Structural Evaluation and Load Zoning of Low-Volume Roads: A Case Study

KOON MENG CHUA, THOMAS SCULLION, AND ROBERT L. LYTTON

Highway departments acutely need to be able to quickly and systematically monitor the structural integrity of low-volume, farm-to-market roads, which are basically two-layer pavement systems. This structural evaluation is often performed in conjunction with other pavement management activities, which include the evaluation of overweight vehicle permit applications and load zoning. The use of a fast and efficient procedure for accomplishing the above is demonstrated by a case study of a county in the State of Texas. Nondestructive tests using a Falling Weight Deflectometer were performed on all of the farm-to-market roads in the county and a program called LOADRATE was used to analyze the data. The solution is semiempirical and is based on field observations and on ILLI-PAVE, a nonlinear, finite element pavement analysis code. The microcomputer-based LOADRATE program uses the deflection basin obtained from the Falling Weight Deflectometer, or the Dynaflect, to determine the nonlinear elastic properties of the base course and the subgrade, and then computes the residual deformation, or rut, that will be caused by a particular repeated load on the pavement. It can also be used to estimate the base course thickness. The model adopted for repetitive loading follows a hyperbolic-shaped loading and reloading load deflection curve with a linear unloading path. The presentation of the case study shows how Falling Weight Deflectometer data are systematically collected, analyzed, and used to determine the relative structural conditions of all of the low-volume roads in the county, and how this information is integrated with the ongoing pavement management efforts. The results of the analyses are also compared with current load-zoned roads. A discussion is also presented of how overweight vehicle permit applications can be evaluated, the various steps that can be taken to decide which farm-to-market roads are to be load-zoned, and what level of effort will be required to lift load restrictions.

Highway departments currently need fast and systematic ways to determine the structural integrity of low-volume, farm-to-market (FM) roads. Few design procedures are available for these thin pavements. In the State of Texas alone, 254 counties are managed by 24 district offices, and the task of monitoring the structural performance of the highways is formidable. In addition, more than 60 percent of the highways in the state consist of low-volume, two-layer pavements. These pavements frequently consist of a surface treatment and a 6- to 8-in-thick granular base course that is laid over a stabilized or unstabilized subgrade. The surface treatment is seldom more than an inch thick and is mainly used to waterproof and resist skids.

Texas Transportation Institute, Texas A&M University System, College Station, Tex. 77843.

In addition to the ongoing development of a pavement management system, the Texas State Department of Highways and Public Transportation (SDHPT) is developing the use of nondestructive testing (NDT) procedures to determine the structural condition of thin pavements for load permitting and design purposes. The use of a fast and efficient procedure to accomplish the above tasks is demonstrated by a case study that involves a county road network in the State of Texas. This study was performed as part of a cooperative research study between the Texas Transportation Institute (TTI) and the Texas SDHPT. Nondestructive tests that used a Dynatest Falling Weight Deflectometer (FWD) were performed on all of the farm-to-market roads in Willacy County and a program called LOADRATE was used to analyze the data (*1, 2*). The solution is semiempirical and was developed from field data and from ILLI-PAVE, which is a nonlinear, finite element pavement analysis code (*3*). The LOADRATE program uses the deflection basins from the FWD, or the Dynaflect, to determine the nonlinear elastic properties of the base course and the subgrade and then to compute the residual deformation or rut that will be caused by a particular load on the pavement. It has been found that the deflection basin can also be used to estimate the effective base course thickness (*2*).

A brief description of the LOADRATE program and its results, and how the FWD survey is performed, is presented in the following sections. The results of the FWD survey of Willacy County and the load zoning considerations are also discussed.

THE METHOD OF EVALUATING LOW-VOLUME ROADS

The development and documentation of the LOADRATE procedure have been described in detail by Chua and Lytton (*1, 2, 4*). In brief, the development of the method first involved obtaining a number of deflection basins using the Dynatest FWD for 70 different sections of FM roads, and then using ILLI-PAVE, a nonlinear, finite element computer program, to back-calculate the nonlinear elastic properties of the base course and the subgrade (*3, 5*). After all deflection basins were successfully matched, ILLI-PAVE was used to generate a data base for a factorial analysis from which the regression equations were obtained. The base course thickness was initially obtained from construction drawings and was checked with the Pavement Dynamic Cone Penetrometer (PDCP) (*6*). The regression equations in the LOADRATE program also related the nonlinear elastic properties of the pavement layers to the rut depth generated under vehicle loading. Dynaflect readings can also be used instead of FWD readings, which is made possible by a correlation obtained between the readings of the two evaluation devices.

Material Properties

The elastic modulus of the base course material can be expressed by

$$E = K_1 \theta^{K_2} \quad (1)$$

where

θ = first stress invariant,
K_1 = modulus number, and
K_2 = modulus exponent, taken to be 0.33 (*1, 3*). A value between 0.30 and 0.33 is commonly used for the ILLI-PAVE analysis (*7*).

The subgrade, which is also nonlinearly elastic, is classified as very soft, soft, medium, or stiff (*3*). When these curves are expressed in the form of Equation 1, a range is given of modulus numbers between 3,000 and 15,000 with modulus exponents ranging from -0.36 to -0.15, respectively.

Load-Deflection Characteristics of Light Pavements

A hyperbolic load-deflection relationship, which is analogous to the stress-strain relation used for soils, was assumed to model the pavement system (*8, 9*). The model is described by the following equation.

$$P = \frac{\Delta}{A + B\Delta} \quad (2)$$

where

A = inverse of the value of the initial tangent modulus,
B = a positive or a negative value describing either the load asymptote or the deflection asymptote, respectively, and
Δ = deflection measured.

This model, which is shown in Figure 1, was found to be most suitable because it is able to fit the observed load-deflection data. Coefficients A and B can be obtained either by curve-fitting the load versus deflection data points or from the FWD deflection basin. It was determined that the hyperbolic load-deflection model could satisfactorily represent the pavement behavior with a single-wheel load level of up to at least 24,000 lbs.

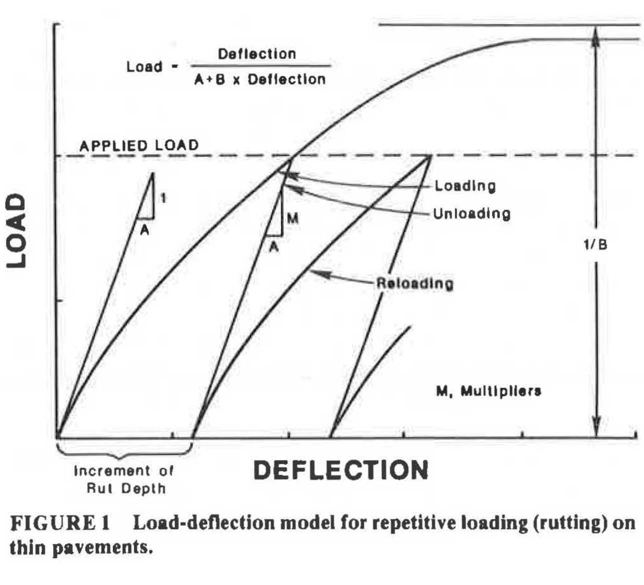

FIGURE 1 Load-deflection model for repetitive loading (rutting) on thin pavements.

The Rutting Model

The unloading path of the load-deflection curve was determined from rut measurements of the recorded number of equivalent single-axle loads (ESALs) and the measured deflection basins of a series of farm-to-market roads from a data base for the State of Texas. These pavements were monitored over a 10-yr period starting in 1972. It is the ability to determine the characteristics of this unloading path that allows for the calculation of rut depths based on any load level. The number of passes of a given wheel load P to cause a rut depth of R can be calculated by the following equation.

$$N = \frac{R}{(\Delta - A \times P \;/\; \text{Multiplier})} \quad (3)$$

The Multiplier is the ratio of the slope of the unloading path to the initial slope of the load-deflection curve. It is at this point that an empirical equation for the Multiplier, which relates rut depth to the number of 18-kip ESALs, is introduced into the procedure and the equation takes the following form.

$$\text{Multiplier} = 1 + 1.2 \times 10^5 \left(\frac{9{,}000\ A}{1 - 9{,}000\ B} \right)^{-0.65} \quad (4)$$

The Multiplier was based on observed field data of 135 pavement sections. The rutting model is shown in Figure 1. The rut depth is the sum of all increments of rut depth for each load application.

When a multiple-wheel assembly is applied to the road, the load should be that of an equivalent single-wheel load (ESWL). The procedure incorporated in the LOADRATE program calculates the ESWL as that load that will cause a deflection at the top of the subgrade of the same magnitude as the most critical sum of all the single-wheel loads. The Boussinesq equation was used to estimate that deflection.

Determining the Base Course Thickness

When using the LOADRATE program, the base course thicknesses were usually obtained from construction drawings or from the results of the Pavement Dynamic Cone Penetrometer (PDCP).

The PDCP that is used by Texas Transportation Institute is illustrated in Figure 2. This PDCP basically consists of a steel rod with a 60° cone of tempered steel at one end. A sliding hammer of about 17.6 lbs that falls over a height of 22.6 in. provides the consistent impact load required to penetrate the pavement. The penetration, which was recorded as inches per blow, gave an indication of the stiffnesses of the pavement

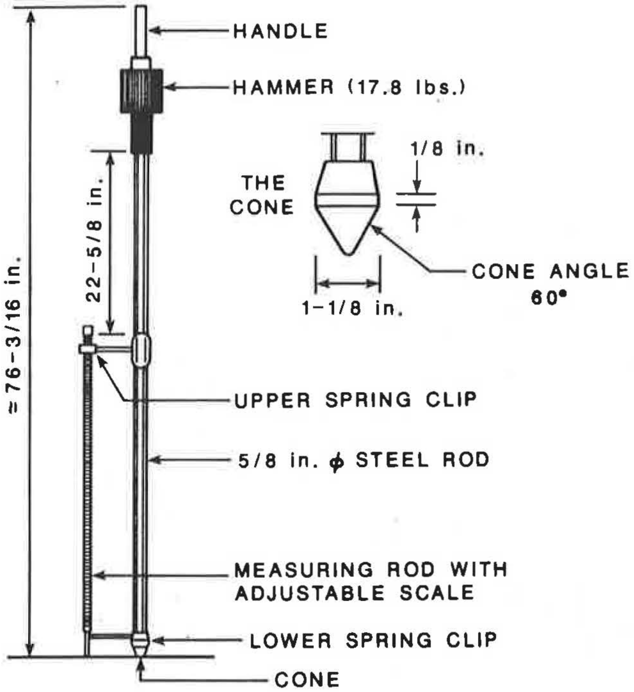

FIGURE 2 Pavement dynamic cone penetrometer.

layers. A plot of the penetration rate versus the depth of a PDCP on a farm-to-market road section is shown in Figure 3. Experience has shown that a penetration rate of about 0.3 in. per blow or less was usually obtained when driving through base courses. When the thickness of base course was obtained in this manner, it is referred to as the effective base course thickness. Faster rates of penetration indicated that either the cone was in base materials mixed with fines from the subgrade or the cone was already in the subgrade.

In cases in which the value of the base course thickness H was not available, it was found that the following equation gave a good approximation of the effective base course thickness.

$$H = \left[\frac{\text{Overall Stiffness}}{F} \times \left(\frac{W1\text{-}W7}{W_7} \right) \right]^n \tag{5}$$

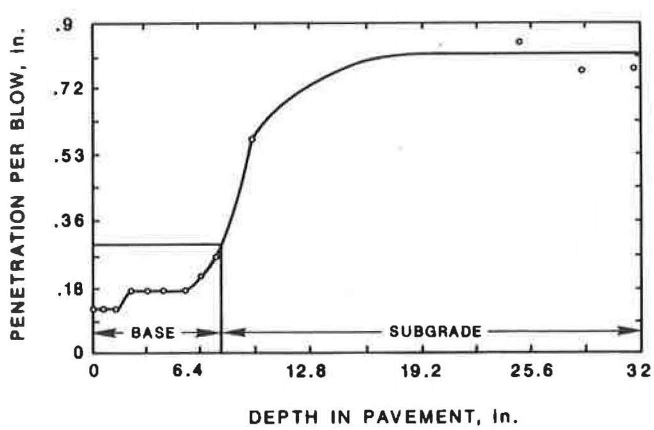

FIGURE 3 Typical pavement dynamic cone penetrometer results on thin pavements.

The overall stiffness is the test load divided by the measured deflection in mils (0.001 of an inch), measured at the load point and $W1$ and $W7$ refer to the FWD deflection measured by Sensor 1, which is just below the load, and Sensor 7, which is 94.5 in away, respectively. When the Dynaflect was used, an FWD equivalent sensor reading was approximated by a procedure described in *Dynatest 8000 FWD Test System* (*5*). A regression analysis that was performed using data from 24 thin pavements resulted in F = 1,958 and n = 1.85 (*2*).

APPROACH TO CASE STUDY

Willacy County is located in District 21, at the southern tip of Texas in an old flood plain of the Rio Grande River valley. A map of the county is shown in Figure 4. The heavy traffic on the county roads consists mainly of agricultural machinery and trucks hauling farm produce. During harvest time, the Texas SDHPT is usually faced with the dilemma of protecting its investment in highways without adversely affecting farm activities. Many of the thin pavements are load-zoned at a gross vehicle weight (GVW) of 58,400 lbs. Operators frequently submit overweight vehicle permit applications to use these pavements. Major operators are sometimes willing to share the costs of upgrading weak pavement sections to allow vehicles with a GVW of up to 80,000 lbs to be used. A need clearly exists for an efficient and technically sound procedure to define pavement upgrade requirements, because experience has shown that these dilemmas have frequently evolved into legal issues.

Data Collection

The FWD data that were collected in Willacy County were part of an effort to implement a maintenance management system in District 21 of Texas. Visual, ride, and skid data were also being collected to document current conditions and to estimate future needs. First, for the network-level evaluation, FWD data were collected on all the farm-to-market roads at .5 mi intervals. This sampling rate was considered sufficient to locate stretches of weak sections along a road and allowed the survey of the whole county to be completed within a reasonable span of time. One can generally cover about 10 mi of road an hour at this pace. The testing load was usually set at about 9,000 lbs, which is within the 8,000- to 12,000-lb range in which predictions from the LOADRATE program are most accurate. In the event that load zoning or upgrading is considered for a particular road, a second pass can be made at 200-ft intervals using the FWD. This would help identify which 200-ft sections needed work.

LOADRATE Results

The FWD data from each FM road were analyzed by the LOADRATE program; a typical printout, which in this case was for FM road 491 from milepost 0.0 to 4.0, is shown in Figure 5. A graphic presentation of some of the results of this analysis is shown in Figure 6. The output was divided into three parts, as follows.

In the first section of Figure 5 it is shown that the analysis called for the prediction of the number of passes it takes a 9,000-lb, single-wheel load to cause a 0.75-in-deep rut in the pavement. A rut depth of 0.75 in in a pavement section would

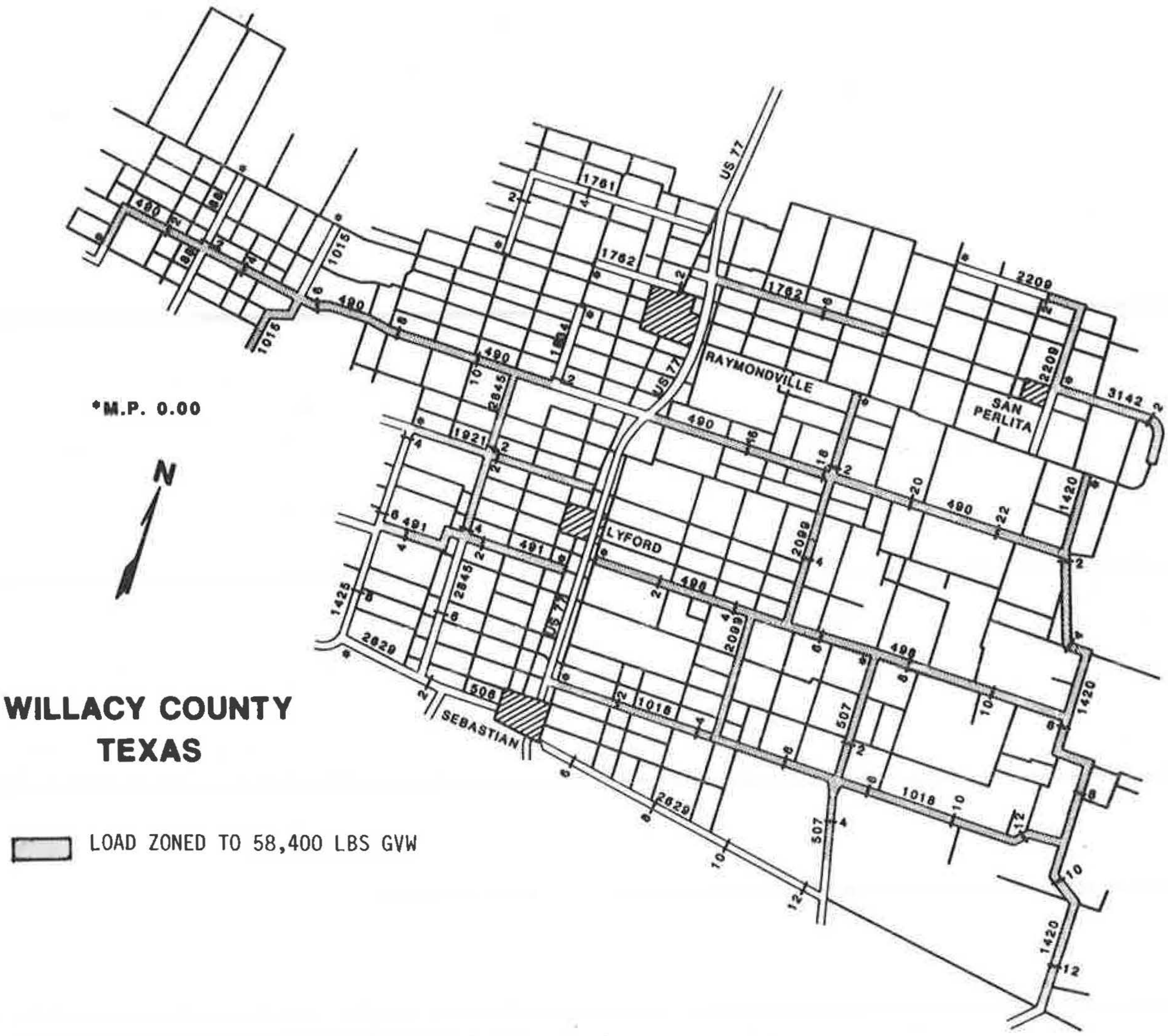

FIGURE 4 Willacy County map showing currently load-zoned roads.

allow water to pool, which could cause hydro-planing; this is specified as a failure criterion. It is shown in Figure 5 that there is no observed rut depth. A 9,000-lb load, which is the same as an 18-kip single-axle load, is specified. One could also specify a number of trucks with different axle and wheel configurations. If the existing rut depth and the number of passes of a particular load (e.g., number of 18-kip ESALs) are known, the program will then determine the multiplier from these values. If the existing rut depth is measured and the number of 18-kip ESALs that caused it is unknown, the number of additional 18-kip ESALs it would take to cause a 0.75-in-deep rut can be calculated by inserting an allowable rut depth equal to 0.75 in minus the existing rut depth.

The FWD deflection basin for the various pavement sections is shown in the second section of Figure 5. The base course thicknesses were estimated using Equation 5 and are graphically depicted in Figure 6(a). It can be seen that the estimated effective base course thickness was between 4 and 6 in. Construction drawings showed a 6-in base course thickness. Three FWD readings at different load levels were usually taken at the start of each FM road section, which in this case was at milepost 0.0.

In the third section of Figure 5 is a list of the modulus number K_1 and a description of the subgrade type for the various sections. The stiffness of the pavement reported is the inverse of the initial tangent modulus, A, and BCOEF refers to the factor B, which is the inverse of the load asymptote. These two values were used in Equation 3 to describe the load-deflection behavior of the pavement section. AMULT refers to the Multiplier given in Equation 4. The number of passes it would take the 9,000-lb, single-wheel load to cause the specified 0.75-in-deep rut is also shown in the third section of Figure 1. The variation of the number of passes to failure along the road is shown in Figure 6(b). WICHECK gives the LOADRATE prediction of the deflection at the center of the FWD loading plate. This can be compared with the measured values of W1 in the second section of Figure 5 and gives an indication of the degree of accuracy to be expected.

The overall status of any farm-to-market road can be evaluated by using a plot of the percentage of the FM road that provides more than a given number of passes of an 18-kip ESAL to reach the critical rut depth, as shown in Figure 6(c). This graph is a particularly useful method of identifying the weak sections and of establishing load zoning requirements.

JOB : FM0491 245 R 099.0 1010H

DISTRICT: 21 COUNTY:WILLACY ROAD:FM491
ALLOWABLE RUT(INS): .75

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

RECORDED RUT(INS): 0 LOAD(LBS): 0 PASSES 0

SECT. 1

DATE:041686 FALLING WEIGHT DEFLECTOMETER (W7@72.0 INS)

SECTION NO.	BASE THICKNESS (INS)	DEFLECTION (MILS) W1	W2	W3	W4	W5	W6	W7	LOAD (LBS)
0	3.7	73.3	37.5	17.0	9.5	6.6	4.8	3.8	8976
.5	5.5	17.1	10.1	7.7	5.8	4.9	3.6	2.8	9048
1	5.4	21.9	14.0	9.3	6.7	4.9	3.7	2.9	9136
1.5	6.5	70.0	28.1	11.5	7.4	5.1	3.7	2.9	9584
2	4.2	79.5	38.4	16.4	9.2	6.4	4.5	3.6	9192
2.5	5.2	72.9	35.0	14.8	8.2	5.7	4.1	3.2	9256
3	3.1	93.4	40.5	15.5	9.2	6.5	4.8	4.5	9544
3.5	4	87.8	39.1	15.7	8.8	6.5	4.6	3.7	9200
4	3.3	95.8	46.8	18.8	10.6	7.7	5.1	4.1	9048

SECT. 2

SECTION NO.	LAYER PROPERTIES ELASTIC MODULUS BASE/SUBB	SUBGRADE	LOAD DEFORMATION CHARACTERISTICS STIFF(LB/IN)	BCOEF	NO. OF ALLOWABLE PASSES	AMULT	W1CHECK
0	112778.8	1584.777	51235.16	-1.587093E-04	14386.72	1.000721	72.2
.5	202093.2	2261.454	585567.3	1.642562E-05	4103860	1.00001	18.1
1	201585.4	2189.654	438467.8	1.664504E-05	2832546	1.000011	24.5
1.5	55365.19	2228.778	70232.8	-1.076816E-04	29719.39	1.000388	67.1
2	68449.21	1696.162	42257.06	-1.987896E-04	9899.041	1.000993	76.9
2.5	79982	1945.273	57164.65	-1.391417E-04	18208.21	1.00059	70.7
3	110362.1	1389.92	24599.82	-3.629644E-04	4434.828	1.001976	86.9
3.5	59380.39	1644.752	28015.31	-3.150637E-04	5219.856	1.001718	84.2
4	71919.07	1461.823	14433.43	-6.397091E-04	2664.842	1.003059	92.3

SECT. 3

LOAD DEFLECTION MODEL
LOAD = DEFLECTION / (BCOEF*DEFLECTION + 1/STIFFNESS)

AVERAGE NUMBER OF PASSES TO CAUSE SPECIFIED RUT : 780104.3

FIGURE 5 Computer printout from LOADRATE.

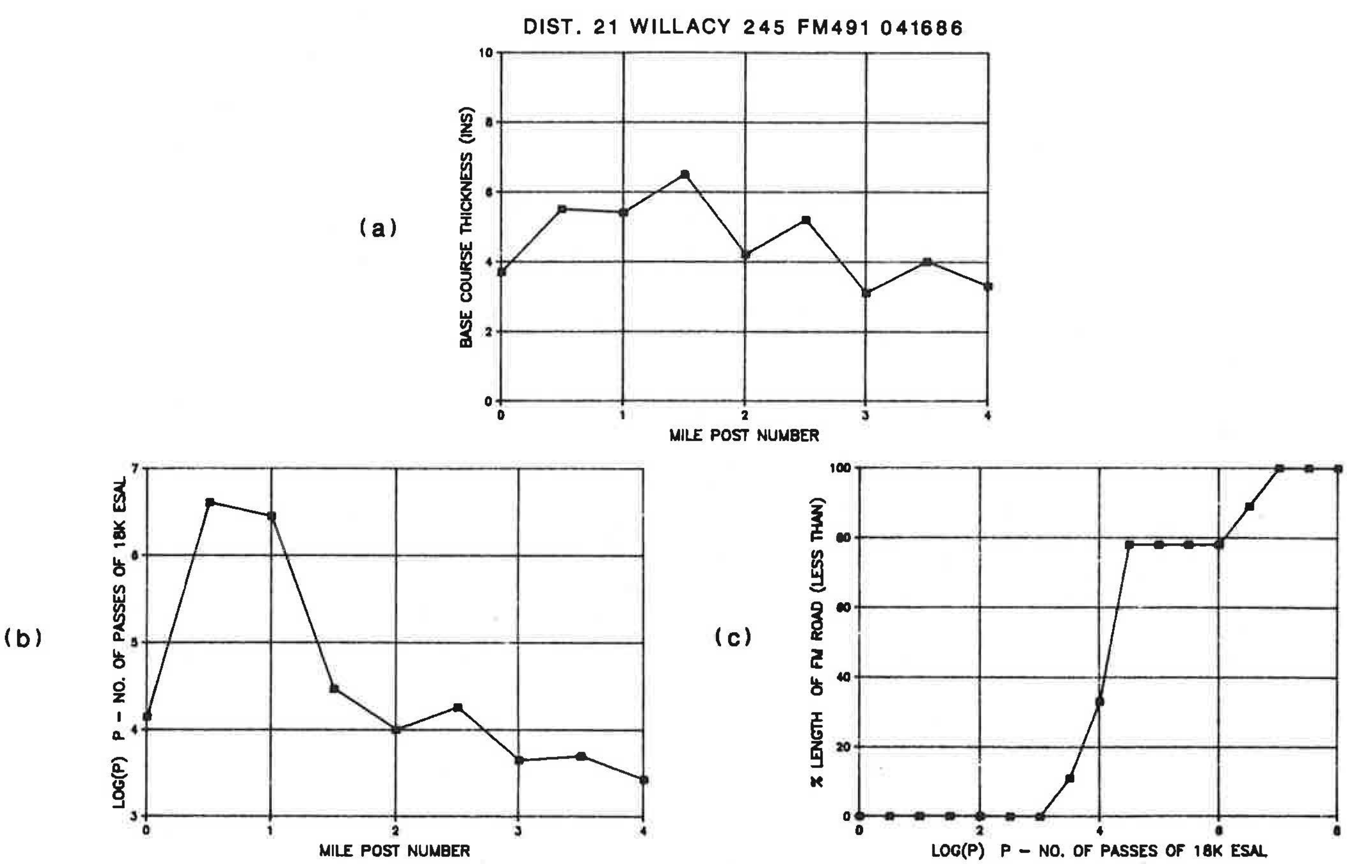

FIGURE 6 Graphic presentation of LOADRATE results.

For example, it can immediately be seen from Figure 6(c) that, for about 11 percent of the 4.0 mi of road, it will take no more than 3,000 passes to exceed the 0.75-in rut depth. Some action may be required in the near future to rehabilitate those sections that can readily be located in Figure 6(b). A visit to the site may reveal that the problem is a result of poor drainage, for instance. If remedial actions are taken soon enough, the cost of rehabilitation could be minimized.

A DISCUSSION OF THE RESULTS OF THE CASE STUDY

Load Zoning Considerations

The Texas SDHPT currently approaches the problem of load zoning by determining the gross allowable loads on the light pavement structure through tests of undisturbed samples of the subgrade. Texas Triaxial Tests are performed on the cored samples, which are soaked for as few as 10 days and as many as 60 days. This method requires a considerable amount of labor in the laboratory and the coring process also disrupts traffic. In view of this fact, only very few samples can be taken along any one road, which results in having to load-zone a whole FM road on the basis of the few samples that were tested. It is shown in Figure 4 that the FM roads are presently load-zoned to a load limit of a gross vehicle weight of 58,400 lbs.

To compare the results of LOADRATE with the current load zoning practice, the number of passes of an 18-kip ESAL that are predicted to cause a 0.75-in-deep rut (obtained from LOADRATE) are plotted on the map of the entire county, as shown in Figure 7. The shaded sections of the figure represent the pavement sections that may fail with less than 10,000 ESALs; the dark sections are the most critical sections, in which less than 1,000 ESALs may cause failure. It should be noted that although these values appear to be conservative, they are good indications of the relative structural integrity among the roads in the county.

A comparison of the LOADRATE procedure and current practice for load zoning shows a strong correlation, as can be seen in Figures 4 and 7. For example, strong pavements such as FM 88 and FM 1834 are not load-zoned. In regard to sections that are load-zoned, FM 490 was also found to have weak sections by using the LOADRATE procedure. However, this should not imply that the whole FM should be load-zoned; the LOADRATE procedure can be used to show which specific sections are weak. In this case the critical pavement sections are identified to be around mileposts 10, 15, and 18 of FM 490.

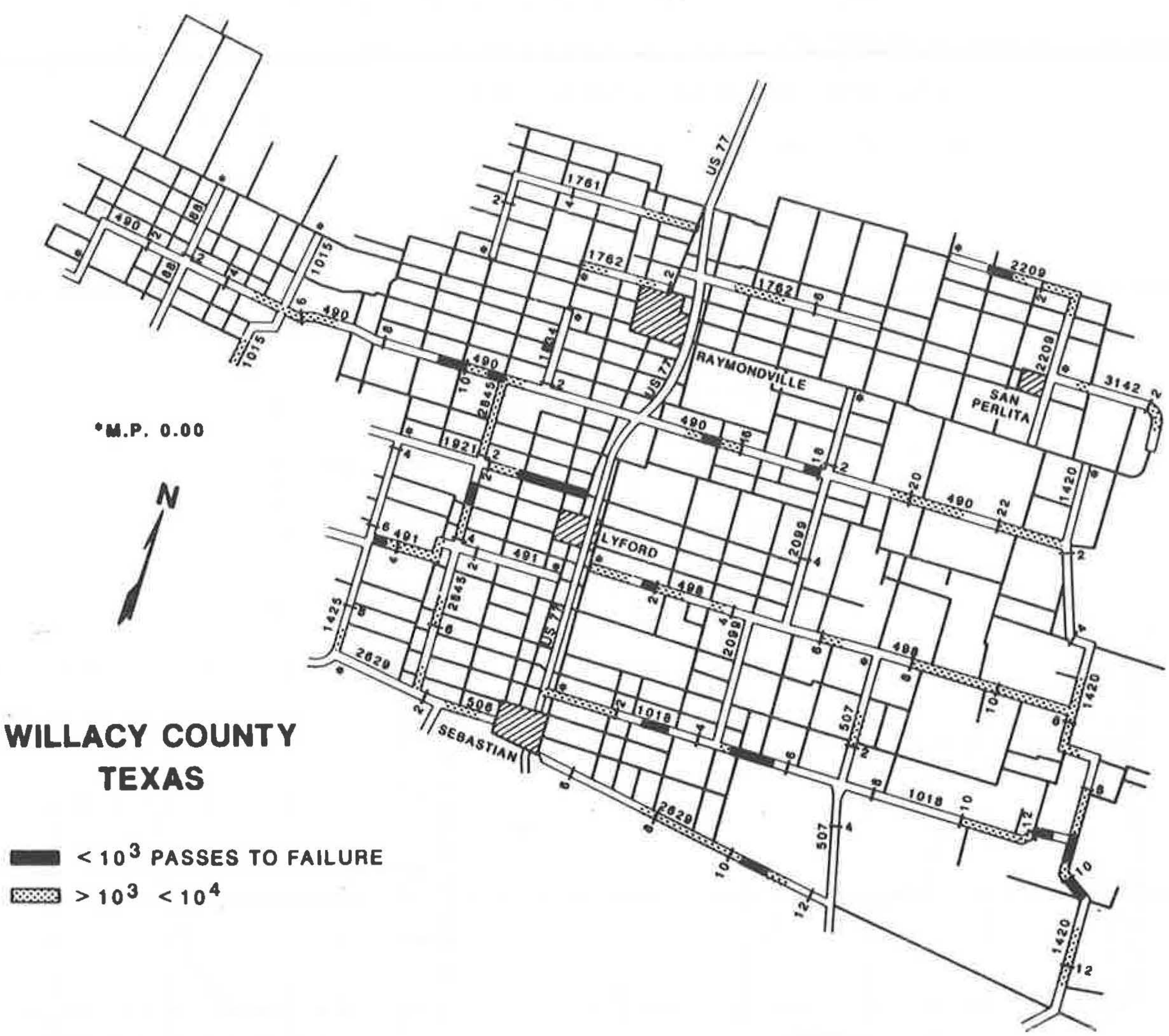

FIGURE 7 Willacy County map showing results of LOADRATE analysis.

However, some discrepancies did occur when the whole county was analyzed. For example, the current load zoning procedure was not able to identify weak sections in FM 2629 and FM 2209. It is interesting to note that most of the weak sections in the county are located near intersections, as shown in Figure 7.

Pavement Monitoring

A routine FWD survey can be performed for any county at least once a year. It is estimated that an FWD survey of this county will take only about 2 weeks with deflection readings taken every 2,500 ft. Another week could be required if a second pass is made at closer intervals of about 200 ft to gather more information on the weak sections. The analysis of the results may take another week, which means that an FWD survey for a county of this size would take about 1 month. With the information available from this survey, the process of planning, budgeting, and scheduling could be performed more effectively. It can be seen that the procedure presented here is a feasible solution to the management of low-volume roads.

The seasonal temperature and rainfall variations are important things to consider when conducting an FWD survey. The effects of seasonal temperature are not critical to a study of Willacy County, as can be seen in Figure 8(a). However, if a conservative estimate of the structural integrity of the FM roads in Willacy County is to be made, then the FWD deflection survey should be conducted around September, which is the wettest month of the year, as can be seen in Figure 8(b). It may be necessary to conduct more FWD surveys in regions in which freeze-thaw cycles occur. For example, surveys should be conducted in the coldest, warmest, and wettest months in order to develop different load zoning maps of the type shown in Figure 7. This would ensure that the structural integrity of the FM roads is more accurately evaluated.

Overweight Vehicle Permit Evaluation

The following four steps should be considered when using the results of LOADRATE to evaluate overweight vehicle permit applications:

1. Trace the route proposed by the applicant on the county map shown in Figure 7 and determine if there are any weak sections along the route. If there are weak sections, perhaps an alternate route can be found.
2. If weak sections are not avoidable, determine the length involved.
3. The expected life of the pavement in years can be calculated from the number of passes it would take an 18-kip ESAL to cause failure as predicted by LOADRATE divided by the estimated annual 18-kip ESAL traffic volume estimated. The life expectancy will then be reduced by the application of the overweight vehicle to be permitted, according to the following formula:

$$T \text{ (years)} = n_o N_o N_{18} / [r_{18} (N_{18}^2 + n_o N_o)] \qquad (6)$$

where

N_o = the number of passes of the overweight vehicle that will cause a critical level of rut depth,

N_{18} = the number of passes of an 18-kip ESAL to cause the same critical rut depth,

n_o = the number of passes of the overweight vehicle being permitted, and

r_{18} = the estimated annual 18-kip ESAL traffic.

This reduction in life expectancy can be converted into additional costs that must be absorbed by the state if the overweight vehicle permit application is approved. The cost required to upgrade those sections can alternatively be estimated.

4. Beyond this point, the evaluation becomes an administrative matter based on economics. For example, the solution may be to impose a fee to cover the costs that will be incurred from the reduced life of the pavement.

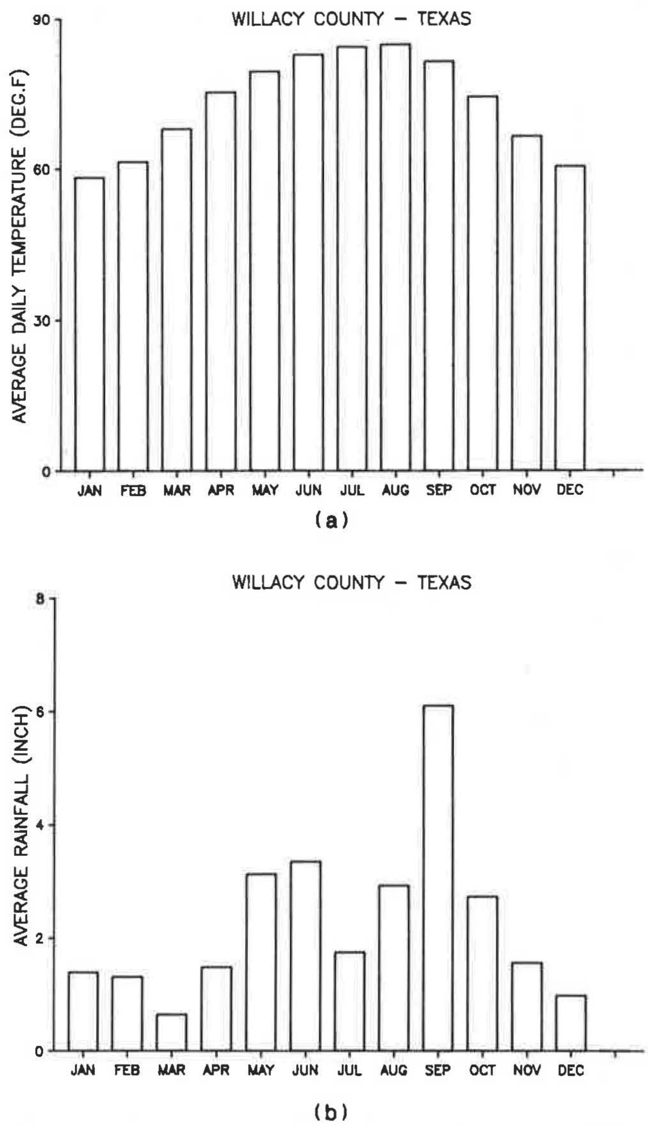

FIGURE 8 Temperature and precipitation of Willacy County, Texas.

SUMMARY AND CONCLUSIONS

The LOADRATE procedure of evaluating the structural integrity of light pavement structures was briefly described. The results of an FWD survey and analysis using the LOADRATE program for an entire county in Texas was presented to illustrate the use of the load rating procedure.

It was determined for Willacy County that an FWD survey of the FM roads at half-mile intervals would be sufficient to locate weak pavement sections. About 10 mi of road per hour could be tested at this rate. A complete survey and LOADRATE analysis of all the FM roads in a county that had about 200 mi of roads could take about 1 month, which means that the procedure described here is feasible, especially for managers of large highway networks. It is also shown that the information obtained from the LOADRATE procedure can help locate weak pavement sections and help manage pavement systems more efficiently. This information can also enable pavement engineers to evaluate overweight vehicle permit applications more efficiently, to decide which FM roads to load-zone, and to determine the level of effort required to lift load restrictions.

REFERENCES

1. K. M. Chua and R. L. Lytton. Load Rating of Light Pavement Structures. In *Transportation Research Record 1043*, TRB, National Research Council, Washington, D.C., 1984.
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. *ILLI-PAVE User's Manual.* Transportation Facilities Group, Department of Civil Engineering, University of Illinois, Urbana-Champaign, May 1982.
4. K. M. Chua and R. L. Lytton. *Load Rating of Light Pavement Structures.* Research Report 284-6F. Texas Transportation Institute, December 1983.
5. *Dynatest 8000 FWD Test System.* Dynatest Consulting, Inc., Ojai, California.
6. E. G. Kleyn, J. H. Maree, and P. F. Savage. The Application of a Portable Pavement Dynamic Cone Penetrometer To Determine In Situ Bearing Properties of Road Pavement Layers and Subgrade in South Africa. Proc., 2nd European Symposium on Penetration Testing, Amsterdam, May 1982, pp. 277-283.
7. J. L. Figueroa and M. R. Thompson. Simplified Structural Analysis of Flexible Pavements for Secondary Roads based on ILLI-PAVE. In *Transportation Research Record 766*, TRB, National Research Council, Washington, D.C., 1980.
8. N. Janbu. *Soil Compressibility as Determined by Oedometer and the Triaxial Tests.* European Conference on Soil Mechanics and Foundation Engineering, Wiesbaden, Germany, Vol. 1, 1963, pp. 19-25.
9. R. L. Kondner. Hyperbolic Stress-Strain Response: Cohesive Soils. ASCE, *Journal of the Soil Mechanics and Foundations Division*, Vol. 89, No. SM1, Feb. 1963.

The Use of Central Tire Inflation Systems on Low-Volume Roads

EDWARD STUART III, ED GILILLAND, AND LEONARD DELLA-MORETTA

A description is provided of a comprehensive program that was conducted by the U.S. Department of Agriculture, Forest Service, to evaluate the effectiveness of central tire inflation (CTI) systems in the transportation of forest products over unpaved low-volume roads. CTI is a mechanical component system for vehicles that allows the operator to adjust the inflation pressure of tires while the vehicle is in motion. The use of this system would allow tire pressure to be varied so that low-strength, low-speed roads could be negotiated with low tire pressures and higher-strength, higher-speed roads could be negotiated at higher tire pressures. A proof-of-concept test and a feasibility study indicated that the use of such systems on low-volume roads is technically and economically feasible. Such systems would provide considerable benefits to both the road agency and the road user in the form of lower costs for construction and maintenance, and lower operating costs and a reduction in driver fatigue, respectively. In 1986 the Forest Service initiated two controlled, quantitative tests on specifically designed and constructed test tracks to measure the effects of tire pressure on the road and the vehicle. A series of qualitative tests were simultaneously conducted on ongoing projects of logging operations and gravel hauling to ascertain and demonstrate the feasibility of using low tire pressures on low-volume roads.

E. Stuart, III, Pleasant Hill Engineering Center, USDA Forest Service, 2245 Morello Ave., Pleasant Hill, Calif. 94523. E. Gililland and L. Della-Moretta, Equipment Development Center, USDA Forest Service, 444 E. Bonita, San Dimas, Calif. 91773.

The USDA Forest Service has been investigating the relationship between tire pressure, road deterioration, and timber haul costs. The tires of commercial logging trucks are typically inflated to pressures above 100 psi. Central tire inflation (CTI) systems, which are now available on some types of trucks, allow