FLEXIBLE PAVEMENT DESIGN IN ONTARIO

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The present design methodology for flexible pavements is based on the accumulated experience of pavement performance. More definitive design procedures are needed to assess alternative designs, stage construction, and maintenance strategies. A deflection-based flexible pavement design methodology linked with economic analysis should complement the experience approach. An alternative design subsystem that considers the properties of materials is discussed, and how this subsystem and suitable criteria can be substituted in the deflection method of design in a modular fashion is indicated. A tightening money supply for highways requires more sensitive economic management tools in the pavement design area.

•A HIGHWAY agency is charged with providing and maintaining a system of roads that adequately serve the present and future highway transportation needs of the community within the scope of allotted funds. The paved highway surface is the visible manifestation of the product and reflects the quality of service that the agency provides. Therefore, pavements must be designed, constructed, and maintained to provide acceptable standards of safety and riding comfort for several years, at an acceptable cost.

Two principal design decision areas must be considered when a pavement is defined: the pavement surface geometry area and the pavement structure area. Figure 1 shows how the various design areas in both geometry and structure contribute to the attainment of the objectives of safety, comfort, and economy. In geometric design, the design elements of alignment, speed, and capacity contribute to safety; in pavement design, adequate skid resistance of the pavement surface contributes to safety. In geometric design, the vertical and horizontal alignment and the highway aesthetics contribute toward riding comfort, whereas pavement structural design is intimately connected with smoothness and riding quality. The economics of pavements depend not onl on the pavement structure but on the alignment and cross-section design as well. Inclusion of vehicle user costs as these are affected by pavement surface conditions will increase management sensitivity to public acceptability of serviceability to be provided.

This paper describes the pavement structure design activities within the Ontario Ministry of Transportation and Communications. Those activities are directed toward the attainment of the pavement surface goals.

PAVEMENT DESIGN MANAGEMENT PROCEDURES

The pavement design function is divided among a number of different areas of responsibility such as traffic, materials, and estimating. The final design is based on data contributed by each area. The management procedures and communication flow that are necessary to produce a design are described below.

The need for a new highway or for a reconstruction improvement to an existing highway is established from planning studies and from district and regional surveys. After approval and priority examination, the work is placed on the ministry's program.

Preliminary pavement design work on the new project is initiated by regional staff. This involves gathering detailed design data on traffic, subgrade soils, and availability of borrow and suitable aggregates and reviewing past performance of pavements in the

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Publication of this paper sponsored by Committee on Theory of Pavement Design.

area. A series of alternative pavement structure designs are then proposed, and rough estimates of quantities are made. Generally the alternative designs considered might consist of one or more of the following pavement types: conventional flexible structure, deep-strength asphalt, full-depth asphalt, composite (asphalt surfacing and concrete base), and concrete. The thickness combinations that are proposed conform to current policies, specifications, past experiences, and practical considerations. The preliminary pavement design data and alternative designs are next considered by the secretary of the Pavement Selection Committee, which is composed of senior management personnel, as shown in Figure 2.

The preliminary quantities for each alternative design are required so that their influence on unit prices can be taken into account when alternative designs are priced. The Estimating Office keeps a current file of unit prices and prepares construction cost estimates for 1 mile of pavement structure for each alternative design. These unit prices are also used to prepare cost estimates of resurfacing work. The estimates for life of original surface and life of subsequent overlays are prepared by the secretary of the Pavement Selection Committee and tabulated with the cost estimates for each alternative design. The present value of total costs for each alternative design and maintenance strategy for a range of life values is calculated and plotted by a computer program. Sometimes other alternative designs may supplement the list at this stage or later, after referral to the Pavement Selection Committee.

The Pavement Selection Committee examines the economic evaluations of alternative designs and maintenance strategies and considers a number of local and other factors before selecting the design that will be used. The factors considered are tailored after the AASHO project procedures (1). Once the selection of an appropriate alternative design is made and approved by the assistant deputy minister of engineering and operations, work on detailed design by regional staff commences. The applicability of the design to each length of road is then examined and, where necessary because of changed local subgrade conditions, the approved pavement structure might be modified or the thickness of subbase or base increased or decreased. Changes may also be necessary because of scarcity or unsuitability of available aggregates.

If, when detailed investigation is completed, conditions are then found to be different from those considered in the preliminary design, new design alternatives have to be given to the Pavement Selection Committee.

When the detailed design is completed, the pavement design is discussed as part of the overall design by the Regional Review Committee, as shown in Figure 3. The regionally approved design is next scrutinized by the Systems Design Branch for conformity to standards before it is submitted to the Head Office Review Committee for final approval. The project is finally passed on to Contract Control for the preparation of tender and contract award. Construction control of the contract is undertaken by district and regional staff. The constructed pavement then becomes the responsibility of maintenance personnel.

The need for resurfacing an existing pavement is generated by district and regional staff road condition reports. Overlay thicknesses are normally the minimum needed to restore distorted cross section and reduce bumps and dips to acceptable amounts. Design procedures follow the flow shown in Figure 3.

The management structure that is involved in the pavement design process is shown in Figure 4.

DATA BANK IN THE MANAGEMENT PROCESS

New pavements must be designed, constructed, and maintained. Each phase in the process requires management attention and decisions. The management structure must be organized so that goals and objectives can be achieved with the greatest efficiency. Each part of the structure must be aware of the role it plays in attaining goals and must, therefore, measure performance and evaluate effectiveness in contributing toward achievement of goals. To do this, records of projects and contracts must be consulted and status and condition reports examined. A great deal of repetitive work of this type can be eliminated and the process speeded up by a data bank that incorporates the in-

Figure 1. Design areas in pavement geometry and structure.

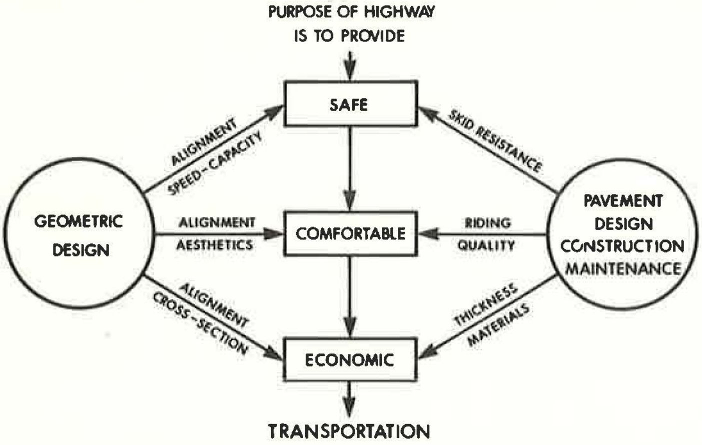


Figure 2. Flow of communication for preliminary thickness design.

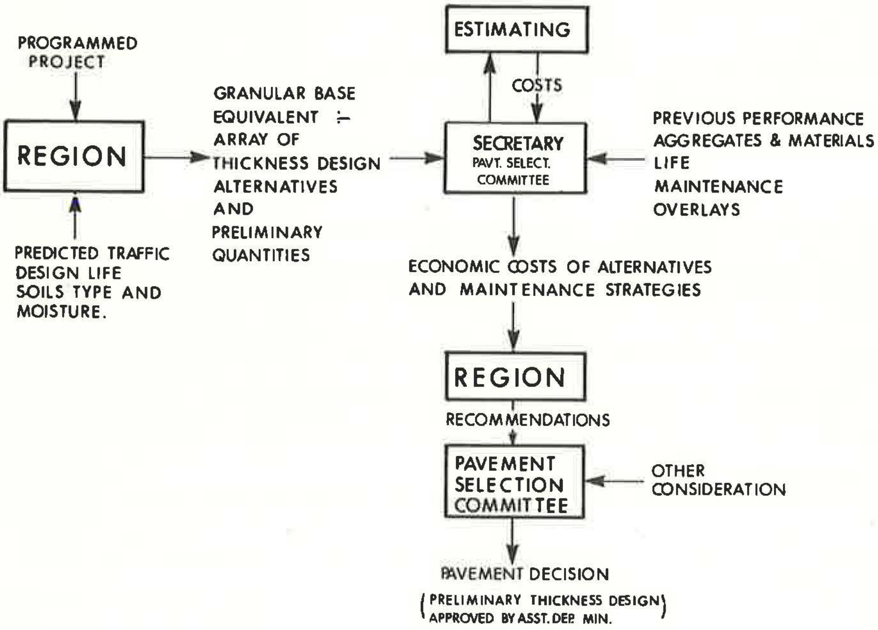


Figure 3. Flow of communication for final design.

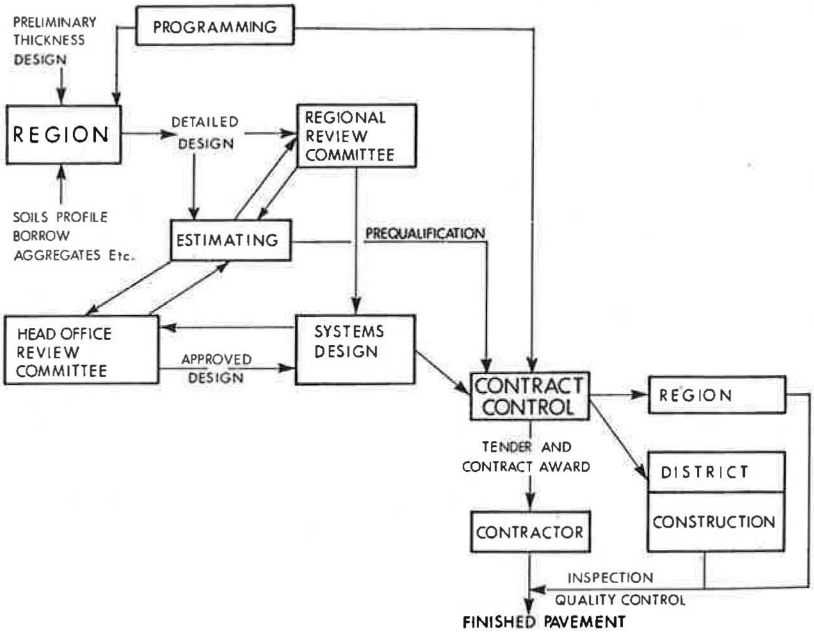
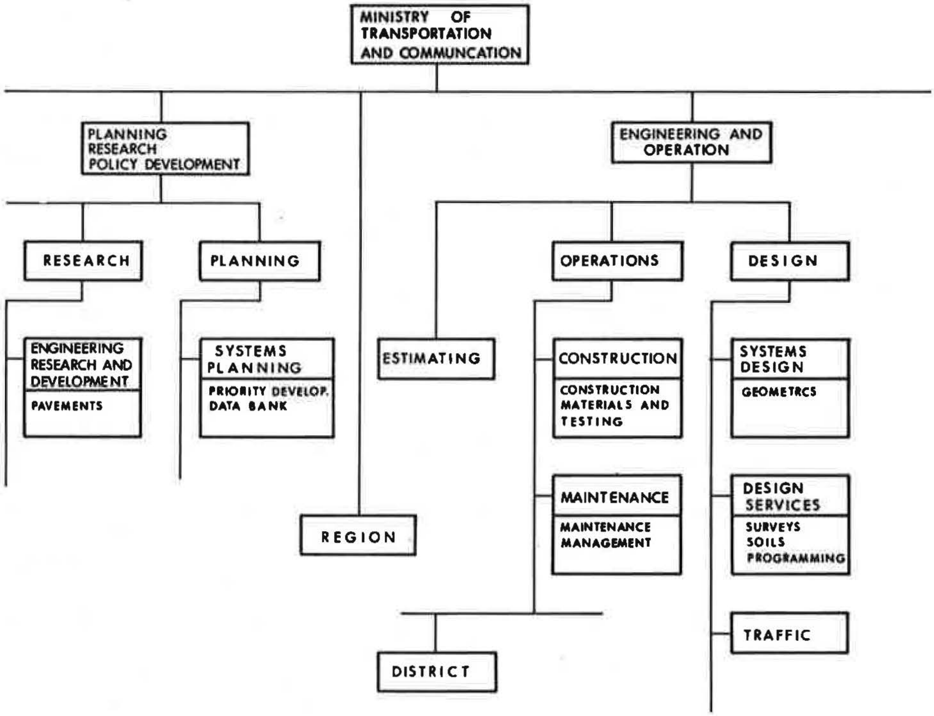


Figure 4. Units involved in pavement design process.



formation relative to pavements and that is accessible to any part of the management structure. Such an arrangement is shown in Figure 5. A pavement management and feedback information system (PMFIS) is now being developed for eventual incorporation in the ministry's data bank.

PAVEMENT DESIGN SUBSYSTEM

The pavement design management procedures described above set the framework in which the actual mechanics of pavement design is conducted. Pavements can be designed by many different methods (3, 4). The method used in Ontario is based on experiences; but, if more sensitive analyses are required or unfamiliar materials are proposed for use, a deflection-based design method (with alternative submodels) is available.

The design methods described below permit the designer to select those alternative designs that will satisfy the traffic needs and the subgrade conditions during a given period of years. To permit the adoption of the most suitable design from these alternatives, a number of additional factors must be considered. The procedures to develop the design alternatives and the related design information constitute the pavement design subsystem.

The procedure starts by obtaining from the design method a requirement for a thickness of the pavement structure in terms of granular base equivalent. The granular base equivalent requirement is converted to layer thicknesses to develop alternative designs according to the following equivalency values:

1 in. (25.4 mm) of hot-mixed asphalt concrete = 2 in. of granular A base (in conventional, deep strength and full-depth asphalt construction).
1 in. of granular subbase = $^2/_3$ in. of granular A base.
1 in. of treated base (either bituminous or portland cement) = 2 in. of granular A base.

The conventional design has thicknesses of asphalt concrete surfacing ranging from $1\frac{1}{2}$ to $5\frac{1}{2}$ in. (38.1 to 139.7 mm) depending on the classification of the highway and on th daily traffic. The well-graded granular A base course is generally 6 in. (152.4 mm) thick and may be of crushed gravel or crushed stone. The remainder of the pavement structural thickness is in the subbase, which is constructed with granular C, a material with wide gradation limits.

In deep-strength design, the asphalt thickness is usually kept between 8 to 10 in. (203.2 to 254 mm). The rest of the equivalent granular thickness needed is usually made up with granular A base material with a minimum of 6 in. (152.4 mm). Subbases are only used where needed. Full-depth asphalt designs are based on 1 in. (25.4 mm) of hot mix = 2 in. of granular base material, although there is evidence that the equivalency can be as high as 3.4 in. (4, 5). Rigid pavement thicknesses are determined from the current design thickness guideline table (6). Composite pavement thickness designs are limited to those previously used successfully, i.e., 3 in. (76.2 mm) of asphalt surfac ing and 7 or 8 in. (180 to 200 mm) of plain concrete base on 4 to 6 in. (100 to 150 mm) o treated or untreated subbase.

Preliminary estimates of quantities of materials needed per linear mile of highway for all parts of the pavement and shoulders above the subgrade are obtained from tables prepared for this purpose. The quantities in the tables were calculated on the basis of standard cross sections, side slopes, and average spread densities.

The list of alternative designs is reviewed by the secretary of the Pavement Selection Committee, who may add other alternatives to the list. The Estimating Office examines these alternatives and, after considering contract price data, quantities needed, the area, and other factors, provides cost estimates for constructing 1 mile of each of the various designs.

Figure 5. Data bank.

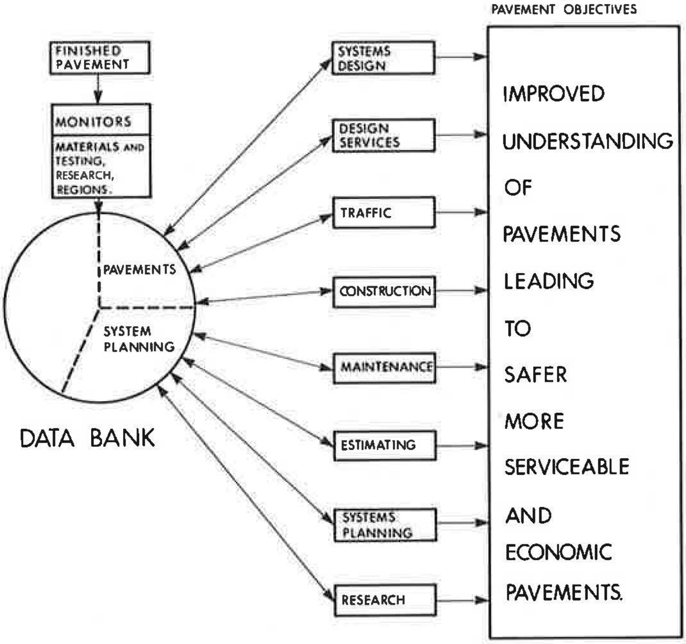


Figure 6. Structural design guidelines for flexible pavements.

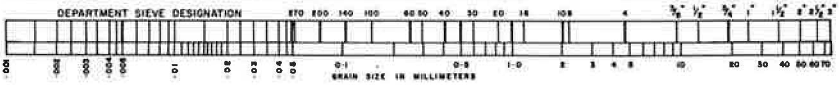
CLASS OF ROAD / SUBGRADE MATERIAL			GRAN. TYPE MATERIALS SUITABLE AS GRAN. BORROW	SANDY SILT AND CLAY-LOAM TILL			LACUSTRINE CLAYS	VARVED AND LEDA CLAYS
				SILT <40 V.F. Sa and Si. <45	SILT 40 - 50 V.F. Sa. and* Si. 45 - 60	SILT >50 V.F. Sa. and Si. >60		
			①	②	③	④	⑤	⑥
KINGS HIGHWAYS	MULTI-LANE	HM	5½"	5½"	5½"	5½"	5½"	5½"
		B	6" - 9"	6"	6"	6"	6"	6"
		SB	–	12" - 18"	18" - 24"	24" - 30"	18"	18" - 42"
		GBE	(17" - 20")	(25" - 29")	(29" - 33")	(33" - 37")	(29")	(29" - 46")
	2 LANES >2000 AADT	HM	4½"	4½"	4½"	4½"	4½"	4½"
		B	6" - 9"	6"	6"	6"	6"	6"
		SB	–	12" - 18"	18" - 24"	24" - 30"	18"	18" - 42"
		GBE	(15" - 18")	(23" - 27")	(27" - 31")	(31" - 35")	(27")	(27" - 43")
	2 LANES < 2000 AADT	HM	3½"	3½"	3½"	3½"	3½"	3½"
		B	6"	6"	6"	6"	6"	6"
		SB	–	12"	12" - 18"	18" - 24"	12" - 18"	18" - 30"
		GBE	(13")	(21")	(21" - 25")	(25" - 29")	(21" - 25")	(25" - 33")
SECONDARY ROADS	PAVED >1000 AADT	HM	1½"	1½"	1½"	1½"	1½"	1½"
		B	6"	6"	6"	6"	6"	6"
		SB	–	6" - 12"	12"	18" - 24"	12" - 18"	18" - 30"
		GBE	(9")	(13" - 17")	(17")	(21" - 27")	(17" - 21")	(21" - 29")
	UNPAVED <1000 AADT	HM	–	–	–	–	–	–
		B	6"	6"	6"	6"	6"	6"
		SB	–	6"	6" - 12"	18"	12"	18"
		GBE	(6")	(10")	(10" - 14")	(18")	(14")	(18")
TOWNSHIP ROADS	PAVED >200 AADT	HM	1½"	1½"	1½"	1½"	1½"	1½"
		B	4" - 6"	6"	6"	6"	6"	6"
		SB	–	6"	6"	6" - 12"	6" - 12"	12" - 18"
		GBE	(7" - 9")	(13")	(13")	(13" - 17")	(13" - 17")	(17" - 21")
	UNPAVED <200 AADT	HM	–	–	–	–	–	–
		B	4" - 6"	6"	6"	6"	6"	6"
		SB	–	6"	6" - 12"	12" - 18"	12"	12" - 18"
		GBE	(4" - 6")	(10")	(10" - 14")	(14" - 18")	(14")	(14" - 18")
MINING & ACCESS	------	HM	–	–	–	–	–	–
		B	4" - 6"	6"	6"	6"	6"	6"
		SB	–	6"	6"	6" - 12"	6" - 12"	12" - 18"
		GBE	(4" - 6")	(10")	(10")	(10" - 14")	(10" - 14")	(14" - 18")

HM - HOT-MIX ASPHALT THICKNESS
B - BASE THICKNESS
SB - SUB-BASE THICKNESS

GBE - GRANULAR BASE EQUIVALENCY THICKNESS
(1"HM ≈ 1" TREATED B. ≈ 2" GRAN. B. ≈ 3" SB)
**U.S. BUREAU OF SOILS CLASSIFICATION*

NOTE: THE RANGE IN TOTAL THICKNESS SHOWN IN THE ABOVE TABLE ARE DEPENDENT UPON THE MOISTURE CONTENT OF THE SUBGRADE.

U. S. BUREAU OF SOILS CLASSIFICATION							
Clay	Silt	Very Fine Sand	Fine Sand	Medium Sand	Coarse Sand	Fine Gravel	Gravel



The secretary of the Pavement Selection Committee evaluates the probable life spans of each alternative design on the basis of past pavement performance or by the deflection design method or does both (7). The maintenance strategy in terms of overlay thickness, probable life span, overlay costs, and annual maintenance costs is also determined on the basis of past experience or by the deflection design method (7) or both. More than one maintenance strategy can be evaluated for each alternative; however, this is not the practice.

The estimated construction costs and probable life spans of the initial pavement, the overlay costs and its probable life spans, and an analysis period and a rate of return are used to calculate the present value of total costs for each design alternative with its related maintenance strategy. The output of these calculations (an example of which is shown in Fig. 12) is a computer plot of total costs versus initial surfacing age. Various lines on the plot define the costs for different lives of the overlays. The most economic alternative can be readily determined from the plots.

On the basis of the economic evaluations and local experience, the regional staff recommends a design to the Pavement Selection Committee. Approval from this committee for the preliminary thickness design is required before work on detailed design can be initiated.

This method of selecting thickness designs evolved for the purpose of allowing input from several groups who are experienced not only in pavement design but also in geometric design analysis and local construction problems. Consideration of all aspects of the project is thus allowed to influence the design decisions.

No optimization techniques have been introduced into the design procedure at this time. However, this might occur later if a study of the constraints and trials of the technique indicate potential savings.

PAVEMENT THICKNESS DESIGN GUIDELINES

Provinces normally provide a 50 percent subsidy for roads in cities, towns, villages, most townships, counties, and regions. Under certain circumstances the subsidy can be as much as 80 percent; for connecting road links to very small communities, the subsidy can be 100 percent.

The pavement thickness design is the concern of the particular municipal authority. Thus, thickness design guideline tables for flexible and rigid pavements have been prepared by the ministry to be used in the preliminary design procedure leading to the selection of a pavement design (6). The flexible pavement design guideline table is in Figure 6.

DEFLECTION DESIGN METHOD FOR FLEXIBLE PAVEMENTS

The thickness guidelines shown in Figure 6 are used as the first level of design. If designers require this design to be confirmed or encounter conditions that are outside o the experience embodied in the guideline tables, an alternative deflection design method is available (3).

The concepts expressed in this method are that the pavement deflection under a standard wheel load represents the strength of the pavement structure and that pavement strength is related to the performance of the pavement under traffic. Implied in these concepts is the realization that the function of pavement structure is to spread the load over the subgrade in such a way as to prevent short-term failure in the subgrade and to minimize the rate at which long-term deformation accumulates in the subgrade under repeated traffic loading.

Pavement Response

Subgrades in Ontario are separated into 4 main classification groups: granular materials, sandy silt and clay loam tills, lacustrine clays, and varved and leda clays. A pavement structure can be represented as a homogeneous layer by applying equivalency values to the different types of surfacings, bases, and subbases. The deflection of the structure over a given subgrade can be represented by an equation (4):

$$D_{18}(H_e + a) = K \tag{1}$$

where

D_{18} = deflection of the pavement surface under an 18-k (80 kN) axle load, in in.;
H_e = equivalent granular base thickness, in in.; and
a and K = constants that depend on the subgrade soil conditions.

The deflection and equivalent thickness curves for Ontario were defined for the 4 principal subgrade types by assigning deflection values to different designs known to be satisfactory for a series of different traffic conditions (7). The curves are shown in Figure 7 and the equations are given in Table 1. By assigning different deflection values to the designs shown in Figure 6, one can arrive at somewhat different values for a and K in the equations. However, the equations as they stand appear to generate designs that are acceptable, and they are now used in this design method.

In an effort to further rationalize this aspect of the design procedure, a parallel procedure was developed to include material characterizations (8). This parallel procedure forms part of a design subsystem that can be substituted for the deflection method of design in a modular fashion. The derivation of the equations and the resulting design curves are described below.

According to N. Odemark (11), the pavement layers above the subgrade can be replaced by a layer of subgrade material with the thickness Z so that the same deflections should occur in this transformed uniform half space as in the layered system. The thickness A is the sum of the equivalent thicknesses of each pavement layer (Fig. 8).

$$Z = \sum_{i=1}^{m-1} 0.9h_1 \sqrt[3]{\frac{Em}{Ei}} \tag{2}$$

The deflection on top of the subgrade can then be calculated by using the formula for the elastic half space.

$$w_s = \frac{Kpa}{Em} \sin \alpha \tag{3}$$

where K is a value between 1.5 and 1.6 (12), depending on Poisson's ratio and on α.

For K = 1.57 ($\pi/2$), and $\sin \alpha = (a/Z)/\sqrt{1 + (a/Z)^2}$, and $P = P/\pi a^2$, Eq. 3 becomes

$$W_s = \frac{P}{2E_m Z} \times \frac{1}{\sqrt{1 + \left(\frac{a}{Z}\right)^2}} \tag{4}$$

We then solve for Z.

$$Z = \sqrt{\frac{P}{2E_m} - a^2} \tag{5}$$

The equivalent subgrade thickness Z can be transformed into an equivalent granular A thickness H_e, with the modulus E_{2g}. If all layers consisted of granular A material of thickness H_e, then, according to Eq. 2,

$$Z = 0.9H_e \sqrt[3]{\frac{E_m}{E_{2g}}} \tag{6}$$

Equations 5 and 6 lead to

Figure 7. Equivalent thickness and design deflection curves.

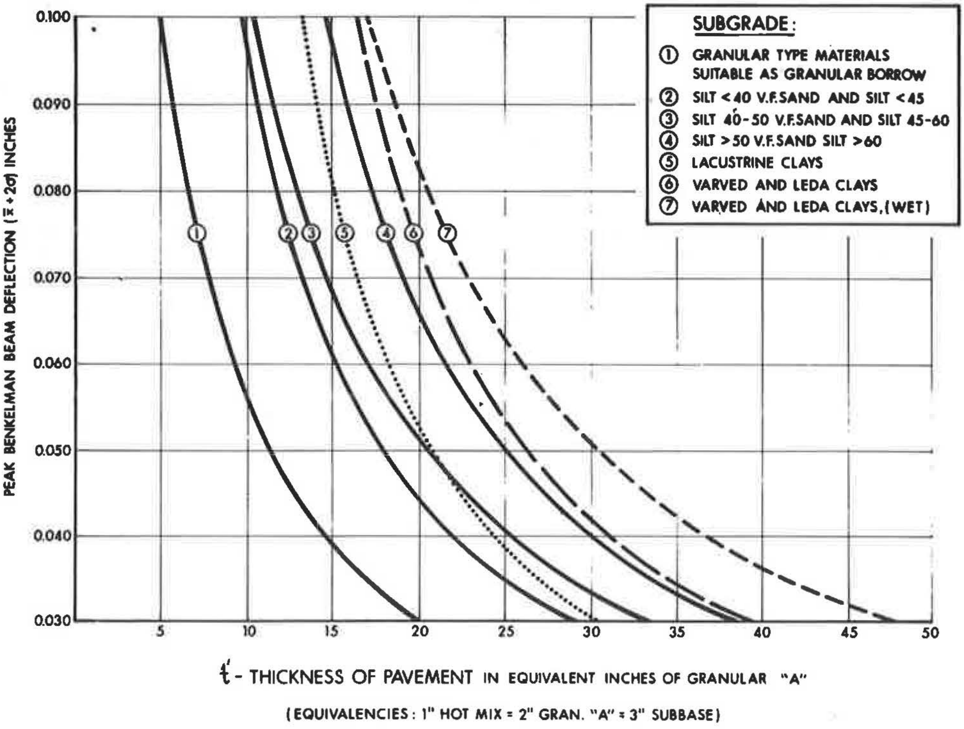
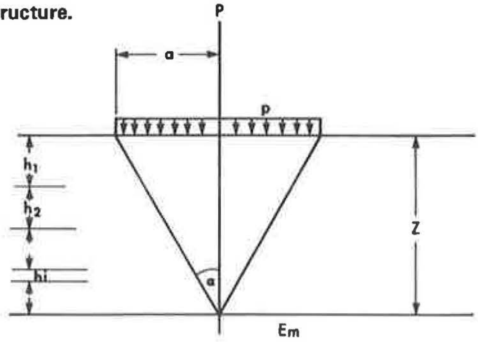


Table 1. Deflection and thickness relations derived from design thickness guidelines.

Subgrade Materials		Regression Equation[a]	Correlation
Number	Type	$\bar{\delta}(t' + a) = K$	Coefficient
1	Granular suitable as granular borrow	$\bar{\delta}(t' + 1.4) = 0.6363$	0.9780
2	Silt <40; very fine sand and silt <45	$\bar{\delta}(t' - 1.6) = 0.8113$	0.9853
3	Silt 40 to 50; very fine sand and silt 45 to 60	$\bar{\delta}(t' - 0.5) = 0.9871$	0.9631
4	Silt >50; very fine sand and silt >60	$\bar{\delta}(t' - 4.4) = 1.0190$	0.9530
5	Lacustrine clays	$\bar{\delta}(t' - 5.9) = 0.7314$	0.9814
6	Varved and leda clays, dry	$\bar{\delta}(t' - 6.5) = 0.9797$	0.9800
7	Varved and leda clays, wet	$\bar{\delta}(t' - 3.8) = 1.3249$	0.9780

[a] t' = thickness in equivalent inches of granular base.

Figure 8. Layered structure.



$$H_e = \frac{1}{0.9} \times \sqrt{\left(\frac{P}{2E_m W_s}\right)^2 - a^2} \times \sqrt[3]{\frac{E_m}{E_{2g}}} \qquad (7)$$

Equation 7 is the first of 2 design equations.

The equivalent granular A thickness H_e is composed of various layers. Equations 2 and 6 lead to

$$H_e = \sum_{i=1}^{m-1} h_i \times \sqrt[3]{\frac{E_{2g}}{E_i}} \qquad (8)$$

where

P = wheel load, in lb;
a = diameter of the loaded area, in in.;
W_s = calculated deflection of the subgrade surface;
E_m = modulus of elasticity of the subgrade; and
E_{2g} = modulus of elasticity of the granular base material.

The terms $\sqrt[3]{E_{2g}/E_i}$ are to be interpreted as layer equivalency factors based on granular A material, and they must be assumed to be in accordance with data on the basis of experience. The equivalencies used for the Ontario designs lead to

$$H_e = 2h_1 + h_2 + \frac{2}{3}h_3 \qquad (9)$$

which is the second design equation.

The flexible pavement design chart based on these equations is shown in Figure 9. The Benkleman beam rebound deflection scale shown was tentatively set after study of various deflection criteria, the Brampton Test Road data, and the AASHO Test Road data (8). This alternative design procedure is still tentative.

Deflection Criteria

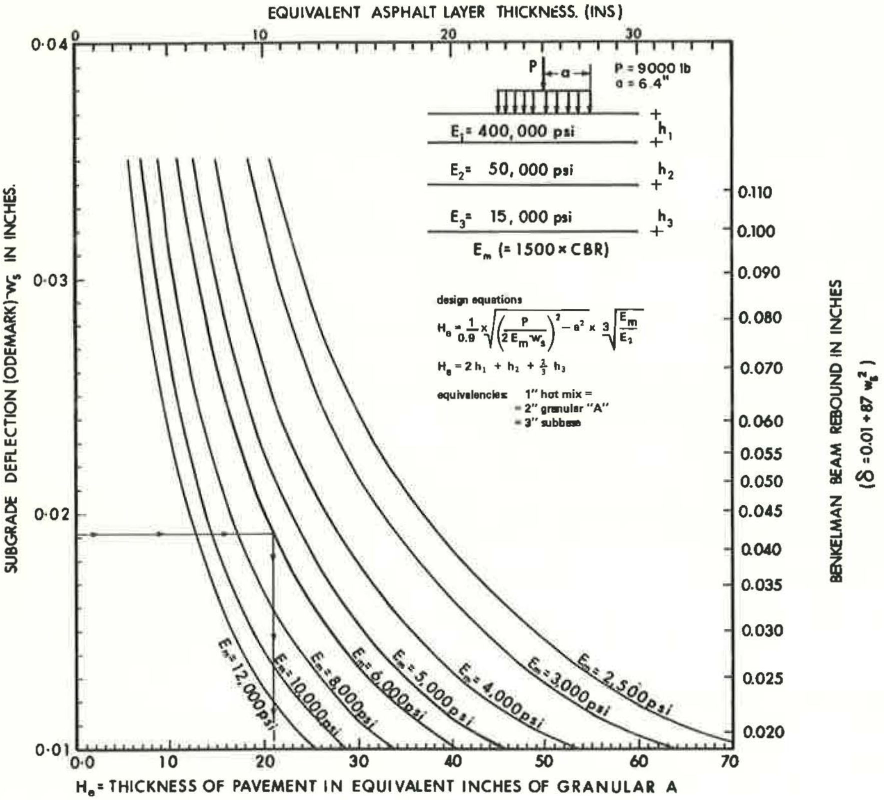
The Brampton Test Road demonstrated that the subsequent performance of a pavement can be predicted from a knowledge of its initial peak Benkelman beam rebound value. On the basis of this finding, a set of deflection criteria was proposed that provided for a higher terminal serviceability rating for strong pavements and a lower terminal serviceability rating for weak pavements (7). The proposed criteria are shown in Figure 10. More recently, further examination of the Brampton Test Road data by nonlinear elastic layer analysis procedures led to the proposal by Kamel (9) of an alternative set of deflection criteria. Also, examination of the AASHO Road Test data by elastic layer analysis procedures using a set of assumed elastic moduli values led to the proposal by Jung and Phang (8) of a third set of deflection criteria. This latter set of proposed criteria corresponds closely with that shown in Figure 10 and is slightly less conservative than the deflection criteria recommended by the Asphalt Institute (10). Further work is being carried out to arrive at firm criteria.

Pavement Life

At the present time, estimates of predicted pavement life for purposes of economic analysis are arrived at by reviewing the performance and ages of similar pavements in the locality. This method, although it may not be suitable for getting the precise values needed in calculation, nevertheless provides a value or range of values in which one can place a fair amount of confidence.

To arrive at the more precise values that are needed if the economic evaluations of alternative designs are to be meaningful, we must at this time apply the deflection and load repetition criteria chart (Fig. 10) and the deflection and equivalent thickness design curves (Fig. 7). By these charts and curves, we can either estimate the life of a given pavement thickness or arrive at a thickness for a proposed life. The solutions,

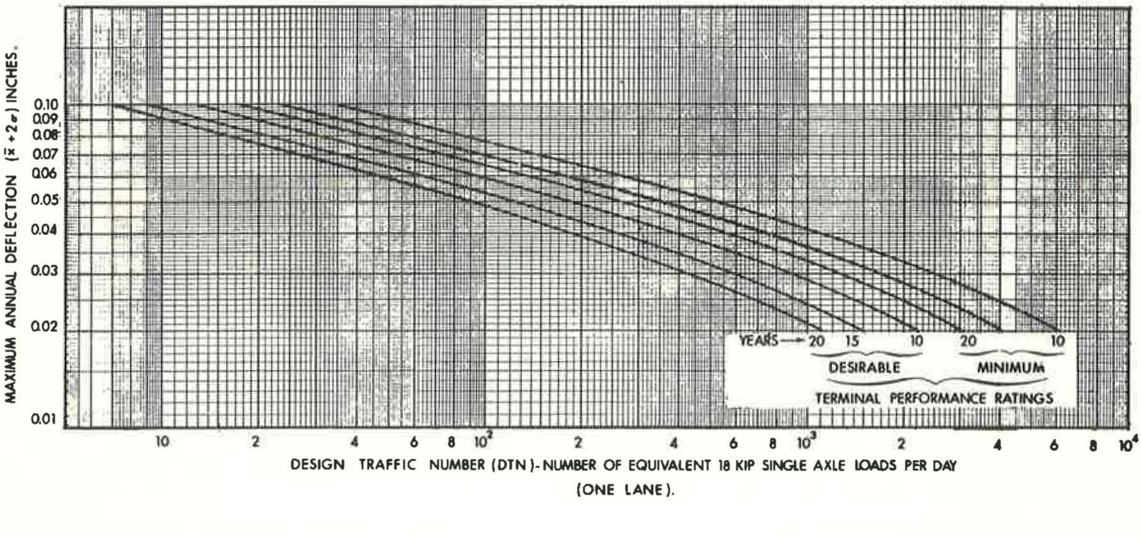
Figure 9. Design chart for flexible pavements in Ontario.



TYPICAL SUBGRADE MODULI IN ONTARIO

GRAN. TYPE MATERIALS SUITABLE AS GRAN. BORROW	SANDY SILT AND CLAY LOAM TILL			LACUSTRINE CLAYS	VARVED AND LEDA CLAYS
	SILT < 40 V.F. Sa and Si. < 45	SILT 40 - 50 V.F. Sa. and Si. 45.60	SILT > 50 V.F. Sa. and Si. > 60		
psi	psi	psi	psi	psi	psi
11,000	5,000 TO 7,000	4,000 TO 6,000	3,000 TO 5,000	3,500 TO 6,000	2,000 TO 4,500

Figure 10. Deflection criteria.



of course, can be obtained from computerized procedures. When the tentative alternative layer analysis procedures are used, pavement life in terms of equivalent 18-k (80 kN) load repetitions up to any desired terminal serviceability can be determined from the curves shown in Figure 11. This is used in conjunction with thickness design curves of Eq. 7.

OVERLAY DESIGN

Present practice in overlay design is to specify the thickness of padding lift, which is required to correct the longitudinal and transverse profiles, and then to specify the subsequent lift or lifts needed to further correct the transverse slope or the grade or to increase the final smoothness of the surface or to add the thickness required for strength. Overlay thickness is in many instances governed more by the need to correct heaves, dips, bumps, and cross section than by the requirement for added strength. This is the result of having to design built-in compensations for strength losses in the spring. In other words, the pavement is overdesigned for most of the year.

If the pavement to be overlaid needs to be strengthened, this is revealed by either the pavement condition report or by Benkelman beam deflection measurements. If Benkelman beam deflections are measured, the overlay thickness requirement can be be arrived at by use of the deflection method described by Phang and Slocum (7). Briefly, the deflection of the initial pavement is assumed to increase with the number of load repetitions because of fatigue and change in state of the materials. A deflection value of the time of overlay can be estimated from the curves shown in Figure 12. For a given overlay thickness, the deflection of the overlaid pavement can be estimated from waves shown in Figure 13. The deflection curves shown in Figure 12 are tentative.

The life of the overlay, for purposes of calculating economic costs in arriving at possible maintenance strategies, is now estimated after an examination of previous overlay performance and ages in the locality. The records available for this purpose are quite scanty; however, this method of estimation is preferred.

If the overlay is designed by a deflection method, an estimate of the overlay life can be obtained by consulting the curves shown in Figure 12.

ECONOMIC ANALYSIS OF NEW HIGHWAYS

The foregoing are brief descriptions of the various elements of the deflection design method with the tentative alternate layer analysis procedures. They are used by the secretary of the Pavement Selection Committee in examining the alternative designs and in setting up the maintenance strategies, which are an integral part of the economic analysis.

The economic evaluation is the output of the alternative strategies shown in Figure 14. Strategy a represents a strong, well-designed, and well-constructed pavement; strategy i represents a less durable initial design that is later strengthened by resurfacings. For purposes of comparing alternative design and maintenance strategies, the economic analysis must produce meaningful relative costs. The measure selected here is the present value of the total costs of both construction and the subsequent maintenance and overlays needed to keep the pavement to minimum standards during a stated period. The present values of future costs are calculated at a suitable discount rate, currently considered to be 6 percent.

An example of the method of presenting the results of the analysis is shown in Figure 15. Here 2 design strategies are considered: Strategy a represents 2 alternative designs [10-in. (254 mm) asphalt concrete, no base, 9-in. (228.6 mm) subbase and 5.5-in. (139.7 mm) asphalt concrete, 6-in. (152.4 mm) base, 13.5-in. (342.9 mm) subbase] with 15 ± 2 years initial surface life and an overlay life ranging between 4 and 8 years. Strategy b represents 2 other alternative designs [10-in. asphalt, no base, 13.5-in. subbase and 5.5-in. asphalt, 6-in. base, 18-in. (457.2 mm) subbase] with 20 ± 2 years initial surface life and an overlay life ranging between 6 and 9 years. The 20-year conventional design is economical and has a smaller spread in costs and therefore smaller risks.

At this stage, the costs that are taken into account are construction costs, admin-

Figure 11. Loss of serviceability and axle load repetitions curves for pavements of different deflections.

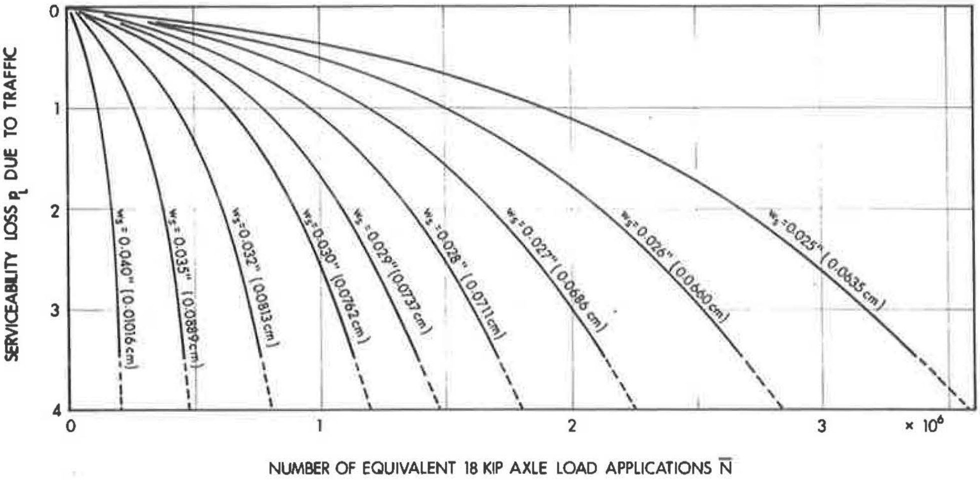


Figure 12. Curves for estimating life of pavement overlays.

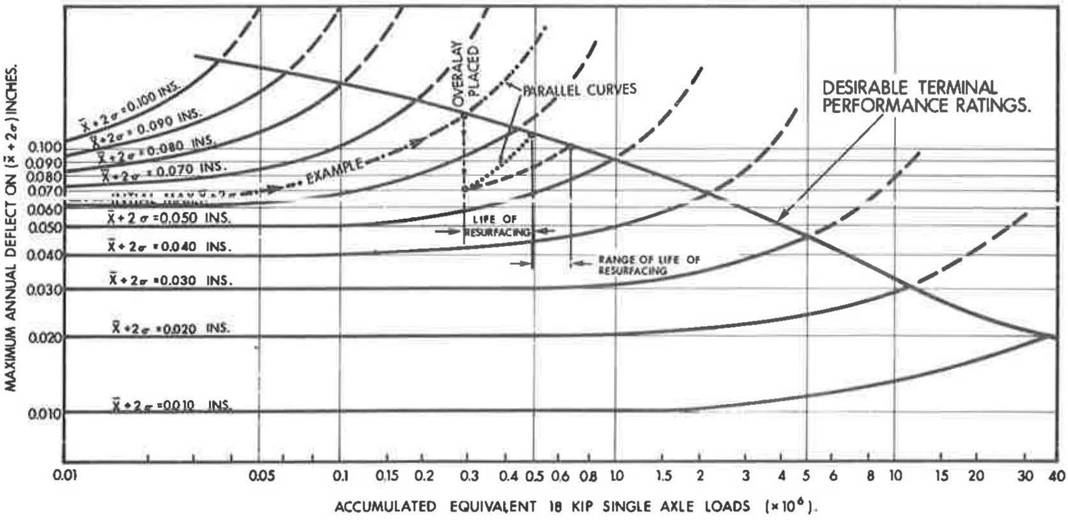


Figure 13. Overlay thickness deflection curve.

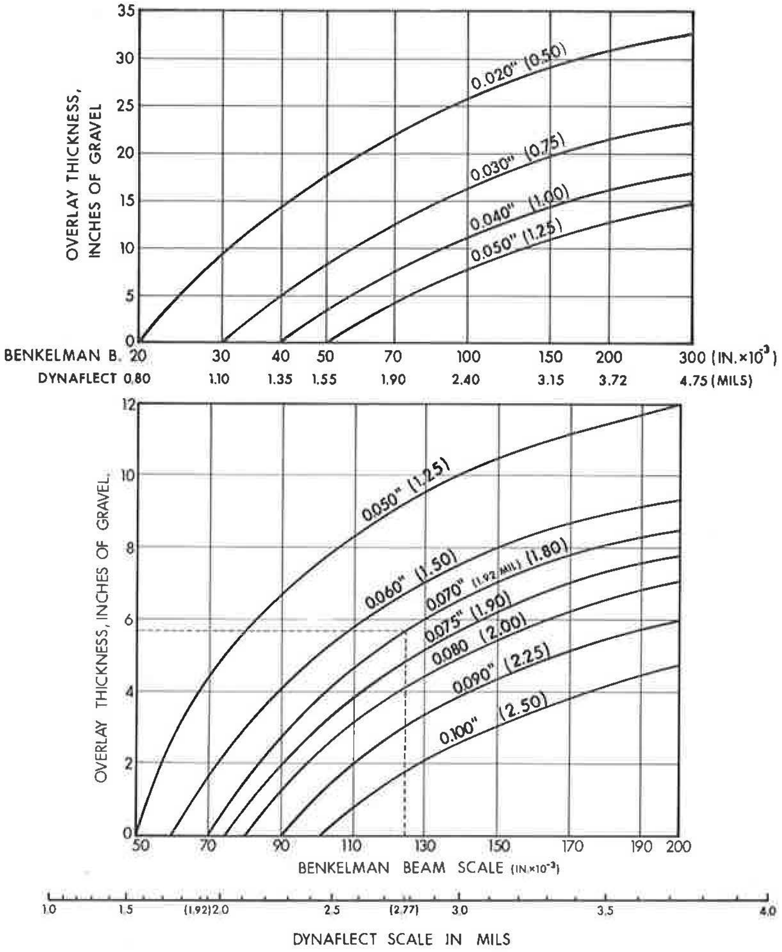


Figure 14. Projected serviceability and age histories of alternative pavement design, construction, and maintenance strategies.

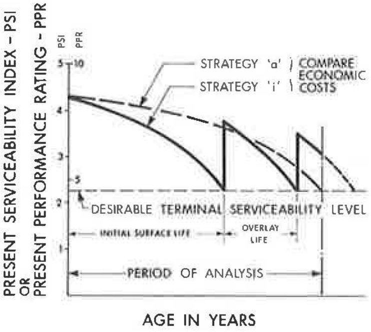
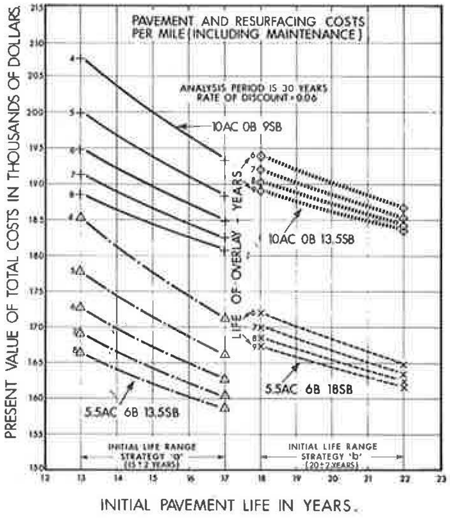


Figure 15. Economic cost evaluation of 4 alternative designs.



istrative costs for the design and supervision of overlays, overlay costs, and annual maintenance costs. At some later stage, cost of traffic detours and control during overlay construction, cost of overlays including premiums for night work where necessary, cost to users due to traffic delays during overlay construction, and some constraints defining public acceptability of the periodic inconveniences involved may be added to complement the basic economic analysis.

When this is done, it may become practical to answer questions regarding the conditions under which the initial pavement should be built to last a long time or a short time, the best time to overlay a pavement (which is not necessarily when it reaches terminal serviceability), and the most appropriate scheduling for stage construction.

DIRECTION OF FUTURE PAVEMENT DESIGN METHODS

Present developments in transportation in Ontario indicate that more effort and funds will go into the provision of public transit facilities in future years. The enlarged transportation responsibility of the Ministry is likely to result in a further tightening of money supply for the highway sector. We must, therefore, explore all avenues by which maximum benefits can be gained for funds expended. Whereas previous pavement design methods were aimed at providing adequate pavements, future design methods must be tailored so that, together with appropriate economic analysis, they serve as sensitive management tools.

Shrinking aggregate supplies may result in use of different materials, so there is the need to provide in future designs for the use of unfamiliar materials. The future design methods must therefore be capable of handling new materials.

Because of the tightened money supply, there is likely to be a limitation on new highways and a corresponding increase in rehabilitation of old pavements. The future method of overlay design must adequately account for deterioration of the existing pavement.

As materials and construction methods change in the future, there will be an urgent need to have a design method that will accommodate the experience gained with these new materials and methods. A computerized data bank that can provide the feedback information for this purpose appears to be very desirable.

CONCLUDING REMARKS

The pavement design procedures in Ontario are designed to take maximum advantage of the experience of the staff. The design guidelines express current experience in thickness design.

In spite of the bias in the procedures toward experience, they are sufficiently flexible to allow new design methods to be introduced. Efforts are under way to provide acceptable new design methods with features that are suitable for future needs. As part of this program, an alternative tentative elastic layer analysis procedure is proposed.

REFERENCES

1. An Informational Guide on Project Procedures. AASHO, Washington, D.C., Nov. 26, 1960, rev. March 1963, pp. 49-50.
2. Interim Guide for the Design of Flexible Pavement Structures. AASHO, Washington, D.C., Oct. 1962.
3. A Guide to the Structural Design of Flexible and Rigid Pavements in Canada. Pavement Design and Evaluation Committee, Canadian Good Roads Association, Ottawa.
4. Phang, W. A. Four Years' Experience at the Brampton Test Road. Highway Research Record 311, 1970, pp. 68-90.
5. Kamel, N. I., et al. Layer Analysis of the Brampton Test Road and Application to Pavement Design. Highway Research Record 466, 1973, pp. 113-126.
6. Pavements Structural Design Guidelines. Ontario Ministry of Transportation and Communications, June 1973.
7. Phang, W. A., and Slocum, R. Pavement Investment Decision-Making and Management Systems. Highway Research Record 407, 1972, pp. 173-194.
8. Jung, F. W., and Phang, W. A. Elastic Layer Analysis Related to Performance of Flexible Pavements. Ontario Ministry of Transportation and Communications, 1974.

9. Kamel, N. I. Developing Structural Design Models for Ontario Pavements. Ontario Ministry of Transportation and Communications, Internal rept., June 1973.
10. Asphalt Overlays and Pavement Rehabilitation. Asphalt Institute, College Park, Manual Series 17, Nov. 1969.
11. Odemark, N. Investigations as to the Elastic Properties of Soils and Design of Pavements According to the Theory of Elasticity. Staten Vaeginstitut, Stockholm, 1949.
12. Szecky, K. Der Grundbau. Springer-Verlag, Vienna, Vol. 1, 1963, p. 249.