Pavement Evaluation in Virginia: State of the Practice

MOHAMED K. ELFINO, BOUZID CHOUBANE, AND ROY D. MCQUEEN

The Virginia state-of-the-practice using the falling weight deflectometer for asphalt concrete pavement evaluation and in situ characterization of pavement layers and subgrade is described. The process is accomplished using the computer program PEDMOD (Pavement Evaluation Design Model) developed at the Virginia Department of Transportation. This mechanistic tool uses layered elastic concepts with the results from nondestructive testing to: (a) estimate the respective elastic moduli of pavement layers and subgrade, (b) evaluate the performance of various pavement systems, (c) provide rehabilitation options and (d) determine the life-cycle cost of rehabilitation alternatives. An example showing PEDMOD application is demonstrated. The procedures described herein are being routinely applied by VDOT personnel in their decision-making process for pavement rehabilitation at the project level.

The major problem that highway engineers face today is not how to design and construct new pavements but how to evaluate, maintain, and upgrade existing ones to meet today's demand of higher magnitudes of traffic loading and frequency.

Nondestructive Testing (NDT) methods have gained popularity in the past decade because of their ease of use and their ability to collect large amounts of data in a short time period. Basically, NDT methods for structural evaluation of pavements consist of performing nondestructive measurements on a pavement surface and relating these measurements to the in situ properties of the pavement system. The in situ pavement properties are then used to evaluate the structural adequacy of the pavement using the multilayered elastic theory.

The Dynatest 8000 Falling Weight Deflectometer (FWD) is currently used by the Virginia Department of Transportation (VDOT) to evaluate asphalt concrete pavement condition and performance. Data collected from the FWD are used, in conjunction with the Pavement Evaluation Design Model (PEDMOD) computer program, to evaluate the pavement structure and to better define its expected performance. This analysis has become an important part of the VDOT pavement management system, since it allows the following tasks to be performed:

1. Evaluation of design alternatives;
2. Determination of optimum time for rehabilitation; and
3. Development of rehabilitation priorities.

At the project level, FWD is used for the following purposes:

1. To separate the project length into relatively uniform analytical units. These are pavement sections exhibiting statistically homogeneous attributes (cross sections, subgrade support, construction histories, etc,) and performance. In other words, FWD is used to delineate unit boundaries when accurate historical data are not available.
2. To provide detailed analysis of the pavement structure for purposes such as the identification of localized base failure.
3. To determine the most appropriate rehabilitation design.

M. K. Elfino and B. Choubane, Virginia Department of Transportation, Materials Division, 1401 East Broad Street, Richmond, Va. 23219. R. D. McQueen, McQueen & Associates, Ltd., 3112 Fox Den Lane, Oakton, Va. 22124.

PAVEMENT EVALUATION DESIGN MODEL

PEDMOD Description

The computer program PEDMOD was developed by McQueen & Associates (*1*) to provide VDOT with an analytical tool for pavement evaluation and analysis. A modular concept was adopted to provide flexibility in updating the program as technology changes. These modules are shown in Figure 1 and include the following:

1. NDT data processing and reduction;
2. Evaluation of pavement performance;
3. Structural design of pavement;
4. Life-cycle cost analysis; and
5. Summary report.

NDT Data Processing and Reduction

A primary requirement for PEDMOD development was to enable VDOT to fully use field data collected with its FWD testing device. Because of the quantity of data collected by FWD to characterize pavement condition, PEDMOD is equipped to perform the following tasks:

1. To automatically input NDT field data to a spreadsheet program (data processing).
2. To reduce the NDT field data to yield the respective elastic moduli of pavement layers and subgrade (data reduction).

Data Processing

The function of the NDT Data Processing Module is to automatically transfer the field data file (XX. FWD) to a spreadsheet without manual keying. This feature alone saves the VDOT approximately 4 hours of keypunch time for every day's worth of acquired NDT field data and eliminates errors normally associated with manual keying. After the field data are input to the spreadsheet, the user can

1. Sort the data as a function of station, test number, deflection, etc.;
2. Process the data statistically; and

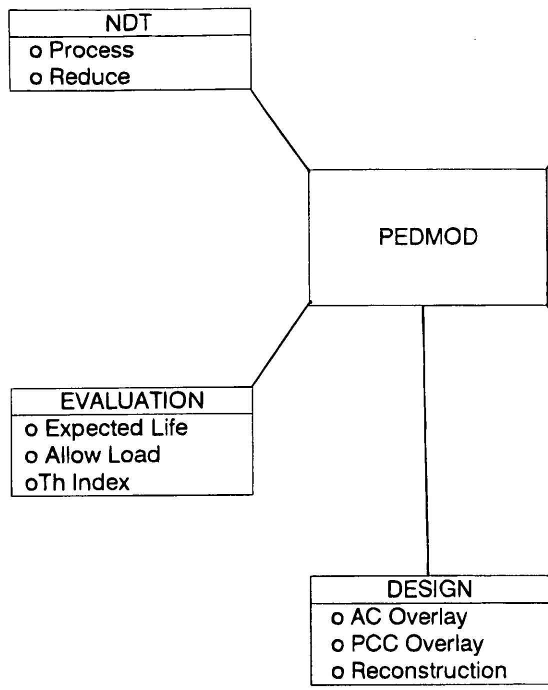

FIGURE 1 PEDMOD major components.

3. Graph the data to analyze trends and select a representative deflection basin.

Before the data are entered into the spreadsheet, preprocessing is done by averaging the three FWD "drops" per test point. The average load and average deflection sensor array (seven distinct averaged deflection measurements) are input to the spreadsheet for each test point along with test location information. The load and average deflections define the deflection basin for a particular test location. The spreadsheet also performs a composite stiffness computation at each test location to normalize minor load variations along a particular road profile. The composite stiffness (load/max deflection) values are then graphed as a function of stations to identify patterns of variability in pavement support for grouping of data for analysis. While grouping is subjective to a point, data should generally be grouped according to stiffness and pavement composition. A representative deflection basin(s) should then be chosen to characterize support conditions along the chosen length of road. While there are no firm rules for selecting a deflection basin, it is usually chosen to represent average or statistical conditions (mean plus or minus one standard deviation). This can either be the processed average or statistical basin or a particular basin in the group closest to the average or statistical basin. Comparing the average and statistically processed data to individual basins using the graph (XY) function is useful in basin selection. The spreadsheet and stiffness plot can be printed for further analysis and documentation as shown in Table 1 and Figure 2.

Data Reduction

Once a representative basin is chosen, that basin can be used in the NDT Data Reduction Module to estimate the elastic moduli of individual pavement layers and subgrade. This requires a knowledge of pavement type, thickness, and composition for each deflection basin (i.e., load and seven deflection sensor array).

To determine modulus values, the pavement structure is modeled as a layered system. PEDMOD uses WESDEF (*2*) as a subroutine for backcalculation.

WESDEF (*2*) determines a set of moduli values that provide the best fit between a measured deflection basin and a computed deflection basin. An example of WESDEF output is shown in Table 2.

VDOT is currently establishing a resilient modulus data base for all bound materials. This involves FWD testing of 54 (1.6 km or 1 mi) sections throughout the state and obtaining five asphalt concrete cores from each for indirect tension resilient modulus (diametrical) testing. Tests are run at 25°C (77°F) and at the average temperature established from the temperature profile in the asphalt concrete layers recorded during FWD testing. These resilient moduli can be used as initial (seed) values that would speed the backcalculations and provide confidence for the uniqueness of the solution obtained from WESDEF (*2*).

EVALUATION OF PAVEMENT PERFORMANCE

The purpose of the evaluation component is to gauge the expected performance of an existing pavement system. The evaluation relies heavily on the pavement strength inputs obtained from the NDT data reduction component output and projected traffic during the evaluation period. The evaluation methodology is based on a multilayered elastic model and limiting stress/strain criteria. The computer program BISAR (*3*) is incorporated into the evaluation component for calculation of stresses, strains, and displacements within the pavement structures.

The evaluation component is composed of the following primary modules.

TABLE 1 PEDMOD Data Processing Output

MP	F1(lbs)	D1(mil)	D2(mil)	D3(mil)	D4(mil)	D5(mil)	D6(mil)	D7(mil)	STIFF(lb/mil)
13.12	10475.00	7.47	4.70	4.46	3.68	2.78	2.01	1.50	1402
13.05	10491.00	9.58	6.77	6.09	5.10	4.02	3.02	2.35	1095
13	10464.00	10.30	6.89	6.34	5.39	4.27	3.26	2.51	1016
12.95	10499.00	9.32	5.20	4.88	4.14	3.29	2.52	1.97	1127
12.9	10504.00	8.52	5.69	5.51	4.61	3.39	2.62	2.06	1233
12.851	10459.00	8.99	5.35	4.96	4.26	3.39	2.61	2.01	1163
12.8	10467.00	9.15	6.74	6.28	5.37	4.31	3.35	2.68	1144
12.749	10461.00	10.27	6.38	6.06	5.06	4.01	3.05	2.39	1019
12.7	10544.00	7.39	4.77	4.22	3.40	2.52	1.79	1.33	1427
12.648	10405.00	9.32	5.66	5.13	4.31	3.40	2.56	1.99	1116
12.6	10429.00	8.86	7.45	6.85	5.83	4.61	3.55	2.80	1177
12.55	10288.00	7.73	5.02	4.61	3.93	3.08	2.33	1.81	1331
12.5	10408.00	6.97	4.05	3.83	3.15	2.42	1.79	1.43	1493
12.45	10400.00	7.73	4.89	4.81	3.62	2.58	1.80	1.38	1345
12.4	10443.00	9.87	6.06	5.59	4.57	3.34	2.22	1.54	1058
12.35	10493.00	6.70	4.48	4.03	3.24	2.45	1.76	1.35	1566
12.3	10427.00	8.61	6.31	5.66	4.69	3.58	2.59	1.94	1211
12.25	10429.00	9.16	5.36	4.95	4.08	3.15	2.32	1.77	1139
12.2	10453.00	8.21	4.88	4.57	3.78	2.92	2.18	1.69	1273
12.15	10456.00	6.33	5.94	5.24	4.19	3.12	2.28	1.70	1652
12.1	10424.00	11.99	5.64	5.42	4.53	3.54	2.62	1.99	869
12.05	10488.00	7.24	6.09	5.61	4.77	3.78	2.93	2.28	1449
12	10435.00	9.03	7.03	6.33	5.26	4.08	3.04	2.32	1156
11.949	10411.00	8.92	5.90	5.61	4.82	3.81	2.92	2.32	1167
11.9	10179.00	14.43	8.75	7.68	6.15	4.60	3.52	2.74	705
11.849	10363.00	9.31	5.85	5.31	4.53	3.55	2.74	2.13	1113
11.8	10427.00	10.84	7.20	6.52	5.54	4.29	3.28	2.52	962
11.75	10376.00	9.86	6.72	6.07	5.09	3.95	2.93	2.24	1052
AVERAGE	10432.07	9.00	5.92	5.45	4.54	3.51	2.63	2.03	1195.03
ST. DEV.	69.41	1.65	1.02	0.88	0.76	0.63	0.52	0.43	205.69
A.+(−S.D.	10501.49	10.65	6.94	6.33	5.30	4.14	3.15	2.45	989.34

1.00 inch = 25 mm
1.00 lbf = 4.45 N
1.00 lbf/mil = 0.175 N/m
1.00 mil = 0.025 mm

Pavement Expected Life

Nondestructive testing of pavement is used to estimate the expected life of an existing pavement and to determine the rehabilitation design thicknesses required to upgrade the pavement. Estimation of the expected life and the determination of the rehabilitation option require knowledge of the failure mechanisms that occur in pavements.

The failure of asphalt pavements is generally defined by cracking and rutting of the asphalt concrete layer along the wheel paths. Fatigue cracking from repeated loading is controlled by the magnitude of the tensile strain at the bottom of the asphalt layer, while rutting is governed principally by the vertical compressive strain at the top of the subgrade. Therefore, future performance and rehabilitation needs will be determined mainly by limiting the vertical compressive strain at the top of the subgrade and limiting the horizontal tensile strain at the bottom of the asphalt concrete layer. The limiting asphalt strain criterion is based on the need to keep the tensile strain at the bottom of the asphalt concrete layer low enough to prevent fatigue cracking. Cracking occurs when the imposed tensile strain exceeds the fatigue strain of the pavement material. Similarly, a limiting vertical subgrade strain criterion is used to limit the permanent deformation of the subgrade. By limiting the vertical strain on top of the subgrade, the deflection caused by the imposed loading can be kept in the elastic range of the soil, precluding permanent (plastic) deformation.

These limiting strain criteria relate allowable strain to the number of load repetitions. Consequently, asphalt pavement performance can be expressed as a function of allowable asphalt concrete layer and subgrade strains. In PEDMOD, the following limiting strain criteria were used for pavement design and evaluation purposes.

Asphalt Concrete Pavement Cracking

The horizontal tensile strain at the bottom of the asphalt concrete layer, a criterion developed by The Asphalt Institute (*4*) to control load-induced cracking, is used.

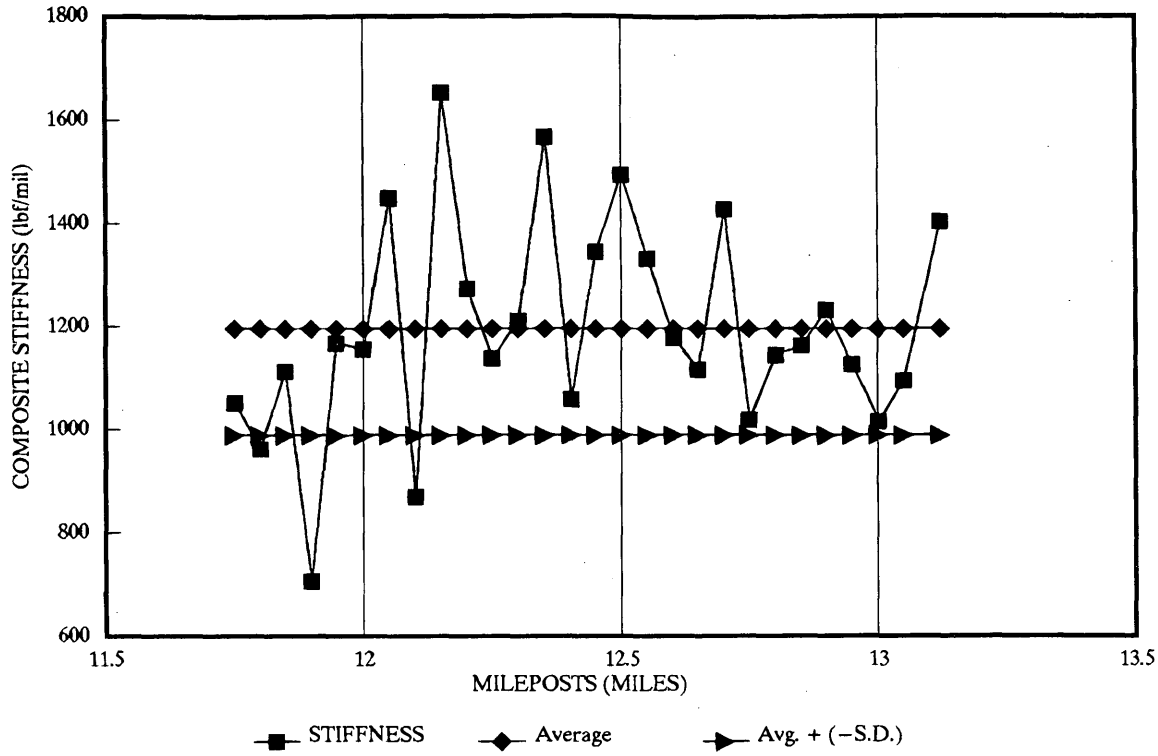

FIGURE 2 Stiffness versus stations.

The criterion is defined in the following equation:

$$N = f0 * [(10^{M}) * (f1 * e^{-f2}) * (E^{-f3})] \quad (1)$$

where

- N = number of load repetitions,
- $M = f4 * [V_b / (V_v + V_b) - f5]$,
- e_t = limiting horizontal strain at the bottom of asphalt layer,
- V_b = volume of asphalt,
- V_v = volume of air voids,
- E = elastic modulus of asphalt layer,
- M = mix adjustment constant relating fatigue life to air voids, and
- $f0$ to $f5$ = constants derived from laboratory testing.

Equation 1 is used in the design process to compute a limiting horizontal tensile strain and, in turn, the asphalt layer thickness for a given number of load repetitions. On the other hand, it can also be used to determine the allowable number of load repetitions for given horizontal tensile strains and, thus, to estimate the expected pavement life from an imposed axle load.

Pavement Rutting

The subgrade vertical strain criterion, also developed by The Asphalt Institute (*4*), is used to control rutting in the asphalt layer. The subgrade vertical strain criterion usually governs the design of asphalt pavements. It is given by the following equation:

$$N = d0 * (e_v^{-d1}) \quad (2)$$

where

- N = number of load repetitions,
- $d0 = 0.1365 * 10^{-8}$,
- $d1 = 4.477$, and
- e_v = limiting vertical strain.

Equation 2 is used in the design process to compute the thickness of pavement layers or overlay for a given number of load repetitions or to determine the allowable number of load repetitions from an imposed axle load.

The purpose of the expected-life module is to estimate the time remaining to a programmed rehabilitation project for an existing pavement. While the expected-life estimate addresses potential load-induced damage, it is used primarily to rank and program repairs and does not necessarily indicate the precise time to structural failure or pavement inoperability. The expected life is highly dependent on the accuracy of the traffic inputs (i.e., weight and number of vehicles). If the traffic input is in doubt, the user should run PEDMOD at several traffic levels to gauge the sensitivity of traffic in affecting the expected-life computation. The expected life is computed by dividing the total allowable number of load repetitions by the estimated yearly load repetitions. The allowable number of load repetitions is computed from Equation 1 or 2 with the imposed stress of strain computed by the BISAR subroutine from layer properties (i.e., elastic modulus, Poisson's ratio, and thickness) and 80 kN (18-kip) axle load application. Table 3 shows PEDMOD pavement expected life output using input data from the WESDEF example.

TABLE 2 WESDEF Output Summary

NUMBER OF ITERATIONS PERFORMED: 1

DEFLECTIONS COMPUTED FOR FINAL MODULUS VALUES

POSITION	SENSOR OFFSET IN.	MEASURED DEFLECTION MILS	COMPUTED DEFLECTION MILS	DIFFERENCE	% DIFF.
1	3.0	5.9	5.9	0.0	-0.4
2	12.0	4.5	4.5	0.0	-1.0
3	24.0	3.2	3.2	0.0	-1.2
4	36.0	2.3	2.3	0.0	2.0
5	48.0	1.6	1.6	0.0	1.9
6	60.0	1.1	1.1	0.0	-0.6
7	72.0	0.8	0.8	0.0	0.4
			ABSOLUTE SUM:	0.2	7.6
			ARITHMETIC SUM:		1.1
			AVERAGE:	0.0	1.1

FINAL MODULUS VALUES

LAYER NO.	MATERIAL TYPE	MODULUS PSI	POISSON'S RATIO	THICK. IN.	INTERFACE VALUE
1	AC	918692.	0.35	10.00	1.
2	BASE OR SUBBASE	35620.	0.35	6.00	1.
3	SUBGRADE	30625.	0.40	223.50	1.
4	RIGID BOUNDARY	1000000.	0.50	1.00	1.
5	RIGID BOUNDARY	1000000.	0.50	SEMI-INF	1.

ABSOLUTE SUM OF % DIFF. WITHIN TOLERANCE
CHANGE IN MODULUS VALUES NOT WITHIN TOLERANCE

1 inch = 25.4 mm
1 psi = 6.89 kPa

Effective Thickness Coefficient

The purpose of this module is to compute the layer coefficient, a_{im}, of existing pavement layers by using the layer elastic modulus, E_{im}, from the NDT data reduction component and standard VDOT layer coefficients, a_{is}, and elastic moduli, E_{is}. For asphalt pavements, the VDOT standard layer coefficients are shown in Table 4. The computational procedure for the flexible pavement effective thickness coefficient is referenced by Equation NN.13 of the 1986 *AASHTO Guide For Design of Pavement Structure,* Volume 2, *(5)* as

$$a_{im} = a_{is} * (E_{im}/E_{is})^{1/3} \quad (3)$$

TABLE 3 PEDMOD Pavement Expected Life Output Using Input Data From WESDEF/Expected Life Calculation—AC (Asphalt Content)

EXPECTED LIFE = 4.02 (YEARS)
NO. OF TOTAL ALLOWABLE 18-kip LOAD REPETITIONS = 1.0050E+07

18 KIP = 80 kN

TABLE 4 Thickness Equivalency Values for Materials Used in Interstate and Primary Road Pavements in Virginia

Location	Location Notation	Material	Material Notation	Thickness Equivalency Value
Surface	a_1	Asphalt Concrete	A.C.	1.0
Binder	a_1	Asphalt Concrete	A.C.	1.0
Base	a_2	Asphalt Concrete	A.C.	1.0
	a_2	[1]Cement treated aggregate material over untreated aggregate or soil cement or soil lime and under less than 4.5" thick A.C. material	C.T.A.	1.0
[2]Drainage Layer	a_3	Cement or Asphalt Stabilized open-graded material	D.L.	0.40
[3]Subbase(s)	a_4	[4]Select material Type I, II & III; and aggregate base Type II No. 21A	Sel. Mat.	0.20
	a_4	Soil cement or soil lime	S.C.	0.40
	a_4	Untreated aggregate material 21A or 21B	Agg.	0.35
	a_4	Cement treated aggregate material over untreated aggregate or soil cement or soil lime	C.T.A.	0.80
	a_4	Cement treated aggregate material directly over subgrade	C.T.A.	0.60
Full depth bituminous concrete shall have a thickness equivalency value of 0.95				

[1]All materials directly under less than 4.5 inches of total asphalt concrete material are considered as base.

[2]All drainage layers must be constructed on top of a filter/separator layer. The filter/separator layer may be either an untreated aggregate base material 21A or 21B primed with asphalt or a cement treated aggregate/soil material.

[3]A subbase may be more than one layer material.

[4]No structural strength shall be given to a select material used to replace unsuitable subgrade material

where

a_{im} = layer coefficient of material in place,
a_{is} = layer coefficient of VDOT standard material,
E_{im} = elastic modulus of material in place, and
E_{is} = elastic modulus of VDOT standard material.

The effective thickness index (equivalent to structural number in AASHTO) of the existing pavement, D_{eff}, is then computed as the summation of the layer coefficient (a_{im}) times the thickness (h_i) for each layer, or

$$D_{eff} = \Sigma\, a_{im} * h_i \tag{4}$$

For program implementation, the following standard elastic moduli for acceptable VDOT materials were used:

- Asphalt concrete (surface, binder, base), 3.8×10^6 kPa at 25°C (550,000 psi at 77°F).
- Aggregate base, 2.1×10^5 kPa (30,000 psi) (from AASHTO).
- Select subbase, 1×10^5 kPa (15,000 psi) (from AASHTO).
- Cement-treated aggregate, 4.3×10^6 kPa (600,000 psi).

For asphalt pavements this module also computes the adjusted asphalt modulus at 25°C (77°F) and 32°C (90°F) based on the AASHTO *(5)* temperature modulus relationship (Appendix L). The 25°C (77°F) asphalt modulus is used for the effective layer coefficient computation and the 32°C (90°F) value is used for design purposes. PEDMOD saves these values as default inputs to other modules.

Since the default VDOT standard elastic moduli used in PEDMOD are based on limited laboratory testing, users should exercise caution when interpreting effective thickness coefficient results. Until a validation study is implemented to verify the default values included in PEDMOD, the following guidelines are suggested:

1. Use experience to gauge the reasonableness of the results.
2. Perform sensitivity analyses with different default moduli to gauge the effect on the output.
3. Use a single asphalt layer to evaluate multiple asphalt layers consistent with NDT data reduction. Since only the asphalt surface layer has a stored temperature modulus relationship, model all asphalt layers as asphalt surface.

Table 5 shows the PEDMOD output for the effective thickness index of the data reduced by WESDEF.

TABLE 5 PEDMOD Output for Effective Thickness Index of Data Reduced by WESDEF

LAYER	MATERIAL	THICKNESS	E-VALUE	LAYER COEFF.
1	AC	10.00	277445	0.80
2	AGBS1	6.00	35620	0.60

EFFECTIVE THICKNESS INDEX AT 77 DEG F. = 11.56

ADJUSTED AC MODULUS @ 77 DEG FOR EFF. THICK. CALC. = 277445
ADJUSTED AC MODULUS @ 90 DEG FOR DESIGN ============ 144235

1 psi = 6.89 kPa
1 inch = 25.4 mm
77°F = 25°C
90°F = 32°C

STRUCTURAL DESIGN OF PAVEMENT

PEDMOD's design component performs structural design for existing and new pavement systems using layered elastic theory. The design component allows computation of asphalt overlays as well as design of new (or reconstructed) asphalt concrete pavement. Each pavement type incorporates either aggregate or cement-stabilized subbase layers.

The design process involves computation of stresses and strains using BISAR (*3*). The computed values are then compared to limiting stresses and strains that are determined based on riding quality (i.e., pavement smoothness) and the need for structural maintenance (i.e., pavement cracking). If either the computed strain or stress from the imposed loading exceeds the limiting values, new computations are made for thicker pavement until computed values are within tolerance. For flexible pavements the limiting strain criteria are indicated by Equations 1 and 2.

PEDMOD will prompt the user for input, including elastic modulus, material type and existing pavement thickness. The program incorporates default values, which can be overridden by the user for:

- Elastic moduli of new pavement materials (e.g., overlay layer of new pavement layers);
- Poisson's ratio;
- Standard 80-kN (18-kip) axle load; and
- Computational points based on selected pavement type.

For asphalt concrete overlay and existing asphalt concrete layers, PEDMOD uses the 32°C (90°F) modulus for asphalt concrete overlay and the modulus of the existing asphalt layer adjusted to 32°C (90°F) stored from NDT data reduction.

At the completion of the design process, PEDMOD will also compute the effective thickness index for asphalt concrete pavement systems for comparison to existing VDOT methods. The asphalt modulus adjusted to 25°C (77°F) is used for the effective thickness index computation. PEDMOD output for asphalt overlay requirement is shown in Table 6, while Table 7 shows the output for new/reconstruction design.

TABLE 6 PEDMOD Output For Asphalt Overlay Requirement/AC Overlay Rehabilitation—AC over AC Pavement

LAYER	MATERIAL	THICKNESS	E-VALUE	LAYER COEFF.
OVL	AC	3.48	576000	1.00
1	AC	10.00	276931	0.80
2	AGBS1	6.00	35620	0.60
3		0.00	30625	0.00

EFFECTIVE THICKNESS INDEX = 15.03

REQUIRED OVERLAY THICKNESS = 3.48 (INS)

1 psi = 6.89 kPa

1 inch = 25.4 mm

TABLE 7 PEDMOD Output New/Reconstruction—AC Pavement CTA Base

LAYER	MATERIAL	THICKNESS	E-VALUE	LAYER COEFF.
1	AC	8.68	576000	1.00
2	CTA1	6.00	600000	1.00
3	AGBS1	6.00	30000	0.60
4		0.00	30625	0.00

EFFECTIVE THICKNESS INDEX = 18.28

1 psi = 6.89 kPa

1 inch = 25.4 mm

LIFE-CYCLE COST ANALYSIS

A life-cycle cost analysis, as applied to VDOT pavement management systems, is also included in PEDMOD. It performs an economic analysis to estimate the total cost of a pavement type over a certain period based on present worth. User inputs include initial cost, necessary maintenance, salvage value, and a discount rate, as shown in Table 8.

SUMMARY REPORT

A copy of a typical report generated by PEDMOD, as illustrated in Table 9, is processed by the Report Module in the main menu. The report summarizes results from the Evaluation and Design Components. NDT reports are generated by printing spreadsheets or graphs and the NDT Data Reduction (WESDEF) output file.

LOADING CONDITIONS

PEDMOD uses the AASHTO standard 80-kN (18-kip) single-axle load as the standard loading condition. Mixed traffic is converted to 80-kN (18-kip) equivalent single-axle load repetitions in the evaluation component. The 80-kN (18-kip) axle load is assumed to be distributed on four dual wheels (two on each side of the axle) with a single wheel load of 20 kN (4,500 lb). For layered elastic computation, the dual wheels are assumed to be spaced at 330 mm (13 in.) on center with 690-kPa (100-psi) tire pressure. Again, the user can override the default wheel loading, tire pressure, and wheel spacing.

CLIMATIC VARIATIONS

The layered elastic design method allows the user to factor climatic effects into the evaluation/design process by adjusting the elastic modulus for a temperature (e.g., asphalt) or moisture (e.g., subgrade) susceptible material.

For asphalt materials, PEDMOD will automatically adjust the elastic modulus backcalculated from NDT field data at the test temperature to the elastic modulus at 25°C and 32°C (77°F and 90°F). The 25°C (77°F) modulus is used for effective thickness computations and the 32°C (90°F) modulus is used for evaluation and rehabilitation design. These values are computed from a default temperature module table taken from the 1986 AASHTO Design Guide (*5*) and are stored by PEDMOD for input to applicable evaluation and design modules. Respective air and asphalt concrete pavement temperatures are recorded during testing. Three holes are drilled into the pavement at a depth of 25 mm (1 in.) from the top, at asphalt concrete base middepth and at 25 mm (1 in.) below the asphalt concrete base, respectively. Pavement temperatures are determined by measuring the temperature of glycerine poured into the hole using a digital thermometer with an accuracy of $\pm 1/2$°C (1°F). The same thermometer is used for measuring air temperature. PEDMOD does not contain automatic adjustments for variations of subgrade or granular base moduli as a function of moisture, since this relationship must be based on a longer-term, field-testing program. However, the user can vary subgrade and base course moduli to model variations in strength from fluctuating moisture content.

BEDROCK CONSIDERATION

The layered elastic computations performed within PEDMOD can incorporate bedrock (e.g., a hard layer) at variable depth. If the user chooses to incorporate the hard layer, PEDMOD will default to hard layer placement at 6-m (20-ft) depth.

PEDMOD also defaults to a hard-layer modulus of 6.9×10^6 kPa (1,000,000 psi) and a Poisson's ratio of 0.5. The user can override these default values and place the layer at any depth should existing information (e.g., soil boring logs) indicate a different placement depth.

TABLE 8 Life-Cycle Cost Analysis (7.3 m/lane-kilometer, 30-Year Life to Reconstruction, March 28, 1995

DISCOUNT RATE: 4%

PROJECT NUMBER SAMPLE

I PAVEMENT TYPE: FLEX
II SHOULDER TYPE: FLEX

YEAR	ACTION	COST
	INITIAL COST INCLUDING SHOULDERS	312,500
1		
2		
3		
4		
5		
6	PATCH (5% BOTH LANES, 40 mm)	1,250
7		
8	MILL & RESURFACE (BOTH LANES, 40 mm)	20,313
9		
10		
11		
12	PATCH (5% BOTH LANES, 40 mm)	1,250
13		
14		
15		
16	MILL & REPL. 15% BOTH LN. (75 mm BASE, 40 mm SURF)	24,688
17		
18		
19		
20	PATCH (5% BOTH LANES, 40 mm)	1,250
21		
22		
23		
24	MILL & REPL. 75 mm TRK LN., + OL BOTH LANES 40 mm	38,875
25		
26		
27		
28	PATCH (5% BOTH LANES, 40 mm)	1,250
29		
30		
PRESENT WORTH (INITIAL COST + MAINTENANCE)		358,445
ESTIMATED SALVAGE VALUE AT END OF 30 YEARS		156,250
TOTAL NET PRESENT WORTH		406,620

SUMMARY

This paper described the implementation of the backcalculation technique and the use of the results in pavement evaluation in Virginia. The development of PEDMOD resulted in a significant reduction of the amount of time required for the data entry process and provided a practical means for analyzing the considerable amount of information for pavement evaluation and for determining cost-effective rehabilitation strategies.

PEDMOD has the capability to perform the following tasks:

1. Determine resilient moduli of pavement layers and subgrade;
2. Compare strength of different pavement segments;
3. Compute pavement expected life;
4. Compute the existing pavement effective thickness index;
5. Establish thickness designs for rehabilitation options and new/reconstructed pavements; and
6. Estimate life-cycle costs.

TABLE 9 PEDMOD Evaluation Summary Report

EVALUATOR : MOHAMED ELFINO
DISTRICT : RICHMOND
ROUTE : 60
COUNTY : HENRICO
MILEPOST : FROM 1 TO 2

DATE TESTED : 03/16/95

LAYER	MATERIAL	THICKNESS	E-VALUE	LAYER COEFF.
1	AC	10.00	918692	0.80
2	AGBS1	6.00	35620	0.60

EVALUATION SUMMARY
==================
EXPECTED LIFE : 4.02 YEARS
ALLOW. LOAD REPS : 1.0050E+07
ALLOW. AXLE LOAD :
EFF. THICK. INCES: 11.56 INS

REHABILITATION OPTIONS
====================
DESIGN LIFE = 20.00 YEARS

[1] AC OVER AC PAVEMENT 3.48 INS

[2] AC STAB. BASE RECONSTRUCTION:
AC 8.68 INS
CTA1 6.00 INS
AGBS1 6.00 INS

1 inch = 25.4 mm
1 psi = 6.89 kPa

REFERENCES

1. McQueen, R. D. *Documentation and User's Manual PEDMOD Pavement Management Software.* Oakton, Va., April 1990.
2. Van Caulelaert, F. J., D. R. Alexander, T. D. White, and W. R. Barker. Multilayer Elastic Program for Backcalculating layer Moduli in Pavement Evaluation. In *Nondestructive Testing of Pavements and Backcalculation of Moduli,* ASTM STP 1026, ASTM, Philadelphia, Pa., 1989, pp. 171–188.
3. Koninklijke/Shell Laboratorium. *BISAR Users Manual; Layered System under Normal and Tangential Loads.* Amsterdam, Holland, July 1972.
4. *Research and Development of The Asphalt Institute's Thickness Design Manual (MS-1),* 9th ed. Research Report 82-2. The Asphalt Institute, August 1982.
5. American Association of State Highway and Transportation Officials. *AASHTO Guide for Design of Pavement Structure.* Vol. 2, Washington, D.C., 1986.

Publication of this paper sponsored by Committee on Pavement Monitoring, Evaluation, and Data Storage.