printing results. At the same time, results appear on the screen. At the end of results, there will be a message "Press Return To Continue.....?". To continue the program press <RETURN>. The Output Menu (Figure A8) will display on the screen.

```
            Base Course Material -

                     Log a = 0.4 ,           b = 0.125

            Subgrade Material    -
                     Log a = 0.11,           b = 0.236


            DO YOU WANT ANY CORRECTIONS - 0=NO, 1=YES?
```

Figure A7. Option to Correct Laboratory Data.

```
                    OUTPUT MENU

              Select Optional Output Format

               (1)  Plot Base Course Elastic Modulus
               (2)  Plot Subgrade Elastic Modulus
               (3)  Plot Number of Vehicle Passes
               (4)  Plot Remaining Life
               (5)  Temperature Correction of Base Modulus
                    (5.1) Rut depth, Passes and Remaining Life
                          for corrected moduli
               (6)  Save the output as a file
               (7)  Exit to Main Menu


              ENTER SELECTION AND <RET> : ?
```

Figure A8. Output Menu in LOADRATE Program.

MENU 4

OUTPUT MENU

Options 1 to 4

The options 1 to 4 in the output menu allow the user to analyze base cause moduli, subgrade moduli, number of vehicles passes and remaining life in a graphical view, for the entire project length. Selection of one of these options allows the user to obtain a plot of the selected variable. As soon as this option is selected, the program ask for a minimum valve for the selected variable. If the user presses <RETURN>, the program takes the default value which is shown in brackets, or the user can enter a minimum value for the selected variable and then press <RETURN>. The program also asks a maximum value for the selected variable. Again by pressing <RETURN>, the user can use the default value or enter desired maximum value. A plot of the selected variables versus distance is produced on the screen. Figure A9 shows a sample plot, where the selected variable is the base course moduli. If a hard copy is needed, just press <RETURN> and then press print screen <PRT SC>. Pressing any other key will return the user to the Output Menu.

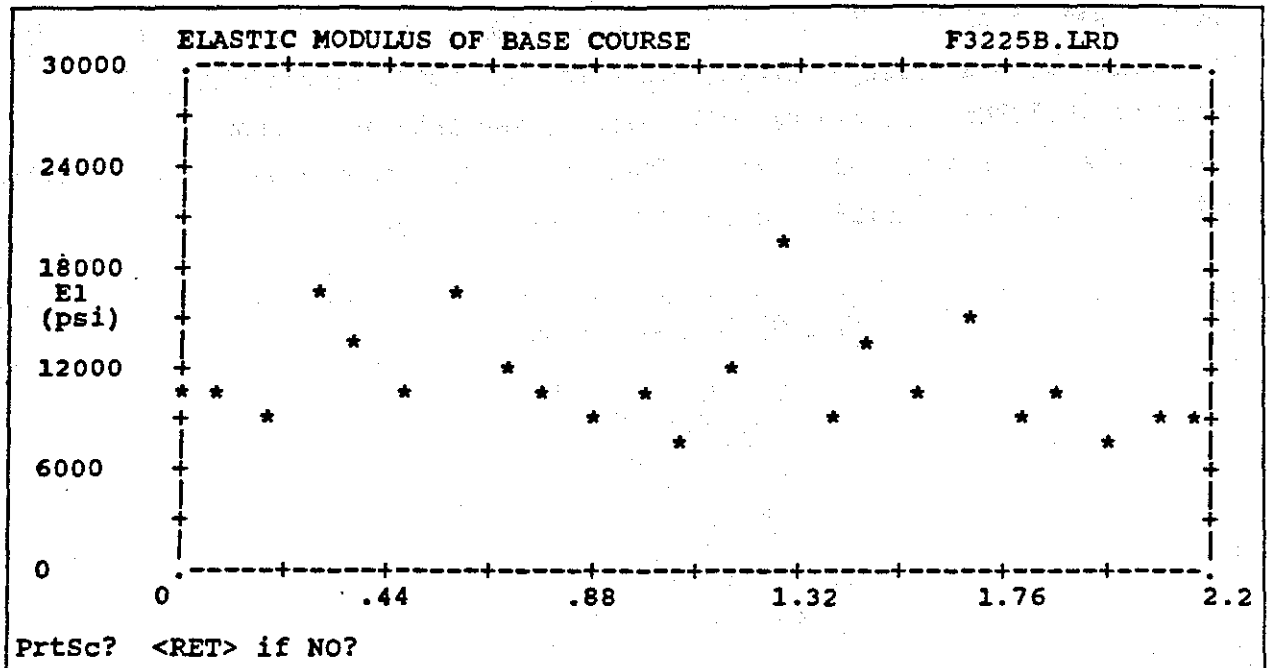


Figure A9. A Sample Plot of Base Course Modulus.

Option 5: Temperature correction of base moduli

This option allows the user to obtain base course moduli values for different temperatures and suction values. When the option is selected the program displays a screen of base course material types (Figure A10). Select the base course material and type and press <RETURN>. The program will display a screen of properties of the selected material (Figure A11). If you want to change these properties, just type 1 and press <RETURN> otherwise press <RETURN>. If you want to change the material, just enter the line number and press <RETURN>. After the selecting of the material type, the program asks for the unit weight of the base material. Enter the unit weight and press <RETURN>. The program will display the statement "Conditions at which the modulus is obtained" and ask for temperature of the base course when testing was made. Enter the temperature and press <RETURN>. You also have to provide the suction value of the base course when testing was conducted. Enter the value and press <RETURN>. The program will ask for temperature and suction values of the condition where the corrected base moduli values are required. Enter temperature in °F for the condition and press <RETURN>. Then enter suction value at the condition in psi and press <RETURN>. Figure A12 shows a sample of this input screen. Once completed, results will appear on the screen with a message "press return to continue" (Figure A13). By pressing <RETURN>, the program will display two options as shown in Figure A14. Select option 1 and press <RETURN> to go back to the Main Menu or select option 2 and press <RETURN> to go to the Output Menu.

```
TYPE OF BASE MATERIAL:

 1 = CRUSHED LIMESTONE
     LIME ORE GRAVEL
     IRON ORE GRAVEL
 2 = RIVER GRAVEL
     CALICHE
     CALICHE GRAVEL
 3 = SANDSHELL
 SELECT YOUR OPTION ?
```

Figure A10. Option to Select Type of Base Material For Temperature and Moisture Correction of Base Modulus.

```
PROPERTIES OF THE MATERIAL SELECTED:
     1.  LINEAR THERMAL EXPANSION            = .000005
     2.  ELASTIC MODULUS OF SOIL GRAIN       = 6400000
     3.  POISSON'S RATIO                     = .17


DO YOU WANT TO CHANGE?  0=NO    1=YES?
```

Figure A11. Option to Enter Material Properties for Selected Base Material.

CONDITIONS AT WHICH THE MODULUS IS OBTAINED

TEMPERATURE, Ti (40 deg.F < Ti < 100 deg.F) : 60
SUCTION, Hi (-145 psi < Hi < 0 psi) : -60

INPUT WANTED CONDITIONS:

TEMPERATURE, To (40 deg.F < To < 100 deg.F) : 80
SUCTION, Ho (-145 psi < Ho < 0 psi : -80

Figure A12. Input of Temperature and Suction Data.

INPUT CONDITIONS: WANTED CONDITIONS

TEMPERATURE = 60.0 deg. F TEMPERATURE = 80.0 deg. F
SUCTION = -60.00 psi SUCTION = -80.00 psi

INPUT MODULUS (psi)	WANTED CONDITION MODULUS (psi)	MODULUS CHANGE DUE TO TEMPER. (psi)	MODULUS CHANGE DUE TO SUCTION (psi)
202312.58	217106.28	10429.55	4364.15
209671.67	223430.22	9699.78	4058.78
226415.52	238186.94	8298.85	3472.57
231238.84	241033.56	6905.27	2889.45
225177.92	237081.06	8391.71	3511.43
214167.39	227345.91	9290.85	3887.67

PRESS RETURN TO CONTINUE.........?

Figure A13. Sample Output From Temperature and Moisture Correction.

1. EXIT TO MAIN MENU

2. EXIT TO OUTPUT MENU

Select the Operation Desired: ?

Figure A14. Options to Go to Main or Output Menu.

Option 5.1: Rut-depth, Passes and remaining life for corrected base moduli:

Selection of option 5.1 must be done only after completion of option 5. This option (5.1) allows the user to calculate rut depth, number of passes and remaining life for the corrected base moduli values.

Once this option is selected, the screen shown in Figure A5 is displayed. The whole procedure for this option is exactly similar to part of option 1 in the Main Menu.

Option 6: Saving output as a file: (Note 7)

Note 7: Select this option to save the results as a DOS file. Before the user selects option 5.1, it is important to save the results of previous analysis.

Once the option is selected, the program will ask for a file name. Enter the file name with drive specifications (Figure A15) and press <RETURN>. It will direct the user to the screen shown in Figure A16. Enter the option to select the format of the output file and press <RETURN>. The program will ask the user whether the results of temperature and moisture correction are to be saved. This option appears only when there was a temperature and moisture correction of base moduli before selecting option 6. Select the option and press <RETURN>. An example Output file is given in Figure A17.

```
TO CREATE OUTPUT FILE
ENTER OUTPUT FILE NAME AND <RET>:? a:test.out
```

Figure A15. Option to Enter Output File Name and Directory.

```
Select the format:

(1)
Sec.   Thick   E1(Base)   E2(Subgr)   Passes   Rut depth  Remaining life
(2)
Sec.  Thick  D1  D7  FWD  load  E1(Base)  E2(Subgr)  Passes Remaining life


ENTER SELECTION AND <RET> : ?
```

Figure A16. Option to Select Format of Output File.

Option 7: Exit to Main Menu: Select this option to end the analysis and to return to the Main Menu.

Option 2 in Main Menu: Temperature correction for base modulus

Once this option is selected, the program displays the screen as shown in Figure A10. Select the base course material type from the list and press <RETURN>. The program will display a screen, as shown in Figure A18. Enter 1 and press <RETURN> to change the material properties or press <RETURN> to accept the material properties. To change the material properties, the program asks for the line number the user wants to make a correction on. Enter the line number and press <RETURN>. The program will request a new value; enter the new value and press <RETURN>. By repeating this procedure, the user can change any material property given in Figure A18. Once the material properties are accepted, the program asks for the unit weight of the base material in pcf. Enter the unit weight of and press <RETURN>. The program will display the statement "Conditions at which the modulus is obtained" and ask for the temperature of the base course when testing was conducted. Enter the temperature and press <RETURN>. User also has to provide the suction value of the base course when testing was made. Enter the value and press <RETURN>. The program then will ask for the temperature and suction values of the condition where the corrected base moduli values are required. Enter the temperature in °F and press <RETURN>. Also enter the suction value in psi and press <RETURN>.

```
TEXAS TRANSPORTATION INSTITUTE
LOAD RATING OF LIGHT PAVEMENT

JOB : fwd testing (inner w. p.)          (INPUT FILE a:osemanu.lrd)

DISTRICT: 0      COUNTY:Cty      ROAD:10810 fm32255
ALLOWABLE RUT(INS): .5      RECORDED RUT(INS): 0

TRUCK NO. 1
AXLE NUMBER   SINGLE WHEEL/ESWL(LBS)
    1               9000

ANNUAL TRAFFIC GROWTH RATE: .05   # OF YEARS: 10   FIRST YEAR TRAFFIC: 37183
TOTAL NUMBER OF PASSES DURING ABOVE PERIOD: 467761

DATE:4-25-89   FALLING WEIGHT DEFLECTOMETER
                                               *            **            *
 SEC  BASE       E1-BASE   E2-SUBGR  NO. OF      RUT DEPTH   REMAINING LIFE
  #   (IN)       (PSI)     (PSI)     PASSES      (IN)         (YEARS)
 0.0  15.0       202314    10787     782754      0.30          14.7
 0.2  15.0       209673    11426     816913      0.29          15.2
 0.4  15.0       226417    11393     826680      0.28          15.3
 0.6  15.0       231236    12945     899199      0.26          16.2
 0.8  15.0       225179    10901     802744      0.29          15.0
 1.0  15.0       214169     9610     643239      0.36          12.8

 *  NUMBER OF PASSES AND REMAINING LIFE FOR SPECIFIED RUT DEPTH OF  .5 in
 ** RUT DEPTH FOR SPECIFIED NUMBER OF PASSES OF  467761  IN  10 YEARS

     Remaining Life(yrs)          Cumulative % Sections
            1                          100.0
            2                          100.0
            3                          100.0
            4                          100.0
            5                          100.0
            6                          100.0
            7                          100.0
            8                          100.0
            9                          100.0
           10                          100.0
           11                          100.0
           12                          100.0
           13                           83.3
           14                           83.3
           15                           66.7
           16                           16.7


                  Allowable Axle Load Limits (kips)
        SINGLE               TANDEM               TRIPLE

        LEGAL                LEGAL                LEGAL

        TEMPERATURE CORRECTION DATA

   INPUT CONDITIONS:                   WANTED CONDITIONS:
  TEMPERATURE =   60.0 deg. F       TEMPERATURE =    80.0 deg. F
  SUCTION     =  -60.0 psi          SUCTION     =   -80.0 psi

   INPUT     WANTED CONDITION   MODULUS CHANGE   MODULUS CHANGE
  MODULUS        MODULUS        DUE TO TEMPER.   DUE TO SUCTION
   (psi)          (psi)             (psi)            (psi)

  202314         217107             10429            4364
  209673         223431              9700            4059
  226417         238188              8299            3473
  231236         241030              6905            2889
  225179         237082              8392            3511
  214169         227347              9291            3888
```

Figure A17. A Sample Output File.

Figure A12 shows a sample of this input screen. Once the temperature and moisture corrections are completed, results will appear on the screen with a message "press return to continue" (Fig. 19). By pressing <RETURN>, the program will display two options as shown in Fig. A20. Select option 1 and press <RETURN> to perform another temperature correction or select option 2 and press <RETURN> to go to the Main Menu.

```
PROPERTIES OF THE MATERIAL SELECTED:

     1.  LINEAR THERMAL EXPANSION            =  .000005
     2.  ELASTIC MODULUS OF SOIL GRAINS      =  6400000
     3.  POISSON'S RATIO                     =  .17
     4.  K1                                  =  14000
     5.  K2                                  =  .4


DO YOU WANT TO CHANGE?   0=NO    1=YES
```

Figure A18. Option to Enter Base Material Properties.

```
        INPUT CONDITIONS                        WANTED CONDITIONS

TEMPERATURE =      60.0  deg. F        TEMPERATURE =     80.0  deg. F
SUCTION     =    -60.00  psi            SUCTION    =    -80.00 psi

  INPUT      WANTED CONDITION     MODULUS CHANGE      MODULUS CHANGE
 MODULUS          MODULUS         DUE TO TEMPER.      DUE TO SUCTION
  (psi)            (psi)              (psi)               (psi)

40000.00         50219.77            7204.93             3014.83


      PRESS RETURN TO CONTINUE.........?
```

Figure A19. A Sample Output From Temperature and Moisture Correction.

```
1. ANOTHER TEMPERATURE CORRECTION
2. EXIT TO MAIN MENU

Select the Operation Desired: ?
```

Figure A20. Option to go to Main Menu or to Do Another Temperature Correction.

Option 3 in Main Menu: Rut depth calculation

To calculate the rut depth, select the option and follow the requests to its completion, as shown in Figure A21.

1. Job Description: example: FM 2818 testing
2. Resilient Modulus - Base Course (psi): example: 40000
3. Resilient Modulus - Subgrade (psi): example: 7000
4. Thickness of Base Layer (in.): example: 8
5. # of Equivalent Standard Wheel (9000 lbs) Passes: example: 320000
6. Allowable Rut Depth (in.): example: 0.5
7. Existing Rut Depth (in.): example: 0

Once this input is completed, the program will display the screen shown in Figure A4.

```
JOB DESCRIPTION :? FM 2818 TESTING
Resilient Modulus - Base Course (psi)? 40000
Resilient Modulus - Subgrade (psi)? 7000
Thickness of Base Layer (in.)? 8
# of Equivalent Standard Wheel (9000 lbs) Passes? 320000
Allowable Rut Depth (in.)?  .5
Existing Rut Depth (in.)?  0
```

Figure A21. Input Data For Rut Depth Calculation.

1. Require subgrade material classification to determine approximate rutting potentials. This option allows user to give subgrade

material type to determine approximate rutting potentials.

2. Require laboratory data on residual deformation behavior of base and subgrade. This option require results of laboratory testing of base and subgrade.

Select your option and press <RETURN>. Selection of option 1 in the program displays a screen to select the subgrade material type (Figure A5). Enter your option and press <RETURN>. In the case of selection of option 2, the user has to provide the laboratory data for base and subgrade materials. (Figure A6)

The program displays all the values and ask the user to confirm (Figure A22). If user wants to correct these values, type 1 and press <RETURN>. This option will allow the user to correct the input values. If values entered are correct just press <RETURN>. The results will appear on the screen as shown in Figure A23. To continue the program, press <RETURN>. The program will display two options, as shown in Figure A24. Select option 1 and press <RETURN> to perform another rut depth calculation or select option 2 and press <RETURN> to go to the Main Menu.

```
JOB:  FM 2818 TESTING

Resilient Modulus (psi) - Base      =  40000

                        - Subgrade  =  7000

Thickness of Base Layer             =  8 in.

# of Equivalent Standard Wheel passes  = 320000

Allowable Rut Depth = .5 in.

Measured Rut Depth = 0 in.

Subgrade     - CH - Clay


DO YOU WANT ANY CORRECTIONS - 0=NO, 1=YES
```

Figure A22. Option to Change Input Data in Rut-Depth Calculation.

```
            EQUIVALENT STANDARD WHEEL PASSES = 320000

            RUT DEPTH CAUSED         =  .557836

            ALLOWABLE RUT DEPTH      =  .5 in.

            EXISTING RUT DEPTH       =  0 in.

            ALLOWABLE WHEEL PASSES   =  286822.6


   PRESS RETURN TO CONTINUE.........?
```

Figure A23. Results of Rut-Depth Calculation.

```
       1.  ANOTHER RUT DEPTH CALCULATION

       2.  EXIT TO MAIN MENU


   Select the Operation Desired:    ?
```

Figure A24. Option to go to Main Menu or to do Another Rut-Depth Calculation.

APPENDIX B

LOADRATE PROGRAM

```
'*****************$$$ PROGRAM - LOADRATE - $$$****************
'*                  Version  AUGUST 1989                        *
'*          Load Rating of Light Pavement Structures            *
'*                 WRITTEN BY K. M. CHUA                        *
'*                      REVISED BY                              *
'*                   B. LANKA SANTHA                            *
'*      Pavement Systems, Texas Transportation Institute        *
'*           TTI Building, Texas A&M University,                *
'*             College Station, Texas 77843                     *
'*                    (409)-845-5982                            *
'*                Update 20th August 1989                       *
'**************************************************************
'Dimensioning ----------------------------------------
'
'
   DIM D(100, 7), SO(100), DE(100, 7)
   DIM AC(100), PFW(100), K1(100), W(100), BC(100), K1S(100)
   DIM WL(100, 8), AM(100), PS(100): DIM SS(100), CK$(100)
   DIM NS(100), H(100), SI(100), BA(100), NX(100)
   DIM SSO(100), BBA(100), WW(100), WP(100), WOS(100)
   DIM E1(100), E2(100), SL(100), Y(100), D7(100)
   DIM DSUM(10), JSUM(10), FSUM(10), DF(10), FW(10), R(10), PRESS(10)
   DIM WLOAD(10), X(10), DYR(100)
   DIM DET(100), DES(100), NE(100), OE(100), TOTDE(100)
   DIM RFINAL(100), passes(100), NY(100)
   DIM XM(100), XL(100), XK(100), XJ(100), XI(100)
   DIM Y1(5), X1(5), YLTEMP(5), YKTEMP(5)
   DIM YJTEMP(5), YITEMP(5), C(5), DD(5)
   REM To initialize FWD sensor spacing
   X(1) = .01: X(2) = 12: X(3) = 24: X(4) = 36: X(5) = 48: X(6) = 60: X(7) = 72
730 GOSUB 6585
   REM SELECT TEMP. CORRECTION OR STRUCTURAL ANALYSIS OR RUT DEPTH CALCULATION
   IF SLECT1 = 2 THEN : CHO1 = 0: GOSUB 10010
   IF SLECT1 = 3 THEN : IF RUT1 <> 1 THEN : INIOPT = 2: GOSUB 12000
   IF SLECT1 = 3 THEN : IF RUT1 = 1 THEN : INIOPT = 2: GOSUB 12400
   IF SLECT1 = 4 THEN : CLS : GOTO 5980
   'GOSUB 6950: REM SELECTION TABLE -- MAIN MENU
   '
    FOR I = 1 TO 100
      NY(I) = 0
      DYR(I) = 0
      PS(I) = 0
    NEXT I
   REM MAIN PROGRAM -----------------------------------
   'Initializing
      CO = 0: OO = 0
   '
   CLS : PRINT : PRINT "    PROGRAM : LOADRATE  Version 2.0 August 1989"
   PRINT : PRINT
   GOTO 1790
1440 IF OP <> 1 AND OO <> 1 THEN : GOTO 1740
   IF OO = 1 THEN : OO = 0: GOTO 3570
   '
1740 IF OO <> 0 THEN GOTO 3080
   GOTO 2290
   '
1790 'To read from file ----------------------------------
   PRINT "    FILE NAME"
```

```
    INPUT X$
    PRINT "Please Wait ......"
    OPEN "I", #1, X$
      INPUT #1, EQ
      INPUT #1, ID
      INPUT #1, C$
      INPUT #1, F$
    INPUT #1, D$
    INPUT #1, a$
    INPUT #1, NC, NT, RX, RM, AL, PA, GR, ESAL1
    FOR NTT = 1 TO NT
      INPUT #1, NX(NTT)
      FOR I = 1 TO NX(NTT)
        INPUT #1, WL(NTT, I)
        NEXT I
      NEXT
    FOR I = 1 TO NC
      IF EQ = 0 THEN : INPUT #1, NS(I), BA(I), D(I, 1), D(I, 2), D(I, 3), D(I, 4), D(I, 5)
      IF EQ = 1 THEN : INPUT #1, NS(I), BA(I), D(I, 1), D(I, 2), D(I, 3)
      IF EQ = 1 THEN : INPUT #1, D(I, 4), D(I, 5), D(I, 6), D(I, 7), PFW(I)
      NEXT
    CLOSE
    GOTO 2290
    '
    '
2290 REM To print input card images ------------------------------------
    '
    '
2320 OPEN "SCRN:" FOR OUTPUT AS #1
    REM ITERATE FOR THE NUMBER OF TRUCKS CONSIDERED
2340 FOR ITE = 1 TO NT
      IF ITE > 1 THEN : PRINT #1, : GOTO 2440
      CLS : PRINT #1, "TEXAS TRANSPORTATION INSTITUTE"
      PRINT #1, "LOAD RATING OF LIGHT PAVEMENT"
      PRINT #1,
      PRINT #1, "JOB : "; a$; "          (INPUT FILE "; X$; ")"
      PRINT #1,
      PRINT #1, "DISTRICT:"; ID; "     COUNTY:"; C$; "     ROAD:"; F$
      PRINT #1, "ALLOWABLE RUT(INS):"; RX; "     RECORDED RUT(INS):"; RM
      PRINT #1,
2440    NTT = ITE
      PRINT #1, "TRUCK NO. "; NTT
      PRINT #1, "AXLE NUMBER   SINGLE WHEEL/ESWL(LBS)"
    '
    '
    ' To loop of the number of axles NX and number of trucks NTT
      FOR I = 1 TO NX(NTT)
         PRINT #1, TAB(5); I; TAB(20); WL(NTT, I)
         NEXT I
      PRINT #1,
    '
    '
    'For more than one truck considered
      IF ITE > 1 THEN : GOTO 3010
      PRINT #1, "ANNUAL TRAFFIC GROWTH RATE:"; GR; " # OF YEARS:"; AL; " FIRST YEAR TRAFFIC:";
ESAL1
      PRINT #1, "TOTAL NUMBER OF PASSES DURING ABOVE PERIOD:"; PA
      IF EQ = 0 THEN : PRINT #1, "DATE:"; D$; "     DYNAFLECT"
```

```
    IF EQ = 1 THEN : PRINT #1, "DATE:"; D$; "   FALLING WEIGHT DEFLECTOMETER"
    REM CONTINUE
    PRINT #1,
    PRINT #1, "SECTION    BASE                          DEFLECTION"
    IF EQ = 0 THEN : PRINT #1, "  NO.   THICKNESS                          (MILS) "
    IF EQ = 1 THEN : PRINT #1, "  NO.   THICKNESS                         (MILS)                LOAD"

    IF EQ = 0 THEN : PRINT #1, "          (INS)    W1     W2     W3     W4     W5    "
    IF EQ = 1 THEN : PRINT #1, "          (INS)    W1     W2     W3     W4     W5     W6     W7
(LBS)"
    IF EQ = 1 THEN : PRINT #1, "(RADIAL DISTANCE)";
    IF EQ = 1 THEN : PRINT #1, USING " ###.#  ###.#  ###.#  ###.#  ###.#  ###.#
###.#"; X(1), X(2), X(3), X(4), X(5), X(6), X(7)
    PRINT #1,
    FOR I = 1 TO NC
    '
    'CALCULATION OF BASE THICKNESS
    IF TBC = 1 THEN : BA(I) = NH
    IF BA(I) <> 0 THEN : GOTO 2890
    '
    WW = (DE(I, 1) - DE(I, 7)) / DE(I, 7)
    BA(I) = (SSO(I) / 1958 * WW) ^ 1.85
    BA(I) = INT((BA(I) * 10 + 5) / 10)
    IF NH = 0 THEN : PPR = 0
    IF PPR = 2 THEN : GOTO 3000
  REM To print image for Dynaflect ---------------------------
2890 '
  REM Check if hardcopy is needed
       IF EQ = 0 THEN : PRINT #1, NS(I); TAB(12); BA(I); TAB(23);
       IF EQ = 0 THEN : PRINT #1, USING "####.##"; D(I, 1), D(I, 2), D(I, 3), D(I, 4), D(I, 5)
  '
  REM To print image for Falling Weight Deflectometer
  '
       IF EQ = 1 THEN : PRINT #1, NS(I); TAB(12); BA(I); TAB(19);
       IF EQ = 1 THEN : PRINT #1, USING "###.##  ###.##  ###.##  ###.##  ###.##
###.##  ###.## ######"; D(I, 1), D(I, 2), D(I, 3), D(I, 4), D(I, 5), D(I, 6), D(I, 7); PFW(I)
  '    IF EQ = 1 THEN : PRINT #1,
3000     NEXT
  PRINT #1,
3010   CLOSE
  '
  '
  REM PR is 1 indicates that hardcopy is required
    IF PR = 1 THEN GOTO 3650
  '
  REM OO is 1 indicates that all corrections had been done
3080   'IF OO=1 THEN GOTO 3570
  '
  '
  '---------------------------------------------
  '
    LOCATE 25, 1: PRINT SPC(132);
  '
  '
  '
    IF CO = 0 AND OO = 0 THEN : GOTO 3570
    IF CO = 0 AND OO = 1 THEN : GOTO 3530
  '
```

```
'
3530 IF OP <> 0 THEN : CLOSE : GOTO 1440
'
3570 'Check point for printing ------------------------------------------
'
      IF ITE <> 1 THEN : GOTO 3640
      IF TBC = 0 THEN : LOCATE 25, 1:                                   INPUT "DO YOU WANT
HARDCOPY? 0=NO 1=YES 2=RESULTS ONLY"; PR
      IF TBC = 1 THEN : LOCATE 25, 1: INPUT "DO YOU WANT HARDCOPY? 0=NO 1=YES "; PR
      LOCATE 25, 1:  PRINT "                                                   "
      IF PR = 2 THEN : PR = 1: PPR = 2: GOTO 3670
3640   IF PR = 1 THEN : CLOSE : OPEN "LPT1:" FOR RANDOM AS #1: GOTO 2340
3650 REM Computation for Dynaflect readings   EQ is 0
   REM Computation for the FWD              EQ is 1
3670 REM CONTINUE
      IF ITE <> 1 THEN : GOTO 4790
    IF DESIGN = 1 THEN : GOTO 4340
      IF EQ = 0 THEN : PL = 1000
      IF EQ = 1 THEN : PL = 10956.3
      FOR I = 1 TO NC
         IF EQ = 1 THEN : SO(I) = PFW(I) / D(I, 1)
         IF EQ = 1 THEN : DE(I, 1) = PL / SO(I)
    REM D(I,7) may not be taken at 94.5" then need to change
      IF (EQ = 1) THEN : GOSUB 7290: 'GEOMBASIN
      IF (EQ = 1) THEN : DE(I, 7) = D7(I) * PL / PFW(I)
      REM D7(I) IS FROM SUBROUTINE GEOMBASIN
    '
    '
    '
    REM ---- To convert Dynaflect readings to DE ---------------
         IF EQ = 0 THEN : DE(I, 7) = 3.38075 * D(I, 5) ^ .639462
         IF EQ = 0 THEN : DE(I, 7) = 4.5688721# * D(I, 5) ^ .578444
         IF EQ = 0 THEN : DE(I, 1) = -7.24474 + (29.6906 * D(I, 1))
    REM To obtain stiffnesses
         IF EQ = 0 THEN : SO(I) = 86.0122 * EXP(.00187211# * PL / D(I, 1))
         IF TBC = 0 THEN : SSO(I) = SO(I)
    '
    '
'SI --- is used only when low overall stiffness is encountered
         SI(I) = -109.663 + 1.31393 * SO(I)
         IF SO(I) <= 83.46183 THEN : SI(I) = SO(I)
         H(I) = BA(I)
         NEXT
    '
    '
    '
    REM To determine the type of subgrade ------------------------
    PRINT "Please Wait ...... "
    '
    REM To convert readings to standard deflection DE --------------
    FOR I = 1 TO NC
    '
    '
    REM To determine subgrade K1S-value
      X = BA(I): Y = DE(I, 7): IF X > 18 THEN : X = 18
      K1S(I) = (9555.651 + 370.3322 * X) * DE(I, 7) ^ (-1.21665 + .016349 * X)
      IF K1S(I) < 5450 THEN : K1S(I) = 5450
      IF K1S(I) > 62200 THEN : K1S(I) = 62200
```

```
    LL1 = .4342945 * LOG(K1S(I))
    A11 = 10 ^ (10.50698 - 1.97986 * LL1)
    A12 = 361.506 - 2131.05 / (K1S(I) * 10 ^ -3) - 18.305 * K1S(I) * 10 ^ -3 + .36743 * (K1S(I) * 10 ^ -3)
^ 2 - .00256 * (K1S(I) * 10 ^ -3) ^ 3
    A13 = -13.6825 + 88.26011 / (K1S(I) * 10 ^ -3) + 1.165388 * K1S(I) * 10 ^ -3 - .0236 * (K1S(I) * 10
^ -3) ^ 2 + .00017 * (K1S(I) * 10 ^ -3) ^ 3
    A1 = A11 + A12 * BA(I) + A13 * BA(I) * BA(I)
    B11 = .032285 - .109 / (K1S(I) * 10 ^ -4)
   B12 = .123403 - .03883 * LL1
   B13 = -.00426 + .001256 * LL1
   B1 = B11 + B12 * BA(I) + B13 * BA(I) * BA(I)
    K1(I) = (DE(I, 1) / A1) ^ (1 / B1)
   IF K1(I) <= 3000 THEN : K1(I) = 3000
    IF K1(I) > 60000! THEN : K1(I) = 60000!
   NEXT I
   'To determine material properties ---------------------------
   '
   '
4340 'FOR I = 1 TO NC
4790 '
   AV = 0
   '
   'To calculate elastic modulus ECAL ---------------------------
   FOR I = 1 TO NC
   GOSUB 6600
   NEXT I
   '
5080 'To calculate the rut depth and number of passes
   IF RUT1 = 1 THEN : INIOPT = 3: GOSUB 12400
   IF RUT1 <> 1 THEN : INIOPT = 3: GOSUB 12000
   '
   FOR I = 1 TO NC
    PS(I) = passes(I)
    AM(I) = RFINAL(I)
    IF GR < 0 THEN : GOTO 5097
   ' REMAINING LIFE
    NY(I) = (LOG(PS(I) * GR + ESAL1) - LOG(ESAL1)) / LOG(1 + GR)
    TOTYR = TOTYR + NY(I)
    IF NY(I) > NYMAX THEN : NYMAX = NY(I)
5097   AV = AV + PS(I)
   '
   NEXT I
   IF GR < 0 THEN : GOTO 5100
   '
   FOR II = 1 TO NYMAX
    FOR I = 1 TO NC
     IF NY(I) >= II THEN : DYR(II) = DYR(II) + 1
    NEXT I
    DYR(II) = (DYR(II) / NC) * 100
    IF DYR(II) = 100 THEN : S100 = II
   NEXT II
   'CALCULATIONS OF ALLOWBLE AXLE LOADS
    AL1 = ((S100 / 10) ^ .2432) * 18
    AL2 = ((S100 / 10) ^ .2467) * 33.5
    AL3 = ((S100 / 10) ^ .2534) * 48.25
    IF AL1 > 18 THEN : AL1 = 18
    IF AL2 > 34 THEN : AL2 = 34
    IF AL3 > 46 THEN : AL3 = 46
```

```
'FOR PLOTS
MINX = NS(1)
MAXX = NS(NC)
5100 'To print results ------------------------------------------------
IF PR = 1 THEN : OPEN "LPT1:" FOR RANDOM AS #1: CLS : PRINT "Printing ....."
IF PR = 0 THEN : OPEN "SCRN:" FOR OUTPUT AS #1: CLS
'
IF GR < 0 THEN : PRINT #1, " SECTION      LAYER PROPERTIES                    NO. OF     RUT"
'
IF GR < 0 THEN : PRINT #1, "   NO.      ELASTIC MODULUS                    ALLOWABLE   DEPTH"

IF (EQ = 0) AND (GR < 0) THEN : PRINT #1, "          E1-BASE    E2-SUBGR                PASSES
(IN)"
IF (EQ = 1) AND (GR < 0) THEN : PRINT #1, "           BASE/SUBB   SUBGRADE
PASSES    (IN)   "
'
IF GR >= 0 THEN : PRINT #1, " SECTION     LAYER PROPERTIES       REMAINING      NO. OF
RUT"
'
IF GR >= 0 THEN : PRINT #1, "   NO.       ELASTIC MODULUS          LIFE         ALLOWABLE
DEPTH"
IF (EQ = 0) AND (GR >= 0) THEN : PRINT #1, "          E1-BASE     E2-SUBGR      (YEARS)
PASSES    (IN)"
IF (EQ = 1) AND (GR >= 0) THEN : PRINT #1, "          BASE/SUBB   SUBGRADE     (YEARS)
PASSES    (IN)   "
'PRINT #1,
'
'
REM CONTINUE
FOR I = 1 TO NC
'
  IF (EQ = 1) AND (NH <> 0) THEN : PRINT #1, NS(I); TAB(8); E1(I); TAB(19); E2(I); TAB(29); SS(I);
TAB(39); BC(I); TAB(54); PS(I);
  IF (EQ = 1) AND (NH <> 0) THEN : PRINT #1, TAB(64); AM(I); TAB(74); "DESIGN"
  IF (EQ = 1) AND (NH = 0) THEN : PRINT #1, TAB(3); NS(I);
  IF (EQ = 1) AND (NH = 0) THEN : PRINT #1, TAB(13); USING "#######"; E1(I);
  IF (EQ = 1) AND (NH = 0) THEN : PRINT #1, TAB(25); USING "######"; E2(I);
  IF (EQ = 1) AND (NH = 0) AND (GR >= 0) THEN : PRINT #1, TAB(39); USING "###.#"; NY(I);
  IF (EQ = 1) AND (NH = 0) THEN : PRINT #1, TAB(51); USING "#########"; PS(I);
  IF (EQ = 1) AND (NH = 0) THEN : PRINT #1, USING "######.##"; AM(I)
'
  NEXT I
  PRINT #1,
  PRINT #1,
  IF GR < 0 THEN : GOTO 5740
  PRINT #1,
  PRINT #1, "                Allowable Axle Load Limits (kips)"
  PRINT #1, "        SINGLE              TANDEM              TRIPLE"
  PRINT #1,
  IF S100 >= 10 THEN : PRINT #1, "        LEGAL              LEGAL               LEGAL"
  IF S100 < 10 THEN : PRINT #1, USING "        ##                 ##                  ##"; AL1; AL2;
AL3
  PRINT #1,
  PRINT #1,
5740   AV = AV / NC
  PRINT #1, "AVERAGE NUMBER OF PASSES TO CAUSE SPECIFIED RUT ("; RX; "): "; AV
  PRINT #1,
  PRINT #1, "NUMBER OF PASSES USED FOR RUT DEPTH CALCULATION : "; PA
```

```
      PRINT #1,
      PRINT #1, "RUT DEPTH USED FOR REMAINING LIFE AND NUMBER OF PASSES CALCULATION :";
RX
   '
      NEXT ITE
    PR = 0
    PRINT
    CLOSE
    '
    IF TBC = 0 THEN : GOTO 5960
    DESIGN = 0
    NH = 0
    '
    GOTO 2320
    '
    REM CONTINUE to get output menu OUTMENU
5960 GOSUB 7580: 'To OUTMENU
5980 END
    '
    '
6510 REM SUBROUTINE to open an output file OUTFILE
    '
6512 CLS : KEY OFF
    LOCATE 5, 1: PRINT "TO CREATE OUTPUT FILE"
    LOCATE 6, 1: INPUT "ENTER OUTPUT FILE NAME AND <RET>:"; XX$
    CLS : KEY OFF
    IF TEMRUT = 1 THEN : SLF = 1: GOTO 6536
    LOCATE 7, 1: PRINT "Select the format:"
    LOCATE 9, 1: PRINT "(1)"
    IF GR < 0 THEN : LOCATE 10, 1: PRINT "Sec.   Thick   E1(Base)  E2(Subgr)  Passes  Rut depth  "
    IF GR >= 0 THEN : LOCATE 10, 1: PRINT "Sec.   Thick   E1(Base)  E2(Subgr)  Passes  Rut depth
Remaining life"
    LOCATE 11, 1: PRINT "(2)"
    IF (EQ = 1) AND (GR < 0) THEN : LOCATE 12, 1: PRINT "Sect.  Thick  D1  D7   FWD load   E1(Base)
E2(Subgr)  Passes  "
    IF (EQ = 0) AND (GR < 0) THEN : LOCATE 12, 1: PRINT "Sect.  Thick  D1  D5   FWD load   E1(Base)
E2(Subgr)  Passes  "
    IF (EQ = 1) AND (GR >= 0) THEN : LOCATE 12, 1: PRINT "Sect.  Thick  D1  D7   FWD load   E1(Base)
E2(Subgr)  Passes  Remaining life"
    IF (EQ = 0) AND (GR >= 0) THEN : LOCATE 12, 1: PRINT "Sect.  Thick  D1  D5   FWD load   E1(Base)
E2(Subgr)  Passes  Remaining life"
    LOCATE 20, 1: INPUT "ENTER SELECTION AND <RET> :"; SLF
    IF (SLF < 1) OR (SLF > 2) THEN : GOTO 6512
6536 OPEN "O", #2, XX$: PRINT #2, "    "
     CLS : PRINT #2, " TEXAS TRANSPORTATION INSTITUTE "
     PRINT #2, "LOAD RATING OF LIGHT PAVEMENT"
     PRINT #2,
     PRINT #2, "JOB : "; a$; "          (INPUT FILE "; X$; ")"
     PRINT #2,
     PRINT #2, "DISTRICT:"; ID; "    COUNTY:"; C$; "    ROAD:"; F$
     PRINT #2, "ALLOWABLE RUT(INS):"; RX; "    RECORDED RUT(INS):"; RM
     PRINT #2,
     PRINT #2, "TRUCK NO. 1"
     PRINT #2, "AXLE NUMBER   SINGLE WHEEL/ESWL(LBS)"
     PRINT #2, TAB(5); "1"; TAB(20); "9000"
     PRINT #2,
   '
   '
```

```
    PRINT #2, "ANNUAL TRAFFIC GROWTH RATE:"; GR; " # OF YEARS:"; AL; " FIRST YEAR TRAFFIC:";
ESAL1
    PRINT #2, "TOTAL NUMBER OF PASSES DURING ABOVE PERIOD:"; PA
    PRINT #2,
    IF EQ = 0 THEN : PRINT #2, "DATE:"; D$; "     DYNAFLECT"
    IF EQ = 1 THEN : PRINT #2, "DATE:"; D$; "   FALLING WEIGHT DEFLECTOMETER"
    REM CONTINUE
    IF GR < 0 THEN : GOTO 6562
   IF TEMRUT = 1 THEN : PRINT #2, "          TEMP. CORRECTED            *         **
  *"
   IF TEMRUT = 0 AND SLF = 1 THEN : PRINT #2, "                                  *         **
    *"
   IF TEMRUT = 0 AND SLF = 1 THEN : PRINT #2, " SEC   BASE     E1-BASE   E2-SUBGR   NO. OF
   RUT DEPTH   REMAINING LIFE"
   IF TEMRUT = 1 THEN : PRINT #2, " SEC   BASE     E1-BASE   E2-SUBGR   NO. OF      RUT DEPTH
  REMAINING LIFE"
   IF TEMRUT = 0 AND SLF = 1 THEN : PRINT #2, " #    (IN)     (PSI)     (PSI)    PASSES ,    (IN)
    (YEARS)"
   IF TEMRUT = 1 THEN : PRINT #2, " #   (IN)    (PSI)    (PSI)   PASSES      (IN)      (YEARS)"

   IF TEMRUT = 0 AND SLF = 1 THEN : FOR I = 1 TO NC: PRINT #2, USING "###.#  ##.#
########   #######  ########       #.##        ##.#"; NS(I); BA(I); E1(I); E2(I); PS(I);
AM(I); NY(I): NEXT
   IF TEMRUT = 1 THEN : FOR I = 1 TO NC: PRINT #2, USING "###.#  ##.#    ########
#######  ########       #.##        ##.#"; NS(I); BA(I); E1(I); E2(I); PS(I); AM(I); NY(I): NEXT

   IF SLF = 2 THEN : PRINT #2, "                                                    *          *"

   IF SLF = 2 AND EQ = 1 THEN : PRINT #2, " SEC   BASE     D1      D7    FWD LOAD  E1-BASE
  E2-SUBG      NO. OF   REMAINING LIFE"
   IF SLF = 2 AND EQ = 0 THEN : PRINT #2, " SEC   BASE     D1      D5    FWD LOAD  E1-BASE
  E2-SUBG      NO. OF   REMAINING LIFE"
   IF SLF = 2 THEN : PRINT #2, " #   (IN)   (MILS)   (MILS)   (LBS)    (PSI)    (PSI)      PASSES
  (YEARS) "
   IF SLF = 2 AND EQ = 1 THEN : FOR I = 1 TO NC: PRINT #2, USING "###.#  ##.#    ###.##
###.##   ######   ########   #######   ##########   ##.#"; NS(I); BA(I); D(I, 1);
D(I, 7); PFW(I); E1(I); E2(I); PS(I); NY(I): NEXT
   IF SLF = 2 AND EQ = 0 THEN : FOR I = 1 TO NC: PRINT #2, USING "###.#  ##.#    ###.##
###.##   ######   ########   #######   ##########   ##.#"; NS(I); BA(I); D(I, 1);
D(I, 7); PFW(I); E1(I); E2(I); PS(I); NY(I): NEXT
   PRINT #2,
   IF SLF = 1 THEN : PRINT #2, " *  NUMBER OF PASSES AND REMAINING LIFE FOR SPECIFIED RUT
DEPTH OF "; RX; "in"
   IF SLF = 1 THEN : PRINT #2, " ** RUT DEPTH FOR SPECIFIED NUMBER OF PASSES OF "; PA; " IN
"; AL; "YEARS":
   IF SLF = 2 THEN : PRINT #2, " *  NUMBER OF PASSES AND REMAINING LIFE FOR SPECIFIED RUT
DEPTH OF "; RX; "in":
   PRINT #2,
   PRINT #2, "     Remaining Life(yrs)          Cumulative % Sections"
   FOR II = 1 TO NYMAX
    PRINT #2, USING "            ##                         ###.#"; II; DYR(II)
   NEXT II
   PRINT #2,
   PRINT #2,
   PRINT #2, "                   Allowable Axle Load Limits (kips)"
   PRINT #2, "        SINGLE              TANDEM             TRIPLE"
   PRINT #2,
   IF S100 >= 10 THEN : PRINT #2, "       LEGAL              LEGAL              LEGAL"
```

```
    IF S100 < 10 THEN : PRINT #2, USING "        ##              ##              ##"; AL1; AL2;
AL3
    GOTO 6563
6562 'SAVE DATA WITHOUT REMAINING LIFE - GR<0
    IF TEMRUT = 1 THEN : PRINT #2, "          TEMP. CORRECTED          *          **
"
    IF TEMRUT = 0 AND SLF = 1 THEN : PRINT #2, "                              *          **
"
    IF TEMRUT = 0 AND SLF = 1 THEN : PRINT #2, " SEC   BASE    E1-BASE   E2-SUBGR   NO. OF
RUT DEPTH   "
    IF TEMRUT = 1 THEN : PRINT #2, " SEC   BASE    E1-BASE   E2-SUBGR  NO. OF    RUT DEPTH
"
    IF TEMRUT = 0 AND SLF = 1 THEN : PRINT #2, " #   (IN)    (PSI)    (PSI)   PASSES     (IN)
"
    IF TEMRUT = 1 THEN : PRINT #2, " #   (IN)    (PSI)    (PSI)   PASSES     (IN)      "
    IF TEMRUT = 0 AND SLF = 1 THEN : FOR I = 1 TO NC: PRINT #2, USING "###.#  ##.#
########   #######  ########     #.##      "; NS(I); BA(I); E1(I); E2(I); PS(I); AM(I):
NEXT
    IF TEMRUT = 1 THEN : FOR I = 1 TO NC: PRINT #2, USING "###.#  ##.#   ########
#######  ########     #.##      "; NS(I); BA(I); E1(I); E2(I); PS(I); AM(I): NEXT
    IF SLF = 2 THEN : PRINT #2, "                                        *          *"

    IF SLF = 2 AND EQ = 1 THEN : PRINT #2, " SEC   BASE    D1     D7    FWD LOAD   E1-BASE
  E2-SUBG     NO. OF   REMAINING LIFE"
    IF SLF = 2 AND EQ = 0 THEN : PRINT #2, " SEC   BASE    D1     D5    FWD LOAD   E1-BASE
  E2-SUBG     NO. OF   REMAINING LIFE"
    IF SLF = 2 THEN : PRINT #2, " #   (IN)   (MILS)   (MILS)   (LBS)    (PSI)    (PSI)     PASSES
  (YEARS) "
    IF SLF = 2 AND EQ = 1 THEN : FOR I = 1 TO NC: PRINT #2, USING "###.#  ##.#   ###.##
###.##   ######   ########   #######   ##########   "; NS(I); BA(I); D(I, 1); D(I,
7); PFW(I); E1(I); E2(I); PS(I): NEXT
    IF SLF = 2 AND EQ = 0 THEN : FOR I = 1 TO NC: PRINT #2, USING "###.#  ##.#   ###.##
###.##   ######   ########   #######   ##########   "; NS(I); BA(I); D(I, 1); D(I,
7); PFW(I); E1(I); E2(I); PS(I): NEXT
    PRINT #2,
    IF SLF = 1 THEN : PRINT #2, " *  NUMBER OF PASSES FOR SPECIFIED RUT DEPTH OF "; RX; "in"

    IF SLF = 1 THEN : PRINT #2, " ** RUT DEPTH FOR SPECIFIED NUMBER OF PASSES OF "; PA; " IN
"; AL; "YEARS":
    IF SLF = 2 THEN : PRINT #2, " *  NUMBER OF PASSES FOR SPECIFIED RUT DEPTH OF "; RX; "in":

    'TEMP. CORR. DATA
6563 IF TEC = 1 THEN : INPUT "  DO YOU WANT TO SAVE TEMPERATURE AND MOISTURE
CORRECTED DATA ? 1=YES, 0=NO "; CHO4
    IF (CHO4 <> 1 AND CHO4 <> 0) THEN GOTO 6563
    IF (CHO4 = 0) GOTO 6584
    PRINT #2, " "
    PRINT #2, "        TEMPERATURE CORRECTION DATA "
    PRINT #2,
    PRINT #2, "  INPUT CONDITIONS:              WANTED CONDITIONS:"
    PRINT #2, USING "  TEMPERATURE =   ###.# deg. F    TEMPERATURE =   ###.# deg. F";
TTEMP; RTEMP
    PRINT #2, USING "  SUCTION      = #####.# psi      SUCTION     = #####.# psi"; HI; HL
    PRINT #2,
    PRINT #2, "  INPUT    WDNTED CONDITION   MODULUS CHANGE   MODULUS CHANGE"
    PRINT #2, "  MODULUS        MODULUS       DUE TO TEMPER.   DUE TO SUCTION"
    PRINT #2, "  (psi)        (psi)         (psi)         (psi)"
    PRINT #2,
```

```
    FOR I = 1 TO KK1
    PRINT #2, USING "  #######        #######        ######        ######"; OE(I); NE(I);
DET(I); DES(I)
    NEXT I: CLOSE
6584 RETURN
6585 REM SUBROUTINE TO SELECT TEMP. CORRECTION OR STRUCTURAL ANALYSIS
6586 CLS : KEY OFF
    LOCATE 3, 10
    PRINT "LOADRATE - STRUCTURAL ANALYSIS OF LIGHT PAVEMENTS"
    LOCATE 5, 10
    PRINT "                MAIN MENU"
    LOCATE 7, 10
    PRINT "          SELECT THE OPERATION DESIRED:"
    LOCATE 9, 10
    PRINT "(1)  Structural analysis of pavements"
    LOCATE 10, 10
    PRINT "  ( moduli, # of passes, rut depth, remaining life and allowable"
    LOCATE 11, 10
    PRINT "    axle load calculations, and analysis of temperature and "
    LOCATE 12, 10
    PRINT "    moisture effects on base material )"
    LOCATE 13, 10
    PRINT "(2)  Temperature correction of base modulus only"
    LOCATE 14, 10
    PRINT "(3)  Rut depth calculation only"
    LOCATE 15, 10
    PRINT "(4)  Exit program"
    LOCATE 20, 10
    INPUT "ENTER SELECTION AND <RET> : "; SLECT1
    IF (SLECT1 < 1) OR (SLECT1 > 4) THEN : GOTO 6586
    RETURN
6600 'SUBROUTINE for elastic modulus calculations ECAL
    '
    'Initializing various values - all changes will be made here
    KO1 = .6: REM SIGR/SIGZ ratio for base course
    KO2 = .82: REM SIGR/SIGZ ratio for subgrade
    'EMOD will be calculated at test load
    AREA = 3.1415927# * 5.9 * 5.9
    'Looping
    FOR I = 1 TO NC
      IF EQ = 0 THEN : PFW(I) = 9000: REM DYNAFLECT - CALCULATE FOR WHEEL LOAD
      SL(I) = PFW(I) / AREA
      ZZ1 = 1 + BA(I) / 2: REM Elastic modulus for base course depth
      ZZ2 = 7! + BA(I): REM Elastic Modulus for subgrade depth
      ALS1 = 2.416966 * SL(I) ^ .477234
      ALS2 = .6007171 * K1S(I) ^ .058992
      ALH = 1.338562 * (1 + BA(I)) ^ -.145887
      RHB = .59614133# * K1(I) ^ 5.593462E-02
      RHH = 3.0385722# * (1 + BA(I)) ^ .419624
      RHS = 272.63462# * K1S(I) ^ -.58427
      NSG = -1.01866 + 1.239625 / (K1S(I) * 10 ^ -3) + .000013 * (K1S(I) * 10 ^ -3) ^ 3 + .061115 *
(K1S(I) * 10 ^ -3) - .00165 * (K1S(I) * 10 ^ -3) ^ 2
      ALPHA = ALS1 * ALS2 * ALH
      RHO = (1 + BA(I)) * LOG(RHH * RHS * RHB / ALPHA) / LOG(2.7182818#)
      ER1 = ALPHA * EXP(-((-RHO / ZZ1) ^ 1)) + 5.9
      ER2 = ALPHA * EXP(-((-RHO / ZZ2) ^ 1)) + 5.9
      SIGZ1 = PFW(I) / (3.1415927# * ER1 * ER1)
      SIGZ2 = PFW(I) / (3.1415927# * ER2 * ER2)
```

```
   SIGR1 = KO1 * SIGZ1
   SIGR2 = KO2 * SIGZ2
   E2(I) = K1S(I) * (ABS(SIGZ2 - SIGR2)) ^ NSG
   E1(I) = K1(I) * (SIGZ1 + 2 * SIGR1) ^ .33
   NEXT
  RETURN
  '
  '
  REM SUBROUTINE  MAINMENU ------------------------------
  '
6970 'KEY OFF: CLS
  '
  '
  REM SUBROUTINE Input for geometric regression GEOMINPUT -----------
  '  for non-standard FWD sensor spacing
  GR = 1: CLS : REM To initialize and activate GEOMBASIN
  'Standard FWD sensor spacing for Texas SDHPT is as follows
  LOCATE 5, 10: PRINT "FWD Sensor          #1  #2  #3  #4  #5  #6  #7"
  LOCATE 6, 10: PRINT "Dist.(ins) from load"; 0; 12; 24; 36; 48; 60; 72
  '
  LOCATE 7, 10: PRINT "Type in new spacing ....."
  LOCATE 8, 10: INPUT "Sensor #1 at (ins) "; X(1)
  LOCATE 9, 10: INPUT "Sensor #2 at (ins) "; X(2)
  LOCATE 10, 10: INPUT "Sensor #3 at (ins) "; X(3)
  LOCATE 11, 10: INPUT "Sensor #4 at (ins) "; X(4)
  LOCATE 12, 10: INPUT "Sensor #5 at (ins) "; X(5)
  LOCATE 13, 10: INPUT "Sensor #6 at (ins) "; X(6)
  LOCATE 14, 10: INPUT "Sensor #7 at (ins) "; X(7)
  IF X(1) = 0 THEN : X(1) = .01
  RETURN
  '
  '
7290 REM SUBROUTINE geometric regression GEOMBASIN
   J = 0: K = 0: L = 0: M = 0: R2 = 0
   N = 4
   IF D(I, 7) = 0 THEN : N = 3
   IF X(7) = 0 THEN : N = 3
   FOR II = 4 TO (3 + N)
     X = X(II): Y = D(I, II)
     X = LOG(X): Y = LOG(Y)
     J = J + X: K = K + Y: L = L + X * X: M = M + Y * Y
     R2 = R2 + X * Y
     NEXT II
   B = (N * R2 - K * J) / (N * L - J * J)
   a = (K - B * J) / N
   J = B * (R2 - J * K / N)
   M = M - K * K / N
   K = M - J
   R2 = J / M
   'print "D7@94.49 =";exp(a)*94.49^b
   D7(I) = EXP(a) * 94.49 ^ B
   RETURN
  '
7580 REM SUBROUTINE  OUTMENU
  CLS : KEY OFF
  LOCATE 2, 10: PRINT "        OUTPUT MENU "
  '
  LOCATE 4, 10: PRINT "Select Optional Output Format"
```

```
'
LOCATE 6, 10: PRINT " (1) Plot Base Course Elastic Modulus"
LOCATE 7, 10: PRINT " (2) Plot Subgrade Elastic Modulus"
LOCATE 8, 10: PRINT " (3) Plot Number of Vehicle Passes"
LOCATE 9, 10: PRINT " (4) Plot Remaining Life"
LOCATE 10, 10: PRINT " (5) Temperature Correction of Base Modulus"
LOCATE 11, 10: PRINT "     (5.1) Rut depth, Passes and Remaining Life"
LOCATE 12, 10: PRINT "           for corrected moduli"
LOCATE 13, 10: PRINT " (6) Save the Output as a file"
LOCATE 14, 10: PRINT " (7) Exit to Main Menu"
'
LOCATE 20, 10: INPUT "ENTER SELECTION AND <RET> : "; SLO
IF SLO = 7 OR SLO = 0 THEN : CLS : SLO = 0: TEMRUT = 0: TEC = 0: GOTO 730
IF SLO = 6 THEN : GOSUB 6510: GOTO 7580: 'To OUTFILE and back
IF SLO = 5 THEN : TEC = 1: GOSUB 10010
IF SLO = 5.1 THEN : FOR I = 1 TO 100: NY(I) = 0: NEXT
IF SLO = 5.1 THEN : FOR I = 1 TO 100: DYR(I) = 0: NEXT
IF SLO = 5.1 THEN : FOR I = 1 TO 100: PS(I) = 0: NEXT
'
IF SLO = 5.1 THEN : TEMRUT = 1: GOSUB 5080
GOTO 7800
END
'
'
7800 REM PROGRAM SBRPLOT
PRCHK = 0
IF PT = 0 THEN : PT = 1: REM 1=Epson/Panasonic    2=Mannesmann Tally
REM ******* THIS PART OF THE PROGRAM SHOULD REMAIN UNTOUCHED *************
CLS
PRINT
REM ************* plot at low resolution graphics
PRINT
RD = 0
PRINT
'INPUT" TITLE : ";T$
IF SLO = 1 THEN : t$ = "ELASTIC MODULUS OF BASE COURSE"
IF SLO = 2 THEN : t$ = "ELASTIC MODULUS OF SUBGRADE"
IF SLO = 3 THEN : t$ = "NUMBER OF PASSES FOR RUT DEPTH"
IF SLO = 4 THEN : t$ = "REMAINING LIFE"
'PRINT "plotting : ";T$
'INPUT "Starting Section Number: "; MINX
'INPUT "Ending Section Number: "; MAXX
PRINT
MINY = 0
'
IF SLO = 1 THEN : INPUT "Minimum E1  [Default=0]: "; MINY
IF SLO = 1 THEN : INPUT "Maximum E1 [Default=100000]: "; MAXY
IF SLO = 1 AND MAXY = 0 THEN : MAXY = 100000!
IF SLO = 2 THEN : INPUT "Minimum E2 [Default= 0   ]: "; MINY
IF SLO = 2 THEN : MAXY = 25000: INPUT "Maximum E2 [Default=25000]: "; MAXY
IF SLO = 2 AND MAXY = 0 THEN : MAXY = 25000
IF SLO = 3 THEN : INPUT "Minimum PASSES [Default=   0 ]: "; MINY
IF SLO = 3 THEN : INPUT "Maximum PASSES [Default=0.5E6]: "; MAXY
IF SLO = 3 AND MAXY = 0 THEN : MAXY = 500000!
IF SLO = 4 THEN : INPUT "Minimum REMAINING LIFE [Default=  0]: "; MINY
IF SLO = 4 THEN : INPUT "Maximum REMAINING LIFE [Default= 24]: "; MAXY
IF SLO = 4 AND MAXY = 0 THEN : MAXY = 24
'
```

```
    '
    PRINT
    SX = 2: 'Number of alphabet for NC
    IF SX = 0 THEN : SX = 1
    PRINT
    'INPUT "hardcopy?   1=yes  0=no  ";PR
    PR = 1
    XSCALE = 60 / (MAXX - MINX)
    YSCALE = 20 / (MAXY - MINY)
    YORG = 22 + MINY * YSCALE
    XORG = 10 - MINX * XSCALE
    KEY OFF
    CLS
    '
    '
    '
8300 REM these are ASCII for the IBM
    IF PRCHK = 0 THEN : PR1 = 196: PR2 = 179: PR3 = 218: PR4 = 191: PR5 = 192: PR6 = 217
    FOR COL = 11 TO 69
       LOCATE 2, COL: PRINT CHR$(PR1)
       LOCATE 22, COL: PRINT CHR$(PR1)
       NEXT
    FOR ROW = 3 TO 21
       LOCATE ROW, 10: PRINT CHR$(PR2)
       LOCATE ROW, 70: PRINT CHR$(PR2)
       NEXT
    LOCATE 2, 10: PRINT CHR$(PR3)
    LOCATE 2, 70: PRINT CHR$(PR4)
    LOCATE 22, 10: PRINT CHR$(PR5)
    LOCATE 22, 70: PRINT CHR$(PR6)
    IF PRCHK = 0 THEN : PR7 = 193: PR8 = 195
    IF PRCHK = 0 THEN : PR9 = 180: PR10 = 194
    '
    '
    '
    FOR I = 1 TO 9
       LOCATE 22, (10 + 6 * I): PRINT CHR$(PR7)
       LOCATE (2 + 2 * I), 10: PRINT CHR$(PR8)
       LOCATE (2 + 2 * I), 70: PRINT CHR$(PR9)
       LOCATE 2, (10 + 6 * I): PRINT CHR$(PR10)
       NEXT
    IF PRCHK = 1 AND PT = 1 THEN : GOSUB 9350
    IF PRCHK = 1 AND PT = 2 THEN : GOSUB 9210
    LOCATE 1, 10: PRINT t$
    LOCATE 1, 55: PRINT X$
    XINT = (MAXX - MINX) / 10
    YINT = (MAXY - MINY) / 10
    LOCATE 23, 8: PRINT (MINX)
    LOCATE 23, 20: PRINT (MINX + 2 * XINT)
    LOCATE 23, 32: PRINT (MINX + 4 * XINT)
    LOCATE 23, 44: PRINT (MINX + 6 * XINT)
    LOCATE 23, 56: PRINT (MINX + 8 * XINT)
    LOCATE 23, 69: PRINT (MINX + 10 * XINT)
    'lOCATE 24,30 :PRINT "Section Numbers"
    LOCATE 2, 1: PRINT MAXY
    LOCATE 6, 1: PRINT INT((MAXY - YINT * 2) * 100) / 100
    LOCATE 10, 1: PRINT INT((MAXY - YINT * 4) * 100) / 100
    LOCATE 14, 1: PRINT INT((MAXY - YINT * 6) * 100) / 100
```

```
    LOCATE 18, 1: PRINT INT((MAXY - YINT * 8) * 100) / 100
    LOCATE 22, 1: PRINT MINY
    IF SLO = 1 THEN : LOCATE 11, 2: PRINT " E1"
    IF SLO = 1 THEN : LOCATE 12, 2: PRINT "(psi)"
    IF SLO = 2 THEN : LOCATE 11, 2: PRINT " E2"
    IF SLO = 2 THEN : LOCATE 12, 2: PRINT "(psi)"
    IF SLO = 3 THEN : LOCATE 11, 2: PRINT "No.of"
    IF SLO = 3 THEN : LOCATE 12, 2: PRINT "Passes"
    IF SLO = 4 THEN : LOCATE 11, 2: PRINT "Remain."
    IF SLO = 4 THEN : LOCATE 12, 2: PRINT " Life"
    IF SLO = 4 THEN : LOCATE 13, 2: PRINT "(years)"
    REM CONTINUE to exit loop
    'get points
    IF PRCHK = 1 THEN : LOCATE 25, 1: PRINT SPC(70);
    IF PRCHK = 1 THEN : LOCATE 25, 1: PRINT "RE-PLOTTING ... ";
    FOR I = 1 TO NC
      X = NS(I)
      IF SLO = 1 THEN : Y = E1(I)
      IF SLO = 1 AND Y > MAXY THEN : Y = MAXY
      IF SLO = 2 THEN : Y = E2(I)
      IF SLO = 2 AND Y > MAXY THEN : Y = MAXY
      IF SLO = 3 THEN : Y = PS(I)
      IF SLO = 3 AND Y > MAXY THEN : Y = MAXY
      IF SLO = 4 THEN : Y = NY(I)
      IF SLO = 4 AND Y > MAXY THEN : Y = MAXY
      'display point and coord
      'display point and coord
    '
      SCY = YORG - INT(Y * YSCALE): SCX = XORG + INT(X * XSCALE)
      IF SCX < 10 THEN GOTO 9050
      IF SCX > 70 THEN GOTO 9050
      IF SCY < 2 THEN GOTO 9050
      IF SCY > 22 THEN GOTO 9050
      LOCATE SCY, SCX: PRINT CHR$(42): GOTO 9050
9050   NEXT
    LOCATE 25, 1: PRINT SPC(75);
    IF PRCHK = 1 THEN : LOCATE 25, 1: INPUT "PrtSc?  <RET> if NO"; NN$
    IF PRCHK = 1 THEN : GOTO 9150
    LOCATE 25, 1: PRINT SPC(75);
    LOCATE 25, 1: PRINT "PRESS ENTER TO CONTINUE ";
    INPUT ; NN$
    IF PRCHK = 1 THEN : GOTO 9150
    IF PR = 1 AND PT = 1 THEN : GOSUB 9350: GOTO 8300
    IF PR = 1 AND PT = 2 THEN : GOSUB 9210: GOTO 8300
    IF PR = 1 AND PT = 3 THEN : GOTO 9150: 'No adjustment required
9150 REM CONTINUE
    CLS
    GOTO 7580: 'To return to OUTMENU
    '
    '
    '
9210 REM SUBROUTINE MT180 to replot the graph for the mannesmann tally
    PR1 = 157: REM FROM IBM 196
    PR2 = 156: REM FROM IBM 179
    PR3 = 134: REM FROM IBM 218
    PR4 = 149: REM FROM IBM 191
    PR5 = 153: REM FROM IBM 192
    PR6 = 154: REM FROM IBM 217
```

```
    PR7 = 158: REM FROM IBM 193
    PR8 = 150: REM FROM IBM 195
    PR9 = 151: REM FROM IBM 180
    PR10 = 152: REM FROM IBM 194
    PRCHK = 1
    RETURN
    '
9350 REM SUBROUTINE EPSON to replot the graph for the epson/panasonic
    PR1 = 45: REM FROM IBM 196
    PR2 = 124: REM FROM IBM 179
    PR3 = 46: REM FROM IBM 218
    PR4 = 46: REM FROM IBM 191
    PR5 = 46: REM FROM IBM 192
    PR6 = 46: REM FROM IBM 217
    PR7 = 43: REM FROM IBM 193
    PR8 = 43: REM FROM IBM 195
    PR9 = 43: REM FROM IBM 180
    PR10 = 43: REM FROM IBM 194
    PRCHK = 1
    RETURN
    '
    '
    '
    OPEN "O", #1, "B:FM421.RES": FOR II = 1 TO 26: PRINT #1, NS(II), BA(II), D(II, 1), D(II, 7), K1(II),
K1S(II), E1(II), E2(II), SS(II), BC(II), PS(II), AM(II): NEXT: CLOSE
    OPEN "O", #1, "B:FM421.SAN": FOR II = 1 TO 26: PRINT #1, PS(II), AM(II): NEXT: CLOSE
10010 CLS
    REM SUBROUTINE for temperature correction TEMP
    'THIS SUBROUTINE PREDICTS THE MODULUS OF GRANULAR MATERIALS
    'AT DIFFERENT TEMPERATURES AND MOISTURES BASED ON A
    'MICROMECHANICAL APPROACH
10130 'CLS
    '
    '=======INPUT========
    PRINT : PRINT : PRINT
    PRINT TAB(25); "TYPE OF BASE MATERIAL:": PRINT
    PRINT TAB(25); "  1 = CRUSHED LIMESTONE "
    PRINT TAB(25); "      LIME ORE GRAVEL"
    PRINT TAB(25); "      IRON ORE GRAVEL"
    PRINT TAB(25); "  2 = RIVER GRAVEL"
    PRINT TAB(25); "      CALICHE"
    PRINT TAB(25); "      CALICHE GRAVEL"
    PRINT TAB(25); "  3 = SANDSHELL"
    PRINT TAB(25); : INPUT "SELECT YOUR OPTION "; MTYPE
    IF (MTYPE <= 0 OR MTYPE > 3) GOTO 10130
    IF (MTYPE = 1) THEN ALP = 5 * 10 ^ (-6): E = 6.4 * 10 ^ 6: U = .17: K1 = 14000: K2 = .4
    IF (MTYPE = 2) THEN ALP = 6.5 * 10 ^ (-6): E = 7.8 * 10 ^ 6: U = .2: K1 = 24000: K2 = .37
    IF (MTYPE = 3) THEN ALP = 5 * 10 ^ (-6): E = 8.534001 * 10 ^ 6: U = .17: K1 = 7210: K2 = .45
10260 CLS : PRINT : PRINT
    PRINT TAB(20); "PROPERTIES OF THE MATERIAL SELECTED:"
    PRINT
    PRINT TAB(25); "1. LINEAR THERMAL EXPANSION        = "; ALP
    PRINT TAB(25); "2. ELASTIC MODULUS OF SOIL GRAINS  = "; E
    PRINT TAB(25); "3. POISSON'S RATIO                 = "; U
    IF SLO = 5 THEN : GOTO 10340
    PRINT TAB(25); "4. K1                              = "; K1
    PRINT TAB(25); "5. K2                              = "; K2
10340 PRINT : PRINT
```

```
10350 PRINT TAB(20); : INPUT "DO YOU WANT TO CHANGE? 0=NO  1=YES "; CHOICE
    IF (CHOICE <> 1 AND CHOICE <> 0) THEN GOTO 10350
    IF (CHOICE = 0) GOTO 10460
    PRINT : PRINT TAB(20); : INPUT "WHICH LINE "; WL
    PRINT TAB(20); : INPUT "INPUT NEW VALUE "; NV
    IF (WL = 1) THEN ALP = NV
    IF (WL = 2) THEN E = NV
    IF (WL = 3) THEN U = NV
    IF (WL = 4) THEN K1 = NV
    IF (WL = 5) THEN K2 = NV
    GOTO 10260
10460 CLS : PRINT : PRINT : PRINT TAB(25);
    INPUT "UNIT WEIGHT OF MATERIAL (pcf) :  ", UW
    CLS
    PRINT : PRINT
    IF SLECT1 = 2 THEN : GOTO 10478
    CHO1 = 1
    GOTO 10500
10478 KK1 = 1
    PRINT : PRINT TAB(25);
    INPUT "MODULUS OF MATERIAL (psi)          : ", EI
10500 PRINT : PRINT
10510 PRINT TAB(20); "CONDITIONS AT WHICH THE MODULUS IS OBTAINED: "
    PRINT
    PRINT TAB(25); : INPUT "TEMPERATURE, Ti (40 deg.F < Ti < 110 deg.F)   :  ", TTEMP
    IF (TTEMP < 40 OR TTEMP > 110) GOTO 10510
10540 PRINT TAB(25); : INPUT "SUCTION, Hi (-145 psi < Hi < 0 psi)          :  ", HI
    IF (HI < -145 OR HI > 0) GOTO 10540
    PRINT : PRINT
10560 PRINT TAB(20); "INPUT WANTED CONDITIONS: "
    PRINT
    PRINT TAB(25); : INPUT "TEMPERATURE, To (40 deg.F < To < 110 deg.F)   :  ", RTEMP
    IF (RTEMP < 40 OR RTEMP > 110) GOTO 10560
10590 PRINT TAB(25); : INPUT "SUCTION, Ho (-145 psi < Ho < 0 psi)          :  ", HL
    IF (HL < -145 OR HL > 0) GOTO 10590
    IF CHO1 = 1 THEN KK1 = NC
    FOR I = 1 TO KK1
    IF CHO1 = 1 THEN EI = E1(I)
    IF CHO1 = 1 THEN K1 = K1(I)
    IF CHO1 = 1 THEN K2 = .33
    '
    '=======CALCULATION========
    VOID = 1 / (UW / 2.67 / 62.4) - 1
    N = VOID / (1 + VOID)        'POROSITY
    X = (.4764 - N) / (.4764 - .2595)
    IF (X < 0) THEN X = 0
    IF (X > 1) THEN X = 1
    PI = 3.1415927#
    PRO1 = 3 / 4 * (1 - U ^ 2) / E
    '==K2 IS THE POWER IN THE EQUATION E=K1*TETHA^K2==
    'K2 = 1 / 3
    THETA = 10 ^ (LOG(EI / K1) / LOG(10) / K2)
    DTEMP = RTEMP - TTEMP'RTEMP IS THE REFERENCE TEMP.
    DT = ABS(DTEMP)
    IF (DTEMP = 0) THEN NE = EI: GOTO 10800
    DELV = DT * ALP * 3
    PSC = X / 2 ^ (1 / 2) / PRO1 * (1 / 3 * DELV) ^ (3 / 2)
    PFCC = (1 - X) / 4 / PRO1 * (1 / 3 * DELV) ^ (3 / 2)
```

```
    PT = (PSC + PFCC) * DTEMP / DT
    DET(I) = K1 * K2 * THETA ^ (K2 - 1) * PT
10800 PS = -(HL - HI) * .13
    DES(I) = K1 * K2 * THETA ^ (K2 - 1) * PS
    TOTDE(I) = DET(I) + DES(I)
    NE(I) = EI + TOTDE(I)
    OE(I) = EI
    NEXT I
    '
    '=======OUTPUT========
    CLS
    PRINT : PRINT : PRINT TAB(10);
    PRINT "INPUT CONDITIONS:                WANTED CONDITIONS:"
    PRINT
    PRINT USING " TEMPERATURE =    ###.#   deg. F      TEMPERATURE =  ###.#   deg. F";
TTEMP; RTEMP
    PRINT USING " SUCTION    = #####.## psi      SUCTION    = #####.## psi  "; HI; HL

    PRINT
    PRINT "   INPUT   WANTED CONDITION   MODULUS CHANGE   MODULUS CHANGE"
    PRINT "  MODULUS      MODULUS        DUE TO TEMPER.   DUE TO SUCTION"
    PRINT "   (psi)        (psi)            (psi)            (psi)"
    PRINT
    FOR I = 1 TO KK1
    PRINT USING "  ######.##      ######.##      ######.##       #######.##"; OE(I);
NE(I); DET(I); DES(I)
    NEXT I
    PRINT : PRINT
    INPUT "        PRESS RETURN TO CONTINUE........."; PRESS
    CLS
    IF SLECT1 <> 2 THEN : GOTO 10988
    PRINT : PRINT : PRINT "       1. ANOTHER TEMPERATURE CORRECTION "
    PRINT : PRINT "       2. EXIT TO MAIN MANUAL "
    PRINT : PRINT : INPUT "      Select the Operation Desired: "; CHO2
    IF CHO2 = 1 THEN : GOTO 10010
    GOTO 730
10988 PRINT : PRINT : PRINT "       1. EXIT TO MAIN MENU "
    PRINT : PRINT "       2. EXIT TO OUTPUT MENU "
    PRINT : PRINT : INPUT "      Select the Operation Desired: "; CHO3
    IF CHO3 = 1 THEN : GOTO 730
    GOTO 7580
    RETURN
    '
12000 '*****************************************************
    ' RUT DEPTH PREDICTION SUBROUTINE FOR LOW-VOLUME ROADS
    '                  BY
    '              K. A. S. YAPA
    '*****************************************************
    ' Pavement Systems, Texas Transportation Institute,
    ' TTI Building, Texas A & M University,
    ' College Station, Texas 77843.
    ' (409)-845-9910.
    ' 24th MARCH 1988.
    '
    'This subroutine predicts the rut depth of a low-volume road by using a data
    'base of rut depths calcualted by the Mechano-lattice program. A
    'multi-dimensional polynomial interpolation routine is used to
    'interpolate among the input parameters. Required inputs are the
```

```
'resilient modulus of both the base course and the subgrade
'layers, the material classification of the subgrade layer
'and the thickness of the base layer.
'Optionally, laboratory data from a permanent deformation test for
'each material layer can be input, in place of the material
'classification.
'
DIM rut(2, 3, 3, 3, 3)
'
' LOAD THE DATA BASE INTO AN ARRAY
'
FOR I = 1 TO 2
FOR J = 1 TO 3
FOR K = 1 TO 3
FOR L = 1 TO 3
READ rut(I, J, K, L, 1), rut(I, J, K, L, 2), rut(I, J, K, L, 3)
NEXT L: NEXT K: NEXT J: NEXT I
'
' READ THE ORIGINAL PARAMETER LEVELS OF THE DATABASE
'
FOR I = 1 TO 3
READ XM(I), XL(I), XK(I), XJ(I), XI(I)
NEXT I
'
' GOTO SUBROUTINE INPUT1 -------------------------
RUT1 = 1
'
12400 GOSUB 14240
' LOOP TO CALCULATE RUT DEPTHS FOR EACH FWD SECTION
'
IF INIOPT = 2 THEN NC = 1
'
FOR INC = 1 TO NC
IF TEMRUT = 1 THEN : E1(INC) = NE(INC)
REM GOTO SUBROUTINE INPUT2 ----------------------
GOSUB 14850
'
'GOTO INPUT1 IF ANY CORRECTIONS ARE NEEDED
IF CORR = 1 THEN GOSUB 14240
CLS
PRINT " Calculating.........."
'
' SELECT PARAMETERS FOR INTERPOLATION
'
FOR I = 1 TO 2
FOR J = 1 TO 3
FOR K = 1 TO 3
FOR L = 1 TO 3
FOR M = 1 TO 3
'
' M - BASE THICKNESS
'
Y1(M) = rut(I, J, K, L, M)
X1(M) = XM(M): NEXT M
'
' CALL THE INTERPOLATION ROUTINE
'
NUM = 3: X = XMM: GOSUB 13700
```

```
YLTEMP(L) = Y: XMFLAG = XFLAG
NEXT L
'
' L - SUBGRADE RUTTING POTENTIAL
'
FOR LL = 1 TO 3: X1(LL) = XL(LL): Y1(LL) = YLTEMP(LL): NEXT LL
NUM = 3: X = XLL: GOSUB 13700
YKTEMP(K) = Y: XLFLAG = XFLAG
NEXT K
'
' K - SUBGRADE RESILIENT MODULUS
'
FOR KK = 1 TO 3: X1(KK) = XK(KK): Y1(KK) = YKTEMP(KK): NEXT KK
NUM = 3: X = XKK: GOSUB 13700
YJTEMP(J) = Y: XKFLAG = XFLAG
NEXT J
'
' J - BASE RESILIENT MODULUS
'
FOR JJ = 1 TO 3: X1(JJ) = XJ(JJ): Y1(JJ) = YJTEMP(JJ): NEXT JJ
NUM = 3: X = XJJ: GOSUB 13700
YITEMP(I) = Y: XJFLAG = XFLAG
NEXT I
'
' I - BASE RUTTING POTENTIAL
'
FOR II = 1 TO 2: X1(II) = XI(II): Y1(II) = YITEMP(II): NEXT II
NUM = 2: X = XII: GOSUB 13700
RUTCAL = Y * CYL / 300000!: XIFLAG = XFLAG
'
' GOTO SUBROUTINE OUTPUT ------------------------
'
GOSUB 15680
NEXT INC
IF INIOPT <> 2 THEN : GOTO 13685
PRINT : PRINT : PRINT
PRINT "          1. ANOTHER RUT DEPTH CALCULATION "
PRINT : PRINT "          2. EXIT TO MAIN MANUAL "
PRINT : PRINT : PRINT : INPUT "          Select the Operation Desired: "; CHO5
IF CHO5 = 1 THEN : GOTO 12400
GOTO 730
'
' DATA BASE OF RUT DEPTHS
'
DATA     0.2609 ,     0.2804 ,     0.3191
DATA     0.2216 ,     0.2152 ,     0.2223
DATA     0.1831 ,     0.1502 ,     0.1253
DATA     0.2705 ,     0.3030 ,     0.3431
DATA     0.2451 ,     0.2491 ,     0.2556
DATA     0.2168 ,     0.1951 ,     0.1680
DATA     0.3674 ,     0.4519 ,     0.5286
DATA     0.3503 ,     0.4172 ,     0.4580
DATA     0.3331 ,     0.3831 ,     0.3882
DATA     0.2702 ,     0.2912 ,     0.3019
DATA     0.2249 ,     0.2185 ,     0.2002
DATA     0.1797 ,     0.1458 ,     0.0991
DATA     0.2804 ,     0.3099 ,     0.3549
DATA     0.2473 ,     0.2490 ,     0.2600
```

```
      DATA    0.2137 ,       0.1882 ,       0.1652
      DATA    0.3900 ,       0.4610 ,       0.5322
      DATA    0.3688 ,       0.4231 ,       0.4561
      DATA    0.3475 ,       0.3842 ,       0.3798
      DATA    0.2946 ,       0.3130 ,       0.3110
      DATA    0.2344 ,       0.2263 ,       0.2031
      DATA    0.1750 ,       0.1403 ,       0.0837
      DATA    0.3013 ,       0.3356 ,       0.3755
      DATA    0.2548 ,       0.2600 ,       0.2687
      DATA    0.2087 ,       0.1842 ,       0.1618
      DATA    0.3977 ,       0.4840 ,       0.5424
      DATA    0.3750 ,       0.4343 ,       0.4541
      DATA    0.3498 ,       0.3834 ,       0.3670
      DATA    0.1613 ,       0.2376 ,       0.3056
      DATA    0.1258 ,       0.1727 ,       0.2086
      DATA    0.0934 ,       0.1082 ,       0.1119
      DATA    0.1901 ,       0.2528 ,       0.3247
      DATA    0.1588 ,       0.1993 ,       0.2374
      DATA    0.1280 ,       0.1457 ,       0.1500
      DATA    0.2607 ,       0.3681 ,       0.4915
      DATA    0.2453 ,       0.3355 ,       0.4217
      DATA    0.2300 ,       0.3038 ,       0.3523
      DATA    0.1951 ,       0.2524 ,       0.2767
      DATA    0.1491 ,       0.1794 ,       0.1747
      DATA    0.1039 ,       0.1072 ,       0.0732
      DATA    0.1957 ,       0.2643 ,       0.3400
      DATA    0.1628 ,       0.2037 ,       0.2453
      DATA    0.1296 ,       0.1433 ,       0.1505
      DATA    0.2920 ,       0.4006 ,       0.5025
      DATA    0.2713 ,       0.3648 ,       0.4262
      DATA    0.2508 ,       0.3230 ,       0.3502
      DATA    0.2254 ,       0.2785 ,       0.2834
      DATA    0.1652 ,       0.1918 ,       0.1736
      DATA    0.1056 ,       0.1059 ,       0.0643
      DATA    0.2256 ,       0.2974 ,       0.3642
      DATA    0.1790 ,       0.2216 ,       0.2574
      DATA    0.1328 ,       0.1461 ,       0.1506
      DATA    0.3322 ,       0.4287 ,       0.5197
      DATA    0.3034 ,       0.3786 ,       0.4327
      DATA    0.2749 ,       0.3287 ,       0.3456
      '
      'INPUT PARAMETERS USED IN CREATING THE DATA BASE
      '
      DATA 18, 0.0100, 25000, 100000, 0.0075
      DATA 12, 0.0060, 15000,  70000, 0.0025
      DATA  6, 0.0020,  5000,  40000, 0.0000
      END
13685 RETURN
      '****************************************************************
13700 'SUBROUTINE FOR POLYNOMIAL INTERPOLATION
      '****************************************************************
      ' X - VALUE OF THE PARAMETER
      ' X1(I) - PARAMETER VALUES USED IN THE DATA BASE
      ' Y1(I) - RUT DEPTHS FROM DATA BASE CORRESPONDING TO PARAMETER
      ' Y - INTERPOLATED VALUE
      ' NUM - NUMBER OF LEVELS OF THE PARAMETER
      '
      NS = 1
```

```
    DIF = ABS(X - X1(1))
    FOR a = 1 TO NUM
    DIFT = ABS(X - X1(a))
    '
    ' SELECT THE BEST STARTING POINT
    '
    IF DIFT < DIF THEN : NS = a: DIF = DIFT
    C(a) = Y1(a): DD(a) = Y1(a)
    NEXT a
    XFLAG = 0
    '
    'ENFORCE LIMITS ON EXTRAPOLATION (MAXIMUM = 1.5 * DIFFERENCE BETWEEN TWO
    'CONSECUTIVE PARAMETER LEVELS)
    '
    IF DIF > 1.5 * (ABS(X1(1) - X1(2))) THEN GOTO 13940 ELSE GOTO 13980
13940 DIF = 1.5 * (ABS(X1(1) - X1(2)))
    IF NS = 1 THEN : X = X1(1) + DIF
    IF NS = NUM THEN : X = X1(NUM) - DIF
    XFLAG = X
13980 Y = Y1(NS)
    NS = NS - 1
    BEND = 1
    FOR B = 1 TO BEND
    AEND = NUM - B
    FOR a = 1 TO AEND
    HO = X1(a) - X
    HP = X1(a + B) - X
    W = C(a + 1) - DD(a)
    DEN = HO - HP
    DEN = W / DEN
    '
    ' D - CORRECTION FROM THE LOWER LEVEL
    ' C - CORRECTION FROM THE UPPER LEVEL
    '
    DD(a) = HP * DEN
    C(a) = HO * DEN
    NEXT a
    '
    ' PICK THE SHORTEST PATH TO MOVE
    '
    IF (2 * NS) < AEND THEN : DY = C(NS + 1): GOTO 14210:     ELSE GOTO 14200
14200 DY = DD(NS): NS = NS - 1
14210 Y = Y + DY
    NEXT B
    RETURN
14240 '*******************************************************************
    ' SUBROUTINE INPUT1
    '*******************************************************************
    '
    CLS
    'USE IF ONLY THE RUT LEVELS ARE NEEDED
    '
    IF INIOPT <> 2 GOTO 14400
    CLS : INPUT "JOB DESCRIPTION :"; AA$
    INPUT "Resilient Modulus - Base Course (psi)"; EBA
    INPUT "Resilient Modulus - Subgrade (psi)"; ESG
    INPUT "Thickness of Base Layer (in)"; TBA
    INPUT "# of Equivalent Standard Wheel (9000 lbs) Passes"; EQPASS
```

```
    INPUT "Allowable Rut Depth (in.)"; RALLOW
    INPUT "Existing Rut Depth (in.)"; REXIST
14380 CLS
'
14400 CLS
    LOCATE 4, 10: PRINT " INPUT DATA OPTIONS FOR RUT DEPTH CALCULATION: "
    LOCATE 6, 10: PRINT " 1) Require subgrade material"
    LOCATE 7, 10: PRINT "    classification to determine approximate "
    LOCATE 8, 10: PRINT "    rutting potentials."
    LOCATE 10, 10: PRINT " 2) Require laboratory data on residual deforma- "
    LOCATE 11, 10: PRINT "    tion behavior of base and subgrade."
    LOCATE 15, 10: INPUT "OPTION: 1=SOIL CLASS, 2=LAB DATA "; OPP
    '
    IF OPP = 2 THEN GOTO 14590
    IF OPP <> 1 THEN GOTO 14380
    '
    REM ALL BASE COURSE MATERIALS ARE CLASSIFIED AS ONE GROUP.
    '
    CLS : LOCATE 4, 10: PRINT "Subgrade Material Type :"
    LOCATE 7, 10: PRINT "1) Heavy Clay - (CH)"
    LOCATE 9, 10: PRINT "2) Light/Silty Clay, Clayey Silt - (CL-ML)"
    LOCATE 11, 10: PRINT "3) Clayey/Silty/Uniform Sand - (SC-SM)"
    LOCATE 15, 10: INPUT "ENTER SELECTION & <RET> "; MSG
    GOTO 14750
14590 CLS : LOCATE 4, 10: PRINT "Laboratory Data Input:"
    LOCATE 6, 10: PRINT "Log a - Intercept of the Straight Line Fit on a "
    LOCATE 7, 10: PRINT "        Log-Log Plot of Accumulated Residual Strain"
    LOCATE 8, 10: PRINT "        vs. Number of Load Repetitions"
    LOCATE 10, 10: PRINT "b     - Slope of the Straight Line Fit"
    PRINT : PRINT
    INPUT "Log a - Base Course Material"; LGABA
    INPUT "b     - Base Course Material"; BBA
    INPUT "Log a - Subgrade Material"; LGASG
    INPUT "b     - Subgrade Material"; BSG
    IF INIOPT = 2 GOTO 14718
    CLS
    IF OPP <> 1 GOTO 14704
    LOCATE 16, 10: IF MSG = 1 THEN PRINT "Subgrade      - CH - Clay"
    LOCATE 16, 10: IF MSG = 2 THEN PRINT "Subgrade      - CL-ML "
    LOCATE 16, 10: IF MSG = 3 THEN PRINT "Subgrade      - SC-SM"
    GOTO 14714
    '
14704 LOCATE 16, 10: PRINT "Base Course Material - "
    LOCATE 17, 10: PRINT "          Log a = "; LGABA; ",     b = "; BBA
    LOCATE 19, 10: PRINT "Subgrade Material    - "
    LOCATE 20, 10: PRINT "          Log a = "; LGASG; ",     b = "; BSG
    '
14714 LOCATE 22, 10: INPUT "DO YOU WANT ANY CORRECTIONS - 0=NO, 1=YES"; CORR
    IF CORR = 1 THEN GOTO 14380
    IF CORR <> 0 GOTO 14714
14718 ABA = 10 ^ LGABA: ASG = 10 ^ LGASG
    IF ((ABA * 50000! ^ BBA) < .015) AND ((ASG * 50000! ^ BSG) < .016) GOTO 14750
    CLS : BEEP: PRINT "Input Data are Incompatible. Check & Re-enter!":
    GOTO 14400
    '
14750 ' SKIP IF ONLY RUT LEVELS ARE CALCULATED
    IF INIOPT = 2 GOTO 14840
    '
```

```
    ' OBTAIN THE TRUCK PASSES AND ALLOWABLE AND MEASURED RUT LEVELS FROM
    ' THE MAIN PROGRAM
    '
    EQPASS = PA
    RALLOW = RX
    REXIST = RM
14840 RETURN
14850 '*********************************************************
    'SUBROUTINE INPUT2 ————————————
    '*********************************************************
    'SKIP IF ONLY RUT LEVELS ARE CALCULATED
    IF INIOPT = 2 GOTO 14940
    '
     EBA = E1(INC)
     ESG = E2(INC)
     TBA = BA(INC)
14940 IF OPP <> 1 GOTO 15280
    '
    REM APPROXIMATE METHOD TO DETERMINE RUTTING BEHAVIOR
    '
    ' e(p) = a* N^b
    ' a - FIRST CYCLE STRAIN       (ABA,ACH,ACL,ASM)
    ' b - RESIDUAL DEFORMATION RATE   (BBA,BCH,BCL,BSM)
    ' N - # OF WHEEL PASSES   (CYL)
    ' a = aa * Mr^ab
    ' aa - COEFFICIENT    (AABA,AACH,AACL,AASM)
    ' ab - EXPONENT    (ABBA,ABCH,ABCL,ABSM)
    ' Mr - RESILIENT MODULUS (ksi)    (EBA,ESG)
    '
    AABA = .0174: AACH = .0933: AACL = .001: AASM = .095
    ABBA = -.57: ABCH = -2.64: ABCL = -.73: ABSM = -1.95
    BBA = .125: BCH = .236: BCL = .162: BSM = .142
    '
    'CALCULATE "a" AND "b" ("a" IS KEPT WITHIN PRACTICAL LIMITS)
    '
    ABA = AABA * (EBA / 1000) ^ ABBA
    IF ABA > .0035 THEN ABA = .0035
    IF MSG <> 1 GOTO 15190
    BSG = BCH
    ASG = AACH * (ESG / 1000) ^ ABCH
    IF ASG > .004 THEN ASG = .004
15190 IF MSG <> 2 GOTO 15230
    BSG = BCL
    ASG = AACL * (ESG / 1000) ^ ABCL
    IF ASG > .001 THEN ASG = .001
15230 IF MSG <> 3 GOTO 15270
    BSG = BSM
    ASG = AASM * (ESG / 1000) ^ ABSM
    IF ASG > .005 THEN ASG = .005
15270 '
15280 REM USE IF ONLY RUT LEVELS ARE NEEDED
    '
    IF INIOPT <> 2 GOTO 15550
    CLS : REM DISPLAY INPUT DATA
    LOCATE 2, 10: PRINT "JOB : "; AA$
    LOCATE 4, 10: PRINT "Resilient Modulus (psi) - Base     = "; EBA
    LOCATE 6, 10: PRINT "                         - Subgrade = "; ESG
    LOCATE 8, 10: PRINT "Thickness of Base Layer             = "; TBA; " in."
```

```
    LOCATE 10, 10: PRINT "# of Equivalent Standard Wheel Passes ="; EQPASS
    LOCATE 12, 10: PRINT "Allowable Rut Depth ="; RALLOW; " in."
    LOCATE 14, 10: PRINT "Measured Rut Depth ="; REXIST; " in."
    IF OPP <> 1 GOTO 15460
    LOCATE 16, 10: IF MSG = 1 THEN PRINT "Subgrade      - CH - Clay"
    LOCATE 16, 10: IF MSG = 2 THEN PRINT "Subgrade      - CL-ML "
    LOCATE 16, 10: IF MSG = 3 THEN PRINT "Subgrade      - SC-SM"
    GOTO 15510
    '
    '
15460 LOCATE 16, 10: PRINT "Base Course Material - "
    LOCATE 17, 10: PRINT "          Log a = "; LGABA; ",     b = "; BBA
    LOCATE 19, 10: PRINT "Subgrade Material    - "
    LOCATE 20, 10: PRINT "          Log a = "; LGASG; ",     b = "; BSG
    '
15510 LOCATE 22, 10: INPUT "DO YOU WANT ANY CORRECTIONS - 0=NO, 1=YES"; CORR
    IF CORR = 1 THEN RETURN
    IF CORR <> 0 GOTO 15510
    '
15550 'ASSIGN VALUES TO INTERPOLATION PARAMETERS
    '
    CYL = 300000!
    XII = ABA * CYL ^ BBA
    XLL = ASG * CYL ^ BSG
    IF XII > .015 THEN XII = .015
    IF XLL > .016 THEN XLL = .016
    IF XLL < .001 AND TBA < 10 THEN XLL = .001
    '
    '
    XMM = TBA: XJJ = EBA: XKK = ESG
    IF TBA < 10 AND ESG > 20000! AND EBA > 100000 THEN XJJ = 100000
    IF TBA < 10 AND EBA < 60000 AND ESG > 30000 THEN XKK = 30000: IF TBA < 6 THEN XMM =
6: IF EBA < 30000 THEN XJJ = 30000
    RETURN
    '***********************************************************************
15680 'SUBROUTINE OUTPUT
    '***********************************************************************
    '
    IF RUTCAL < 0 THEN RUTCAL = 0!
    RFINAL(INC) = RUTCAL * EQPASS / CYL
    REXTRA = RALLOW - REXIST
    IF RUTCAL = 0 THEN passes(INC) = 0: GOTO 15760
    passes(INC) = CYL * REXTRA / RUTCAL
15760 IF INIOPT <> 2 GOTO 15860
    CLS
    IF EQPASS = 0 GOTO 15810
    LOCATE 6, 10: PRINT "EQUIVALENT STANDARD WHEEL PASSES ="; EQPASS
    LOCATE 8, 10: PRINT "RUT DEPTH CAUSED          = "; RFINAL(1); " in."
15810 LOCATE 10, 10: PRINT "ALLOWABLE RUT DEPTH      = "; RALLOW; " in."
    LOCATE 12, 10: PRINT "EXISTING RUT DEPTH        = "; REXIST; " in."
    LOCATE 14, 10: PRINT "ALLOWABLE WHEEL PASSES  = "; passes(1)
    IF passes(1) = 0 THEN : LOCATE 16, 5: PRINT "INPUT DATA MAY BE INCOMPATIBLE. CHECK &
RERUN!"
    PRINT : PRINT : PRINT
15860 IF INIOPT = 2 THEN : INPUT "     PRESS RETURN TO CONTINUE ......."; PRESS
    CLS
    RETURN
```

APPENDIX C

LDATA PROGRAM

```
*****************$$$$ PROGRAM - LDATA - $$$$************************
*  PROGRAM TO CONVERT FWD DATA FILES TO LOADRATE INPUT FILES   *
*                    WRITTEN BY                                 *
*                 B. LANKA SANTHA                               *
*     Pavement Systems, Texas Transportation Institute          *
*          TTI Building, Texas A&M University,                  *
*            College Station, Texas 77843.                      *
*                  (409)-845-5982                               *
*                  20th April 1989                              *
*****************************************************************
*    LDATA PROGRAM
     INTEGER I,J,L,YEAR,MONTH,DAY,DISTRICT,TRUCK,AXLE,WLOAD
     INTEGER LOAD,PASSES, ESAL1,TOTPASS,ESAL,NY,K2(100),MM
     REAL ARUT,RRUT, RI
     CHARACTER*7 DATA(150,10)
     CHARACTER*7 FLOAD,D1,D2,D3,D4,D5,D6,D7
     CHARACTER ROAD*30,COUNTY*20,JOB*72,OPNAME*30, CHO*1
     CHARACTER SECTION*9,FNAME*30,B*1,SEC*9,BASE*4,SECT(150)*10
     CHARACTER*1 QUO
     DATA QUO/1H'/
 500 J = 0
     I = 0
     L = 0
     II = 0
*************************************************************
*    PRINT INTRODUCTORY MESSAGE                             *
*************************************************************
     WRITE(*,*)' CONVERSION OF FALLING WEIGHT DEFLECTOMETER DATA TO
    $ LOADRATE DATA FILE'
     WRITE(*,*)'ENTER THE NAME OF THE FWD DATA FILE:'
     WRITE(*,*)'NOTE: DRIVE,FILE NAME,AND EXT:a:filename.ext'
     READ(*,21) FNAME
  21 FORMAT(A30)
     OPEN (UNIT=2,FILE=FNAME,STATUS='OLD')
     WRITE(*,*)'ENTER THE NAME OF THE OUTPUT FILE:'
     WRITE(*,*)'NOTE: DRIVE,FILE NAME,AND EXT:a:filename.ext'
     READ (*,22) OPNAME
  22 FORMAT(A30)
     OPEN (UNIT=3,FILE=OPNAME,STATUS='NEW')
     WRITE(*,*)' ENTER THE JOB TITLE:title'
     READ(*,25) JOB
  25 FORMAT(A72)
      TRUCK = 1
      AXLE = 1
      WLOAD = 9000
      LOAD = 0.0
     WRITE(*,*)' ENTER THE ALLOWABLE RUT(INS):'
     READ(*,*) ARUT
     WRITE(*,*)' ENTER THE RECORDED RUT(INS):'
     READ(*,*) RRUT
     CALL TRAFFIC ( ESAL1, TOTPASS, RI, NY)
     WRITE(*,*)' ENTER THE THICKNESS OF BASE COURSE (INS):'
     READ(*,26) BASE
  26 FORMAT(A4)
**************************************************************
*          READING OF FWD DATA FILE                          *
**************************************************************
 555 WRITE(*,*) '  SELECTION OF DEFLECTION BOWLS FOR ANALYSIS'
```

```
      WRITE(*,*) '        (1) All the deflection bowls'
      WRITE(*,*) '        (2) Only one deflection bowl from each'
      WRITE(*,*) '            test point'
      WRITE(*,*)
      WRITE(*,*) '  ENTER YOUR OPTION'
      READ (*,*) KK
      IF (KK .NE. 1 .AND. KK .NE. 2) GOTO 555
      IF (KK .EQ. 2) THEN
        WRITE(*,*) '  ENTER DEFLECTION BOWL NO.'
        READ (*,*) KK1
      END IF
      READ(2,200) YEAR,MONTH,DAY
  200 FORMAT(T14,3I2)
      DO 55 I = 1,3
      READ(2,*)
   55 CONTINUE
      READ(2,220) ROAD
  220 FORMAT(A30)
      DO 15 I =6,24
        READ(2,*)
   15 CONTINUE
      READ(2,42)DISTRICT,COUNTY
   42 FORMAT(A2,A3)
   43 WRITE(*,*) 'Please select option for FWD data format'
      WRITE(*,*)
      WRITE(*,*) 'VERSION 9.0  = 0'
      WRITE(*,*) 'VERSION 10.0 = 1'
      WRITE(*,*)
      READ (*,81) MM
   81 FORMAT(I1)
      IF (MM .LT. 0 .OR. MM .GT. 1) GOTO 43
      IF (MM .EQ. 1) THEN
      DO 52 I =27,38
        READ(2,*)
   52   CONTINUE
      ELSE
        DO 53 I = 27,31
        READ(2,*)
   53   CONTINUE
      END IF
  400 READ(2,50) B,SEC,FLOAD,D1,D2,D3,D4,D5,D6,D7
   50 FORMAT (A1,T2,A8,T33,A6,7A6)
        IF (B .EQ. 'E') GO TO 410
        IF (B .EQ. 'S') GO TO 420
        IF (B .EQ. '*') GO TO 400
        IF (FLOAD .EQ. '      ') GO TO 400
        IF (B .EQ. QUO) GO TO 400
          L = L+1
        GO TO 430
  420   SECTION = SEC
        II = II + 1
        K2(II) = L
        GO TO 400
  430   SECT(L) = SECTION
        DATA(L,3)=D1
        DATA(L,4)=D2
        DATA(L,5)=D3
        DATA(L,6)=D4
```

```
      DATA(L,7)=D5
      DATA(L,8)=D6
      DATA(L,9)=D7
      DATA(L,10)=FLOAD
      GO TO 400
 410  WRITE(3,300)
 300  FORMAT(1X,'1')
     WRITE(3,310) DISTRICT
 310  FORMAT(1X,A2)
     WRITE(3,320) COUNTY
 320  FORMAT(1X,A20)
     WRITE(3,330) ROAD
 330  FORMAT(1X,A30)
     WRITE(3,340) MONTH,DAY,YEAR
 340  FORMAT(1X,I2,'-',I2,'-',I2)
     WRITE(3,350)JOB
 350  FORMAT(1X,A72)
     IF (KK .EQ. 2) THEN
      NDB = K2(II) - K2(II-1)
**      WRITE(*,*) NDB
      L1 = L/NDB
      WRITE(3,560)L1,TRUCK,ARUT,RRUT,NY,TOTPASS,RI,ESAL1
 560    FORMAT(1X,I4,2X,I3,2X,F4.2,2X,F4.2,2X,I3,2X,I10,2X,F7.3,2X,I8)
     ELSE
     WRITE(3,360)L,TRUCK,ARUT,RRUT,NY,TOTPASS, RI, ESAL1
 360  FORMAT(1X,I4,2X,I3,2X,F4.2,2X,F4.2,2X,I3,2X,I10,2X,F7.3,2X,I8)
     END IF
     WRITE(3,370)AXLE
 370  FORMAT(1X,I1)
     WRITE(3,380)WLOAD
 380  FORMAT(I5)
     IF (KK .EQ. 2) THEN
      K = KK1
     ELSE
      K = 1
     END IF
  35    WRITE(3,390) SECT(K),BASE,DATA(K,3),DATA(K,4),
    $DATA(K,5),DATA(K,6),DATA(K,7),DATA(K,8),DATA(K,9),DATA(K,10)
 390  FORMAT(A10, A4, 8A7)
     IF (KK .EQ. 2) THEN
      K = K + NDB
     ELSE
      K=K+1
     END IF
     IF (KK .EQ. 2) THEN
      LK = L - K
      IF (LK .GE. 0) GO TO 35
     ELSE
      IF (K .LE. L )GO TO 35
     END IF
     CLOSE (2)
     CLOSE (3)
 510  WRITE(*,*) ' Do you want to convert another FWD data file to '
     WRITE(*,*) ' LOADRATE input file, Y or N'
     READ(*,23) CHO
  23  FORMAT(1A)
     IF (CHO .EQ. 'Y') GOTO 500
     IF (CHO .NE. 'Y' .AND. CHO .NE. 'N') GOTO 510
```

```
      WRITE(*,*)'FORTRAN ENDS'
      STOP
      END
      SUBROUTINE TRAFFIC ( ESAL, TPASS, R, N)
      INTEGER ESAL, NN, TPASS, N
      REAL F, R, ADT1, ADT20
333   WRITE(*,*) '        INPUT OF TRAFFIC DATA'
      WRITE(*,*) '        '
      WRITE(*,*) 'The options 1 and 2 allow to find the remaining'
      WRITE(*,*) 'life of the pavement in years'
      WRITE(*,*) ' '
      WRITE(*,*) '(1) USING CURRENT ANNUAL TRAFFIC (IN ESAL), TRAFFIC'
      WRITE(*,*) '    GROWTH RATE AND NUMBER OF YEARS'
      WRITE(*,*) '(2) USING 1st AND 20th YEAR ADT AND TOTAL NUMBER OF'
      WRITE(*,*) '    ESAL PASSES IN 20 YEARS'
      WRITE(*,*) '(3) 10 YEAR PROJECTED ESAL'
      WRITE(*,*) '(4) 20 YEAR PROJECTED ESAL'
      WRITE(*,*) '   '
      WRITE(*,*) 'ENTER YOUR OPTION'
      READ(*,*) NN
      IF(NN .EQ. 1) THEN
        WRITE(*,*) 'Please enter first year traffic in ESAL:'
        READ(*,*) ESAL
        WRITE(*,*) 'Please enter precent annual rate of TRAFFIC GROWTH:'
        READ (*,*) R1
        WRITE(*,*) 'Please enter NUMBER OF YEARS to be used for analy:'
        READ (*,*) N
          IF (R1 .EQ. 0.0) THEN
            TPASS = ESAL * N
            R = R1/100
          ELSE
            R = R1/100
            TPASS = ESAL * ((1+R)**N - 1)/R
          END IF
      ELSE IF (NN .EQ. 2) THEN
        WRITE(*,*) 'Please enter 1st year ADT'
        READ (*,*) ADT1
        WRITE(*,*) 'Please enter 20th year ADT'
        READ (*,*) ADT20
        WRITE(*,*) 'Please enter total number of ESALs in 20 years'
        READ (*,*) TPASS
        N = 20
          R = (ADT20/ADT1)**.05 - 1
        IF (R .LT. 0) THEN
          WRITE(*,*) 'Please check your ADT values'
          GO TO 333
        ELSE IF (R .EQ. 0) THEN
          ESAL = TPASS/N
        ELSE
          ESAL = TPASS/(((1+R)**N - 1)/R)
        END IF
      ELSE IF (NN .EQ. 3) THEN
        WRITE(*,*) 'Please enter the total ESAL traffic in 10 years'
        READ (*,*) TPASS
        R = -1.0
        N = 10
      ELSE IF (NN .EQ. 4) THEN
        WRITE(*,*) 'Please enter the total ESAL traffic in 20 years'
```

```
  READ (*,*) TPASS
  R = -1.0
  N = 20
ELSE
  GO TO 333
END IF
RETURN
END
```