Pavement Structural Design Practices Across Canada

April 2002 **C-SHRP Technical Brief # 23**

In April 2001, the Transportation Association of Canada (TAC) held its annual Spring Technical Meetings in Hull, Quebec. During the TAC Pavements Standing Committee (PSC) meeting, a series of presentations were made to discuss the pavement evaluation and design practices used by provincial agencies and the federal government of Canada. This brief has been prepared from those presentations. Also presented is an overview of the 2002 Pavement Design Guide that is currently under development through the National Cooperative Highway Research Program (NCHRP) Project 1-37A in the United States, commonly referred to the "AASHTO 2002 Guide" reflecting the fact that the American Association of State Highway and Transportation Officials (AASHTO) will adopt the guide once completed. This brief is the third of its kind, following similar briefs issued in 1999 and 2000 to summarize pavement smoothness specifications and seasonal load restrictions, respectively.

BACKGROUND

In 1997, the Transportation Association of Canada (TAC) released the "Pavement Design and Management Guide," which represented the culmination of a national 5-year project to incorporate new information and advancements in the broad area of pavement management including evaluation, design, maintenance and rehabilitation activities. Much of the background material presented in this brief is from the 1997 TAC Guide.

Overview of Pavement Structural Design

Pavement structural design is a comprehensive and stepwise process. Due to the large number of required design inputs, as well as the number of potential solutions, pavement design involves the selection of an optimum design under given performance, cost and even political considerations. Figure 1 illustrates the general pavement design procedure.

To some degree, traffic loading, environmental conditions, subgrade soil type, pavement material properties and thickness, the expected quality of construction and other design constraints such as available funds influence pavement designs. Pavement structural design methods may be classified into three main categories as listed below:

i) Experience-based methods, incorporating standard sections;

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ii) Empirical methods, involving relationships between a measured response (often deflection) and structural thickness;

iii) Theory based methods, using calculated stresses, strains or deflections.

A brief introduction to each method is provided in the following sections.

Experience-Based Methods (Standard Sections)

As the name implies, procedures based on standard sections attempt to replicate past "successful" designs by providing standard layer thickness for various design conditions in the hope that those sections will again provide adequate performance. The major limitation of this method concerns extrapolating the past experience to future conditions such as increased traffic volumes, different subgrade soils and environmental conditions, new materials and construction techniques, etc.

Empirical Methods

With empirical methods, the results of a measured response, such as deflection, are used to establish limits for different "successful" pavement structures under various traffic volumes. As with experience-based methods, empirically based methods also suffer from limitations when extrapolating for future conditions.

AASHTO Guide for Design of Pavement Structures (1993)

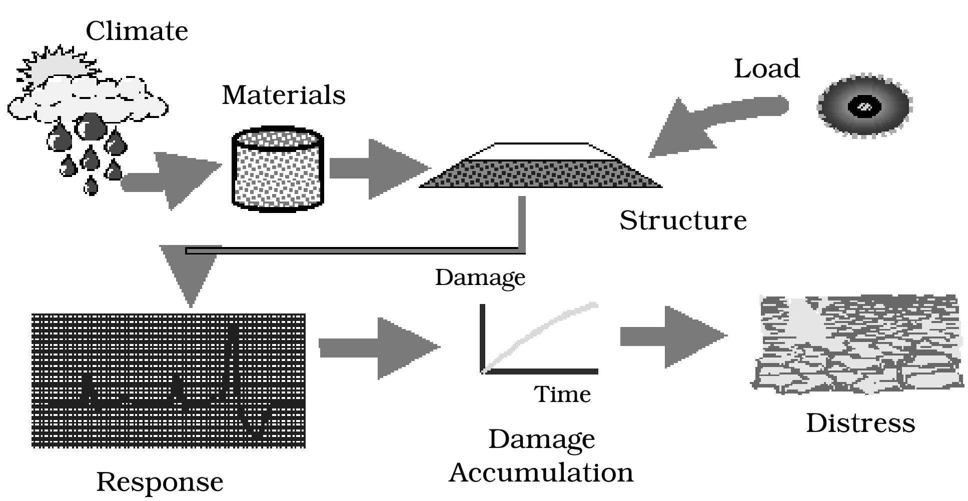
The AASHTO Pavement Design Guide is the most widely used document for the design of pavement structures in North America. It provides state-of-the-art approaches to pavement design including design and management principles, procedures for new construction or reconstruction, procedures for rehabilitation of existing pavements, and mechanistic-empirical design procedures. This guide provides a comprehensive set of procedures, which can be used for the design and rehabilitation of both rigid and flexible pavements, as well as aggregate surfaced low volume roads. The design process is facilitated by a user-friendly DARWin® pavement design software.

The method of design provided in this guide includes considerations of pavement performance, traffic, roadbed soil, materials of construction, environment, drainage, reliability, life-cycle costs, and shoulder design and gives designers the ability to adapt local experience to the guide for specific conditions.

Surface Deflection Based Method

The most common Surface Deflection Based method used in Canada was developed/adapted by the Canadian Good Roads Association/Roads and Transportation Association of Canada in the 1960s and 1970s. The methodology uses a Benkelman beam device to measure the elastic rebound of the pavement surface once a single axle truck loaded to an axle load of 80 kN is driven away from the test location. The magnitude of the rebound deflection provides an indication of the overall structural capacity of the pavement. The measured rebound deflection is corrected to provide a deflection at a standard pavement temperature and to represent the pavement deflection during spring conditions when the pavement is traditionally in its worst condition from a structural

Figure 1: General Pavement Design Procedure and Analysis



capacity point of view. The corrected deflection values can then be compared to 'standard' curves to determine the pavement structural adequacy or to establish any necessary strengthening (overlay) required reducing the pavement deflection to an acceptable level.

The advancement of pavement surface deflection measuring technology (RoadRater, Dynaflect and Falling Weight Deflectometer) has resulted in the use of additional deflection indices such as: deflection basin area, surface condition index, base condition index, composite pavement modulus and impulse modulus.

Theory-Based Methods

Theory based methods involve the relation of calculated values of stress, strain or deflection at strategic points throughout the pavement structure to observed performance under various conditions of climatic and traffic loading. Full-scale experimental test roads and tracks have provided much of the performance data for the development of theory based pavement design procedures. Modern pavement design methods are usually referred to as "mechanistic-empirical" methods, acknowledging the fact that the methods are developed and calibrated using observed performance. While mechanistic-empirical methods are extremely useful and flexible, they are not completely applicable to all combinations of the factors influencing pavement design, particularly those that were not experienced during the field experiment.

PAVEMENT DESIGN IN CANADA

Unlike the Federal Highway Administration (FHWA) in the United States, there is no single agency responsible for funding pavement construction and rehabilitation or setting pavement design standards in Canada. Pavement design for the primary highway network in Canada is under Provincial jurisdiction with the Federal government responsible for National Parks roadways. Each agency is free to use whatever design procedure they choose for pavement design and rehabilitation. A summary of the general pavement design methods and parameters used by the Provinces and the Federal Government are given in Table 1.

Table 1 – General Pavement Design Methods and Parameters

Agency	Subgrade Soil Classification for Pavement Design	Subgrade Soil Adjustments for Strength	Method to Determine Overall Pavement Strength	Method to Determining Pavement Layer Thickness	Layer Thickness Adjustments for Moisture/Frost
British Columbia	• Drilling • Unified Soil • FWD	--	• AASHTO '93 • FWD	• Drilling • Road Radar	AASHTO Guidelines
Alberta	• Resilient Modulus (Mr) - based on back-calculated value from adjacent section	Modulus correction value of 0.36	• AASHTO '93	Staged method: • Year one 60mm to 90mm depending on functional classification. • Staged 2 90 mm. • ACP Factor 0.40 Remaining SN usually Granular Base Factor 0.14	Drainage Coefficient
Saskatchewan	• CBR (Determined from relationship to Group Index (G.I.))	Soaked CBR	• Shell	• Shell	Modify Subgrade Support Value CBR
Manitoba	• Group Index • Mr	None	• AASHTO '93	• Granular Base Equivalency (GBE)	Frost Susceptible soil adjustment
Ontario	• Mr • CBR • K-value	OPAC Effective Mr	• AASHTO '93 (Adapted for local conditions)	• GBE	Drainage Coefficient
Quebec	• Mr (usually based on soil, unified classification)	Effective Mr	• AASHTO	• AASHTO	MTQ Frost protection curve

New Brunswick	--	--	• Shell used originally to determine basic strength	• Standard Sections	--
Prince Edward Island	• CBR	Soaked CBR	• Benkelman Beam	• GBE	--
Nova Scotia	• CBR • Mr	Soaked CBR	• AASHTO '93	• GBE	--
Newfoundland	--	--	--	• Standard Sections	--
PWGSC	• CBR	Soaked CBR	• FWD or B Beam	• GBE	None

Note: CBR – California Bearing Ratio; Mr – Resilient Modulus; FWD – Falling Weight Deflectometer;
GBE – Granular Base Equivalency;
Shell – Shell Pavement Design Manual; OPAC – Ontario Pavement Analysis of Costs;
PWGSC – Public Works and Government Services Canada

The majority of Canadian agencies use the AASHTO design procedure either as a primary design tool or to verify designs completed using an alternative methodology. A summary of design methodologies and economic analyses used by Canadian agencies, for both flexible and rigid pavement designs, are given in Table 2a and 2b respectively.

Table 2 – Design Methodologies and Economic Analysis

(a) Flexible (Asphalt Concrete) Pavements

			Economic Analysis			
Agency	**General Design Method(s)**	**Design Life (years) New/ Rehabilitation**	**Analysis Method**	**Period (years)**	**Discount Rate (%)**	**Include Salvage Value?**
British Columbia	AASHTO '93	20 / -	Present Worth	20	4	No
Alberta*	AASHTO '93 (new & rehab)	20 / 20	Present Worth	30	4	Yes
Saskatchewan**	Shell Method *** · Asphalt Institute	15 / 15	Present Worth	30	4	Yes
Manitoba	AASHTO '93 (new construction) Asphalt Institute (rehabilitation)	20 / 20	Present Worth	30	5	Yes
Ontario	AASHTO '93 Asphalt Institute Ontario Standards	20 / 20	Present Worth	30	7	No
Quebec	AASHTO '93 CHAUSSEE 1.1	Major highways: 20 / 20 Other Projects: 15 / 15	Present Worth	40	5	Yes
New Brunswick	AASHTO '93 (now being considered for implementation) Rebound Values ****	20 / 15	N/A	-	-	-
Prince Edward Island	Asphalt Institute Thickness Design	20 / 12	N/A	-	-	-

Nova Scotia	• AASHTO '93 • Correlation Charts using AADT & grain size of subgrade	20 / -	-	-	-	-
Newfoundland	• Standard Section Used	-	-	-	-	-
PWGSC	• AASHTO '93 • State of Alaska Design Method	20/12	Present Worth	40	4	Yes

* Economic analysis not conducted between alternate pavement designs at time of construction. All pavements are considered to be an asphalt layer over a granular base layer unless traffic is extremely high at which point a subbase layer is considered.

** In Saskatchewan, most Rehabilitation projects are based on lowest initial cost and not Present Worth.

*** The structural design method used in Saskatchewan for flexible pavement employs Shell design charts calibrated so that actual thickness of granular base and subbase materials used are reflected in the curves.

**** Currently use rebound values (Dynaflect converted to Benkelman Beam values).

(b) Rigid (Portland Cement Concrete) Pavements

			Economic Analysis			
Agency	**General Design Method(s)**	**Design Life (years) New/ Rehabilitation**	**Analysis Method**	**Period (years)**	**Discount Rate (%)**	**Include Salvage Value?**
British Columbia	• PCC is generally not used	-	-	-	-	-
Alberta	• PCC generally not used. When used in special cases a consultant selects the design procedure to be used • PCA Concrete Thickness Design • FHWA Concrete Pavement design	30 / -	Present Worth	30	4	Yes
Saskatchewan	• PCC is generally not used.	-	-	-	-	-
Manitoba	• AASHTO '93	20 / 20	Present Worth	30	5	Yes
Ontario	• AASHTO '93 • PCA • Ontario Standards	30 / 30	Present Worth	30	7	Yes
Quebec	• PCA Concrete Thickness Design • AASHTO '93 • PAS 5.01 (Pavement Analysis Software)	30 / -	LCCA	40 to 50	5 to 9	Yes
New Brunswick	• PCC is generally not used.	-	-	-	-	-
Prince Edward Island	• PCC is not used.	-	-	-	-	-
Nova Scotia	• AASHTO '93	25 / -	-	-	-	-
Newfoundland	• There are no Rigid Pavements	-	-	-	-	-
PWGSC	• PCC is not used.	-	-	-	-	-

A summary of specific pavement design input data is summarized in Table 3. These summaries include the design parameters for both flexible and rigid pavements using AASHTO, as well as factors used for deflection method designs.

Table 3 – Pavement Design Input Data

a) AASHTO Pavement Design Inputs (Flexible)

Agency	Structural Evaluation	Serviceability		Structure Layer Coefficients			Minimum Thickness Specification
				Typical Materials Used	Base Value	Adjusted for Moisture/ Frost?	
British Columbia	• Visual Distress Survey • Coring • FWD	Design Terminal Loss	4.2 2.5 1.7	Asphalt Granular Base Granular Subbase	0.4 0.14 0.10	1.0	100 mm HMA no minimum but typically 300mm CBC and 300 mm of Subbase
Alberta*	• FWD (new & rehab) • IRI (rehab) • Visual Condition (rehab)	Design Terminal Loss	4.2 2.5 1.7	Asphalt Stabilized Base Granular Base Granular Subbase	0.40 0.23 0.14 0.10	1.0 1.0 1.0 1.0	60 mm (new) - 100 mm -
Saskatchewan	• AASHTO is not used	-	-	-	-	-	-
Manitoba	• Benkelman Beam • FWD (limited use)	Design Terminal Loss	4.5 2.5 2.0	Asphalt Wearing Asphalt Base Granular Base Granular Subbase	0.42 0.37 0.14 0.12	1.25	50 - 125 mm 35 mm 100 mm 100 mm
Ontario	• Visual Distress Survey • Coring/Drilling • FWD (new & rehab)	Design Terminal Loss	4.2 2.0-3.0 1.5-2.5	Asphalt Stabilized Drainage Layer Granular Base Granular Subbase	0.42 0.25 0.14 0.09	1.0	40 mm - 150 mm -
Quebec	• Visual Distress Survey • Coring / Boring • FWD (new & rehab) • Benkelman Beam (rarely used)	See table below		Asphalt Granular Base Granular Subbase Other Subbase	0.43 to 0.50 0.09 to 0.19 0.08 to 0.115 0.09 to 0.13	m=0.8	60 mm 150 mm 300 mm 300 mm
New Brunswick ***	• Visual Distress Surveys • Coring • Benkelman Beam (converted from Dynaflect) • RCI readings taken into consideration	Design Terminal Loss	N/A	Asphalt Wearing Asphalt Base Granular Base Granular Subbase	----	No	38 mm 100 mm 150 mm 450 mm
Prince Edward Island	• Visual Distress Survey • Coring / Boring • Benkelman Beam	-	-	-	-	-	-
Nova Scotia	• Visual Distress Survey • Coring • Dynamic Deflection • Pit Excavation	Design Terminal Loss	4.2 2.5 1.7	Asphalt Granular Base Granular Subbase	0.42 0.14 0.08	1.0	100 mm 150 mm 400 mm
Newfoundland	• AASHTO is not used	-	-	-	-	-	-
PWGSC	• Visual Distress Survey • Coring / Boring • FWD (new and rehab) • Benkelman Beam	Design Terminal Loss	4.2 1.5 1.7	HMAC GBC GSC	0.42 0.14 0.10	1.0 1.0 1.0	40 mm 150 mm

* Alberta Currently re-evaluating their rehabilitation options. Taking a closer look at more maintenance and shorter life overlays and other treatments such as Hot-in-Place Recycling and Mill and Inlay.

** Structural Layer coefficient of base and subbase depend on state of stress (thickness over the layer)

*** Our Planning Branch establishes recap priorities based on the following weightings: Road Roughness – 40%, Pavement Distress – 35%,Pavement Strength – 25%. We then obtain priority lists from each of our district offices. Design Branch staff then visits each site and, with the above – noted inputs, develops a list of priority recap projects.

Serviceability goals in Quebec Ministry of Transportation

Road Classification	Projected AADT	Design life (years)	$PSI_{initial}$	PSI_{final}	ΔPSI	Reliability, R (%)
Locale	< 1 000	15	3.8	1.8	2.0	50
	> 1 000	15	3.8	1.8	2.0	66
Collectrice et Régionale	< 2 000	15	4.0	2.0	2.0	66
	2 000-3 000	15	4.0	2.0	2.0	75
	> 3 000	15	4.0	2.0	2.0	80
Nationale	< 5 000	15	4.3	2.3	2.0	80
	5 000-20 000	15	4.3	2.3	2.0	85
	> 20 000	20	4.3	2.5	1.8	90
Autoroute	< 20 000	20	4.3	2.5	1.8	90
	> 20 000	20	4.3	2.5	1.8	95

b) AASHTO Pavement Design Inputs (Rigid)

Agency	Structural Evaluation	Serviceability		28-day Mean PCC Modulus of Rupture	28-day Mean Elastic Modulus of Slab	Load Transfer Coefficient	Overall Drainage Coefficient
British Columbia	PCC is generally not used						
Alberta	PCC is generally not used						
Saskatchewan	PCC is generally not used						
Manitoba	• FWD • Visual Distress Survey	Design Terminal Loss	4.5 2.5 2.0	4,600 kPa	29,000,000 kPa	2.5- 3.2	1.0
Ontario	• Visual Distress Survey • Coring/Boring • FWD (new & rehab)	Design Terminal Loss	4.5 2.0-3.0 1.5-2.5	5,100 kPa	30,000,000 kPa	3.2 – 4.0	0.7 – 1.2
Quebec	• Visual Distress Survey • Coring / Boring • FWD (new & rehab)	Design Terminal Loss	*	5,175 kPa (correction included)	30,000,000 kPa	2.7	On granular: 0.9 On OGDL: 1.0
New Brunswick **	• Benkelman Beam (readings being obtained regularly on existing rigid surfaces) • Visual Distress Survey • No new pavement designs	Design Terminal Loss	-	-	-	-	-
Prince Edward Island	PCC not used						
Nova Scotia	• Visual Distress Survey • Coring • Pit Excavation • Plate Loading	Have Not Actually Designed a Rigid Pavement					
Newfoundland	PCC not used						
PGWSC	PCC is generally not used						

* PSI, same table as for flexible pavements except R = 50% for every project (ref. New York)
** See Comment for Table 3a.

c) Asphalt Institute Deflection Method and CGRA Surface Deflection Method

Agency	Deflection Adjustment Methods/Factors		
	Temperature	**Subgrade Adjustment (Spring Correction Factors)**	**Threshold Deflection**
British Columbia	-	Spring adjustment based on frost probes and historical data	Maximum allowable deflection based on roadway category
Alberta	• Procedure not used by province.	-	-
Saskatchewan	• Temperature adjustment to 20 degrees Celcius	• During April – June, each Rehab Candidate is beamed as follows: • 1 Concentrated Run (~beam every 200 m) • Bi-weekly Skeleton Runs (~beam every 2 km) • Arithmetic Adjustment done to concentrated run to account for max deflection during skeleton run OR: • Percentage Adjustment done to concentrated run to account for max deflection during skeleton run	-
Manitoba	• CGRA	None. Spring testing	Statistical Value M+ 2x
Ontario	• Corrected to 20°C	1.5	Obtained from design curves
Quebec	• Corrected to 20°C	1.6	Secondary roads: TD = 25.074 ESALs $^{-0.2553}$ Major roads: TD = 16.266 ESALs$^{-0.2196}$
New Brunswick	-	Planning Branch incorporates seasonal correction factors in our design deflections	Arterials 300 µm Collectors 350 µm Locals 400 µm
Prince Edward Island	-	1.5	Arterials 760 µm Collectors 1500 µm
Nova Scotia	• Corrected to 15 °C	1.00 – 2.5 Varies Regionally*	Freeways 320 µm Arterials and collectors 370 µm Local roads 480 µm
Newfoundland	• CGRA	1.2 – 1.6	Maximum Tolerable Deflection (MTD), based on Traffic
PWGSC	• YES	Yes, factor depends on area	Depends of geographical area

* Control sections monitored annually for spring peak deflections and used to calculate spring correction factors.

The "AASHTO" 2002 GUIDE – WHAT TO EXPECT

The overall objective of the AASHTO 2002 Guide is to provide the highway community with a state-of-the –art practice tool for the design of new and rehabilitated pavement structures, based on mechanistic-empirical principles, accompanied by the necessary computational software. This objective will be accomplished through developing: (a) the 2002 Guide based on pavement-design procedures that use existing mechanistic-empirical technologies, including a methodology for calibration, validation, and adaptation to local conditions; (b) user-oriented computational software and documentation based on the 2002 Guide. In addition, the Guide will be accompanied by plans and materials for implementation and training services to facilitate adoption of the guide and associated software and by strategies to promote national interest and maximize acceptance by the transportation community.

The benefits of the 2002 AASHTO Guide include the following:

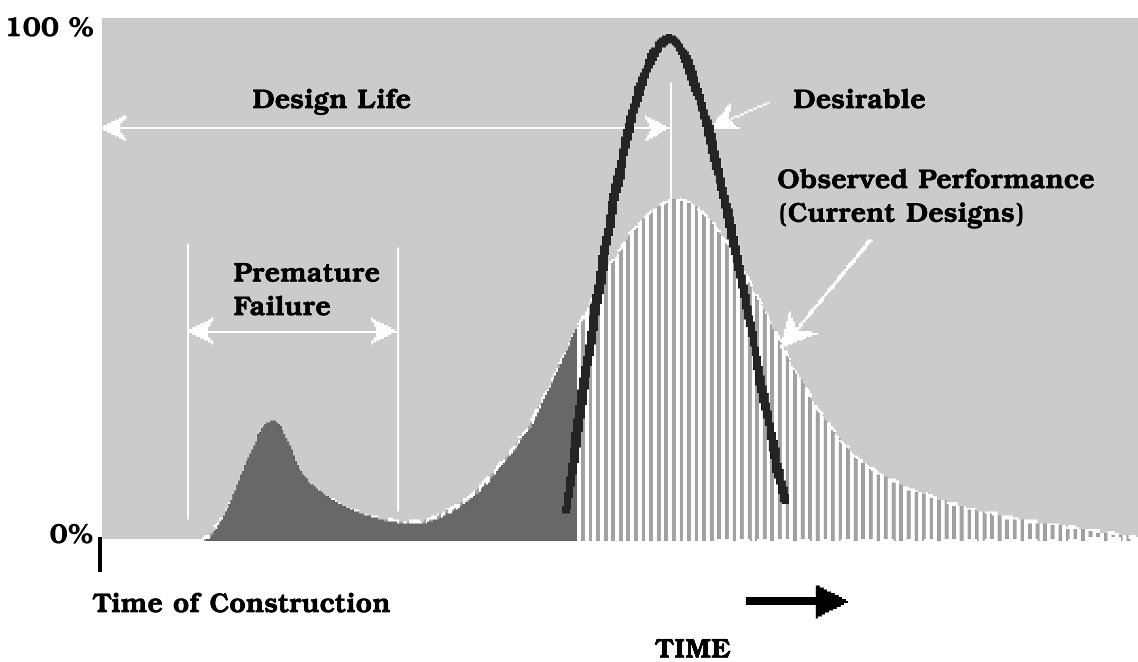
- Inherent variations in materials, traffic and environmental factors and in construction processes are considered in the design analysis such that there are rational relationships between construction and materials specifications and the design of the pavement structure. The improved relationship between design and real pavement life means agency managers will be better able to weigh life-cycle costs and cash flow in their decision-making processes.
- Cost-responsibility studies will be enhanced by the improved ability to evaluate the consequences of new pavement loading conditions and the damaging effects of increased loads, high tire pressure and multiple axles.
- Designers will be better able to use available and evolving materials and, in many cases, the expected benefits of those materials will be modeled and evaluated without the expense of elaborate testing programs.
- Improved environmental data analysis will permit a better assessment of the effects of aging as well as that of the freeze-thaw cycle and the provision of improved drainage.
- Unlike typical regression-based empirical procedures, mechanistic concepts are generally applicable in such a way that a full range of future enhancements that can be readily developed and implemented. Therefore, the new procedure will not become outmoded with changes in construction materials, traffic patterns, vehicle types or tire types and configurations.

Another major extrapolation is design life. Because of the short duration of the road test, the long-term effects of climate and aging of materials were not addressed. The AASHO Road Test was conducted over 2 years, while the design lives for many of today's pavements are 20 to 50 years.

The AASHTO 2002 design guide and its associated software and training courses are expected to provide pavement designers and government agencies not only in the United States, but also in Canada, with a strong set of tools to help affectively manage road infrastructure.

Figure 2: Potential Pavement Cost Savings

Percentage of Projects Rehabilitated



SUMMARY

While many pavement design procedures are utilized by Canadian highway agencies, most use the AASHTO pavement design methodology for either primary pavement design or to verify designs. While there is some variation in the individual parameters used by the agencies for AASHTO designs, the majority of values are similar for similar types of materials. The majority of Canadian highway agencies use a 20 year initial flexible pavement design life and use a 30 year analysis period for life-cycle costing. For rigid pavements, the design life and analysis period for life-cycle costing is 30 years. Discount rates for life-cycle costing vary from 4 to 7 percent.

Several agencies are actively using Falling Weight Deflectometer testing and mechanistic-empirical based pavement design procedures for pavement rehabilitation projects. The pending release of the AASHTO 2002 design procedure through NCHRP 1-37A will likely result in the more widespread use of mechanistic-empirical pavement design throughout Canada.

FOR MORE INFORMATION

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