Pavement Evaluation and Rehabilitation of Low-Volume Urban Roads

LOUIS BERGER AND JACOB GREENSTEIN

A structural evaluation was made of 90 miles of city streets in Plainfield, New Jersey, to determine their life expectancy and rehabilitation requirements. Evaluation was made by a nondestructive test procedure based on measuring the dynamic deflections of the pavement surface and the curvature of the deflection basin. These tests were carried out at 200-ft intervals along the outer wheelpaths in each traffic lane for purposes of structural evaluation. The different pavement subgrade systems were replaced by mathematical models, and the measured surface deflections were used as the input to calculate parameters of each layer in the model. The results of the nondestructive tests were then calibrated with results from in situ destructive tests to validate the relation between modulus of elasticity and California bearing ratio (CBR). The minimum overlay required for the desired future life expectancy was calculated on the basis of both CBR methodology and criteria of allowable subgrade strain. It was found that the subgrade strain methodology was the most simple, economical, and practical to apply and gave more consistent results for the local conditions encountered. The methodology and applications developed from this study are presented in detail.

A pavement evaluation study was conducted in Plainfield, New Jersey, from July to November 1981. The city streets carried from 1000 to 10 000 vehicles/day and, based on the percentage of heavy vehicles, 2500-25 000 equivalent axle loads (EALs). The average vehicle speeds were 30-50 km/h, somewhat slower than the normal speed allowable on major through streets or on rural roads. Consequently, for purposes of design and rehabilitation, higher values of rut depth (up to 50 mm) were permissible than would be desirable for roads subject to higher traffic speeds.

Although a considerable amount of study has been devoted to the maintenance and rehabilitation of rural roads in both developing and developed countries, comparable research has not been carried out to develop a systematic evaluation and rehabilitation methodology for low-volume city streets. As is to be expected with older communities, the pavement structure is heterogeneous and reflects the accumulated experience and variations of road construction over the past century. Some city streets in Plainfield were originally constructed more than 80 years ago. Consequently, our pavement inventory included flexible, rigid, and stabilized unsurfaced roads and all variations in between.

The purpose of this study was, first, to evaluate the condition of all city streets in Plainfield and, second, to determine the minimum reinforcement required to achieve a pavement life expectancy of 5-10 years. Pavement evaluation of typical unsurfaced and surfaced roads is shown in Figure 1, and a typical pavement cross section is shown in Figure 2. Pavement thicknesses varied between 10 and 20 cm.

DESIGN CRITERIA

Most design methods that incorporate the results from the American Association of State Highway Officials (AASHO) Road Test of 1962 (1) use rutting as a failure criterion of flexible pavement. Rutting is considered to occur only on the subgrade and is controlled by limiting the value of the vertical compressive strain of the top subgrade. This implies that the pavement layers above the subgrade will be structurally adequate so that only negligible plastic deformation will occur with each layer. The Dormon's Shell Method (2), for example, is asso-

Figure 1. Pavement evaluation of urban roads in Plainfield: (top) unpaved road and (bottom) paved road.

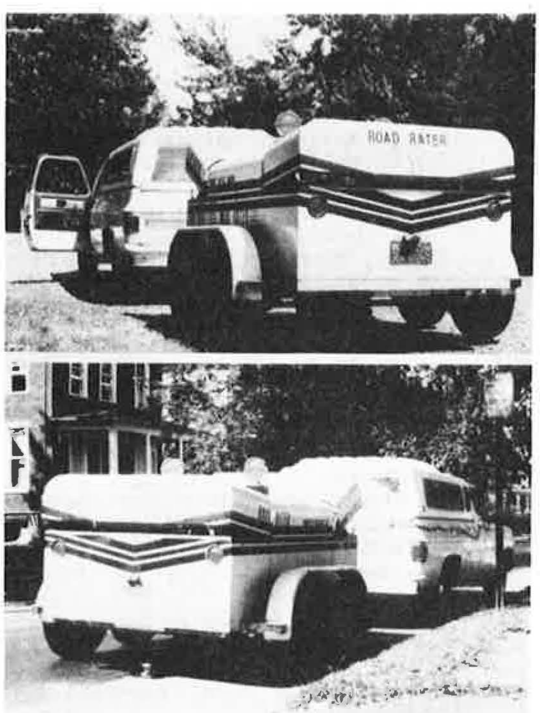
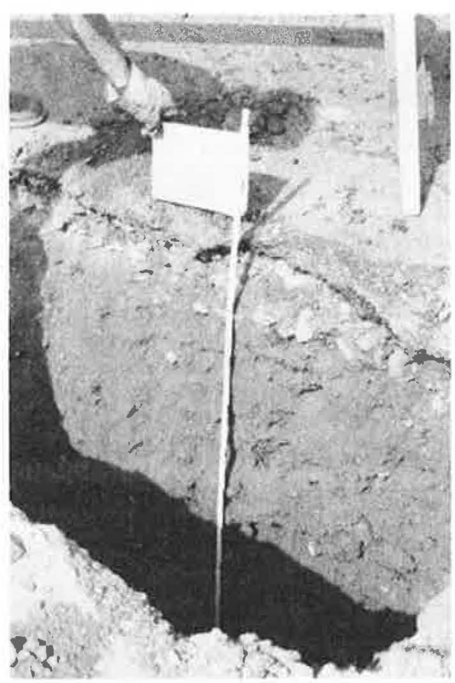


Figure 2. Typical pavement cross section.



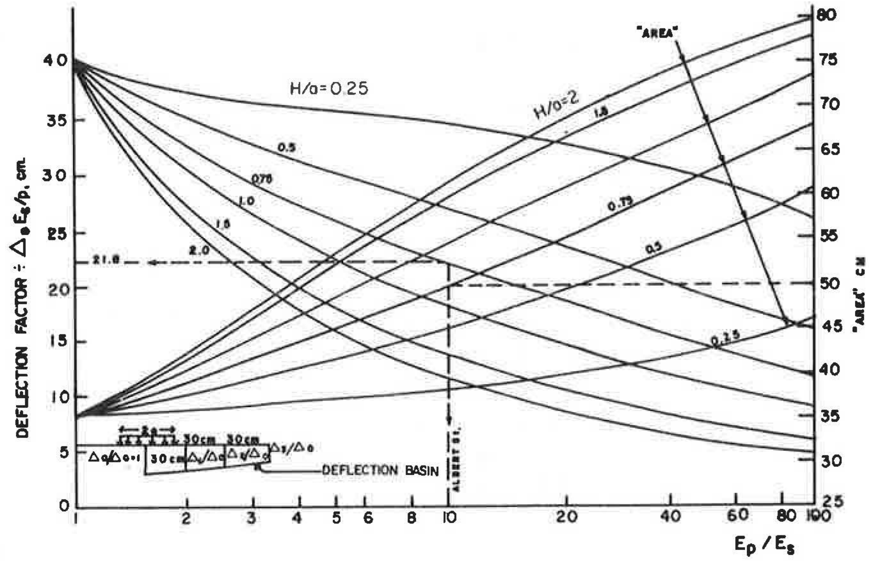


Figure 3. Variation of area and maximum deflection factor in a two-layer linear elastic model.

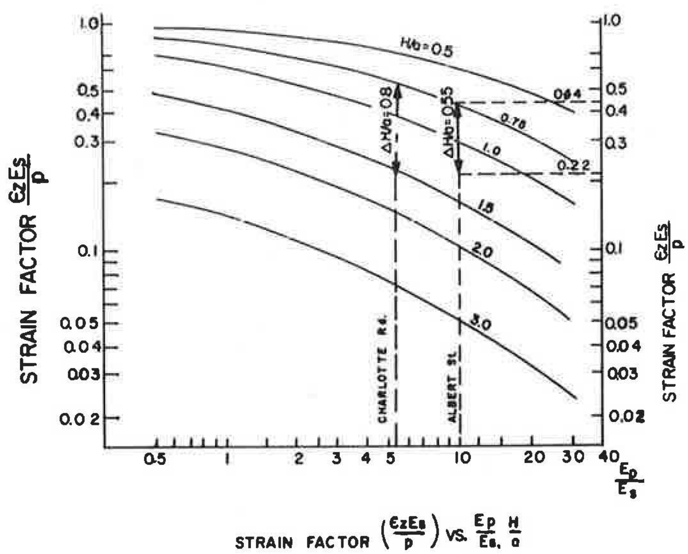


Figure 4. Strain factor ($\epsilon_z \cdot E_s$)/p versus E_p/E_s and H/a.

ciated with ultimate rut depths of about 19 mm. The subgrade strain criterion was verified by the U.S. Army Engineer Waterways Experiment Station (WES) after analysis of the pavement performance of test sections. These studies are reported elsewhere (3,4). It is worthwhile to mention that for a given subgrade the ratio between the California bearing ratio (CBR) required and the vertical strain induced is constant (5,6). Subgrade strain criterion is also used for pavement design of low-volume roads (7). In this case, the associated rut depths for paved and unpaved roads are 50 and 100 mm, respectively (6,8). According to local experience, an ultimate rut depth of about 38-50 mm is used as a failure criterion for rehabilitation and maintenance planning.

METHODOLOGY OF PAVEMENT EVALUATION

To a certain extent, the structural evaluation of a pavement system is an inverted design process. If the pavement cross section and the properties of the paving materials and subgrade soil are known, it is possible to compute pavement responses (stresses, strains, and deflections) under a given load at any point within the structure. In the evaluation process, the response of the pavement is observed and material properties are back calculated. Of the different responses of the pavement to load, the only practical measurements are deflections. For structural evaluation, the real pavement-subgrade system is replaced by a mathematical model and the measured surface deflections are used as input to back calculate the model parameters. Two mathematical models are used to evaluate the elastic modulus of the subgrade and the pavement. The first mechanical model is based on a two-layered linear elastic model (9) and includes the following parameters (see Figures 3 and 4):

1. Deflection factor is defined as $\Delta_0 E_s/p$, where Δ_0 is the surface center deflection developed under a circular load area that has contact pressure p. E_s denotes the subgrade elastic modulus.
2. Pavement thickness is defined as H/a, where H is the pavement thickness and a is the radius of the circular loading area.
3. Modulus is defined as E_p/E_s (pavement and subgrade modulus, respectively).

4. Area of the elastic deflection basin is defined in Figure 3 as

$$\text{Area} = (30\ \text{cm}/2)/[(\Delta_0/\Delta_0) + 2(\Delta_1/\Delta_0) + 2(\Delta_2/\Delta_0) + (\Delta_3/\Delta_0)] \quad (1)$$

where area is in centimeters and Δ_0, Δ_1, Δ_2, and Δ_3 are center and offset deflections at 30, 60, and 90 cm, respectively. The following example demonstrates how to use the monograms of Figure 3 to determine the subgrade and the pavement modulus: Area = 50 cm, Δ_0 = 102.6 µm, and H/a is equal to 0.75 [H = 17 cm (15 cm of macadam plus 2 cm of asphalt concrete) and a = 23 cm]. According to Figure 3, E_p/E_s = 10, and $\Delta_0 E_s/p$ = 21.8. The subgrade modulus is therefore 115 MPa.

5. Strain factor, $\epsilon_z E_s/p$ (Figure 4), can be determined for any given value of E_p/E_s and H/a. For example, in the case of Albert Street, for E_p/E_s = 0.75 the strain factor equals 0.44.

The second mathematical model is the Hogg model, which includes a thin plate (representing the pavement) supported on an elastic foundation (the subgrade). With the Hogg model (10,11), the pavement and the subgrade can be expressed in terms of the following basic parameters:

1. Flexibility (F): The pavement flexibility is the center deflection per unit force and is reported in microns per kilonewton:

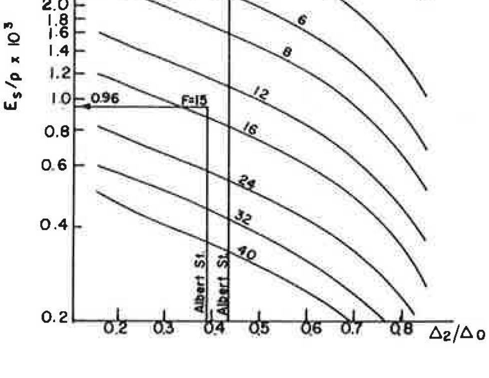
$$F = \Delta_0/P \quad (2)$$

where Δ_0 is the center deflection (µm) and P is the total load (kN), equal to peak-to-peak force.

2. Characteristic length: Presents the shape of the deflection basin, which can be computed from the deflection ratio Δ_2/Δ_0. Δ_0 and Δ_2 are the center and the 60-cm offset deflection.

3. Subgrade modulus (E_s): The relation between F, E_s/p, and the deflection ratio Δ_2/Δ_0 is shown in Figure 5. For example, for two sections of Albert Street, Δ_2/Δ_0 = 0.38 and 0.43 and F = 15 and 6. E_s/p = 0.96 and 2.2, respectively. The term p denotes the contact pressure between the circle load and the plate.

Figure 5. Relation between F, E_s/p, and Δ_2/Δ_0 (Hogg model).



ANALYSIS OF DESTRUCTIVE TEST RESULTS

The nondestructive test (NDT) results should always be calibrated with destructive tests such as classification, density, moisture, and CBR. In Plainfield, the cost of the destructive test program was 10 percent of the total study cost, which was approximately \$250/km. The conclusions of the destructive test results are shown in Figure 6, which presents the relation between the subgrade modulus E_s determined by means of nondestructive testing and the CBR determined in situ. It is worthwhile to note that both E_s and CBR were determined between July and November 1981. It would be logical to assume that lower values of E_s and CBR would be obtained during the springtime and that the ratio E_s/CBR would remain constant. Figure 6 also shows that the relation between E_s and CBR obtained in Plainfield is between the lower and upper limits presented by WES. This E_s versus CBR relation indicates that, for a given subgrade CBR, the E_s determined by the linear elastic model is higher than the E_s determined by the Hogg model. The reason for this difference is that the implementation of the Hogg model (10,11) is based on the existence of a rigid bottom at a depth of H/a = 10. H denotes the pavement thickness and is the characteristic length. The E_s versus CBR relation for the Hogg model (10) is given by

$$E_s = 20\ \text{CBR} \quad (3)$$

where E_s and CBR are in megapascals and percentage, respectively.

IMPLEMENTATION OF METHODOLOGY AND REHABILITATION PROGRAM

NDT was carried out at approximately 61-m intervals and on the outer wheelpaths along the 145 km of the city streets of Plainfield. The equipment (a road rater) was set to vibrate at a frequency of 25 Hz with a dynamic force of 8.8 kN peak to peak. The dynamic loads were applied through a 45-cm-diameter plate, and the deflection was measured at the offset of 0, 30, 60, and 90 cm. The interpretation of the surface deflection was carried out as indicated in Figures 3-5, and pavement characteristics such as subgrade and pavement modulus, subgrade CBR, flexibility, and vertical strain on top of the subgrade were calculated. These data were used to design the minimum overlay thickness required to carry the traffic loading of 1000-2500 and 2500-25 000 equivalent axle loads (EALs) (80 kN) for design periods of

Figure 6. In situ CBR versus subgrade modulus of elasticity.

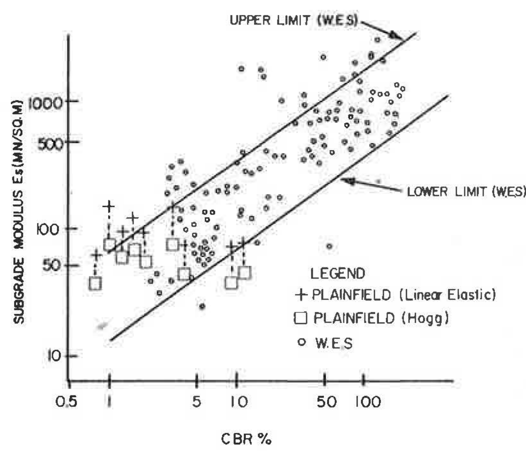


Table 1. Evaluation of Plainfield city streets.

Example	Street	Stations	EALs (000s) Five Years	Ten Years	H/a	Deflection (μm) Δ_0	Δ_1	Δ_2	Δ_3	Area (cm)	E_p/E_s	$\Delta_0 E_s/p$ (cm)	$\epsilon_z E_s/p$	E_s/p	$E_2 x10^{-4}$	E_s (MPa) Linear Elastic	Hogg	F (μm/kN)
A	Albert Street																	
	Failed section	2-10	6.0	13.0	0.75	102.6	71.4	38.9	16.3	50	10	21.8	0.44	2124	2.07	115	52	15
	Reference section	0-2	6.0	13.0	0.56	55.9	40.4	23.9	16.5	54	35	19.0	0.35	3399	1.03	184	119	6
B	Abbond Street																	
	Failed section	0-3	1.1	2.5	0.67	198.6	154.4	55.6	32.3	49	12	22.5	0.45	1133	3.97	61	42	22
	Brewster Court																	
	Reference section	0-2	1.1	2.5	0.75	94.2	65.3	52.3	16.8	55	20	18.2	0.32	1932	1.66	104	55	11
C	Charlotte Road																	
	Failed section	0-5	9.0	20.0	0.81	172.5	108.5	54.6	34.8	46	5.3	24.7	0.52	1432	3.63	78	45	19
	Reference section	5-19	9.0	20.0	0.81	74.5	44.2	26.8	16.3	47	5.4	24.8	0.51	3329	1.53	180	98	8

5-10 years, respectively. Both the CBR and the subgrade strain criteria were analyzed. Knowing the subgrade CBR, the traffic loading, and the pavement thickness enables one to determine, by means of the existing design charts (12), the additional pavement thickness. The second approach is based on the subgrade strain criterion. According to this approach, the minimum overlay thickness required to reduce the subgrade strain to a reference value is determined. This reference strain value is calculated from the deflection basin determined by the same NDT equipment and belongs to local road sections with similar traffic loading. These sections developed rut failures of less than 50 mm for design periods of 5-10 years. The NDT survey for both of the analyzed reference roads was carried out simultaneously in order to minimize the influence of environmental conditions, mainly temperature and humidity, on the elastic moduli and through it on the subgrade strain. The following three examples demonstrate the implementation of this methodology (see also Table 1).

Albert Street (Section 2-10)

The following design information applies to the 244 m of road section for Section 2-10 of Albert Street:

1. Projected traffic loadings are 6000 and 13 000 EALs for 5 and 10 years of future life, respectively.
2. The existing pavement is 15 cm of macadam and 2 cm of asphalt concrete, or H/a = 17/23 = 0.75.
3. The deflections at the offsets of 0, 30, 60, and 90 cm are Δ_0 = 102.6, Δ_1 = 71.4, Δ_3= 38.9, and Δ_4 = 16.3 μm, respectively.
4. The area of the deflection basin determined by means of Equation 1 is 50 cm.
5. According to Figure 3, for the given area = 50 cm and H/a = 0.75, the modulus ratio E_p/E_s = 10 and the deflection factor $\Delta_0 E_p$ = 21.8 cm, or $E_s/p = 21.8/102.6 x 10^{-4} = 2125$.
6. The subgrade modulus determined by the linear elastic model $E_s = (E_s/p)p = 2125 \times 54.2 x 10^{-4}$ = 115 MPa, and the E_s determined by the Hogg model (Figure 5) is 52 MPa. The subgrade CBR calculated according to Equation 3 is 2.6 percent.
7. According to Figure 4, for a given E_p/E_s = 10 and H/a = 0.75, the strain factor $\epsilon_z F_s/p$ = 0.44 and the strain ϵ_z = $0.44/(E_s/p = 2124) = 2.07 x 10^{-4}$. On the referenced road section, which in this case is a 61-m long section of Albert Street between stations 0 and 2 (Table 1), the traffic loading is the same--i.e., 6000 and 13 000 EALs for design periods of 5 and 10 years, respectively. On this reference section, the subgrade strain determined by the NDT testing device is $1.03 x 10^{-4}$. According to the methodology presented in this paper, the minimum pavement strengthening of Albert Street, between sections 2 and 10, is the additional thickness required to reduce the subgrade strain from $2.07 x 10^{-4}$ to $1.03 x 10^{-4}$. This analysis is done as indicated in Figure 4. For this change of ϵ_z, and in this example where E_p/E_s = 10 and E_s/p = 2124, the subgrade factor $\epsilon_z E_s/p$ decreases from 0.44 to 0.22 and H/a varies between 0.75 and 1.30. In other words, the additional overlay thickness equals (1.30 - 0.75) (23 cm) = 12.7 cm. These 12.7 cm of macadam pavement (E_p/E_s = 10) are equivalent, according to the experience of the Plainfield Engineering Department, to 5 cm of high-quality asphalt concrete.

It should be mentioned that the application of the CBR methodology (12) results in a total overlay of about 10 in of macadam pavement.

Abbond Street (Section 0-3)

Section 0-3 of Abbond Street is a 91-m-long gravel road. The pavement thickness is 15 cm or H/a = 0.67. The projected traffic loading for this street varies between 1100 and 2500 EALs for design periods of 5 and 10 years, respectively. The subgrade strains determined on Abbond Street and on the reference street, Brewster Court, are $3.97 x 10^{-4}$ and $1.66 x 10^{-4}$, respectively. To achieve the latest strain value on Abbond Street, 15 cm of gravel pavement is required. According to the CBR criterion (12), 30.5 cm of gravel is required. The conclusion in this case was to reconstruct this gravel road section--in other words, to recompact the subgrade and construct 12.7 cm of gravel pavement covered by 1.3 cm of double bituminous surface treatment. This low-cost pavement structure is planned to carry 2500 EALs for a design period of 10 years.

Charlotte Road (Section 0-5)

Section 0-5 of Charlotte Road is a 152-m-long road section with about 18 cm of macadam pavement. The projected traffic loading is 9000 and 20 000 EALs for design periods of 5 and 10 years, respectively. According to the NDT results (E_p/E_s = 5.3, E_s/p = 1432, and $\epsilon_z = 3.63 x 10^{-4}$), the subgrade CBR is 2.3 percent. A reduction of ϵ from $3.63 x 10^{-4}$ to $1.53 x 10^{-4}$ reduces the strain factor from 0.52 to 0.22; and, according to Figure 4, for E_p/E_s = 5.3 the subgrade strain reduction is associated with the change of H/a from 1.6 to 0.8, or the additional required pavement thickness is (1.6 - 0.8) (23 cm) = 18 cm. A greater overlay thickness of 33 cm is recommended according to the CBR methodology (12).

CONCLUSIONS

Three main conclusions can be drawn from the work described in this paper:

1. An economical rehabilitation program for low-volume urban roads should be based on actual performance under local conditions. Overlay requirements based on subgrade strain criteria proved to be practical and more economical than CBR and are consistent with previous local experience in designing and maintaining these roads.
2. NDT appears to be a useful and economical procedure for determining the engineering properties of the pavement and subgrade system. Where heterogeneous construction methods have been used in the past, NDT should be supplemented by some destructive testing. The approximate cost of the destructive tests was budgeted at 10 percent of the NDT design and engineering costs.
3. The design charts and relations between subgrade modulus and CBR presented in this paper can easily be programmed into desk calculators. In this way, the pavement and subgrade moduli and the CBR can quickly be determined after NDT. This process is very useful in correlating the NDT results with actual pavement conditions.

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Use of Geotextiles in County Road Construction

WAYNE A. FINGALSON

The experience of the Wright County Highway Department in Minnesota in the use of geotextiles as part of county road construction is described. This is essentially a technical case study for two projects that specified geotextiles for embankment stabilization. Both projects involved roadbed construction over unstable, boggy ground with peat thicknesses up to 12 ft. Engineering fabric was specified for these areas in lieu of muck excavation. A woven polypropylene filter fabric was used for both projects. The use of the fabric, which was quite successful, resulted in a savings of about $75 000 over conventional muck excavation. The geotextile specifications used for the projects are discussed, and a section dealing with the construction experience is also included. The stabilization abilities of the engineering filter fabric used were impressive. Geotextiles appear to be a cost-effective aid in constructing embankments over soils that have low load-carrying capacity.

The experience of Wright County, Minnesota, in the use of geotextiles as part of county road construction is described. This is essentially a technical case study for two Wright County Highway Department projects that specified geotextiles for embankment stabilization.

BACKGROUND INFORMATION AND PROJECT DESIGN DATA

Wright County is one of several counties that constitute a ring adjacent to the Minneapolis and St. Paul metropolitan area. It is located 25 miles northwest of the Twin City area (Figure 1). The Wright County Highway Department for the past few years has had a construction program of $2-4 million annually.

One of the projects included in the County's 1979 construction program was a 4-mile grading job on Wright County Road 111 in northern Wright County (CP 77-C111-121, Figure 2). The subgrade soils on this project had a design Hveem stabilometer (AASHTO T190) R-value of 12. The R-value reflects a soil's resistance to lateral deformation under a vertical loading (1, p. 2). The traffic on CR-111, which is adjacent to Lake Maria State Park, consists primarily of recreational and local vehicles; there is very little heavy-truck traffic. This is reflected in the 20-year design sigma N18 of 10 168. Sigma N18 is the total number of equivalent 18-kip single-axle load applications anticipated or experienced to date by a pavement during the design period (1, p. 2).