Report Number 1999-34

MINNESOTA DEPARTMENT OF TRANSPORTATION

Minnesota Low Volume Road Design 1998

Research

LRRB
Minnesota Local Road Research Board

MnROAD
Office of Minnesota Road Research

FUNDING ACKNOWLEDGEMENT

This project was conducted with funding provided by the Minnesota Local Road Research Board (LRRB). The LRRB's purpose is to develop and manage a program of research for county and municipal state aid road improvements. Funding for LRRB research projects comes from a designated fund equivalent to 1/2 of one percent of the annual state aid for county and city roads.

4360 9981

Technical Report Documentation Page

1. Report No. MN/RC - 1999-34	2.	3. Recipients Accession No.	
4. Title and Subtitle MINNESOTA LOW VOLUME ROAD DESIGN 1998		5. Report Date September 1999	
		6.	
7. Author(s) Eugene L. Skok David E. Newcomb David H. Timm		8. Performing Organization Report No.	
9. Performing Organization Name and Address University of Minnesota Department of Civil Engineering 122 CivE Bldg., 500 Pillsbury Dr., S.E. Minneapolis, Minnesota 55455-0220		10. Project/Task/Work Unit No.	
		11. Contract (C) or Grant (G) No. 74708 TOC # 55	
12. Sponsoring Organization Name and Address Minnesota Department of Transportation 395 John Ireland Boulevard, Mail Stop 330 St. Paul, Minnesota 55155		13. Type of Report and Period Covered Final Report 1997 - 1999	
		14. Sponsoring Agency Code	
15. Supplementary Notes			

16. Abstract (Limit: 200 words)

In this project, researchers examined the current practices that local agencies use and evaluated the thickness design procedures by comparing predicted lives for the current designs with those obtained from the mechanistic-empirical design procedure ROADENT.

Researchers determined current practices by sending a questionnaire to all cities and counties and visiting two counties and one city. In general, the questionnaire responses show that cities and counties use a variety of practices for the design, construction, and management of low volume pavements in Minnesota.

Relative to the current designs, ROADENT predictions of fatigue behavior require a thicker design for medium and high-traffic roads than the Soil Factor design, and a thicker design for high-traffic roads than the R-Value procedure. The required thicknesses based on development of rut depth are not consistent with the current designs.

To develop consistent procedures for the design, construction, and management of low volume roads in Minnesota, the report recommends converting the differences in performance predictions to thicknesses through the use of existing procedures and the mechanistic-empirical procedure; developing a best practices manual; and implementing the design procedure and manual.

17. Document Analysis/Descriptors Pavement design Flexible pavement design	Low volume road pavement design ROADENT	18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 78	22. Price

MINNESOTA
LOW VOLUME
ROAD DESIGN
1998

Final Report

Prepared by

Eugene L. Skok
David E. Newcomb
David H. Timm

University of Minnesota
Department of Civil Engineering
122 CivE Building
500 Pillsbury Dr. SE
Minneapolis, MN 55455-0220

September 1999

Published by

Minnesota Department of Transportation
Office of Research Administration
200 Ford Building Mail Stop 330
117 University Avenue
St. Paul, Minnesota 55155

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Local agencies in Minnesota currently have two thickness design procedures available to them: the Soil Factor design (1) which was developed in 1954 and the R-Value design (2) which has been used by the Minnesota Department of Transportation (Mn/DOT) since about 1970. These procedures have evolved over the years; however, changing traffic and technology plus data from the Minnesota Road Research Project (Mn/ROAD) require that the procedures be evaluated and updated.

Specifications, construction procedures and pavement management practices are also quite variable from one agency to another. The purpose of this project is to determine the current practices used by local agencies and evaluate the thickness design procedures by comparing predicted lives for the current designs with those obtained from the Mechanistic-Empirical design procedure developed at the University of Minnesota (ROADENT) (8).

Current practices were determined by: 1) sending a questionnaire to all cities and counties and 2) visiting two counties and one city. Sixty-four (64) out of 87 counties responded and 50 of the 120 cities responded. The responses indicate that:

- Most cities use the R-Value procedure, some use typical cross sections; most counties use the Soil Factor procedure
- Compaction subcuts of various depths are used
- Mn/DOT mixes 2331 and 2340 are mostly used
- Rehabilitation times for new hot mix asphalt pavements vary from five years to 30 years with the median between 20 and 25 years
- Rehabilitation times for overlaid pavements are between five and 25 years with the median time less than ten years for cities and about 15 years for counties
- Performance problems are mostly structural
- About 1/3 of the counties and 1/2 of the cities have pavement management systems
- Essentially all counties and 2/3 of the cities apply spring load restrictions; however, the timing and enforcement are variable.

In general, the questionnaire responses show that there is a variety of practice used for the design, construction and management of low volume pavements in Minnesota.

The mechanistic-empirical design procedure calculates strains in a pavement section assuming the pavement is an elastic layered system. Moduli of each layer must be determined for various conditions in-situ. The calculated strains are then correlated with load cracking (horizontal tensile strain in the asphalt layer) and rut depth development (vertical compressive strain on the embankment soil). Predictions of performance with this program are based on conditions observed and strains measured at Mn/ROAD. Variation in the layer properties throughout the year are also based on backcalculation of falling weight deflectometer (FWD) data from Mn/ROAD. Soil factor and R-value designs have been compared to the mechanistic-empirical design by: 1) converting soil factors and R-values to moduli for the soils and 2) converting the annual average daily traffic (AADT) and heavy commercial average daily traffic (HCADT) values to equivalent single axle loads (ESAL) for the Soil Factor Design.

Relative to the current designs, ROADENT predictions of fatigue behavior:

1. requires a thicker design for medium and high traffic roads than the Soil Factor design
2. requires a thicker design for high traffic roads than the R-Value procedure.

The required thicknesses based on development of rut depth are not consistent with the current designs. Chapter 4 includes more details on these design comparisons.

RECOMMENDATIONS:

To develop consistent procedures for the design, construction and management of low volume roads in Minnesota, it is recommended that:

1. Differences in performance predictions be converted to thicknesses by using the existing procedures and the mechanistic-empirical procedure. The version of ROADENT used for this report does not include reliability. Thickness comparisons should be based on the next version of ROADENT which will include the reliability factor. The resulting designs then need to be field checked using city and county roads for which design and performance information is available.
2. A best practices manual be developed. Include recommended procedures for the design, construction and management of the low-volume road system in Minnesota.
3. Implementation of the design procedure and manual needs to be accomplished so that the recommended procedures are put into practice as soon as possible.

CHAPTER 1

INTRODUCTION

The thickness design procedures used for low volume roads in Minnesota have evolved over many years. The Soil Factor Design procedure which is in the State Aid Manual (1) was the procedure developed in the 1950's and used for all flexible pavements in Minnesota until the 1970's when Mn/DOT started to use the R-Value design. The Soil Factor Design results in a Granular Equivalent (G.E.) thickness based on the type of soil for seven levels of traffic based on ADT and HCADT. The R-Value Design which is in the current Mn/DOT Road Design Manual (2) uses the laboratory-based or estimated R-Value to evaluate the soil. There is some correlation between R-Value and Soil Factor. There have been comparisons made between design thicknesses for the two procedures (3). Generally the R-Value procedure requires greater thicknesses, especially at higher traffic levels. The purpose of this report is to review these design procedures in light of performance observed at Mn/ROAD and summarize current practices used by local agencies in Minnesota.

This report includes the following:

1. A brief presentation of the Soil Factor and R-Value design procedures as used in Minnesota.
2. A summary of local design practices for not only thickness design, but also for specifications, construction practices, and performance expectations. These all need to be tied together to get a good indication of the design practice used by local agencies.
   A questionnaire was distributed to 120 cities and 87 counties in Minnesota. Replies have been tallied and reviewed in Chapter 3 of this report. There are a number of design procedures and applications used by the local agencies. Two counties and one city were also visited. Their replies and discussions have been included with the questionnaire replies.
3. A comparison between design thicknesses resulting from the Soil Factor and R-Value

design procedures. The mechanistic-empirical design procedure based on life predictions (pavement performance) from Mn/ROAD was used for comparisons.

4. Recommendations are made for continuing the evaluations to review thicknesses determined from the mechanistic procedure and developing a best practices manual to establish the most efficient use of existing materials.

CHAPTER 2

CURRENT MINNESOTA PAVEMENT THICKNESS DESIGN PROCEDURES

INTRODUCTION

There are two flexible pavement thickness design procedures now used in Minnesota. In addition some pavements, especially at the local level, are designed by experience based on what has worked in the past. The two formal thickness design procedures are the Soil Factor Design found in the Mn/DOT State Aid Manual (1) and the Stabilometer R-Value Design found in the Mn/DOT Design and Geotechnical Manuals (2 and 3). The Soil Factor procedure is a carryover from the Mn/DOT procedure used before the R-Value was adopted in the early 1970's. In this section both procedures are presented along with the factors required for thickness determination.

SOIL FACTOR DESIGN

Since 1954 some pavements in Minnesota have been designed using a chart similar to the one shown as Figure 1. This is the 1998 version which uses metric units. The chart uses seven traffic categories and types of embankment to determine a thickness in terms of Granular Equivalent (G.E.). Each design also has a specified maximum spring axle load in tonnes (1.1 tons).

The traffic factors are Average Daily Traffic (ADT) and Heavy Commercial Average Daily Traffic (HCADT). The ADT and HCADT are two-way values. The ADT includes all vehicles and the HCADT includes all trucks with six or more tires; thus HCADT does not include cars, small pickup and panel-type trucks. The ADT and HCADT normally used for design are values predicted for 20 years in the future. Local conditions must be considered and the projected value may either be increased or decreased based on predicted future use of the road.

As noted in Figure 1 a soil factor of 100% represents an A-4 or A-6 soil. Stronger soils have soil factors less than 100% and weaker soils have soil factors greater than 100%. There are ranges of percents shown for A-1, A-2 and A-4 soils. Therefore, it is possible to use some judgment relative to the capabilities of the soils after evaluating drainage and other design considerations.

6.4 TON - LESS THAN 400 ADT

S.F.	Minimum Bit. G. E.	Total G. E.
50	75	180
75	75	235
100	75	290
110	75	310
120	75	330
130	75	350

8.2 TON -150-300 HCADT

S.F.	Minimum Bit. G. E.	Total G. E.
50	175	350
75	175	440
100	175	525
110	175	560
120	175	595
130	175	630

8.2 TON - MORE THAN HCADT

S.F.	Minimum Bit. G. E.	Total G. E.
50	200	510
75	200	660
100	200	815
110	200	875
120	200	935
130	200	995

6.4 TON - 400 - 1000 ADT

S.F.	Minimum Bit. G. E.	Total G. E.
50	75	225
75	75	300
100	75	440
110	75	475
120	75	515
130	75	550

8.2 TON - 300-600 HCADT

S.F.	Minimum Bit. G. E.	Total G. E.
50	175	400
75	175	515
100	175	625
110	175	670
120	175	715
130	175	760

MATERIAL	TYPE OF MATERIAL	GRAVEL EQUIV. mm/mm
Plant-Mix Bit.	Type 41, 61	2.2
Plant-Mix Bit.	Type 31	2.0
Road-Mix Bit.	Spec. 2321	1.4
Bit. Treat. Base	Spec. 2204	1.2
Aggregate Base	(Cl. 5 & 6) 3138	1.0
Aggregate Base	(Cl. 3 & 4) 3138	0.8
Select Granular	Spec 3149.2B	0.5

8.2 TON - LESS THAN 150 HCADT

S.F.	Minimum Bit. G. E.	Total G. E.
50	175	255
75	175	300
100	175	440
110	175	475
120	175	515
130	175	550

8.2 TON - 600 - 1100 HCADT

S.F.	Minimum Bit. G. E.	Total G. E.
50	200	465
75	200	595
100	200	725
110	200	780
120	200	830
130	200	885

AASHTO SOIL CLASS	SOIL FACTOR (S.F.) %	ASSUMED R-VALUE
A - 1	50 - 75	70 - 75
A - 2	50 - 75	30 - 70
A - 3	50	70
A - 4	100 - 130	20
A - 5	130 +	--
A - 6	100	12
A - 7 - 5	120	12
A - 7 - 6	130	10

NOTE: If 9.1 t design is to be used, see Road Design Manual 7-50 (10) & 7-50 (12). For full depth bituminous pavements, see Road Design Manual 7-50 (12).

Figure 1. Flexible pavement design using soil factors. Gravel equivalencies (GE) for various soil factors (SF). Units of mm for GE.

The granular equivalent defines a pavement section by equating the thickness of each layer to an equivalent thickness of granular base material (see Equation 1). In Minnesota, this is a Class 5 or Class 6 gravel or crushed base material. The granular equivalent factors are also shown on the right side of Figure 1. Minimum bituminous and total granular equivalent are shown for each traffic category. The total granular equivalent can be defined using Equation 1.

$$\text{G.E.} = a_1D_1 + a_2D_2 + a_3D_3 \qquad (1)$$

where: D_1 = thickness of asphalt mix surface, mm.

D_2 = thickness of base course, mm.

D_3 = thickness of subbase course, mm.

a_1, a_2, a_3 = G.E. factors listed in Figure 1.

The required design thicknesses are listed in two categories (minimum bituminous G.E. and total G.E.). The maximum granular base thickness can be calculated by subtracting the minimum bituminous G.E. from the total G.E. Other design combinations of bituminous and granular materials can be determined using the G.E. factors.

R-VALUE DESIGN

The R-Value design chart shown in Figure 2 is in the Mn/DOT Design and Geotechnical Manual. The procedure uses the R-Value measured with a laboratory test or estimated from the soil type or classification. The R-Value laboratory procedure used in Minnesota is presented in Reference 3. An exudation pressure of 1655 kPa (240 psi) is used for design. Predictions of R-Value from soil classification are presented in Chapter 4 of this report.

The traffic is evaluated in terms of 80-kN (18,000-lb) equivalent standard axle loads (ESAL's). For a particular road to be designed, the ESAL's are estimated for a design lane in one direction.

The thickness is determined in Granular Equivalent in inches. Granular equivalent factors (a_1, a_2, a_3) for the R-Value design are listed in Figure 1. Equation 1 is used to calculate the total

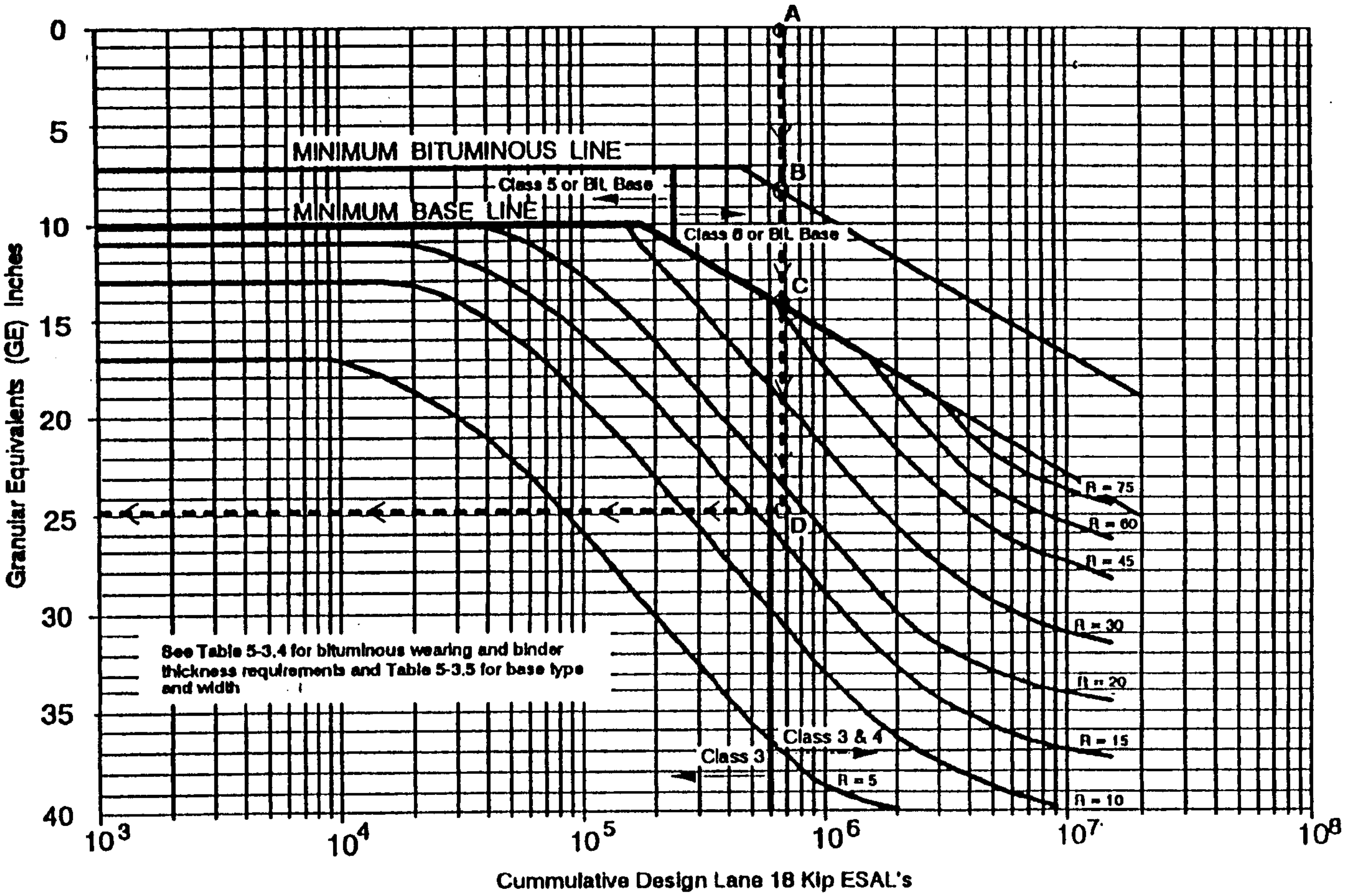


Figure 2. Bituminous pavement design chart (aggregate base).

Granular Equivalent the same as for the Soil Factor design.

Minimum bituminous and base granular equivalents are plotted on the chart. The minimum bituminous and bituminous surface plus base thicknesses can be calculated using the appropriate G.E. Factors.

Design thicknesses for various traffic levels and soil types will be determined using these design charts. Expected design lives using the mechanistic-empirical design procedure (ROADENT) for thicknesses determined from each of the procedures will then be predicted in Chapter 4.

CHAPTER 3

SURVEY OF LOW-VOLUME ROAD PAVEMENT DESIGN PRACTICE IN MINNESOTA

In July, 1998, a questionnaire was sent to the 87 county highway departments and 120 city and municipality public works departments in Minnesota. The purpose was to gain insights into actual local pavement design and construction practices along with what parameters are used along with how they are determined for specific design applications.

The items covered were:1) thickness design, 2) specifications, 3) construction, 4) performance and 5) load restrictions as part of the management of the road system. Copies of the four-page questionnaire with the number of replies for each question are attached as Appendix A. A total of 114 replies were received (64 counties and 50 cities). This helps establish the present state-of-the-practice (technology) in Minnesota.

The summary presented is based on the total responses only. The number of agencies replying with respect to a given procedure is presented. The replies have been retained so it will be possible to regionalize or categorize the responses if desired. In some cases there are more responses noted than questionnaires returned because most agencies used more than one procedure depending on traffic level, have more than one soil type in their area, etc. The summaries discussed in this chapter are numerical only and do not cover every question in detail.

Figures A1 and A2 of Appendix A show the replies for each of the items from the counties and the cities respectively. The following are brief discussions of the response summaries in each category.

DESIGN

The numbers for each paragraph refer to the item numbers on the questionnaire.

1. Over ½ of the cities use the soil R-Value design procedure. A number of agencies

use the R-Value procedure for high traffic roads only. Figure 3 shows that:

> Most cities use R-Value design
> Most counties use Soil Factor design
> Some design only for high traffic
> Two cities and one county use typical cross sections.

2. Figure 4 shows the distribution of soils throughout Minnesota by the cities and counties, respectively. The most predominant soils are A-6, A-4, A-7-6 and A-7-5 types respectively. The occurrence of A-5 soils is a mystery. The type of soils reported reflect the anticipated soil types throughout the state with the exception of A-3 and A-5 soils. There are generally more counties with A-3 and granular soils than indicated(1). Also there have been no laboratory A-5 soil classifications over the past 40 years.

3. Generally, soils are determined by a combination of sampling, classification and what materials have been encountered previously. Very few use the USDA maps.

4. Figure 5 shows that about half of the cities use compaction subcuts and that 90% of the counties do as well. In rural areas compaction subcuts are very important because they result in more uniform soil conditions and support and thus a smoother ride.

   Figure 6 shows the depth of compaction subcuts used by cities and counties. Most counties use 0.6-m (2-ft) subcuts and most cities use 0.3-m (1-ft) subcuts while some use 0.6-m (2-ft). The greater need for uniformity makes it necessary for deeper subcuts on county roads.

5. and 6. Figure 7 is a summary of the responses to what traffic input is used. Combinations of ADT and HCADT obtained from Mn/DOT are used to calculate

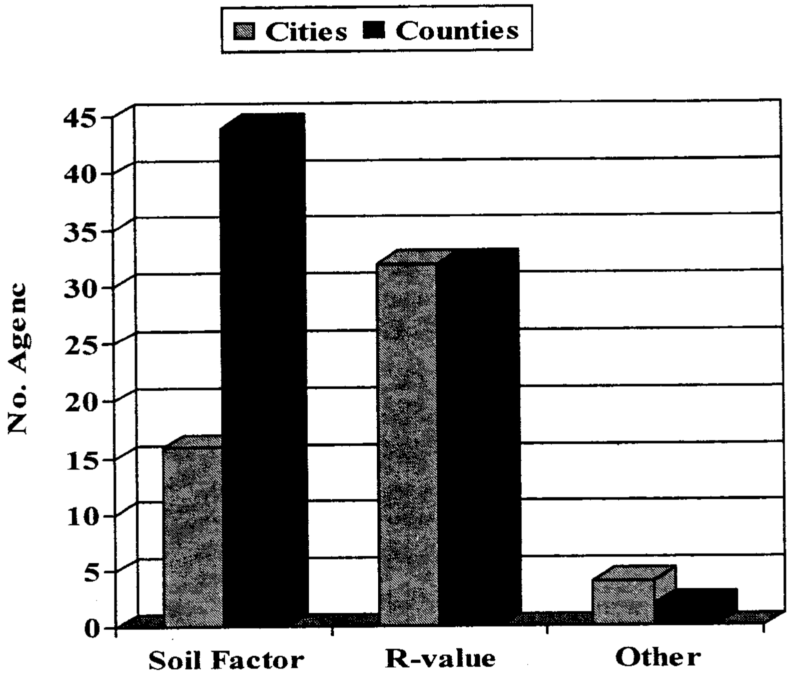


Figure 3. Use of current Minnesota design methods.

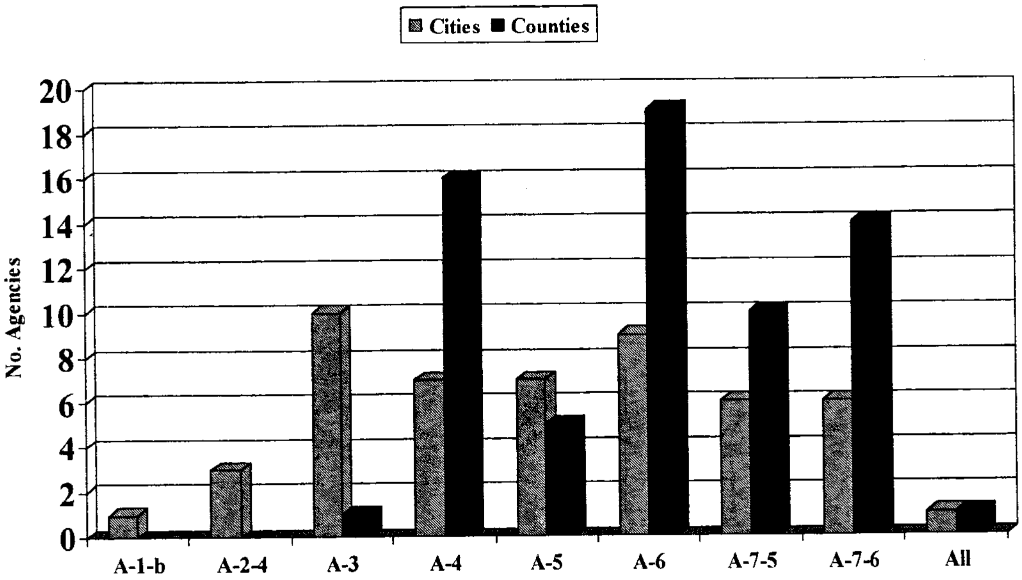


Figure 4. Predominant soil types.

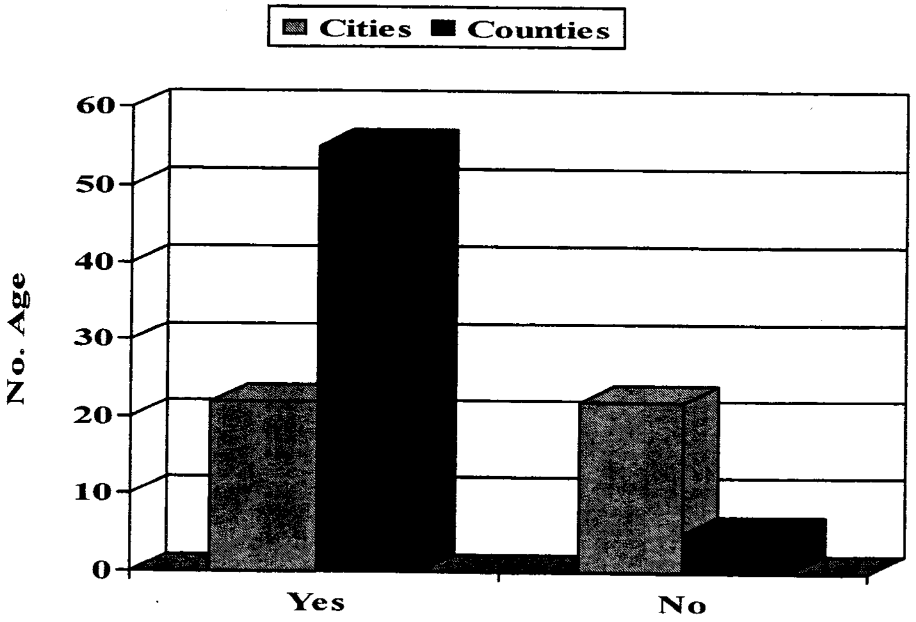


Figure 5. Use of compaction subcuts

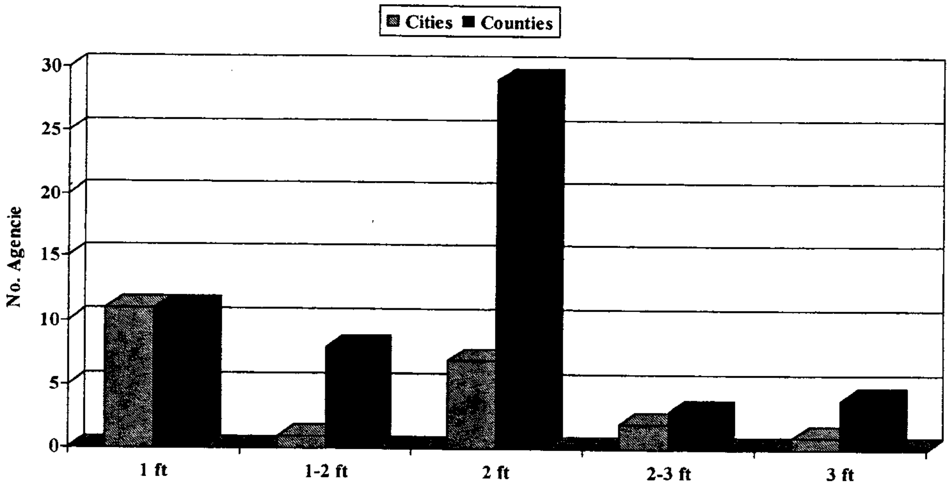


Figure 6. Depth of compaction subcuts.

ESAL for traffic input. Classification of traffic with automated devices is used by three agencies. Mn/DOT through the State Aid and Traffic Offices is developing procedures to determine vehicle factors for estimating ESAL when the percents of various vehicles are known. ADT only can be used for a given location if the distribution of vehicle types and axle weights are consistent.

7. Essentially all counties use ditches of some configuration as a drainage feature. About 1/3 use edge drains, but only five use a drainage layer. Edge drains generally should not be used unless a good drainage layer is incorporated to transmit water to the pavement edges.

SPECIFICATIONS

1. Figure 8 illustrates the number of agencies using the various Mn/DOT bituminous mixture specifications. Most cities use Mn/DOT 2331, fewer use 2340, and fewer yet use 2350 (the VMA Spec). Most counties use the 2340 with fewer using 2331 and fewer yet using 2350. Only one county and one city are using the Superpave (2360) specification. The 2350 and 2360 specifications have been developed by Mn/DOT during the last two years and the local agencies are just starting to use them. Mn/DOT is using the 2360 specification only on roads with more than 3 million ESAL. This criterion would include only a very small percentage of city and county roads.

2. Figure 9 shows that 50 of the counties and 27 cities allow RAP (Recycled Asphalt Pavement) in their mixes. However, three allow it only in leveling, five in base mixes and one on shoulders only.

3. Figure 10 shows that the predominant granular base specification for both cities and counties is Mn/DOT 3139, Class 5 with Class 2 and 3 used by a few counties as subbase. Class 6 is used by only two counties and one city.

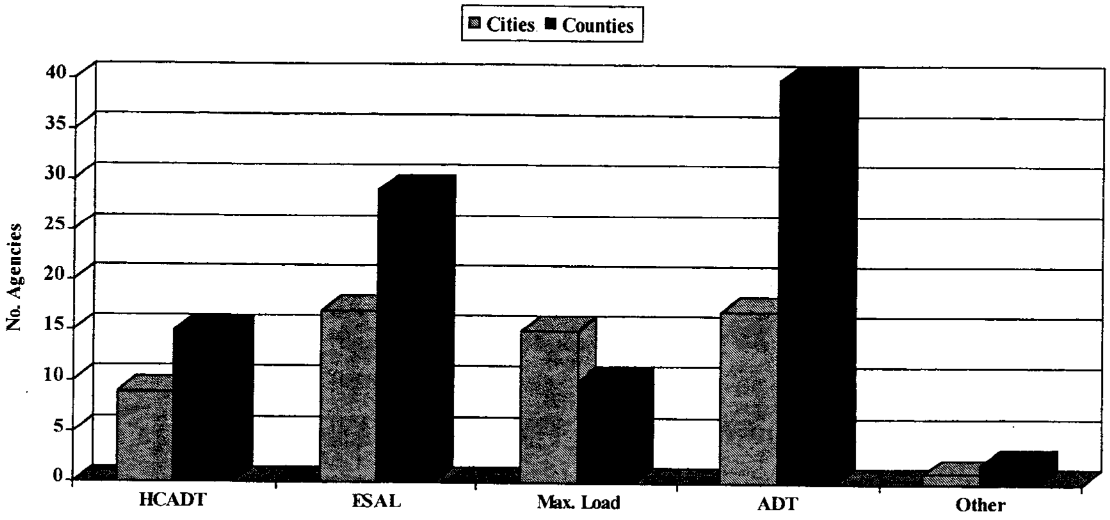


Figure 7. Traffic input for design methods.

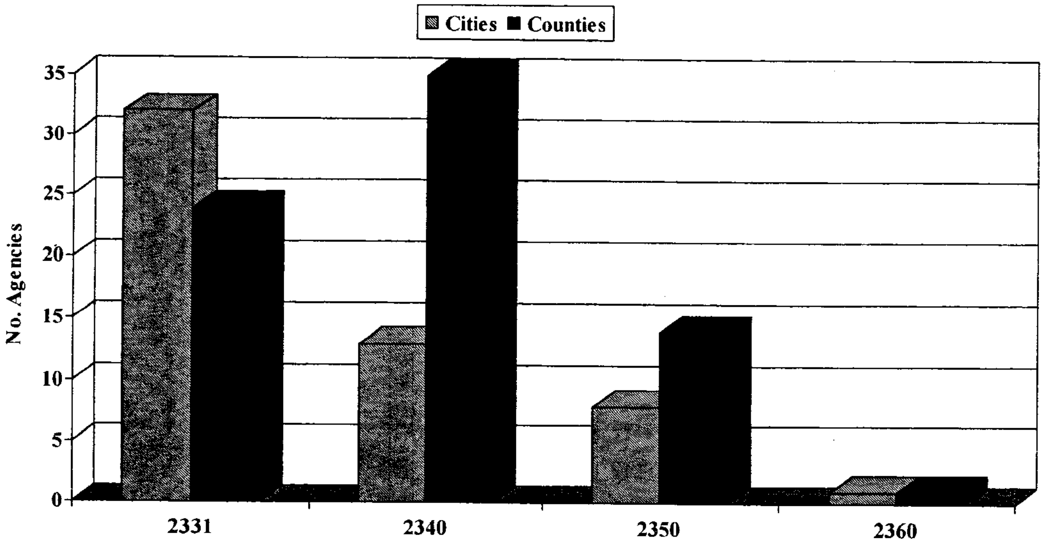


Figure 8. Asphalt specifications.

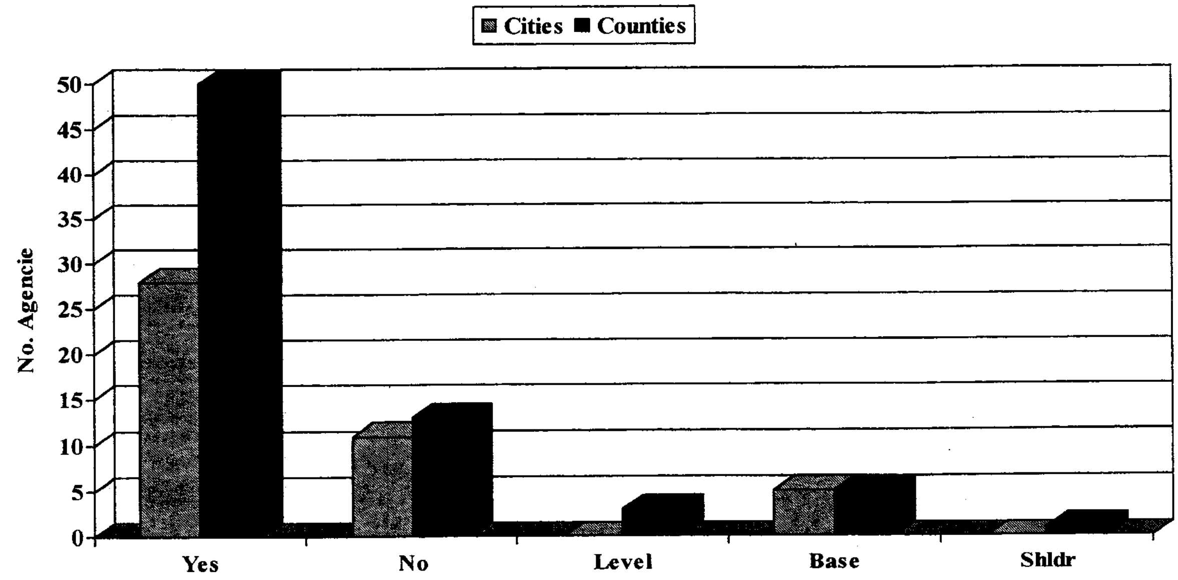


Figure 9. Use of recycled asphalt pavement (RAP).

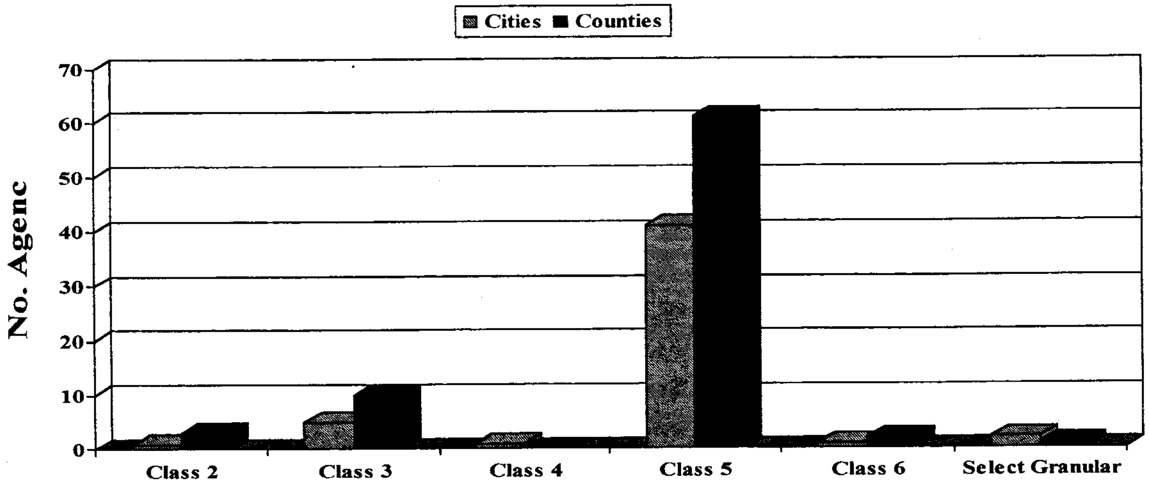


Figure 10. Granular base/subbase specifications.

4. As shown in Figure 11, 52 of the counties and 22 cities use ordinary compaction to control embankment construction, and 23 of the cities and only six counties use specified density. Twenty-three counties use test rolling, and 20 use the standard Proctor (95%) for specified density control.

   Fourteen counties use a 45 tonne (50-ton) roller and Mn/DOT specification 2111. Two counties use a loaded truck and two use a scraper as the load for test rolling.

   Ordinary compaction works well only with a very experienced inspector; specified density gives a more definitive indication of density at a given location.

CONSTRUCTION

Soils

1. Soil testing during construction is summarized in Figure 12. The cities control embankment soil construction using in-situ density (35) moisture content (26) and classification/gradation control (22). However, of the counties, only eight use density, seven use moisture control and 32 check only gradation for uniformity. Thirteen counties do not use any testing for soils construction control.

2. The in-situ density is measured using nuclear measurements more than sand cone (29 - 13) for cities. Consultants do most of the inspection (33), followed by the agencies (11) and the contractor (3).

   About half of the counties use nuclear gauges and half sand cone to measure in-situ density. Seventy-five (75) percent of the counties do their own inspection testing.

Granular base/subbases

3. The number of agencies using various maximum specified lift thicknesses for granular materials are plotted in Figure 13. The maximum lifts range from 50 mm (2 in.)

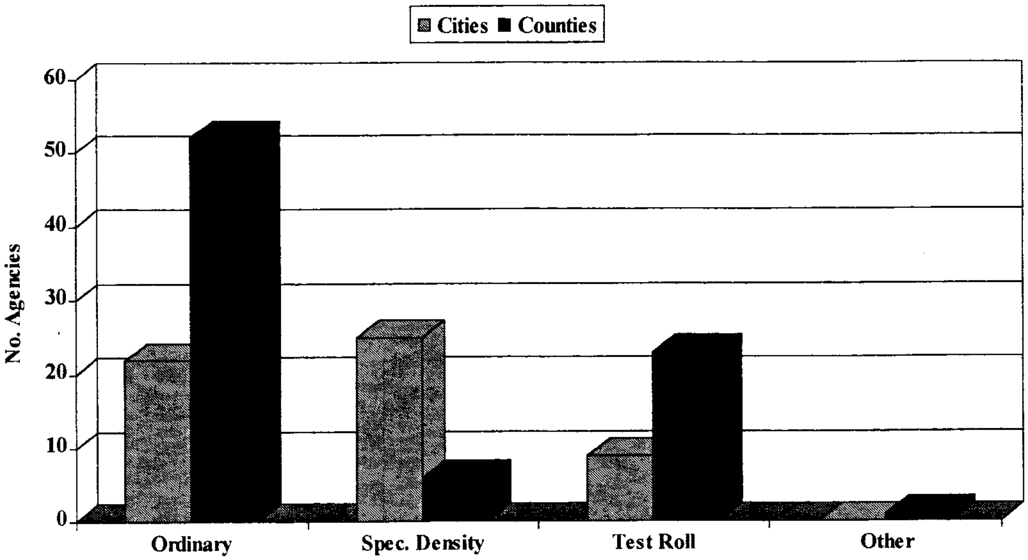


Figure 11. Types of embankment specifications.

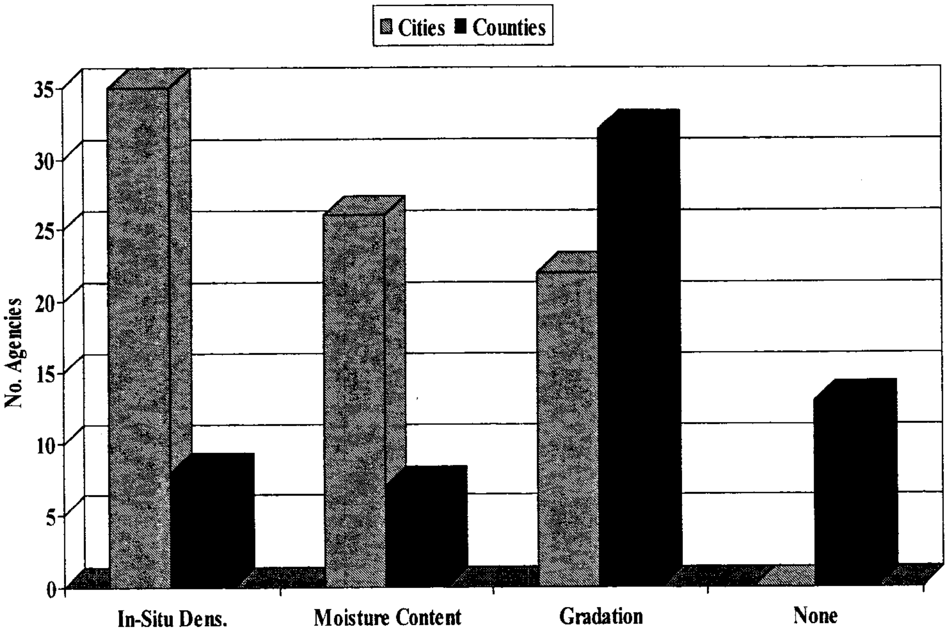


Figure 12. Typical soils testing required during construction.

to 400 mm (16 in.). One agency indicated each lifts of 230, 305, 350, 400-mm (9, 12, 14, and 16 in.). These may have misinterpreted the question. Most of the counties indicated a 75-mm (3-in.) maximum whereas most of the cities stated 150-mm (6-in.) with some 200-mm (8-in.) maximum thicknesses used.

4. and 5. Figure 14 illustrates the tests run during construction of granular bases/sub-bases. A majority of the cities run density and gradation control tests whereas a majority of the counties (54) control based only on gradation tests. One city uses test rolling.

Thirty-three of the agencies use nuclear density devices and 17 use the sand cone.

Fifty-four counties and 11 cities do their own testing whereas three counties and 36 cities have consultants do their testing and inspection. The contractor does the testing for seven counties and two of the cities.

Asphalt Layers

6. Only eight of the 61 counties responding and three of the 46 cities responding use a prime coat on granular bases before paving.

Most counties (50) specify maximum lift thicknesses between 40 mm (1-1/2 in.) and 75 mm (3 in.) for bituminous base and binder layers. For the surface mixes a maximum lift of 40 mm (1-1/2 in.) is used.

The maximum lift for 18 cities was between 50 mm (2 in.) and 75 mm (3 in.) and maximum thicknesses for binder courses were mostly 50 to 100 mm (2 to 4 in.). Three cities allowed 75-mm (3-in.) lifts and one allowed 100 mm (4 in.).

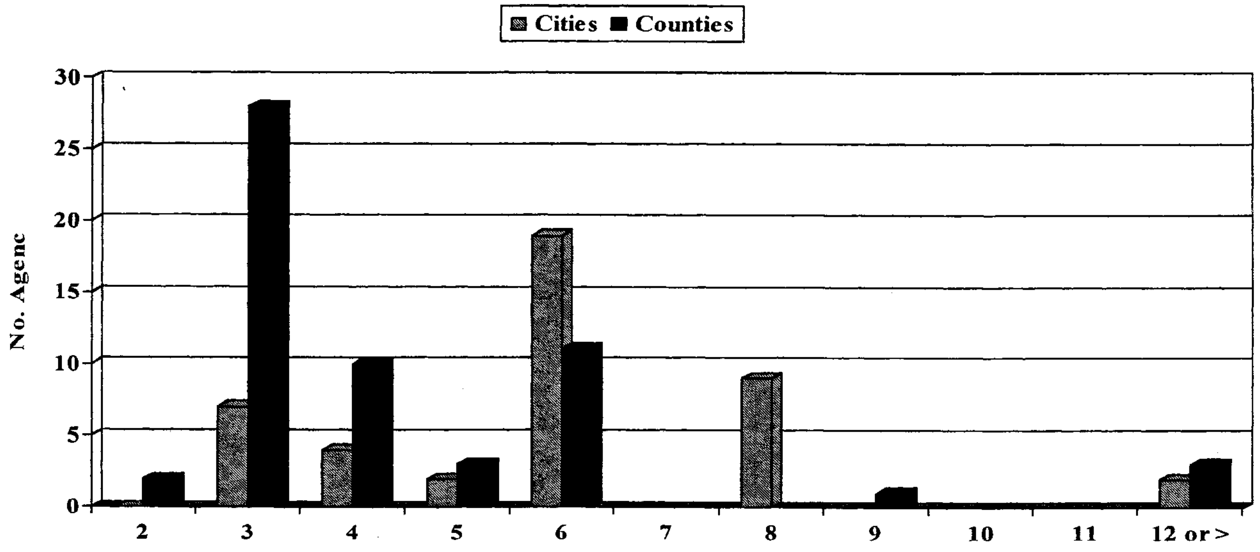


Figure 13. Aggregate base lift thickness, in.

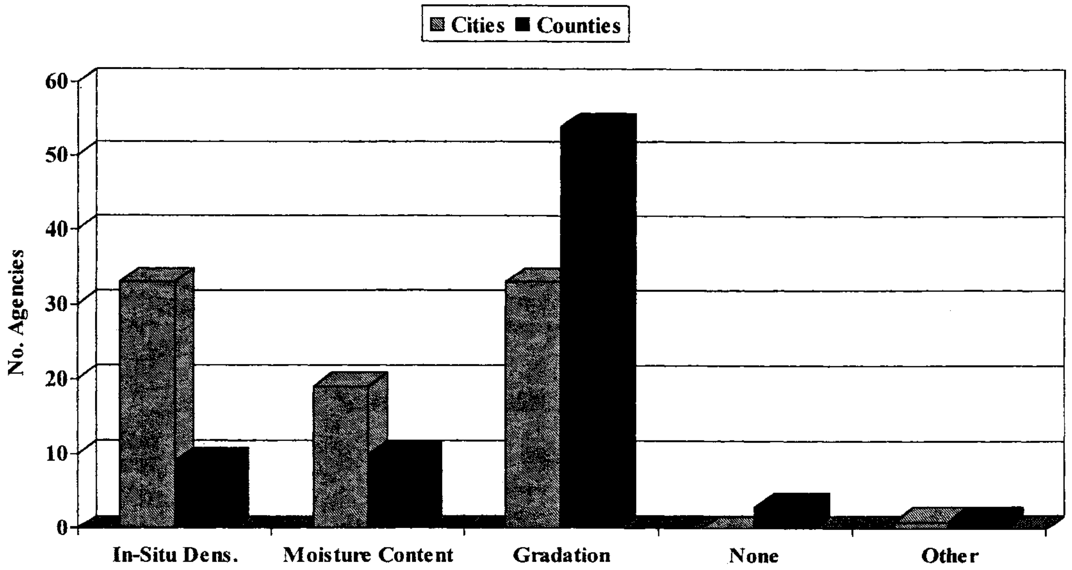


Figure 14. Granular base testing required

7. Figure 15 shows that 18 cities use Quality Management and 27 do not, whereas 44 counties use QM and 20 do not.

PERFORMANCE

1. Figure 16 shows that a majority of the counties (39) at least partially use ride to evaluate performance. Condition surveys are used by 27 counties and 27 cities; 14 counties and only two cities use deflection testing. A combination of these factors is used by most agencies.

2. Twenty-two of 50 cities have a pavement management system. Nine have the Braun ICON system, five the PMS/Stanley and two the Wisconsin Paver system. Only 20 of the 64 counties responding have a pavement management system. Seven have the cartegraph system, three developed in-house systems and three use the ICON software.

3. Figure 17 shows the length of time experienced before rehabilitation is required on a new pavement. The city experience ranges from five years (1) to 50 years (1). The time most (9) indicated was 25 years. Twenty years was approximately the median time for cities. Two-thirds of the expected lives were between 15 and 25 years.

   For the county respondents the range of expected life for a new asphalt pavement is from 5-7 years up to 30-40 years. Only two counties reported lives less than seven years and two 30 years or more. The majority of lives reported are also between 15 and 20 years.

4. Figure 18 shows the life expected from asphalt overlays. Most of the cities (27/42) indicated overlay lives of 10-15 years. In Mankato the expected life is related to total traffic. An overlay on a high traffic road (> 10,000 ADT) is expected to last 5-10

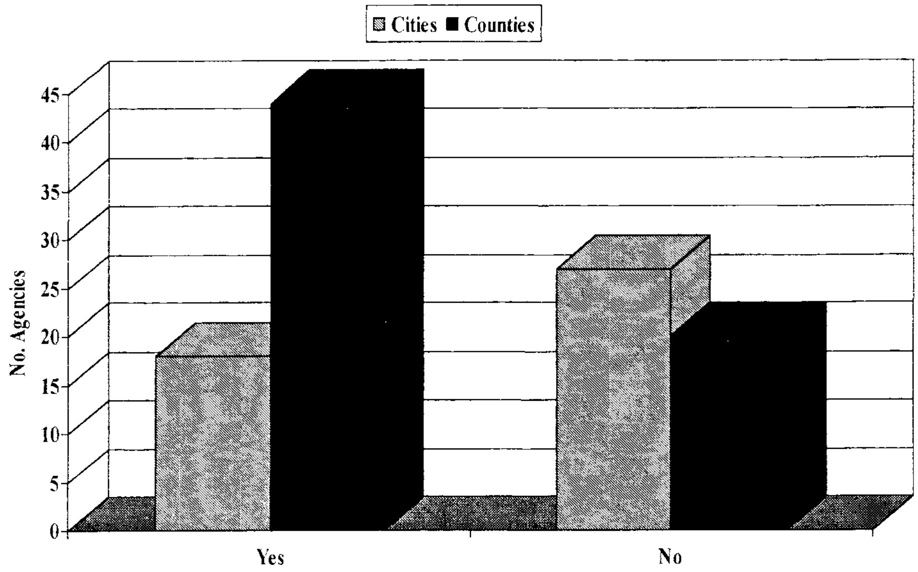


Figure 15. Use of quality management practices in hot mix construction.

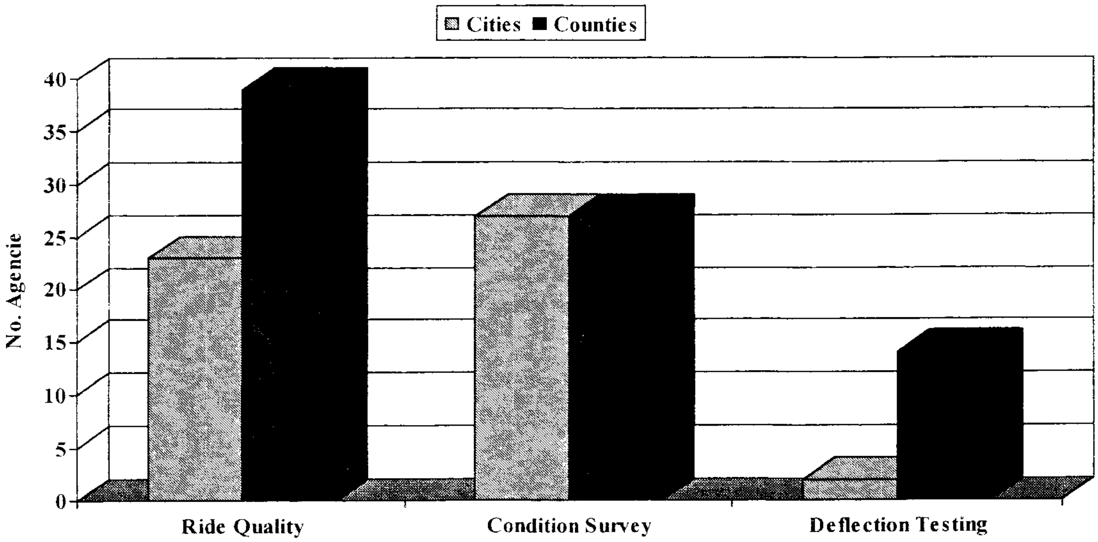


Figure 16. Types of performance evaluation.

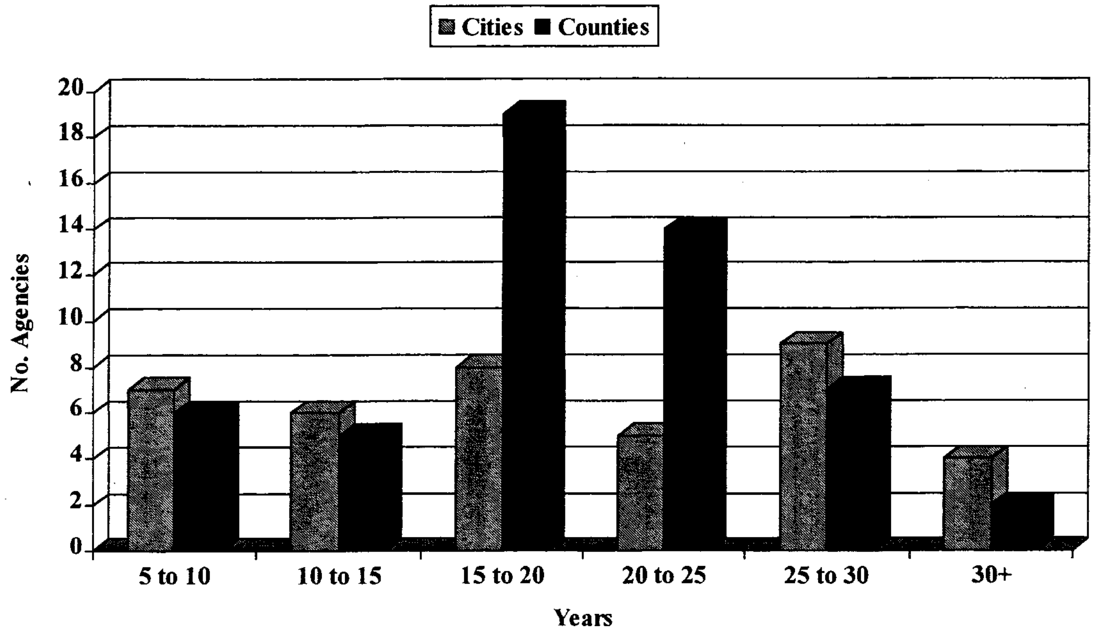


Figure 17. Time to rehabilitation for new HMA pavements.

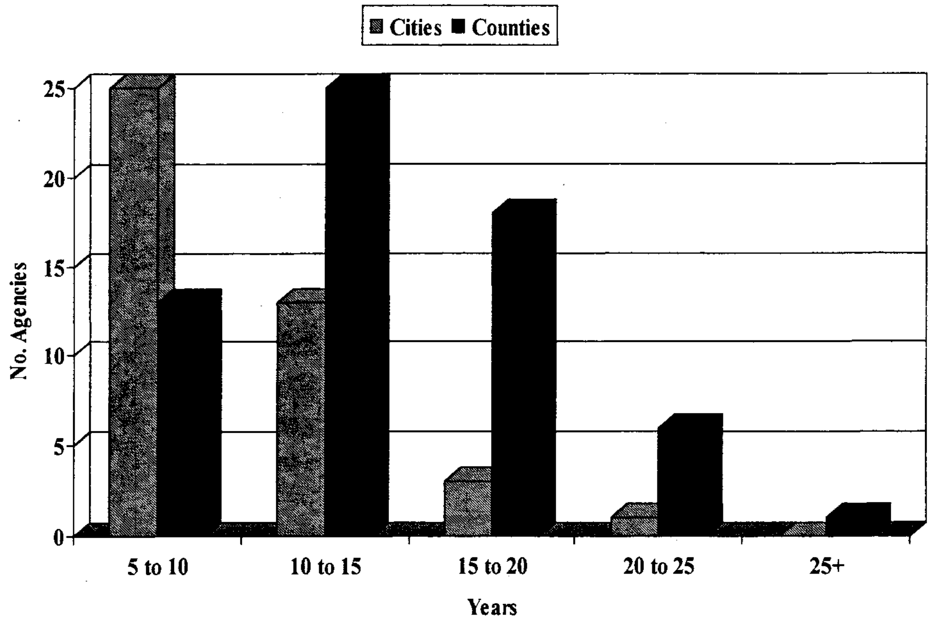


Figure 18. Time to rehabilitation for HMA overlays.

years; a medium traffic road (4,000 - 10,000 ADT) is 15-20 years and on low traffic roads (100-4,000 ADT) 25-35 years. A number of cities indicated the life of an overlay depends on the strength and condition of the underlying layers.

The county experience shows somewhat more life for overlays. Six counties reported lives less than seven years, but these were for seal coats. Twenty-five counties reported lives of 10-15 years and 18 reported 15 to 20 years. The median age of overlays for the counties is between 15 and 20 years.

There are many factors which affect the lives of new pavements and overlay pavements. These include to some extent all of the items included in this questionnaire. In Chapter 4 the materials and conditions to determine the relative effect of these factors will be modeled using the format of the computer program ROADENT.

5. The motivation for rehabilitation of pavements was categorized into a) Mixture, b) Structural/Environmental and c) Construction. Each of these was further subdivided. A number of agencies indicated more than one of these overall categories. Most of the reasons were structural/environmental for both cities and counties. About the same number indicated mixture and/or construction problems were the reason for performance problems. Figure 19 is a summary of these responses.

    a. Figure 20 shows that raveling and rutting are the primary mixture problems affecting performance for cities and counties (but in reverse order). Stripping was noted by only eight agencies, and flushing and tenderness are only minor problems.

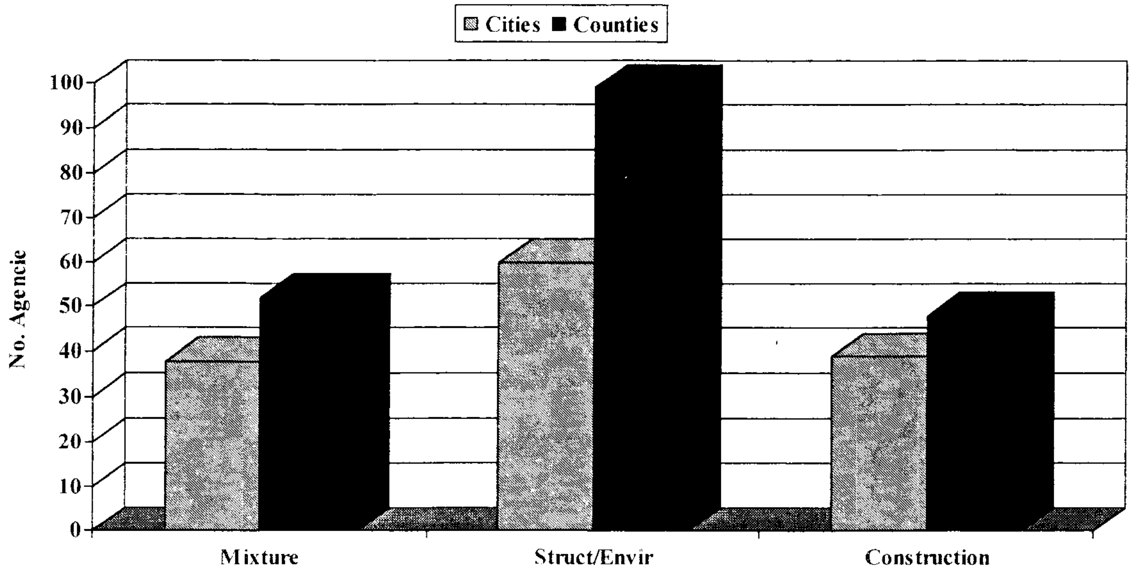


Figure 19. Major categories of performance problems.

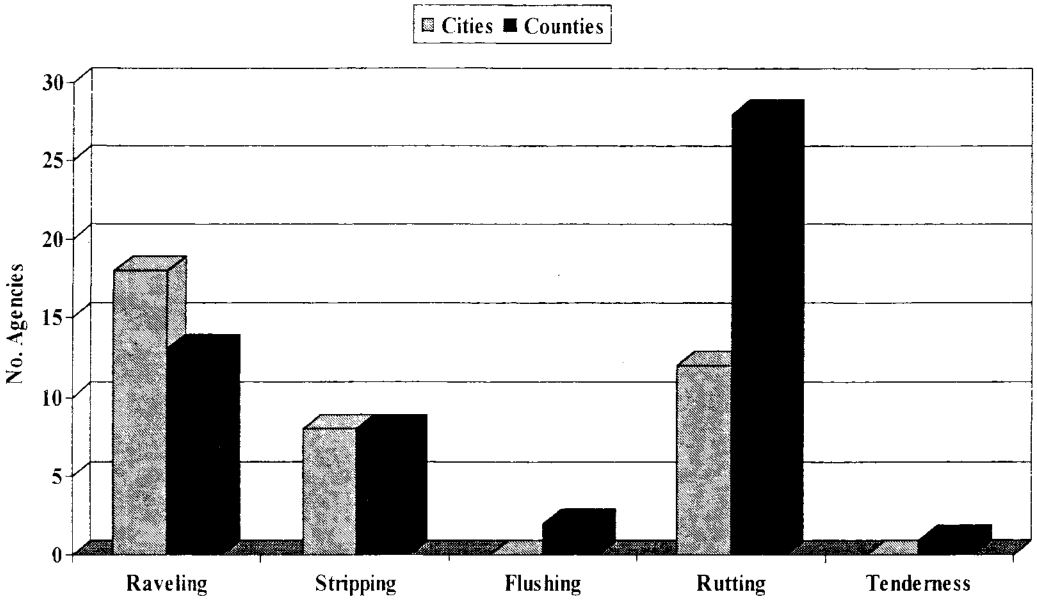


Figure 20. HMA related performance problems.

b. The type of Structural/Environmental problems are summarized in Figure 21. Fatigue cracking and transverse cracking are noted by over half of the respondents with rutting indicated by less than one-third of the respondents. If rutting as a mix problem is combined with rutting as a structural problem, over half of the counties are concerned with rutting overall. Some of the fatigue cracking could be associated with wet conditions caused by open transverse cracks.

c. Joint deterioration is listed mostly as a construction problem requiring rehabilitation by both cities and counties. Poor ride quality and lack of uniformity are listed by fewer cities and counties as shown in Figure 22.

LOAD RESTRICTIONS

1. Figure 23 shows that all 64 counties and 32 of the 50 cities limit loads during some portion of the year. None of the counties and 13 cities do not use load restrictions.

2. Figure 24 shows that load limits are usually set based on the design of the roadway. About one-third of the counties and only two of the cities use deflection testing along with consideration of the design to establish load restrictions.

3. Load limits should be applied consistently in a given area so that engineers, law enforcement and the public can plan and coordinate their activities efficiently. It is counterproductive for load restrictions to be applied non-uniformly. Figure 25 shows that most local agencies rely on Mn/DOT for guidance when setting load restrictions. Using neighboring agencies also helps develop consistency in a given area. One county uses Mn/ROAD information for guidance to help establish the timing of load limits. As Mn/DOT develops this process, local agencies should follow suit.

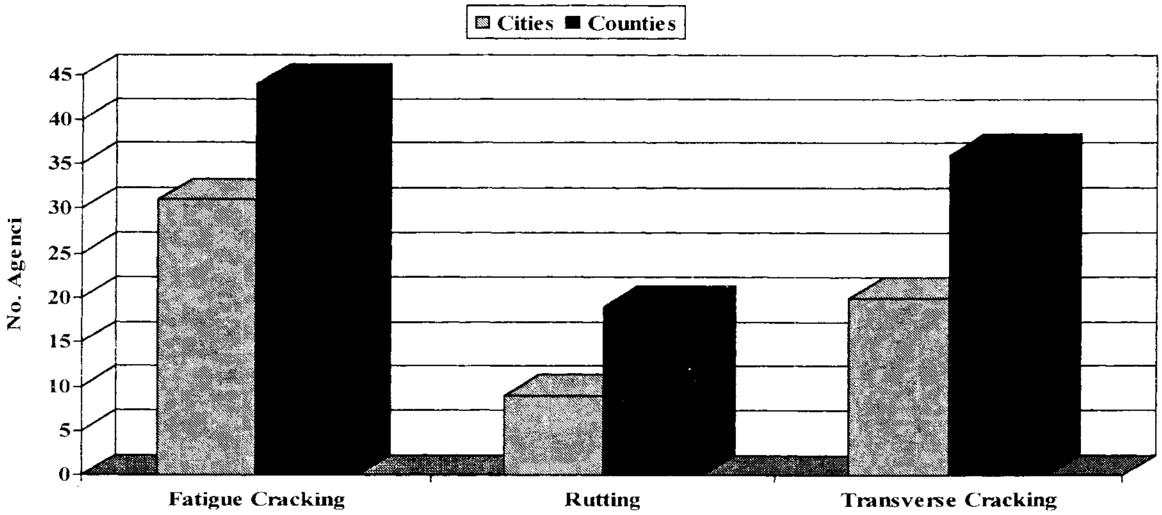


Figure 21. Structural/environmental related performance problems.

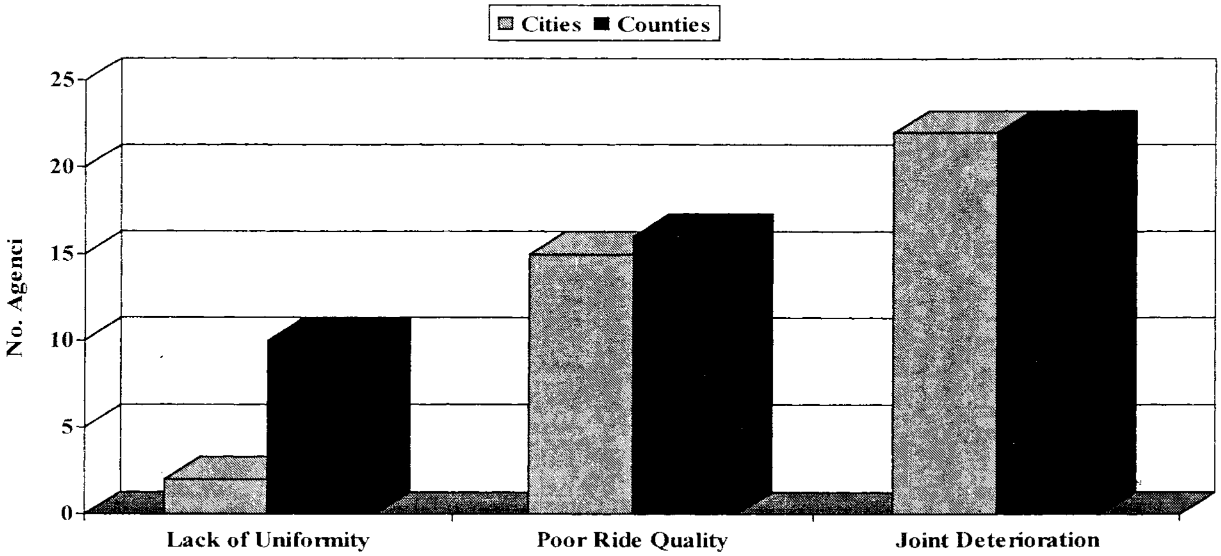


Figure 22. Construction related performance problems.

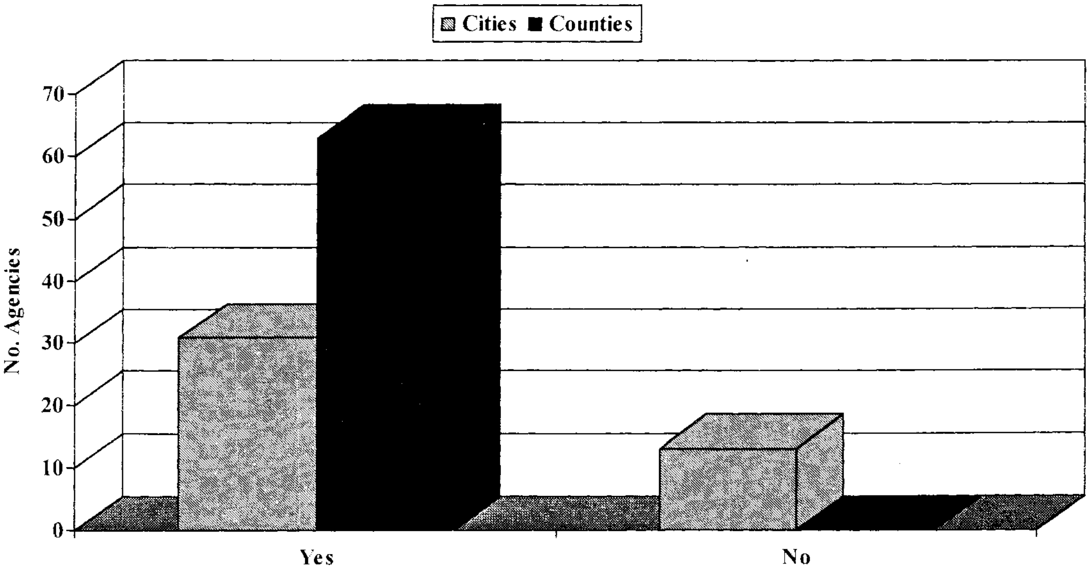


Figure 23. Use of spring thaw load limits.

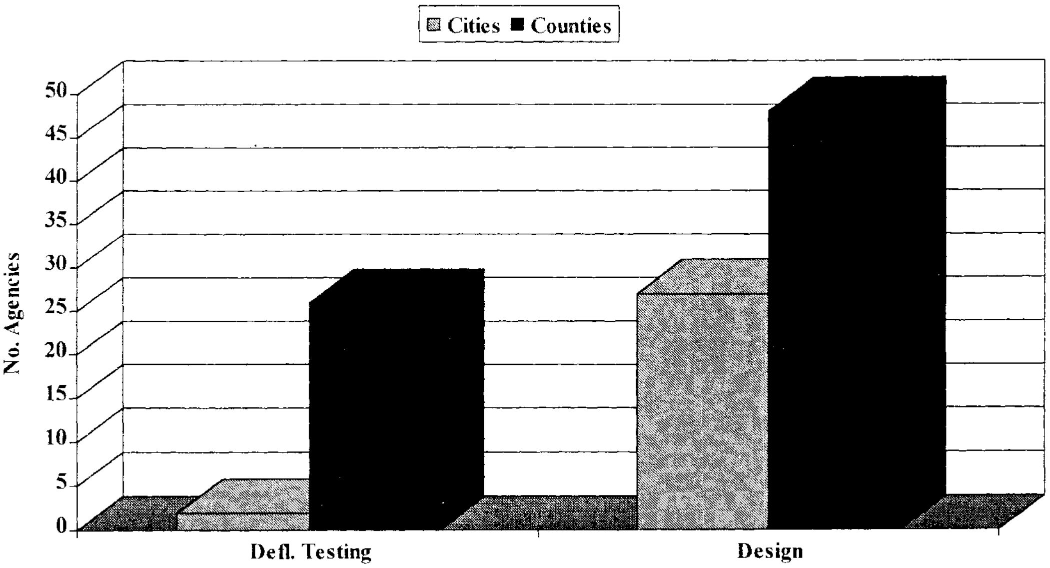


Figure 24. Means for establishing load limits.

4. In order for load limits to be effective they must be enforced. Enforcement starts with the local police or sheriff's department and they must be backed by judges who are willing to make penalties stick. Figure 26 shows that enforcement is only intermittent for most cities and counties. Less than 25% of the agencies have active enforcement. More than 25% of the counties and four cities indicate no enforcement at all.

5. A summary of the responses to the parts of Question 5 is presented in Appendix B. The data indicate that essentially all of the local roads are bituminous and that 25% to 70% of the roadways are restricted and are posted.

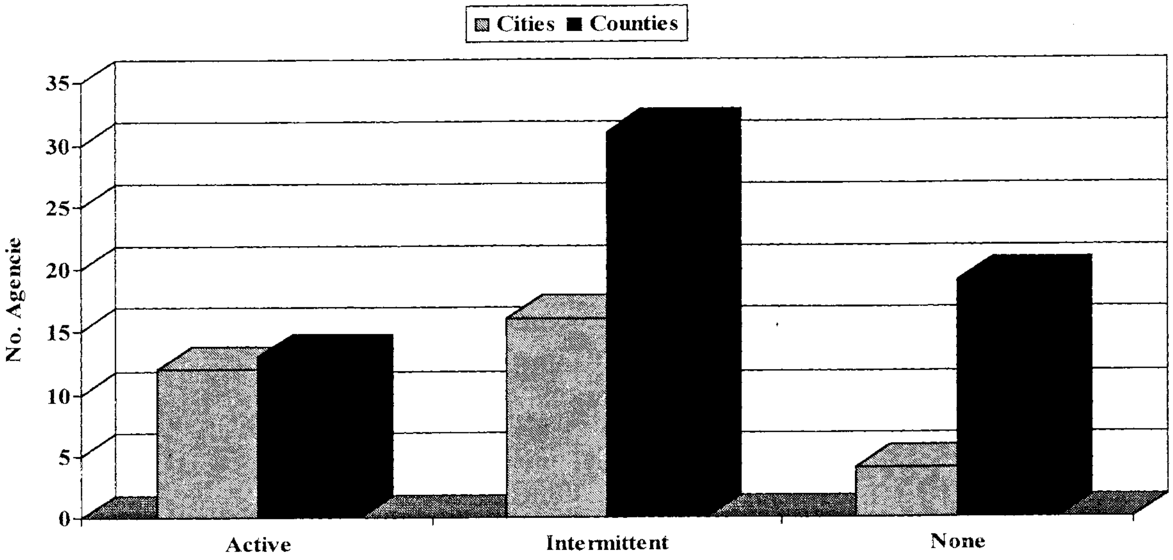


Figure 25. Level of enforcement for load limits.

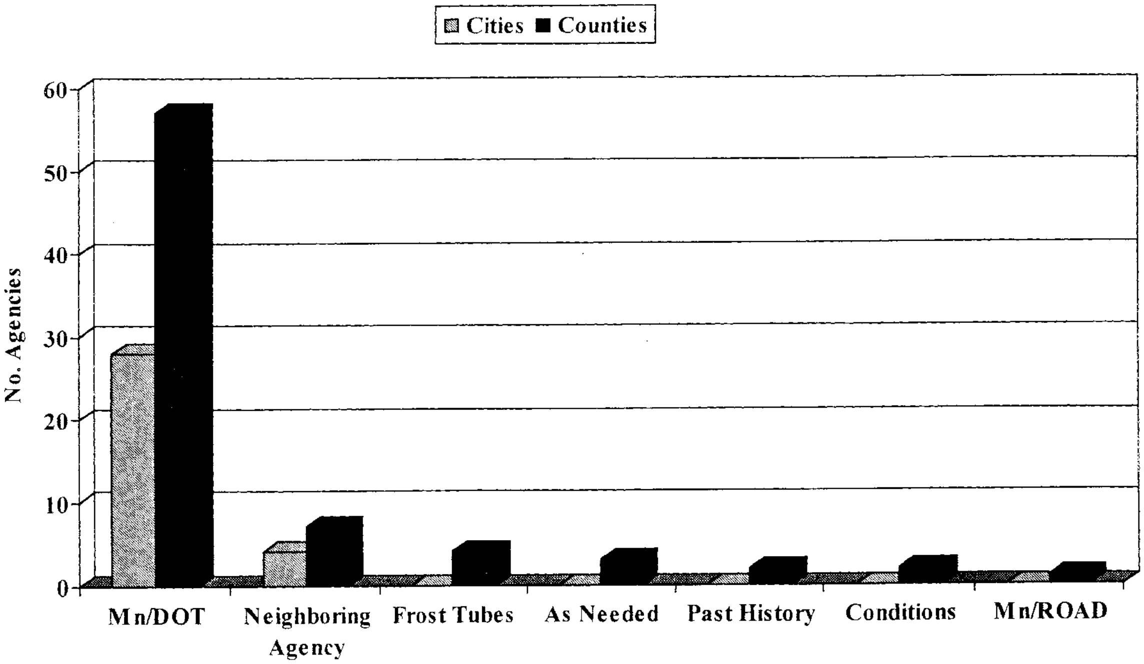


Figure 26. Timing of load restriction placement.

CHAPTER 4

CORRELATION BETWEEN SOIL FACTOR AND R-VALUE THICKNESS DESIGN PROCEDURES WITH THE MECHANISTIC-EMPIRICAL DESIGN

INTRODUCTION

The Mn/DOT State Aid Manual (1) includes the latest version of the Soil Factor Flexible Pavement Design Procedure as a guide for the design of city and county roads. This design table (Figure F5-892.210) is an updated version of the flexible pavement design which was used before the Minnesota Highway Department adopted the R-value procedure in the early 1970's. The soil factor design was used by the Minnesota Highway Department until about 1972. A "standard" design was set up for a typical A-6 soil which was given a soil factor of 1.0 (100%). The thickness of bituminous mixture and base were set for given traffic levels. The percentage (called soil factor) was then applied to the thickness of the granular base and subbase. The thicknesses recommended have been revised somewhat with experience throughout the years.

Newcomb and Timm (8) have developed a mechanistic-empirical design procedure using the measured characteristics (moduli) of the Mn/ROAD materials along with traffic measured on the mainline and low volume sections. Calculated and measured tensile strains in the asphalt layer and compressive strains on the subgrade have been correlated with the development of load cracking and rut depth for the specific test section thicknesses at Mn/ROAD. Traffic is measured in terms of ESAL and load spectra. Load spectra are the distribution of axle weights (8).

The factors that are used for flexible pavement thickness design are:

1. Soil characteristics
2. Traffic
3. Pavement layer characteristics
    a. Material stiffnesses (moduli)
    b. Thicknesses
4. Drainage characteristics

5. Reliability

Each of these factors is discussed and procedures are presented showing how the factors, as presented in the soil factor design, can be translated to values to be used in the mechanistic-empirical design analysis. The factors are then used along with the soil factor design thicknesses to determine if the soil factor procedure appears conservative or not. A similar comparison is made using designs from the R-Value design procedure.

SOIL CHARACTERISTICS

In this section correlations are presented to convert the soil factors to resilient moduli. The steps used are:

1. Convert soil factor (classes) to AASHTO soil classification
2. Convert AASHTO classification to R-Values measured in Minnesota
3. Convert R-Value to resilient modulus
4. A discussion is then presented on how resilient moduli can be estimated (calculated) from FWD or RoadRater results.

1. Soil Factor to AASHTO Soil Class

The table in the lower right hand corner of the soil factor design table (Figure 1) relates soil factor to AASHTO soil class and R-Value. Table 1 shows the correlation in a different way; the AASHTO classes represented by given soil factors are listed.

Table 1. AASHTO Classifications Representing Various Soil Factors

Soil Factor	AASHTO Classification(s)
50	A-1-b, A-2-4, A-3
75	A-1-b, A-2-4
100	A-4, A-6
120	A-7-5
130	A-7-6
130+	A-5

An A-5 soil has a soil factor of 130+. This is a relatively soft, hard-to-compact material. It is defined as a diatamaceous material (mostly originating from sea shells). This material occurs only very rarely in Minnesota.

2. The Minnesota DOT Design (2) and the State Aid Manuals (1) show various correlations between AASHTO Soil Class and R-Value. These correlations have been obtained from work done by Wolfe (6) in 1960 and R-Values measured on soils of the various classifications in the Mn/DOT laboratory over the years. Mn/DOT has used an exudation pressure of 1655 kPa (240 psi) to establish a design R-Value. Table 2 shows this general correlation.

Table 2. Relationship between AASHTO Soil Classification and Stabilometer R-Value*

AASHTO Class	Range of R-Values
A-1-a, b	70 - 75*
A-2-4	30 - 60
A-3	70
A-4	20 (10 - 75)
A-6	12 (8 - 20)
A-7-5	12 (6 - 18)
A-7-6	10 (6-18)

* If 15-20% passes the 0.075-mm (No. 200) sieve, the R-Value could be as low as 25

3. Prediction of Resilient Modulus (M_R) from Stabilometer R-Value

The AASHTO Guide for Design of Pavement Structures (7) presents a number equations for predicting resilient modulus (M_R) from design R-Value. The following equations are suggested for fine-grained and granular soils, respectively. An R-Value of

20 generally differentiates between a granular and fine-grained soil.

Fine-grained soils, $R < 20$

$$M_R = 1000 + 555\ (\text{R-Value}) \qquad (2)$$

Granular Soils, $R > 20$

$\ominus \cong 69$ kPa (10 psi)

$$M_R = 1000 + 250\ (\text{R-Value}) \qquad (3)$$

$\ominus \cong 138$ kPa (20 psi)

$$M_R = 1000 + 350\ (\text{R-Value}) \qquad (4)$$

Where: R-Value = stabilometer R-Value @ 1655 kPa (240 psi) exudation pressure.

M_R = Resilient modulus, psi

$\ominus$ = Confining stress in granular material $= \sigma_v + 2\,\sigma_h$, kPa (psi)

Equation (4) should be used for base courses closer to the surface and Equation (3) for materials farther down in the pavement section (subbases and subgrades).

The relationships listed in Tables 1 and 2, along with Equations 2, 3 and 4 are used to calculate the range of resilient moduli represented for the various AASHTO soil classifications. The resulting correlations are listed in Table 3.

Table 3. Resilient Modulus Predicted from R-Value Ranges Determined for AASHTO Soil Classifications and Stress Conditions for Granular Soils

AASHTO Soil Classification	Confining Stress, kPa (psi)	R-Value	Calculated Resilient Modulus, MPa (psi)
A-1	69 (10)	70	128 (18,500)
		75	138 (19,750)
	138 (20)	70	176 (25,500)
		75	189 (27,250)
A-2	69 (10)	30	59 (8,500)
		60	111 (16,000)
	138 (20)	30	80 (11,500)
		60	152 (22,000)
A-3	69 (10)	70	128 (18,500)
	138 (20)	70	176 (25,500)
A-4	-	20	84 (12,100)
A-5	-	10	45 (6,550)
A-6	-	12 (8 - 20)	53 [38-84] (7,660 [5440-12,100])
A-7-5	-	10 (6 - 18)	45 [30-76] (6,550 [4330-10,990])
A-7-6	-	8 (6 - 18)	38 [30-76] (5,440 [4330-10,990])

The listings shown in Table 1 and Table 3 have been used to establish a range of resilient moduli (M_R) implied for the soil factors. The ranges are given for confining stresses (⊖) of 69 and 138 kPa (10 and 20 psi) for granular soils.

Table 4. Resilient Moduli Ranges Based on Soil Factor

Soil Factor	Confining Stress, kPa (psi)	Resilient Modulus Range, Mpa (psi)	Based on asssumed R-Value
50	138 (20)	80-189 (11,500 - 27,250)	176 (25,500)
	69 (10)	59-137 (8,500 - 19,750)	128 (18,500)
75	138 (20)	80-189 (11,500 - 27,250)	
	69 (10)	59-137 (8,500 - 19,750)	
100	-	37-84 (5,400 - 12,100)	53 (7,660)
120	-	30-76 (4,330 - 10,990)	53 (7,660)
130	-	30-76 (4,330 - 10,990)	45 (6,550)

Table 4 is a summary of the relationships shown in Tables 1 and 3. The confining stress of 69 kPa (10 psi) for granular materials is for granular materials at the subbase and subgrade level and 138 kPa (20 psi) confining stress values can be used for granular materials when used as base courses. The moduli values will be used as input for the mechanistic simulations of the design thicknesses recommended in the Soil Factor Pavement Design Procedure.

THE TRAFFIC FACTOR

The traffic on a road is composed of applications of axle loads of various weights and configurations. The weights range from less than 8.9 kN (2000 lb) on a single axle to over 222 kN (50,000 lb) on multiple axles. To determine the load effect on a pavement during a particular design period, it is necessary to obtain an estimate of the weight distribution of various axle configurations over the design period.

One method of estimating the traffic effect is to use the Average Daily Traffic (ADT) and/or the number of daily heavy trucks (HCADT) expected. The two-way ADT and HCADT are the traffic factors used for the current Soil Factor Flexible Pavement Design procedure.

To determine the design lane traffic for a two-lane road, the total ADT is divided by two unless some other factors are known. For four or greater numbers of lanes, the traffic must be proportioned by lane.

The calculations of ESAL requires that the total traffic in the design lane be estimated. Most ADT values are two-way. The second factor required to calculate ESAL is vehicle type distribution. Vehicles are classified using ten vehicle types. Figure 27 shows the ten types used in Minnesota. Types 1-10 represent the ADT in the design lane and Types 4-10 represent the HCADT in the design lane. The HCADT includes all six - or more - tired vehicles. In the Mn/DOT Road Design Manual, typical distributions are given for (1) rural, (2) metro and (3) local roads.

The ESAL effect of each vehicle type has also been determined using weight data accumulated by Mn/DOT over a period of time. The Soil Factor design uses ADT (Average Daily Traffic) for traffic evaluation for the lowest two categories and HCADT (Heavy Commercial Average Daily Traffic) for the other five. The ESAL factors representing each type of roadway are obtained by multiplying the % ADT times the factor. These are then added to calculate the average ESAL effect per 100 ADT.

The calculations show:

1. 10.5% HCADT for rural roads
   5.9% HCADT for metro roads
   5.9% HCADT for local roads

2. The ESAL per 100 ADT are:
   5.178 for rural roads
   2.63 for metro roads
   1.98 for local roads

With these factors 20-year design ESAL are calculated for the traffic factors used in the Soil Factor design. Calculations were made assuming 0% and 4% growth. The results of these calculations are listed in Table 5.

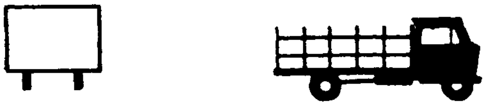
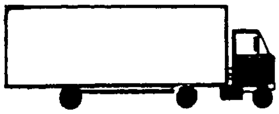
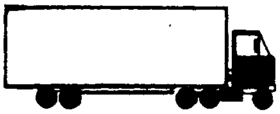
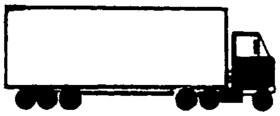
Vehicle Type Number	**Illustrated Example**	**Vehicle Description**
1		Passenger Cars
2		Panel and Pickups (Under 1 ton)
3		Single Unit — 2 axle, 4-tire
4		Single Unit — 2 axle, 6-tire
5		Single Unit — 3 axle and 4 axle
6		Tractor semitrailer Combination — 3 axle
7		Tractor Semitrailer Combination — 4 axle
8		Tractor Semitrailer Combination — 5 axle
9		Tractor Semitrailer Combination — 6 axle
10		Trucks with Trailers and buses

Figure 27. Minnesota vehicle types.

Table 5. Estimated ESAL for Traffic Levels Defined in the Soil Factor Design Table

	20-Year Design Lane ESAL	
Traffic Category *	0 % Growth	4% Growth
< 400 ADT	22,420	33,400
1000 ADT	78,200	119,400
150 HCADT		
Rural	270,000	402,100
Metro	244,100	363,400
Local	183,400	273,100
300 HCADT		
Rural	540,000	804,000
Metro	488,100	726,800
Local	366,800	546,100
600 HCADT		
Rural	1,080,000	1,610,000
Metro	976,200	1,453,600
Local	733,500	1,090,000
1100 HCADT		
Rural	1,980,000	2,950,000
Metro	1,789,700	2,664,800
Local	1,350,000	2,000,000

* The ADT and HCADT are two-way values. To obtain the design lane ESAL the calculated values are divided by two.

The highest category of loading is greater than 1100 HCADT. The predicted ESAL can be in excess of 3 million for that traffic category.

Calculation of ESAL

The traffic factor in terms of ESAL requires a determination, calculation and/or estimate of:

1. the total traffic in the design lane
2. the distribution of vehicle types
3. the weight distribution of axles for each vehicle type
4. the annual percent increase in traffic for that roadway

i. The total traffic is available for all roads in Minnesota on traffic maps. For two-lane roads the design lane ADT is the total ADT ÷ 2. For four lane roads the design lane ADT is usually calculated by multiplying the two-way ADT by 0.45 which assumes 90% of the ESAL are in the driving lane.

The traffic flow maps are partially updated annually. For design purposes it may be appropriate to do a traffic study for that particular or a similar roadway.

ii. Ten vehicle types are used to define the vehicle type distribution in Minnesota. Figure 27 illustrates the vehicle types. Studies have been made over the past 25 years to estimate the vehicle type distribution on various classes of roadways. Typical distributions are listed in the Mn/DOT Design and Geotechnical Manuals.

PAVEMENT LIFE PREDICTIONS

In this section, life predictions for the thickness designs resulting from the Soil Factor (1) and R-Value (2) designs which are currently used for pavement design in Minnesota are made using the mechanistic-empirical procedure developed at the University of Minnesota (8). This software (ROADENT) predicts pavement life using strain levels for pavement cracking or fatigue and permanent deformation or rutting. Fatigue is predicted using the tensile strain in the bottom of the asphalt surface layer and progression of rutting is predicted based on the compressive strain at the top of the subgrade.

The strains are dependent on:

1. Weight and configuration of axle loads
2. The stiffness (modulus) of the soil
3. The stiffness of the various pavement layers
4. The thickness of the pavement layers.

The algorithms used to predict life are based on relationships developed from the performance of sections at Mn/ROAD.

For this study, lives are predicted using six sets of runs of ROADENT. The first three are based on thicknesses from the Soil Factor Design, and the second three the R-Value Design. The purpose of the comparisons is to establish how the current designs relate to the mechanistic-empirical predictions.

Loading

Four of the seven traffic categories used for the Soil Factor Design have been converted to ESAL using typical vehicle type and weight distributions published in the current Mn/DOT Manuals (1) and (2) in the traffic section. Ranges of ESAL were found using typical rural, metro and local distributions with 0% and 4% growth over 20 years. The lowest ESAL predictions at a given ADT or HCADT level are for local roads at 0% growth and the highest is for rural roads at 4% growth. A listing of the ESAL for the traffic categories is shown in Table 5.

Soil Strength

Soil strength is based on the moduli predicted from the Soil Factor and R-Value relationships presented above. Table 6 is a listing of the moduli used to represent three levels of soil stiffness (modulus) for the mechanistic-empirical design with ROADENT.

Table 6. Soil Moduli used for ROADENT Life Predictions

Run No.	Soil Factor	R-Value	Soil Resilient Moduli, MPa (psi)				
			Summer		Fall	Winter	Spring
			Range	Default			
1	50	-	59-137 (8,500-19,750)	128 (18,500)	173 (25,000)	277 (40,000)	173 (25,000)
2	100	-	37-84 (5,400-12,100)	53 (7,660)	104 (15,000)	277 (40,000)	104 (15,000)
3	130	-	30-76 (4,330-10,990)	45 (6,550)	83 (12,000)	277 (40,000)	83 (12,000)
4	-	70	- -	138 (20,000)	173 (25,000)	277 (40,000)	173 (25,000)
5	-	20	- -	55 (8,000)	104 (15,000)	277 (40,000)	104 (15,000)
6	-	10	- -	45 (6,550)	83 (12,000)	277 (40,000)	83 (12,000)

The resilient moduli estimated from the Soil Factors were considered to be summer values. The moduli listed for fall, winter and spring are based on ratios of moduli obtained from MnROAD throughout the year. The summer moduli are assumed for 26 weeks, Fall - 8 weeks, Winter - 12 weeks, and Spring - 6 weeks. These are typical time periods found from the four years of Mn/ROAD data.

Stiffness of the Pavement Layers

The stiffness (resilient modulus) of the pavement layers also varies throughout the year. Table 7. lists the seasonal moduli for the surface, base and subbase layers for the six simulations.

Table 7. Seasonal Pavement Layer Moduli

	Pavement Layer Resilient Moduli, MPa (psi)				
	Summer	Fall	Winter	Spring	Poisson's Ratio
Weeks	26	8	12	6	52
Layer:					
* 1. (Asphalt Concrete)	2,010 (290,472)	6,832 (987,278)	10,480 (1,513,888)	6,832 (987,278)	0.35
* 2. (Granular Base)	173 (25,000)	208 (30,000)	277 (40,000)	104 (15,000)	0.40
**3. (Granular Subbase)	118 (17,000)	173 (25,000)	277 (40,000)	90 (13,000)	0.40

* Same for all six sets of runs

** Used only for runs 5 and 6

For the runs with the stiff subgrade (1 and 4), the moduli of the subgrade were actually slightly higher than the subbase during the spring. This can occur when the melt water in the subbase is trapped before the subgrade (layer 4) thaws.

Thickness of Pavement Layers

The thickness of the pavement layers has been determined from the two design procedures as listed in Figure 1 for the Soil Factor Design and Figure 2 for the R-Value design respectively. Design thicknesses have been determined using first the Soil Factor Table. Four of the seven traffic categories have been used:

	Category
< 400 ADT	Low
< 150 HCADT	Medium
300-600 HCADT	Medium - High
> 1100 HCADT	High

Depending on the vehicle type weight distributions and growth, the predicted ESAL will vary as shown in Table 5. The Soil Factor design thickness will be the same for each of calculated ESAL values within the given traffic category.

Design thicknesses were established for soil factors of 50, 100 and 130. The thicknesses of asphalt surface and granular base are listed in Tables 9, 10 and 11 for the Soil Factors of 50, 100 and 130, respectively. Two different combinations of thicknesses are shown: 1) using the minimum bituminous G.E. with a hot mix asphalt G.E. Factor of 2.0 and 2) the remainder of the G.E. is made up of aggregate with a G.E. Factor of 1.0 (class 5 or 6 material). The alternate designs use a nominal plant mix surface of 150 mm (6 in.) with the remainder of the required G.E. thickness made up of granular base.

Similar designs were made using the R-Value design chart. Two designs for each set of conditions were again made [1. with minimum surface thicknesses and 2. with a nominal 150-mm (6-in.) Hot Mix Asphalt surface.] Tables 12, 13 and 14 list the resulting pavement section thicknesses.

A set of runs was then made with the mechanistic-empirical design procedure (ROADENT) to predict if the fatigue and/or rutting life of these pavement sections would be used up. For each of the strengths of soil and pavement materials and thicknesses, a life factor is calculated based on the particular conditions. A factor (ratio) less than 1.0 indicates that the pavement would not fail at the respective ESAL value; whereas, a ratio greater than 1.0 indicates that failure in that mode is predicted at that level of ESAL.

Six sets of ROADENT runs were made to represent the various levels of traffic and soil strength with predicted thicknesses as indicated above. Each run has a set of designs with minimum asphalt surface thicknesses and with 150 mm (6-in.) thickness of surface.

Table 8. Summary of Embankment Stiffness Used for Mechanistic Design Simulations

		Soil Strength		
Runs	Procedure	S.F.	R-Value	M_R, MPa (psi)
1A	Soil Factor	50	-	128 (18,500)
1B	"	50	-	128 (18,500)
2A	"	100	-	53 (7.660)
2B	"	100	-	53 (7,660)
3A	"	130	-	45 (6,550)
3B	"	130	-	45 (6,550)
4A	R-Value	-	70	138 (20,000)
4B	"	-	70	138 (20,000)
5A	"	-	20	55 (8,000)
5B	"	-	20	55 (8,000)
6A	"	-	10	45 (6.550)
6B	"	-	10	45 (6,550)

The soil factor, R-Value and mechanistic design procedures are compared using the life factors calculated from ROADENT. A value less than 1.0 indicates that less thickness would be appropriate for that traffic. A factor greater than 1.0 indicates that the life would be used up and therefore a greater thickness is needed for the traffic level. The resulting damage factors are listed in Tables 9 through 14. Table 9 is for a Soil Factor of 50, Table10 a Soil Factor of 100 and Table 11 a Soil Factor of 130. Table 12 is an R-Value of 70, Table 13 an R-Value of 20 and Table 14 an R-Value of 10.

Table 9. Soil Factor Method vs. Roadent – Run 1: SF = 50, Resilient Modulus = 128 MPa (18,500 psi).

		Soil Factor Method		ROADENT Damage		ROADENT, Optimized		ROADENT Damage	
	ESALs	AC, mm	GB, mm	Fatigue	Rutting	AC, mm	GB, mm	Fatigue	Rutting
Low Traffic (<400 ADT)	22,420	38	105	0.22	2.33	30	160	0.19	0.99
	33,385	38	105	0.32	3.47	30	180	0.29	0.92
	22,420	90	--	0.09	0.65	82	--	0.12	0.93
	33,385	90	--	0.14	0.97	90	--	0.14	0.97
Medium Traffic (<150 HCADT)	183,380	88	80	0.61	1.98	67	180	0.95	0.98
	402,050	88	80	1.34	4.34	95	165	1	0.98
	183,380	128	--	0.26	1.17	128	20	0.24	1
	402,050	128	--	0.57	2.58	128	76	0.46	1
Medium Traffic (300-600 HCADT)	735,000	88	225	2.12	1.31	120	160	0.94	0.96
	1,610,000	88	225	4.65	2.87	150	160	0.96	0.98
	735,000	150	150	0.44	0.48	150	70	0.49	0.98
	1,610,000	150	150	0.97	1.05	150	160	0.96	0.98
High Traffic (>1100 HCADT)	1,350,000	100	310	2.73	0.8	142	170	0.97	0.93
	2,950,000	100	310	5.97	1.76	175	160	0.97	0.99
	1,350,000	150	210	0.78	0.56	150	140	0.92	0.94
	2,950,000	150	210	1.7	1.22	150	NOT POSSIBLE		

Table 10. Soil Factor Method vs. Roadent – Run 2: SF = 100, Resilient Modulus = 53 MPa (7,660 psi).

		Soil Factor Method		ROADENT Damage		ROADENT, Optimized		ROADENT Damage	
	ESALs	AC, mm	GB, mm	Fatigue	Rutting	AC, mm	GB, mm	Fatigue	Rutting
Low Traffic (<400 ADT)	22420	38	215	0.33	2.6	30	280	0.3	0.94
	33385	38	215	0.49	3.88	34	305	0.46	0.96
	22420	150	--	0.05	0.26	115	--	0.13	0.99
	33385	150	--	0.07	0.4	130	--	0.12	0.82
Medium Traffic (<150 HCADT)	183380	80	265	1.02	2.76	82	360	0.89	0.98
	402050	80	265	2.23	6.06	110	370	0.9	0.97
	183380	150	110	0.23	1.27	150	150	0.2	0.99
	402050	150	110	0.5	2.79	150	250	0.37	1
Medium Traffic (300-600 HCADT)	735000	80	450	3.63	1.66	130	390	0.97	0.92
	1610000	80	450	7.95	3.65	162	400	0.96	0.9
	735000	150	295	0.64	1.27	150	330	0.62	0.95
	1610000	150	295	1.4	2.77	150	NOT POSSIBLE		
High Traffic (>1100 HCADT)	1350000	91	615	4.73	0.55	155	390	0.96	0.96
	2950000	91	615	10.34	1.21	190	400	0.95	0.92
	1350000	150	485	1.03	0.51	150	550	1	0.31
	2950000	150	485	2.24	1.11	150	NOT POSSIBLE		

Table 11. Soil Factor Method vs. Roadent – Run 3: SF = 130, Resilient Modulus = 45 MPa (6,550 psi).

		Soil Factor Method		ROADENT Damage		ROADENT, Optimized		ROADENT Damage	
	ESALs	AC, mm	GB, mm	Fatigue	Rutting	AC, mm	GB, mm	Fatigue	Rutting
Low Traffic (<400 ADT)	22,420	38	275	0.19	0.82	30	280	0.18	0.91
	33,385	38	275	0.29	1.22	30	305	0.27	0.98
	22,420	150	50	0.04	0.33	150	NOT POSSIBLE		
	33,385	150	50	0.05	0.49	150	NOT POSSIBLE		
Medium Traffic (<150 HCADT)	183,380	88	375	0.53	0.72	68	385	0.88	1
	402,050	88	375	1.16	1.57	95	410	0.95	0.94
	183,380	150	250	0.14	0.53	150	180	0.16	0.98
	402,050	150	250	0.3	1.17	150	270	0.29	0.98
Medium Traffic (300-600 HCADT)	735,000	88	585	1.98	0.38	120	420	0.91	0.91
	1,610,000	88	585	4.34	0.83	150	430	0.96	0.98
	735,000	150	460	0.43	0.35	150	340	0.48	0.97
	1,610,000	150	460	0.94	0.76	150	430	0.96	0.98
High Traffic (>1100 HCADT)	1,350,000	100	795	2.59	0.11	141	440	0.99	0.91
	2,950,000	100	795	5.66	0.24	180	440	0.9	0.92
	1,350,000	150	695	0.72	0.11	150	410	0.82	0.97
	2,950,000	150	695	1.58	0.24	150	NOT POSSIBLE		

Table 12. R-Value Method vs. Roadent – Run 4: R = 70, Resilient Modulus = 138 MPa (19, 750 psi).

		R-Value Method		ROADENT Damage	
	ESALs	AC, mm	GB, mm	Fatigue	Rutting
Low Traffic (<400 ADT)	22420	89	76	0.07	0.2
	33385	89	76	0.1	0.3
	22420	127	--	0.03	0.13
	33385	127	--	0.04	0.19
Medium Traffic (<150 HCADT)	183380	89	76	0.56	1.66
	402050	89	140	1.16	1.37
	183380	152	--	0.12	0.45
	402050	152	--	0.27	0.98
Medium Traffic (300-600 HCADT)	735000	114	254	1.01	0.42
	1610000	140	152	1.2	1.1
	735000	152	102	0.42	0.51
	1610000	152	127	0.89	0.95
High Traffic (>1100 HCADT)	1350000	140	152	1.01	0.92
	2950000	165	152	1.19	1.08
	1350000	152	102	0.77	0.95
	2950000	152	152	1.61	1.47

Table 13. R-Value Method vs. Roadent – Run 5: R = 20, Resilient Modulus = 55 MPa (8,000 psi).

		Soil Factor Method			ROADENT Damage	
	ESALs	AC, mm	GB, mm	SB, mm	Fatigue	Rutting
Low Traffic (<400 ADT)	22,420	89	102	--	0.11	1.27
	33,385	89	102	--	0.17	1.9
	22,420	152	--	--	0.04	0.23
	33,385	152	--	--	0.06	0.34
Medium Traffic (<150 HCADT)	183,380	89	76	191	0.7	0.96
	402,050	89	140	292	1.25	0.8
	183,380	152	102	--	0.18	1.1
	402,050	152	229	--	0.28	0.91
Medium Traffic (300-600 HCADT)	735,000	114	152	330	1.16	0.53
	1,610,000	140	152	406	1.32	0.39
High Traffic (>1100 HCADT)	1,350,000	140	152	381	1.12	0.39
	2,950,000	165	152	432	1.33	0.37

Table 14. R-Value Method vs. Roadent – Run 6: R = 10, Resilient Modulus = 45 MPa (6,550 psi).

		Soil Factor Method			ROADENT Damage	
	ESALs	AC, mm	GB, mm	SB, mm	Fatigue	Rutting
Low Traffic (<400 ADT)	22420	89	279	--	0.07	0.24
	33385	89	279	--	0.1	0.36
	22420	152	178	--	0.02	0.12
	33385	152	178	--	0.03	0.17
Medium Traffic (<150 HCADT)	183380	89	152	432	0.54	0.14
	402050	89	229	406	1.11	0.19
	183380	152	330	--	0.11	0.23
	402050	152	394	--	0.23	0.32
Medium Traffic (300-600 HCADT)	735000	114	152	546	1.12	0.15
	1610000	140	152	635	1.28	0.12
High Traffic (>1100 HCADT)	1350000	140	152	610	1.08	0.12
	2950000	165	152	686	1.28	0.11

Another way of stating the comparison between the mechanistic design and the Soil Factor or R-value procedure is: For a damage factor less than 1.0 the Soil Factor or R-Value design procedure would result in a greater thickness than ROADENT whereas a factor greater than 1.0 indicates a lesser thickness and a less conservative design.

A damage factor between 0.8 and 1.0 is defined as a level at which the design procedures are equivalent.

Figures 28 through 30 illustrate the comparisons between the Soil Factor Design and the mechanistic design. Figure 28 is for a soil factor of 50, Figure 29, 100 and Figure 30, 130. For the fatigue predictions the soil factor designs are thicker, whereas at the high traffic levels the thicknesses are less. For the 150-mm (6-in.) surface, the Soil Factor Design results in a thicker design at the higher traffic level. The rutting analysis does not show consistent trends with embankment stiffness.

Figures 31, 32 and 33 show similar comparisons with the R-Value design for similar embankment strengths as the Soil Factor Design. The fatigue analysis, again, shows consistent trends from thicker to thinner designs for the R-value procedure as the traffic increases. For the high R-value design the rut depth analyses are not consistent with the minimum surface thicknesses, but do follow the fatigue analysis.

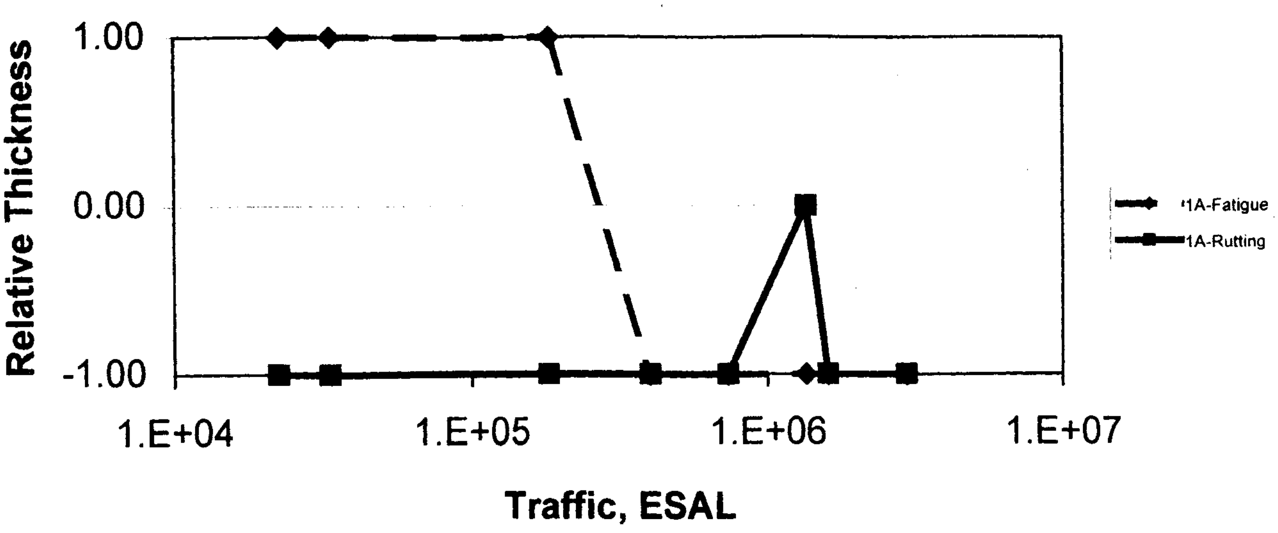
Figure 32 shows that the R-Value = 20 design is thicker up to the medium traffic level based on the fatigue analysis, whereas the rutting analysis generally indicates the reverse.

Figure 33 shows that the R-Value = 10 design is consistent with the others with crossover to a thinner design at a higher traffic level. All of the R-Value designs are thicker than the ROADENT design based on the rut depth analysis.

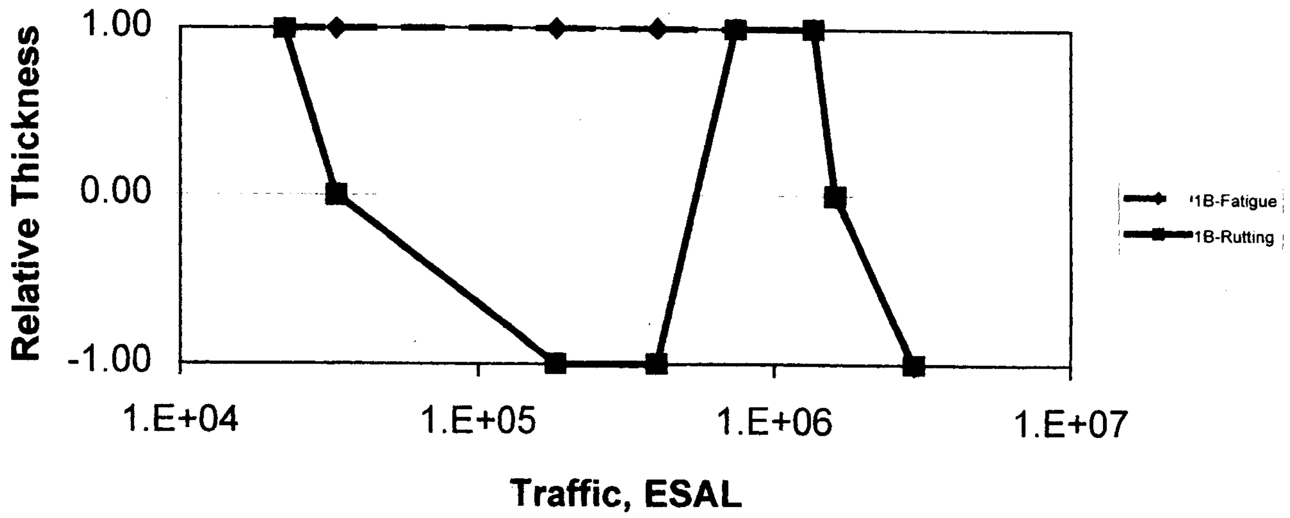
The comparisons shown in Figures 28 through 33 are generally consistent for the fatigue analyses using ROADENT, but are not using the rutting analyses. More work needs to be done with the comparison because:

1. The comparisons show that one design is thicker, thinner or the same, but the thickness levels to achieve life predictions have not been determined.
2. Reliability has not been included in the current version of ROADENT. Reliability is now being incorporated into an updated version of ROADENT and should be available in 1999.
3. The thicknesses resulting from these design procedures need to be compared with field

performance. This can be accomplished using information from cities and counties which have Pavement Management Systems or have good records on the construction, maintenance and performance of specific road sections.

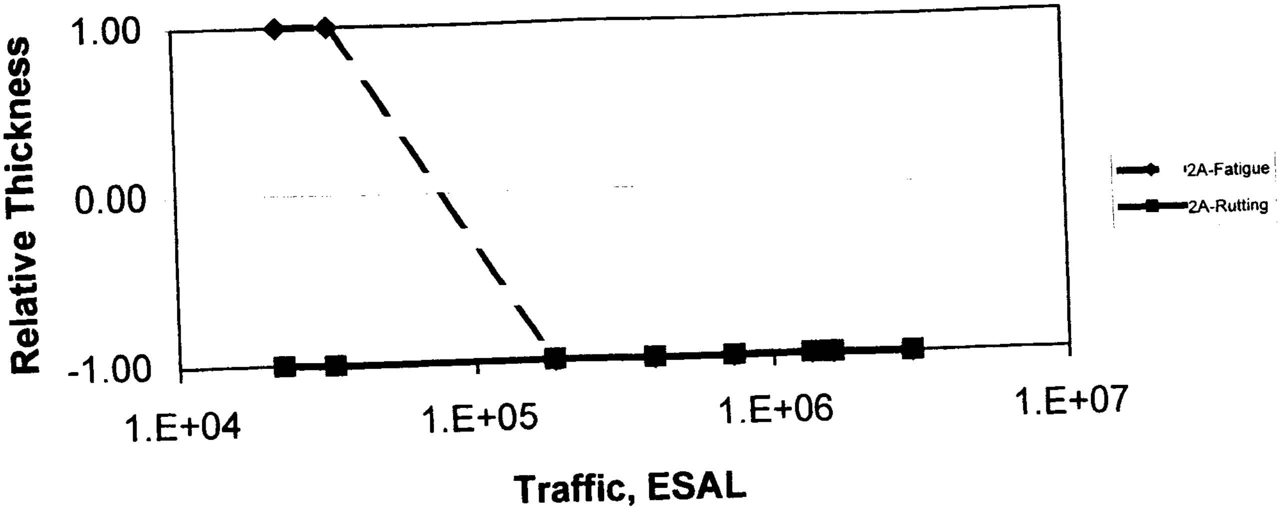


(a). Run 1A – SF = 50.

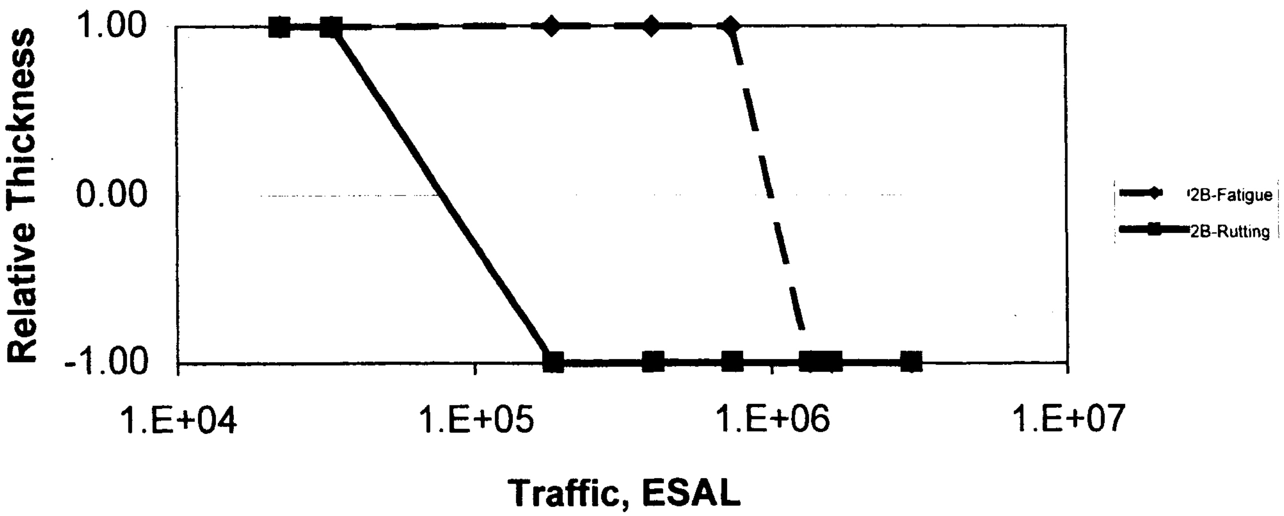


(b) Run 1B – SF = 50.

Figure 28. Comparison of Minnesota LVR Designs with Roadent (SF = 50) (1 = Thicker, 0 = Same Thickness, -1 = Thinner).

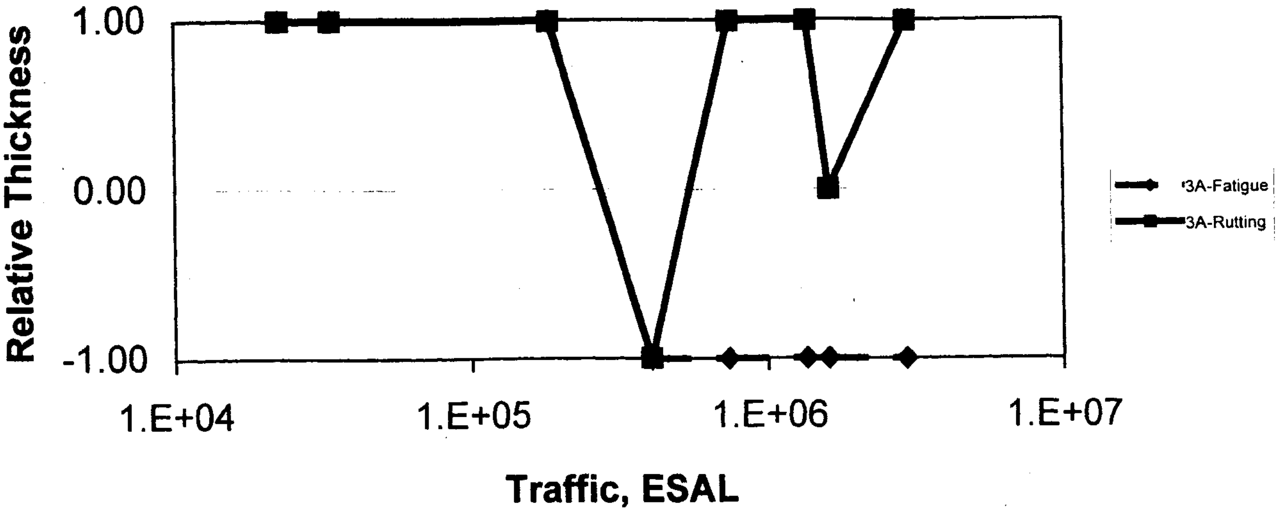


(a). Run 2A – SF = 100.

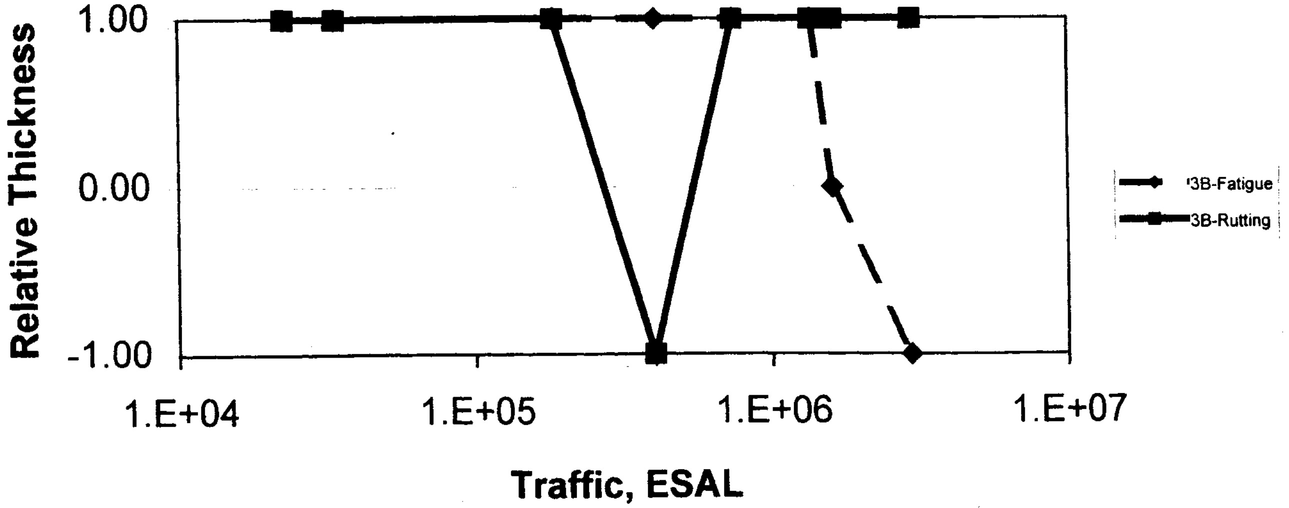


(b) Run 2B – SF = 100.

Figure 29. Comparison of Minnesota LVR Designs with Roadent (SF = 100) (1 = Thicker, 0 = Same Thickness, -1 = Thinner).

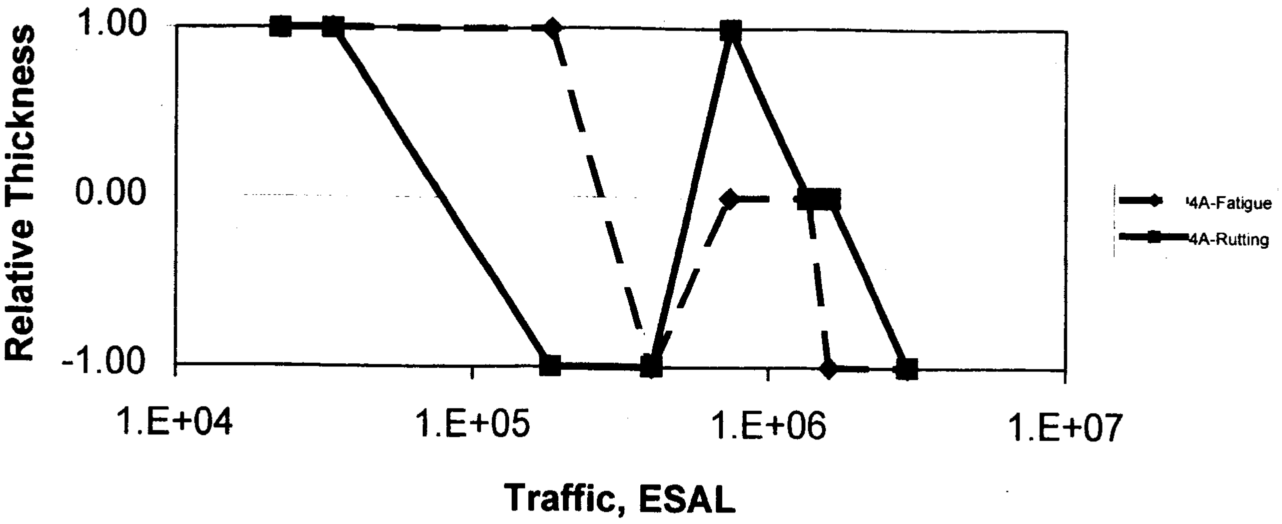


(a). Run 3A – SF = 130.

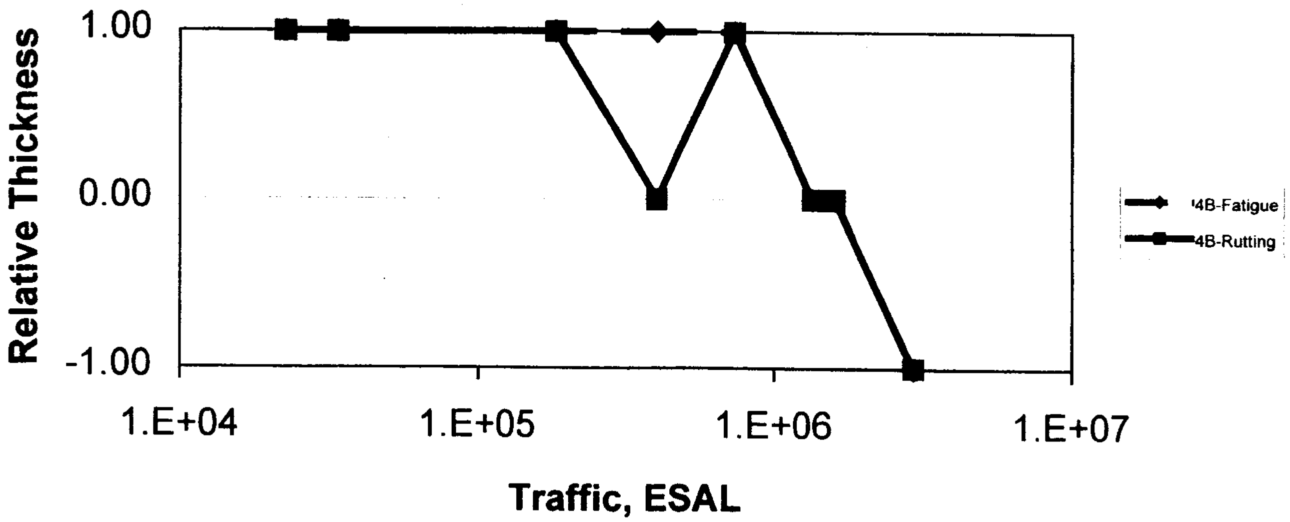


(b) Run 3B – SF = 130.

Figure 30. Comparison of Minnesota LVR Designs with Roadent (SF = 130) (1 = Thicker, 0 = Same Thickness, -1 = Thinner).

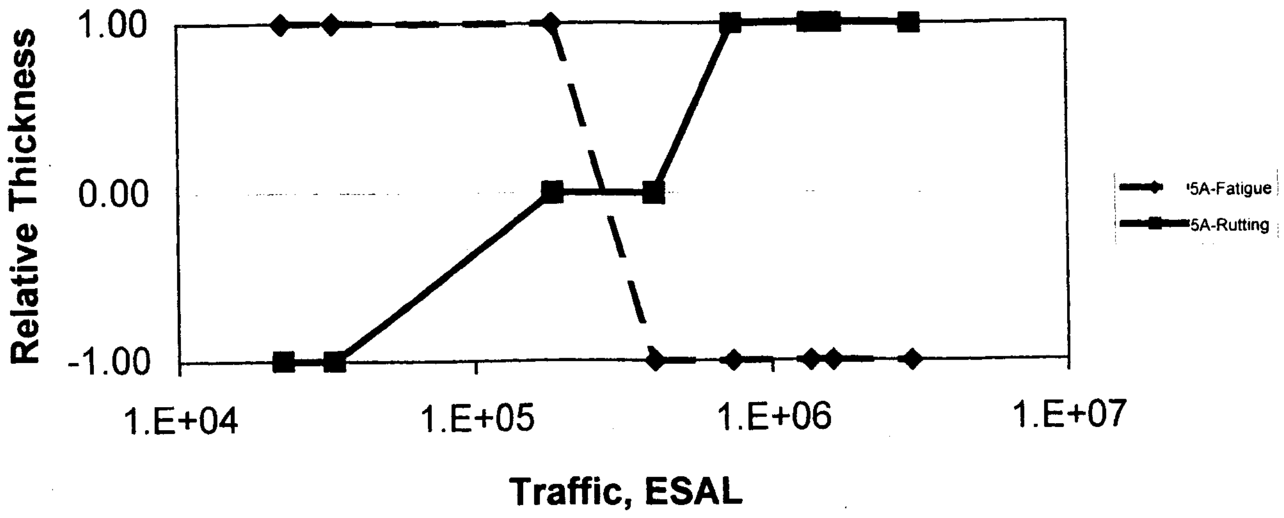


(a). Run 4A – R = 70.

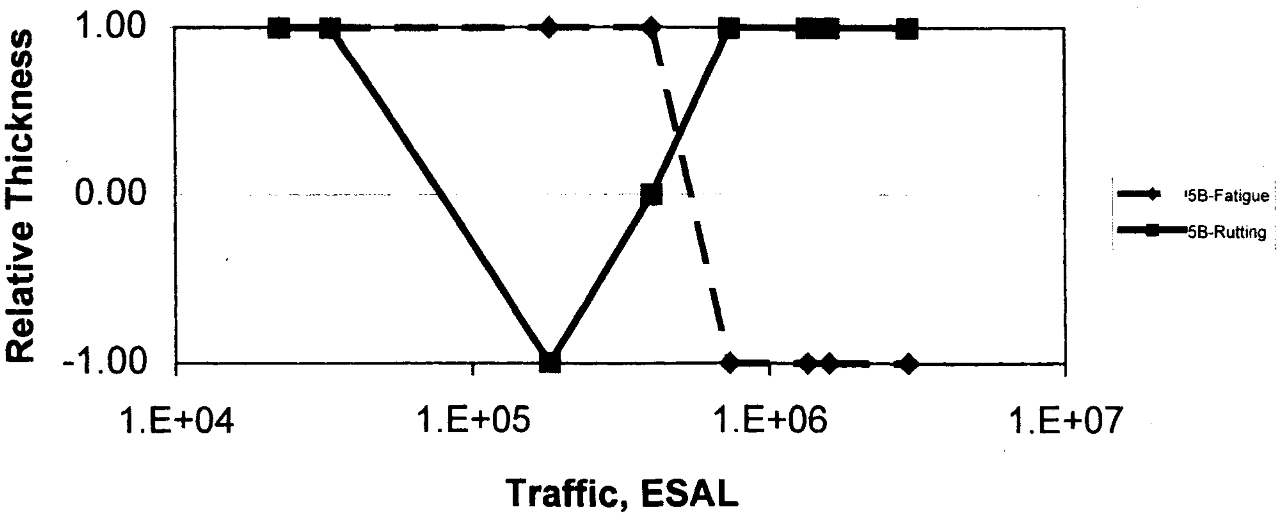


(b) Run 4B – R = 70.

Figure 31. Comparison of Minnesota LVR Designs with Roadent (R = 70) (1 = Thicker, 0 = Same Thickness, -1 = Thinner).

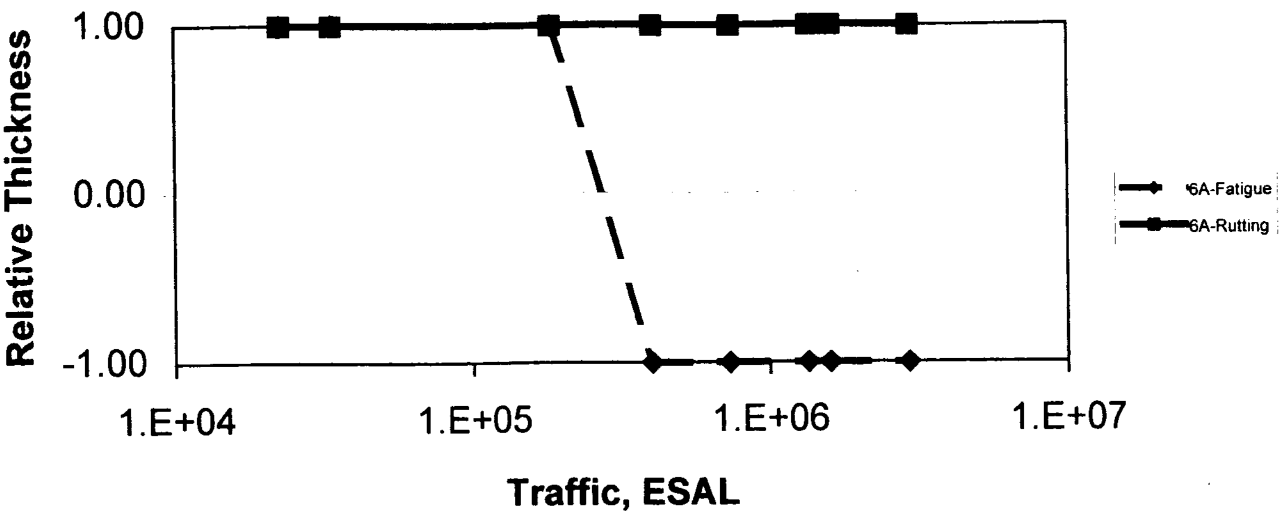


(a). Run 5A – R = 20.

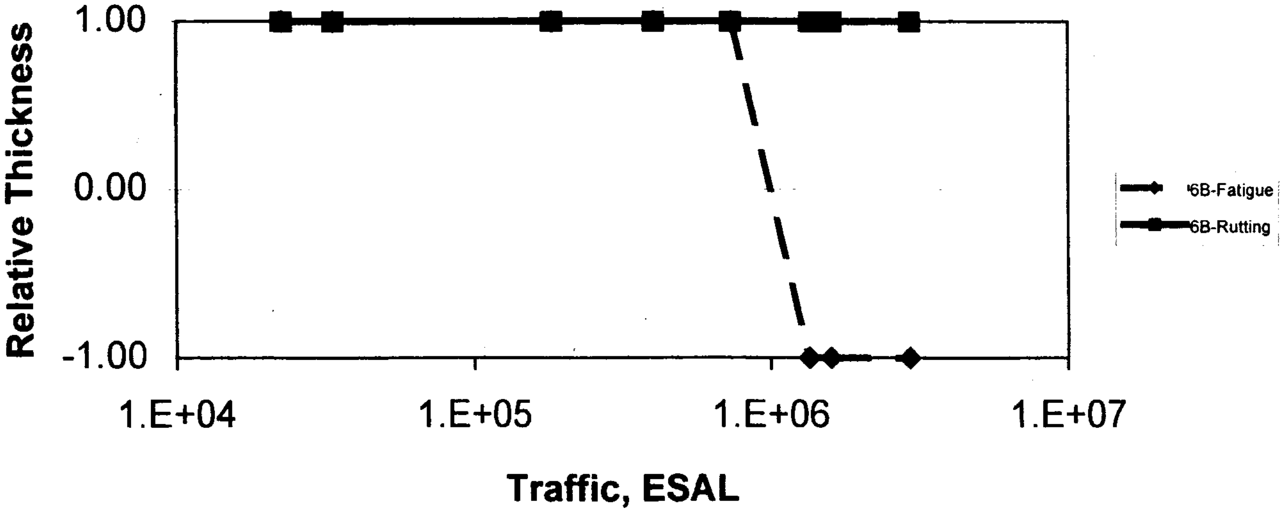


(b) Run 5B – R = 20.

Figure 32. Comparison of Minnesota LVR Designs with Roadent (R = 20) (1 = Thicker, 0 = Same Thickness, -1 = Thinner).



(a). Run 6A – R = 10.



(b) Run 6B – R = 10.

Figure 33. Comparison of Minnesota LVR Designs with Roadent (R = 10) (1 = Thicker, 0 = Same Thickness, -1 = Thinner).

CHAPTER 5

SUMMARY, CONCLUSIONS and RECOMMENDATIONS

This report has summarized the two flexible pavement thickness design procedures used in Minnesota, the Soil Factor and R-Value procedures. The Soil Factor procedure is found in the Mn/DOT State Aid Manual (1) and the R-Value procedure is in the Mn/DOT Design (2) and Geotechnical Manuals (3).

The current procedures used by cities and counties for design, specifications, construction and managing of pavements were determined by sending a questionnaire to all 87 counties and 120 cities. A summary of the replies shown in Chapter 3 indicates that there are a wide variety of practices used, especially for construction specifications and management procedures. The results show the need for some uniformity.

The survey results indicate that most counties are using the Soil Factor thickness design procedure and a majority of the cities use the R-Value procedure. Both of these procedures are over 25 years old. In Chapter 4 these procedures were evaluated by calculating expected lives based on the mechanistic-empirical procedure (ROADENT) developed at the University. This program uses the elastic layered system to calculate strains in a simulated pavement and relates these to the development of fatigue cracking and rutting. The relationship between strains and performance are based on observations at Mn/ROAD.

The comparisons are made by:

1. Converting Soil Factors and R-Values to soil moduli
2. Using backcalculated moduli for base and surface materials from Mn/ROAD, falling weight deflectometer backcalculations (including season variations)
3. Converting ADT and HCADT categories used for the soil factor design to ESAL using typical Minnesota vehicle type and weight distributions
4. Calculating expected lives based on ROADENT for thicknesses resulting from the two procedures

The comparisons show:

Soil Factor procedure:

1. The fatigue analyses relative to the mechanistic-empirical design, the soil factor design thicknesses are adequate up to medium traffic with minimum surface and base thicknesses, and are adequate to about 1,500,000 ESAL using a 150-mm (6-in.) asphalt mix thickness for the three soil types checked
2. The rut depth analyses show the soil factor design thicknesses are generally not adequate for high and medium strength soils, but are adequate for the lower strength soils.

R-Value procedure:

1. For the fatigue analyses the thicknesses are adequate at low traffic levels but not adequate for high traffic
2. The rut depth analyses do not show a consistent pattern except for the low strength soils the thicknesses are adequate at all levels of traffic.

These analyses are based on the determination of life predictions. The time and scope of this project did not make it possible to establish thicknesses required to achieve adequate life predictions.

Recommendations:

Based on the results of the survey and analyses using the mechanistic-empirical the following recommendations are made:

1. Continue the life predictions using the mechanistic-empirical design procedure ROADENT
   a. An updated version will now include reliability
   b. Thicknesses should be established for various levels of reliability; the reliability is based on variations in material properties and thicknesses measured at Mn/ROAD
   c. Reliability of "typical" local road construction should be evaluated so that appropriate levels can be used for city and county road performance evaluation
   d. The model should be calibrated for city and county roads; this can be

accomplished using reasonable data which are available for construction, traffic and performance. These evaluations should be for relatively urban and rural conditions.

   e. Compare reliability levels for city and county construction with Mn/DOT.

2. Develop a best practices manual for local agencies in Minnesota. The results of the survey show a wide variety of designs and specifications are currently used. An evaluation of the current practices needs to be made in light of thickness reductions indicated for higher levels of reliability. The manual should include:
   a. Thickness design
   b. Soils evaluation
   c. Traffic
   d. Construction specifications and standard procedures
   e. Management practices for pavement:
      > Evaluation
      > Maintenance
      > Rehabilitation

Good documentation of design, construction and management of pavements will also make it possible to calibrate the performance models used to predict performance with the mechanistic-empirical design analyses.

REFERENCES

(1) Mn/DOT State Aid Manual

(2) Mn/DOT Design Manual

(3) Mn/DOT Geotechnical Manual

(4) Mn/DOT Standard Specifications for Construction, 1995 Edition

(5) Duane Young, Mn/DOT Memo to Julie Skallman, "Low Volume Road Flexible Pavement Design, April 18, 1988

(6) R.E. Wolfe, "Resistance R-Value of Embankment Soils and Aggregate for Use as Bases and Subbase, Inv. 176, State of Minnesota Department of Highways, 1960

(7) Guide for Design of Pavement Structures, AASHTO, 1993

(8) Newcomb and Timm, Development of ROADENT

APPENDIX A

TABULATION OF
64 COUNTY AND 50 CITY
QUESTIONNAIRE RESPONSES

APPENDIX A

TABULATION OF 64 COUNTY AND 50 CITY QUESTIONNAIRE RESPONSES

Date: August, 1998 Agency: Minnesota Counties

Respondent: 64 Counties

Address: ______

______

Survey of Local Pavement Design Practice

The Local Road Research Board is sponsoring a study to review and refine the practice of designing and constructing pavements at the local government level. The investigators for this project devised this questionnaire to gain insight into local practice. The topics covered here include design, specifications, construction and performance. Please respond according to your normal practice. If you have additional information to provide, please provide written comments. Thank you.

Design

1. What is your current design procedure?

44 32

a. Soil Factor b. R-value c. Other both (2)

(high traffic) R-Value for 10-ton routes

2. What are the primary types of soils in your jurisdiction?

1 16 5 19 10 14 1

a. A-3 b. A-4 c. A-5 d. A-6 e. A-7-5 f. A-7-6 all

3. How do you determine the soil input values for design?

24 28 3

a. Testing b. Soil Classification c. USDA Map

d. Past History e. Other R-Value-2

25 FWD - 1 Needs Study - 1

4. Do you normally design for a compaction subcut?

58 5

a. Yes b. No

If yes, how deep is a normal subcut? 1 ft. 1-2ft 2ft 2.5ft 3ft

11 8 29 3 4

5. What type of traffic input do you use for design?

15 29 10

a. HCADT b. ESAL c. Maximum Load (5-ton, 7-ton, etc.)

d. ADT e. Other ESAL's for 10-ton 1

40 HCADT " " " 1

6. How do you determine the traffic input for design?

14 3

a. ADT Count by Your Agency b. Classification Count by Your Agency

c. Provided by Mn/DOT d. Roadway Classification

55 3

7. What types of drainage features do you commonly incorporate?

61 23 5

a. Ditches b. Edge Drains c. Drainage Layer d. Other tile 4

culvert 1

storm Sewers 1

Specifications

1. What material specifications do you use for asphalt concrete?

24 35 14 1

a. 2331 b. 2340 c. 2350 d. Other 2360

2. Do you allow the use of RAP in your asphalt mixtures?

50 13 Leveling 3

a. Yes b. No Base Only 5

Shoulders 1

3. What material specifications do you use for granular base and subbase?

10 – 61 2 3 1

a. Class 3 b. Class 4 c. Class 5 d. Class 6 e. Other class 2 <6-in. rock

4. What type of embankment specifications do you use?

52 6 23 1

a. Ordinary Compaction b. Specified Density c. Test Rolling (50-ton) quality

If you use Specified Density, do you use (choose one) 95% or 100% of:

7

a. Standard Proctor b. Modified Proctor

If you use Test Rolling, what specification or device is used? MnDOT 2111 - 14

loaded truck - 2 scraper - 2

Construction

In this section, quality control will refer to the activities of the contractor to ensure that the product is consistent and meets the minimum requirements of the agency. Quality Assurance refers to the activities of the agency to ensure that minimum quality standards are being met by the contractor.

1. What types of tests are performed on soils during construction?

8 7 32 13

a. In-Situ Density b. Moisture Content c. Classification/Gradation None

If in-situ density is measured, what method is used?

5 7

a. Sand Cone b. Nuclear

2. Who performs testing on soils during construction?

4 32 6

a. Contractor b. Agency c. Consultant

3. What is the maximum lift thickness for aggregate base? __________ in.

None	2 in.	3 in.	4 in.	5 in.	6 in.	9 in.	12 in.	14 in.	16 in.
1	2	28	10	3	11	1	1	1	1

4. What types of tests are performed on granular bases during construction?
9 10 54 3 1
a. In-Situ Density b. Moistur Content c. Classification/Gradation None Ordinary

If in-situ density is measured, what method is used?
5 7 1 1
a. Sand Cone b. Nuclear Quality none

5. Who performs testing on granular bases during construction?
7 54 3
a. Contractor b. Agency c. Consultant

6. Concerning the construction of asphalt layers:

Do you use a prime coat on aggregate base?
8 53
a. Yes b. No

(2) (13) (10) (10) (3)
What is the maximum lift thickness for the bituminous base course? 1.5, 2 in. 3 3 3
What is the maximum lift thickness for the bituminous binder course? 1.5, 2 in. 2 3 2
What is the maximum lift thickness for the bituminous wear course? 1.5, 2 in. 2 1½ 1½

2½ 3 3½ 3 4 6 8
2½ 3 2½ 1½ 3 3 1½
2 2-3 2 1½ 2 1½ 1
(6) (8) (3) (2) (2) (1) (1)

7. Do you use Quality Management specifications for asphalt mixtures?
44 20
a. Yes b. No

Performance

1. How do you evaluate performance?
39 27 14
a. Ride b. Condition Survey c. Deflection Testing

2. Do you have a pavement management system?
20 45
a. Yes b. No

3 1 7 1 1 1 3 1
If yes, what is the name of the system? in house, Road Pro, Cart-graph, Micro Paver, Manual, RQI, ICON Braun, Customize SW.

3. What is the approximate length of time before rehabilitation for a new asphalt pavement in your experience? — years 5-7, 7, 7-10, 10-15, 15, 15-20, 18, 20+, 20-25, 25, 5-25, 30, 30-
1 1 4 5 12 2 5 14 3 7 1 1 1

4. How long does an asphalt overlay last in your experience? — years
3(s.c), 4(s.c), 5(s.c), 7-10, 10, 8-12, 12, 10-15, 15±, 15-20, 20, 23-25,
3 1 2 6 6 3 5 12 12 8 4 1
10-20, 10-30, 5-25, 30-40
1 1 1 1

5. What is the main motivation for rehabilitation in your experience?

a. Mixture Problems

52 13 8 2 28 1

i. Raveling ii. Stripping iii. Flushing iv. Rutting v. Tender Mixes

b. Structural or Environmental Problems

99 44 19 36

i. Fatigue Cracking ii. Rutting iii. Transverse Cracking

c. Construction Problems

48 10 16 22

i. Lack of Uniformity ii. Poor Ride Quality iii. Joint Deterioration

Load Restrictions

1. Do you use load limits on your roadways?

63 —

a. Yes b. No

2. How are load limits established?

26 48

a. Deflection Testing b. Design

3. How is the timing of load restrictions established?

57 1 2 7 4 3 1 1

a. Mn/DOT b. Other Maint. Div. Past Hist. Neighboring Cty Frost tubes As needed Conditions Mn Road

4. How well are load limits enforced?

13 31 19

a. Actively b. Intermittently c. Not at All

5. How many total miles of road in your county? ____________ miles

Miles of State Aid Roads paved:
asphalt? ____________ concrete? ____________

Miles of Non-State Aid Roads paved:
asphalt? ____________ concrete? ____________

Percentage of system that is 7-ton? __________
Percentage of 7-ton that is posted during spring? ___________

Thank you for your help in answering this questionnaire. Please return by August 1, 1998 to:

Dr. Eugene Skok
Department of Civil Engineering
University of Minnesota
500 Pillsbury Dr. SE
Minneapolis, MN 55455

Date: August, 1998 Agency: Minnesota Cities

Respondent: 50 Cities

Address: ____________________

____

Survey of Local Pavement Design Practice

The Local Road Research Board is sponsoring a study to review and refine the practice of designing and constructing pavements at the local government level. The investigators for this project devised this questionnaire to gain insight into local practice. The topics covered here include design, specifications, construction and performance. Please respond according to your normal practice. If you have additional information to provide, please provide written comments. Thank you.

Design

1. What is your current design procedure?

16 32 Typical Crosssection 2
a. Soil Factor b. R-value c. Other Consultant 2

2. What are the primary types of soils in your jurisdiction?

10 7 7 9 6 6 1 3 1
a. A-3 b. A-4 c. A-5 d. A-6 e. A-7-5 f. A-7-6 All A-2-4 A-1-b

3. How do you determine the soil input values for design?

29 11 –
a. Testing b. Soil Classification c. USDA Map
d. Past History e. Other ____________
21 –

4. Do you normally design for a compaction subcut?

22 22
a. Yes b. No

If yes, how deep is a normal subcut? __________ ft. 1ft 1-2' 2.0, 2-3, 3
11 1 7 2 1

5. What type of traffic input do you use for design?

9 17 15
a. HCADT b. ESAL c. Maximum Load (5-ton, 7-ton, etc.)
d. ADT e. Other ____________
17 F. Mn DOT Design 1

6. How do you determine the traffic input for design?

26 4
a. ADT Count by Your Agency b. Classification Count by Your Agency
c. Provided by Mn/DOT d. Roadway Classification
15 11

7. What types of drainage features do you commonly incorporate?

a. Ditches b. Edge Drains c. Drainage Layer d. Other Curb & gutter + storm sewer 15
7 (rural) 25 9 granular subcut 2
for poor wet soils only, 1 drain tiles 3

Specifications

1. What material specifications do you use for asphalt concrete?

   32 13 8
   a. 2331 b. 2340 c. 2350 d. Other Superpave(1999) 1
   PG grade AC 1

2. Do you allow the use of RAP in your asphalt mixtures?

   28 11 5
   a. Yes b. No Base only

3. What material specifications do you use for granular base and subbase?

   1 5 1 41 1 2
   class 2 a. Class 3 b. Class 4 c. Class 5 d. Class 6 e. Other Select Granular

4. What type of embankment specifications do you use?

   22 25 9
   a. Ordinary Compaction b. Specified Density c. Test Rolling

   If you use Specified Density, do you use (choose one) 95% or 100% of:

   10 18 3
   a. Standard Proctor b. Modified Proctor
   95% 100%

   If you use Test Rolling, what specification or device is used? MnDOT 2111 2
   Fully loaded tandem truck 10

Construction

In this section, quality control will refer to the activities of the contractor to ensure that the product is consistent and meets the minimum requirements of the agency. Quality Assurance refers to the activities of the agency to ensure that minimum quality standards are being met by the contractor.

1. What types of tests are performed on soils during construction?

   35 26 22
   a. In-Situ Density b. Moisture Content c. Classification/Gradation

   If in-situ density is measured, what method is used?

   13 29
   a. Sand Cone b. Nuclear

2. Who performs testing on soils during construction?

   3 11 33
   a. Contractor b. Agency c. Consultant

3. What is the maximum lift thickness for aggregate base? __________ in.

   3 in 4in. 5in. 6 in. 8 in. 12in
   7 4 2 19 9 2

4. What types of tests are performed on granular bases during construction?

33	19	33	1
a. In-Situ Density	b. Moisture Content	c. Classification/Gradation	d. Test Roll

If in-situ density is measured, what method is used?

12	26
a. Sand Cone	b. Nuclear

5. Who performs testing on granular bases during construction?

2	11	36
a. Contractor	b. Agency	c. Consultant

6. Concerning the construction of asphalt layers:

Do you use a prime coat on aggregate base?

3	43
a. Yes	b. No

	①	②		–	⑥	④	③	⑤	①
What is the maximum lift thickness for the bituminous base course?	2	2½	in.	3	3	3	3	4	4
What is the maximum lift thickness for the bituminous binder course?	2	2	in.	1½	2	3	3	4	4
What is the maximum lift thickness for the bituminous wear course?	1	1½	in.	1½	2	2	3	2	4

7. Do you use Quality Management specifications for asphalt mixtures?

18	27
a. Yes	b. No

Performance

1. How do you evaluate performance?

23	27	2
a. Ride	b. Condition Survey	c. Deflection Testing

2. Do you have a pavement management system?

21	27
a. Yes	b. No

9	1	5	1	2	1	1
Braun ICON	Cartgraph	PMS Stanley	In-house	Wisc Paver	APWA Paver	Eagle Point

If yes, what is the name of the system? ____________

3. What is the approximate length of time before rehabilitation for a new asphalt pavement in your experience? ______ years

years	5	7	10	15	18	20	20-30	25	25-30	28	30	50
No.	1	3	3	6	1	7	5	4	4	1	3	1

4. How long does an asphalt overlay last in your experience? ______ years

	5	5-10	7	8-10	10	10-15	15	15-20	20+
No.	2	4	3	2	14	7	6	3	1

1 - depends on traffic

traffic	yrs
>10,000 ADT	5-10
4000 - 10,000 ADT	15-20
100 - 4000 ADT	25-35

5. What is the main motivation for rehabilitation in your experience?

a. Mixture Problems

(38)
18 8 – 12
i. Raveling ii. Stripping iii. Flushing iv. Rutting

b. Structural or Environmental Problems

(60)
31 9 20
i. Fatigue Cracking ii. Rutting iii. Transverse Cracking

c. Construction Problems

(39)
2 15 22
i. Lack of Uniformity ii. Poor Ride Quality iii. Joint Deterioration

Load Restrictions

1. Do you use load limits on your roadways?

31 13
a. Yes b. No

2. How are load limits established?

2 27
a. Deflection Testing b. Design

3. How is the timing of load restrictions established?

28 4
a. Mn/DOT b. Other County 3/1 to 5/1 by council 1
3-ton on city streets during restriction

4. How well are load limits enforced?

12 16 4
a. Actively b. Intermittently c. Not at All

5. How many total miles of road in your county? ____________ miles

Miles of State Aid Roads paved:
asphalt? ____________ concrete? ____________

Miles of Non-State Aid Roads paved:
asphalt? ____________ concrete? ____________

Percentage of system that is 7-ton? __________
Percentage of 7-ton that is posted during spring? __________

Thank you for your help in answering this questionnaire. Please return by August 1, 1998 to:

Dr. Eugene Skok
Department of Civil Engineering
University of Minnesota
500 Pillsbury Dr. SE
Minneapolis, MN 55455