



Research

Best Practices for the Design and Construction of Low Volume Roads



Minnesota Local
Road Research
Board

Technical Report Documentation Page

1. Report No. MN/RC –2002-17	2.	3. Recipients Accession No.	
4. Title and Subtitle BEST PRACTICES FOR THE DESIGN AND CONSTRUCTION OF LOW VOLUME ROADS		5. Report Date March 2002	
		6.	
7. Author(s) Eugene L. Skok, David H. Timm, Marcus L. Brown and Timothy R. Clyne		8. Performing Organization Report No.	
9. Performing Organization Name and Address Department of Civil Engineering University of Minnesota 500 Pillsbury Drive SE Minneapolis, MN 55455		10. Project/Task/Work Unit No.	
		11. Contract (C) or Grant (G) No. c) 74708 wo) 123	
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 1999-2002	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract (Limit: 200 words) This report presents information about the use of the mechanistic-empirical procedure (MnPAVE) in designing hot-mix asphalt pavements in Minnesota. Researchers developed the MnPAVE software program using information from the Minnesota Road Research Project (Mn/ROAD) test facility and from 40-year-old test sections around Minnesota. MnPAVE procedures use Equivalent Standard Axle Loads (ESALs) to evaluate traffic loading, and the report includes methods to estimate these values for design purposes over a 20-year design life, as well as a procedure to measure vehicle type distributions. In addition, the report presents an evaluation of subgrade soils for each thickness design procedure, summarizes Minnesota Department of Transportation specifications that relate to embankment soil construction and to construction of the pavement section materials, and recommends specific density or quality compaction using a control strip. It also includes best practices on setting up projects most effectively to follow specifications.			
17. Document Analysis/Descriptors Mechanistic-Empirical Soil Factor Pavement Section Construction Specifications R-Value ESAL's Resilient Modulus Subgrade Soil Granular Equivalent Flexible Pavement Thickness Design		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 178	22. Price

BEST PRACTICES FOR THE DESIGN AND CONSTRUCTION OF LOW VOLUME ROADS

Final Report

Prepared by:

Eugene L. Skok
David H. Timm
Marcus L. Brown
Timothy R. Clyne

Department of Civil Engineering
University of Minnesota
500 Pillsbury Dr. S.E.
Minneapolis, MN 55455

March 2002

Published by:

Minnesota Department of Transportation
Office of Research Services
Mail Stop 330
395 John Ireland Boulevard
St. Paul, MN 55155

This report represents the results of research conducted by the authors and does not necessarily represent the views or policies of the Minnesota Department of Transportation or the Minnesota Local Road Research Board. This report does not contain a standard or specified technique.

ACKNOWLEDGEMENTS

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

TABLE OF CONTENTS

Chapter 1 Introduction.....	1
1.1 Introduction	1
1.2 Minnesota Thickness Design Procedures.....	3
1.2.1 Soil Factor Design Procedure.....	3
1.2.2 R-Value Procedure	5
1.2.3 MnPAVE Procedure.....	7
1.2.4 Pavement Design Options for 2002	9
1.3 Traffic Estimates	9
1.4 Subgrade (Embankment) Soil	10
1.4.1 Background	10
1.4.2 Drainage	11
1.4.3 Subgrade (Embankment) Soil Construction.....	11
1.4.3.1 General	11
1.4.3.2 Specifications	11
1.4.3.3 General Design Considerations.....	12
1.4.3.4 Construction Notes and Procedures	14
1.4.3.5 Subgrade Enhancement.....	14
1.5 Pavement Section Materials.....	14
1.5.1 General	14
1.5.2 Pavement Layer Construction.....	15
1.5.2.1 General	15
1.5.2.2 Specifications	15
1.5.2.3 Field Control Procedures to Meet Specifications.....	16
1.5.2.3.1 General	16
1.5.2.3.2 Aggregate	16
1.5.2.3.3 Hot Mix Asphalt.....	18
1.6 Summary and Recommendations.....	19

Chapter 2 Thickness Design Procedures.....	23
2.1 Background and Introduction.....	23
2.2 Soil Factor Design.....	23
2.3 Stabilometer R-Value Design.....	25
2.4 MnPAVE Design.....	27
2.4.1 General	27
2.4.2 Set Up.....	29
2.4.3 Start Up	29
2.4.3.1 Control Panel.....	29
2.4.3.2 General Operation	29
2.4.4 Inputs.....	30
2.4.4.1 General	30
2.4.4.2 Climate Inputs (Seasonal Design).....	30
2.4.4.3 Structural Inputs	31
2.4.4.4 Traffic Inputs.....	33
2.4.5 Outputs	34
2.5 Which Procedure Should be Used in 2001-02?	34
 Chapter 3 Traffic Predictions	 37
3.1 Background and Definitions.....	37
3.2 Determination of AADT	38
3.3 Determination of HCADT.....	39
3.4 ESAL Calculations	39
3.4.1 Estimate AADT.....	39
3.4.2 Vehicle Type Distribution.....	40
3.4.3 Determination of ESAL Factors by Vehicle Type	41
3.4.4 Determination of Growth Factor	42
3.4.5 Design Lane Distribution	43
3.4.6 ESAL Calculation Spreadsheet	43
3.5 Summary and Conclusions.....	45

Chapter 4 Subgrade (Embankment) Soil Design and Construction	47
4.1 Background and Definitions.....	47
4.2 Soil Surveys and Sampling	48
4.3 Subgrade Soil Design Factors	49
4.3.1 General	49
4.3.2 Laboratory Testing	50
4.3.2.1 The AASHTO Soil Classification System	50
4.3.2.2 Stabilometer R-Value	52
4.3.2.3 Resilient Modulus (M_r)	54
4.3.3 Field Measurements of Subgrade Stiffness	57
4.3.3.1 General	57
4.3.3.2 Falling Weight Deflectometer.....	57
4.3.3.3 Dynamic Cone Penetrometer	59
4.3.3.4 Additional <i>In Situ</i> Factors	60
4.3.4 Use of Subgrade Design Factors	62
4.3.4.1 General	62
4.3.4.2 Soil Factor	62
4.3.4.3 R-Value	62
4.3.4.4 MnPAVE.....	62
4.4 Drainage	64
4.5 Construction of the Subgrade (Embankment).....	65
4.5.1 General	65
4.5.2 Specifications	65
4.5.2.1 MnDOT Specification 2105 (Excavation and Embankment)	65
4.5.2.1.1 Materials.....	66
4.5.2.1.2 Construction Requirements	66
4.5.2.1.3 Compaction Requirements	67
4.5.2.1.3.1 Specified Density Method.....	68
4.5.2.1.3.2 Quality or Visual Inspection Method.....	68
4.5.2.2 MnDOT Specification 2111 (Test Rolling)	69
4.5.2.2.1 Description	69

4.5.2.2.2 Equipment	69
4.5.2.2.3 Construction Requirements	69
4.5.3 General Design Considerations	69
4.5.3.1 General	69
4.5.3.2 Excavation and Embankment Construction	70
4.5.3.3 Soils Evaluation.....	70
4.5.3.4 Soils Preparation	71
4.5.3.5 Subgrade Correction.....	71
4.5.3.6 Placement of Embankment and Backfill Materials.....	72
4.5.3.7 Compaction	72
4.5.4 Construction Notes and Procedures	73
4.6 Subgrade Enhancement Summary	75
4.6.1 General	75
4.6.2 Categories of Enhancement.....	75
4.6.2.1 Improvement of Existing Materials.....	75
4.6.2.2 Remove and Replace.....	76
4.6.2.3 Modification.....	76
4.6.2.4 Geosynthetics	76
Chapter 5 Pavement Section Materials.....	79
5.1 General	79
5.2 Definitions.....	80
5.2.1 Granular Subbase and Select Granular (Mn/DOT Specification 3149-B2).....	80
5.2.1.1 Granular.....	80
5.2.1.2 Select Granular	80
5.2.1.3 Subbase Course (Mn/DOT Specification 3138, Class 4).....	80
5.2.2 Aggregate Base Course	80
5.2.2.1 Granular (Mn/DOT Specification 3138, Class 3, 5, and 6).....	80
5.2.2.2 Salvage Materials (Mn/DOT Specification 3138, Class 7).....	80
5.2.3 Stabilized Base Materials	80
5.2.3.1 Portland cement, lime and/or fly ash.....	81

5.2.3.2 Asphalt cement, asphalt emulsions and cutbacks.....	81
5.2.4 Recycling and Reclaiming	81
5.2.4.1 Cold In-Place Recycling.....	81
5.2.4.2 Full Depth Reclamation	81
5.2.5 Hot Mix Asphalt (HMA).....	81
5.3 Pavement Design Factors	81
5.3.1 General	81
5.3.2 Granular Equivalency Factors	82
5.3.3 Resilient Modulus for Pavement Materials	82
5.4 Construction of the Pavement Layers	83
5.4.1 Specifications Review	83
5.4.1.1 Granular Materials Properties and Gradations	83
5.4.1.1.1 Granular Subbase (Specification 3149.2B2).....	83
5.4.1.1.2 Aggregate Base and Subbase Materials (Mn/DOT Specification 3138)..	84
5.4.1.1.3 Stabilized Base	84
5.4.1.1.4 Recycled and Reclaimed Materials	84
5.4.1.1.5 Sampling and Testing.....	85
5.4.1.2 Construction of Aggregate Base (Mn/DOT Specification 2211).....	85
5.4.1.2.1 Construction Requirements	86
5.4.1.2.1.1 General	86
5.4.1.2.1.2 Placing and Mixing	86
5.4.1.2.1.3 Spreading.....	86
5.4.1.2.1.4 Compaction	87
5.4.1.2.1.5 Workmanship and Quality	87
5.4.1.2.1.6 Aggregate in Stockpiles	88
5.4.1.2.1.7 Random Sampling Gradation Acceptance Method.....	88
5.4.1.2.1.8 Payment.....	88
5.4.1.3 Hot Mix Asphalt (HMA) Mixtures	88
5.4.1.3.1 General	88
5.4.1.3.2 MnDOT 2350 Specification.....	89
5.4.1.3.3 Mn/DOT 2360 Specification (Gyratory Mix Design).....	96

5.4.2 Field Control Procedures to Meet Specifications.....	109
5.4.2.1 General	109
5.4.2.2 Granular Subbases and Aggregate Bases	109
5.4.2.2.1 General	109
5.4.2.2.2 Schedule of Materials Control.....	110
5.4.2.2.3 Standard Methods of Testing	110
5.4.2.2.4 Methods of Compaction Control for Granular Bases.....	111
5.4.2.2.5 Job Guide for Aggregate Base Construction.....	111
5.4.2.3 Hot Mix Asphalt (HMA) Construction	112
5.4.2.3.1 General	112
5.4.2.3.2 Standard Methods of Testing	113
5.4.2.3.3 Methods of Compaction Control for HMA.....	113
5.4.2.3.4 Job Guide for Plant Mix Bituminous Paving	115
 Chapter 6 Summary and Recommendations.....	 119
6.1 General	119
6.2 Thickness Design Procedures.....	119
6.3 Traffic.....	119
6.4 Subgrade (Embankment) Soil	121
6.5 Pavement Section Materials	122
6.5.1 General	122
6.5.2 Specifications and Design Factors	123
6.5.3 Construction of Granular Bases	123
6.5.4 Construction of Hot Mix Asphalt Materials.....	124
 References	 127
 Appendix A Use of Investigation 183 and 195 Test Sections As a Long Term Performance Comparison with the Minnesota M-E Design Procedure	
 Appendix B Vehicle Classification Field Guide for Low Volume Roads	

LIST OF TABLES

Table 1.1 MnPAVE Design Moduli Correlation	6
Table 3.1 Vehicle Classification Percentages – Rural CSAH or County Road	40
Table 3.2 Average ESAL Factors by Vehicle Type.....	41
Table 3.3 Sample Computation of ESAL Factor	42
Table 3.4 Growth Factors.....	43
Table 3.5 Lane Distribution Factors.....	43
Table 3.6 ESAL Calculation Worksheet.....	44
Table 4.1 Sampling Rates.....	49
Table 4.2 AASHTO Soil Classification	51
Table 4.3 AASHTO-Soil Factor Correlation	52
Table 4.4 General Correlation Table for Strength and Stiffness Tests	60
Table 4.5 MnPAVE Design Moduli Correlation	64
Table 5.1 Granular Equivalent (G.E.) Factors	82
Table 5.2 Default Resilient Modulus Values to Use in MnPAVE.....	83

LIST OF FIGURES

Figure 1.1 Flexible Pavement Design Using Soil Factors	4
Figure 1.2 R-Value Design Chart.....	5
Figure 2.1 Flexible Pavement Design Using Soil Factors	24
Figure 2.2 R-Value Design Chart.....	26
Figure 4.1 Stabilometer R-Value Testing Apparatus	54
Figure 4.2 Resilient Modulus Testing Apparatus	55
Figure 4.3 Load and Deformation vs. Time for Resilient Modulus Test.....	56
Figure 4.4 FWD Unit	58
Figure 4.5 FWD Deflection Basin	59
Figure 4.6 MnDOT DCP.....	61

EXECUTIVE SUMMARY

Currently, Hot Mix Asphalt (HMA) pavements in Minnesota are designed using one of three thickness design procedures: the Soil Factor, the R-Value or the Mechanistic-Empirical Procedure (MnPAVE). The Soil Factor and R-Value, which refer to the methods of evaluating the design soil, have been used by MnDOT and local agencies for the past 25 plus years. A software program MnPAVE has been developed using information from MnROAD and some 40-year-old test sections around Minnesota. It is now recommended that city and county agencies calculate thickness designs using the existing procedure they would normally use and then use the MnPAVE software for an alternate design.

The Soil Factor Design uses two-way Annual Average Daily Traffic (AADT) and Heavy Commercial Average Daily Traffic (HCADT) to define the loading. The R-Value and MnPAVE procedures use Equivalent Standard Axle Loads (ESAL's) to evaluate traffic loading. Chapter 3 presents methods for estimating these values for design purposes over a 20-year design life. A procedure is presented for measuring vehicle type distributions rather than using assumed statewide average values. The procedure was evaluated in a separate study discussed in Chapter 3.

The evaluation of subgrade (embankment) soils for each of the procedures is presented in Chapter 4. The Soil Factor is a function of the AASHTO Classification. The R-Value can be measured using a standard laboratory procedure or estimated from the AASHTO Classification. The Resilient Modulus (M_r) can be estimated from the classification or from the R-Value (7). A laboratory method to measure M_r is now being developed.

Construction of the embankment soil requires that MnDOT Specifications 2105, 2111, and 2123 be followed carefully (9). These specifications are summarized in Chapter 4 along with recommendations on how they can best be implemented in the field. The procedures presented should provide the stiffest (strongest) most uniform subgrade using the soils available at the construction site. A checklist is also provided for the engineer and inspector to help set up and conduct a well organized project (10, 11).

The pavement section materials for the Soil Factor and R-Value procedures are defined in terms of the granular equivalency which when totaled yields the Granular Equivalent Thickness of the pavement. The granular equivalency factors are defined based on the Specification that the

given material passes. A Specification 3138, Class 5 or 6 material has a factor of 1.0. The resilient modulus of a particular material is used to define it for MnPAVE. For both the subgrade and the pavement materials the resilient modulus can be varied throughout the year. Five seasons have been defined using the moduli measured at MnROAD (8). HMA materials passing Specifications 2350 or 2360 have granular equivalency factors of 2.25. The moduli can also be varied throughout the year.

Construction of the pavement section materials requires that the layer be constructed according to Specification 3138 and 2211 for the granular materials and Specification 2350 or 2360 for the HMA materials. These specifications are summarized in Chapter 5 along with recommendations on how they can be implemented in the field. The 2360 (Superpave) specification is only used for pavements for which the traffic exceeds 7 million ESAL's.

Compaction is also very important for the construction of the pavement materials. Specified Density or the use of the DCP are recommended for granular materials. For HMA materials specified density or quality compaction using a control strip are recommended. Quality or ordinary compaction is not recommended.

The Inspector's Guide for Construction (11) is summarized for subgrade, granular subbase, base, and HMA surface materials is summarized to help set up projects to most effectively follow the respective specifications.

CHAPTER 1

INTRODUCTION

1.1. Introduction

This report has been developed to present methods for design and construction of Hot Mix Asphalt (HMA) local roads in Minnesota. At this time, Mn/DOT and the flexible pavement industry are in a time of transition for thickness design and construction procedures. The MnPAVE thickness design procedure is a computer software mechanistic-empirical based method that takes into account many variables that could not be considered previously. The MnPAVE procedure is based on work done at the University of Minnesota using an elastic layered system (WESLEA) developed by the Corps of Engineers. The University of Minnesota program called ROADENT used performance prediction equations for HMA fatigue and subgrade rutting based on material properties and performance of test sections at Mn/ROAD. The computer software based methodology implemented in ROADENT provided the concepts used by Mn/DOT to develop MnPAVE. The performances of some 40-year old test sections were used to check the performance prediction equations used in ROADENT. Appendix A of the full report presents the results of these comparisons. A significant advantage of using a mechanistic-empirical design procedure is that the properties of various materials and conditions can be entered into the software. This allows various combinations of materials of different thicknesses to be considered and the most cost efficient pavement structure selected.

Chapter 2 of the report reviews the three HMA thickness design procedures currently used in Minnesota – the Soil Factor, Stabilometer R-Value and MnPAVE. A survey of the city and county engineers in Minnesota indicated that both the Soil Factor and R-Value are currently being used. About two-thirds of the counties use the Soil Factor and about two-thirds of the cities use the R-Value.

The Soil Factor Design is presented in the Mn/DOT State Aid Manual. The R-Value method is presented in the Mn/DOT Geotechnical and Pavement Design Manual. The MnPAVE software Beta Version is now available for review. This version can be downloaded from the Mn/ROAD internet site:

http://Mn/ROAD.dot.state.mn.us/research/MN/ROAD_Project/restools/mnpave.asp

The two-way Annual Average Daily Traffic (AADT) and Heavy Commercial Average Daily Traffic (HCADT) predicted for the design year (usually 20 years in the future) are used for the Soil Factor Method. Current AADT and HCADT maps for Minnesota can be found on the Mn/DOT internet site. The R-Value and MnPAVE Procedures use Equivalent Single Axle Loads (ESAL's) to predict the traffic effect. The ESAL concept equates the effect of various axle weights and configurations to the effect of an 80-kN (18,000-lb) single axle load. Eventually, the MnPAVE procedure will use the Load Spectrum concept to evaluate traffic. Load spectrum gives a distribution of axle loads and types predicted to use that road over the design period. The advantage of load spectrum is that predetermined equivalency factors are not used. The ESAL equivalency factors are based on the relative performance of pavements at the AASHO Road Test based on the drop in Present Serviceability Index (PSI).

The subgrade and embankment evaluation procedures for the three design procedures are presented in Chapter 4. These are the soil factor, R-Value and resilient modulus (M_r) determined for the soils used for a given project. The soil factor is based on the AASHTO soil classification and the R-Value can be measured in the laboratory or estimated from the soil classification. The resilient modulus can be estimated from either the R-Value or soil classification using established relationships (Chadborn et al, 2002). For large projects, the estimates of resilient modulus should be verified by laboratory testing. The resilient modulus of the soil varies throughout the year and this variation has been estimated using measured Mn/ROAD soil stiffness. Five seasons have been defined for a given year in Minnesota. These are early spring, late spring, summer, fall and winter (Ovik, Newcomb, Birgisson, 2000).

The strength, stiffness, and variability of a given subgrade soil are very dependent on the construction procedures used for selecting, mixing, placing and compacting the soils. The design procedures start with a good survey of what soils and moisture conditions exist at the construction site and knowledge of how these materials will react under construction, environment and loading conditions. The construction procedures start with a good set of specifications. The specifications recommended for the construction of subgrades are Specifications 2105, 2111 and 2123 (Mn/DOT Standard Specifications for Construction, 2000). These specifications are summarized in Section 1.4.

Methods for carrying out the specifications from the Mn/DOT Grading and Base Manual and the Geotechnical and Pavement Design Manual are summarized. General design considerations

and notes from the Inspector's Job Guide for Construction published by the Mn/DOT Office of Construction, Technical Certification Section are also presented to help show what procedures and documentation are recommended for successful subgrade construction.

Methods of subgrade enhancement are also summarized in Section 1.4. The procedures listed are proper layer construction and compaction of the existing soils, soil modification, soil stabilization, and reinforcement of the in-place soils. Proper placement and compaction of the subgrade soils are covered in more detail in Chapter 4. A subsequent study will look at the various methods of modification, stabilization and reinforcement since they can also be used with the MnPAVE design procedure.

The methods of evaluating the various pavement layers are presented in Section 1.5. The materials discussed are select granular and granular subbases, aggregate bases, salvaged/recycled aggregates and HMA Mixtures. The specifications used to define and construct these materials are Mn/DOT 3149, 3138, 2350 and 2360 respectively. The pavement material design parameters used for each thickness design procedure are presented.

Field control procedures needed to meet the specifications are also presented. The Inspector's Job Guide for Construction sections for aggregate base and HMA construction are summarized to present items that will help field personnel and provide checklists to properly construct each pavement layer. In order to realize the performance predicted by the respective design procedures in terms of strength, stiffness, and durability the specifications must be followed.

1.2. Minnesota Thickness Design Procedures

1.2.1. Soil Factor Design Procedure

The Soil Factor Design Procedure is shown in Figure 1.1 (Mn/DOT State Aid Manual, 1999). The chart uses seven categories of traffic based on the projected 20-year two-way Annual Average Daily Traffic (AADT) and Heavy Commercial Average Daily Traffic (HCADT). AADT and HCADT flow maps are available for the entire state; however, it is recommended that a District Traffic Engineer or the Office of Transportation Data and Analysis be contacted to make the 20-year design predictions. Traffic estimates should be based on future development planned for the area and this information may be available at both the state and local level.

FLEXIBLE PAVEMENT DESIGN USING SOIL FACTORS Required Gravel Equivalency (G.E.) for various Soil Factors (S.F.) For new construction or reconstruction use projected ADT. For resurfacing or reconditioning use present ADT. All units of G.E. are in inches with millimeters (mm) in parenthesis.								
7 TON @ LESS THAN 400 ADT			9 TON -150-300 HCA DT			9 TON - MORE THAN 1100 HCA DT		
S.F.	Minimum Bit. G.E.	Total G.E.	S.F.	Minimum Bit. G.E.	Total G.E.	S.F.	Minimum Bit. G.E.	Total G.E.
50	3.0 (75)	7.25 (180)	50	7.0 (175)	14.00 (350)	50	8.0 (200)	20.30 (510)
75	3.0 (75)	9.38 (235)	75	7.0 (175)	17.50 (440)	75	8.0 (200)	26.40 (660)
100	3.0 (75)	11.50 (290)	100	7.0 (175)	21.00 (525)	100	8.0 (200)	32.50 (815)
110	3.0 (75)	12.40 (310)	110	7.0 (175)	22.40 (560)	110	8.0 (200)	35.00 (875)
120	3.0 (75)	13.20 (330)	120	7.0 (175)	23.80 (595)	120	8.0 (200)	37.40 (935)
130	3.0 (75)	14.00 (350)	130	7.0 (175)	25.20 (630)	130	8.0 (200)	39.80 (995)
7 TON @ 400 - 1000 ADT			9 TON - 300-600 HCA DT			MATERIAL	TYPE OF MATERIAL	G.E. FACTOR*
S.F.	Minimum Bit. G.E.	Total G.E.	S.F.	Minimum Bit. G.E.	Total G.E.			
50	3.0 (75)	9.00 (225)	50	7.0 (175)	16.00 (400)	Superpave Hot Mix	Spec. 2360	2.25
75	3.0 (75)	12.00 (300)	75	7.0 (175)	20.50 (515)	Plant Mix Asp Pave	Spec 2350	2.25/2.25/2.00
100	3.0 (75)	15.00 (375)	100	7.0 (175)	25.00 (625)	Plant-Mix Bit.	Type 41,61	2.25
110	3.0 (75)	16.20 (405)	110	7.0 (175)	26.80 (670)	Plant-Mix Bit.	Type 31	2
120	3.0 (75)	17.40 (435)	120	7.0 (175)	28.60 (715)	Aggregate Base	(Class 5 & 6) 3138	1
130	3.0 (75)	18.60 (465)	130	7.0 (175)	30.40 (760)	Aggregate Base	(Class 3 & 4) 3138	0.75
						Select Granular	Spec 3149.2B	0.5
9 TON @ LESS THAN 150 HCA DT			9 TON - 600 @ 1100 HCA DT			AASHTO SOIL CLASS	SOIL FACTOR (S.F.) %	ASSUMED R-VALUE
S.F.	Minimum Bit. G.E.	Total G.E.	S.F.	Minimum Bit. G.E.	Total G.E.			
50	7.0 (175)	10.25 (255)	50	8.0 (200)	18.50 (465)	A-1	50 - 75	70 - 75
75	7.0 (175)	13.90 (350)	75	8.0 (200)	23.70 (595)	A-2	50 - 75	30 - 70
100	7.0 (175)	17.50 (440)	100	8.0 (200)	29.00 (725)	A-3	50	70
110	7.0 (175)	19.00 (475)	110	8.0 (200)	31.10 (780)	A-4	100-130	20
120	7.0 (175)	20.50 (515)	120	8.0 (200)	33.20 (830)	A-5	130 +	-
130	7.0 (175)	22.00 (550)	130	8.0 (200)	35.30 (885)	A-6	100	12
						A-7-5	120	12
						A-7-6	130	10

NOTE: If 10 ton (9.1 t) design is to be used, see Road Design Manual 7-3.
 For full depth bituminous pavements, see Road Design Manual 7-3.
 * Granular Equivalent Factor per MNDOT Technical Memorandum 98-02-M RR-01.

Figure 1.1 Flexible Pavement Design Using Soil Factors

The soil is defined using the soil factor, which is based on the AASHTO classification of the soil. Section 4.2 reviews methods for determining the appropriate soil classification that represents the embankment conditions on the project. Soil classification systems and correlations with other properties are presented in Chapter 4.

The Granular Equivalent (GE) thickness is the equivalent thickness for the Soil Factor Design Procedure. A Specification 3139 Class 5 or 6 material has an equivalency factor of 1.0. A Class 4 material has a factor of 0.75 because it has a less restrictive gradation band. The specifications for the other pavement materials are listed in Figure 1.1. Minimum bituminous GE and total granular GE are shown for each traffic category. The soil factors shown in Figure 1.1 represent the percentage of GE thickness required relative to the

“typical” A-6 clay loam soil found in Minnesota. For granular type soils the soil factor is less than 100% and for heavy clay and some silty soils the soil factors are greater than 100%.

The thicknesses recommended by the Soil Factor Design Procedure have changed somewhat through the years because of increased traffic loadings and improved construction procedures. The construction specifications and procedures presented in Sections 1.4 and 1.5 must be followed to realize the design life predicted by the Soil Factor Design Procedure.

1.2.2. R-Value Procedure

Figure 1.2 is the R-Value design chart currently used by Mn/DOT for HMA pavement aggregate base thickness design. The embankment soil R-Value should be determined using the Mn/DOT standard laboratory test procedure.

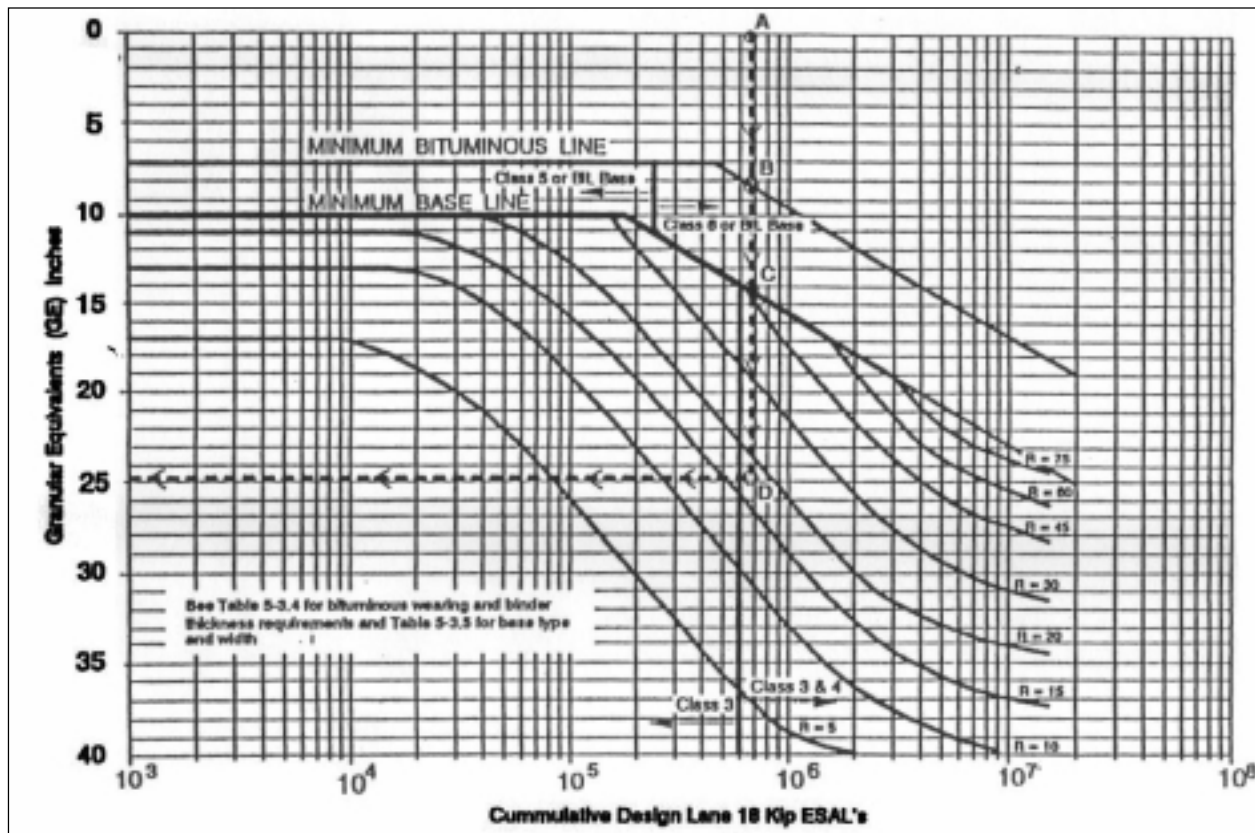


Figure 1.2 R-Value Design Chart

The R-Value can also be roughly estimated from the AASHTO soil classification as shown in Table 1.1. The traffic for the R-Value procedure is defined using equivalent standard [80-kN (18,000-lb)] axle loads (ESAL's). An ESAL quantifies the effect of the axle

load magnitude and configuration on the serviceability decrease of a pavement. ESAL's in the design lane are calculated from:

- The total traffic predicted during the design period
- The vehicle type distribution
- The average serviceability decrease of each vehicle type

Table 1.1 MnPAVE Design Moduli Correlation

Soil Classification			Strength Tests				MnPAVE Design Moduli							
Textural Class	AASHTO	Mn/DOT Soil Factor	R-Value (240 psi Exudation Pressure)		CBR Percentage	DCP mm/blow	Winter & Early Spring		Late Spring		Summer		Fall	
			Estimated	Measured Ave (SD)	Estimated	Estimated	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
Gravel (G)	A-1	50-75	ND	ND	21	ND	350	50	-	-	-	-	-	-
Sand (S)	A-1 A-3	50-75	61	ND	21	13	350	50	60	8.7	73	10.5	85	12.4
Loamy Sand (LS)	A-2	50-75	39	60 (14)	6.2	14	350	50	52	7.6	63	9.2	75	10.8
sl pl S Loam pl S Loam	A-2 A-2,A-4	100-130 100-130	30 16	- 33 (16)	5.5 4.4	14 16	350 350	50 50	47 39	6.8 5.7	57 48	8.3 7.0	67 56	9.7 8.2
Loam (L)	A-4	100-130	14	20 (6)	4.2	18	350	50	35	5.0	42	6.1	50	7.2
Silt Loam (SiL)	A-4	100-130	11	25 (15)	3.9	31	350	50	19	2.7	23	3.3	27	3.9
Sandy Clay Loam (SCL)	A-6	100-130	17	21 (6)	4.5	16	350	50	42	6.1	51	7.4	60	8.7
Clay Loam (CL)	A-6	100-130	14	17 (4)	4.1	18	350	50	35	5.1	43	6.2	51	7.3
Silty Clay Loam (SiCL)	A-6	120-130	11	16 (5)	ND	27	350	50	22	3.2	27	3.9	32	4.6
Sandy Clay (SC)	A-7	120-130	14	ND	ND	ND	350	50	ND	ND	ND	ND	ND	ND
Silty Clay (SiC)	A-7	120-130	8	ND	3.4	23	350	50	27	3.9	33	4.8	39	5.6
Clay (C)	A-7	120-130	11	14 (3)	3.9	18	350	50	35	5.1	42	6.1	50	7.2

The values in Table 1.1 are interim values. As more data become available it will be revised (Chadborn, et. al, 2002).

A software program named Mn/ESAL's is also available from the Mn/DOT Office of Transportation Data and Analysis to calculate design ESAL's.

The resulting structure from the R-Value Design is the Granular Equivalent thickness (GE) using the same definition of thickness as the Soil Factor Design Procedure.

The three GE levels obtained from Figure 1.2 are:

- Total GE,
- Bituminous plus base GE and
- Minimum bituminous GE.

Another HMA design termed full-depth is presented in Figure 5-3.7 of the Mn/DOT Geotechnical and Pavement Manual. Mn/DOT discontinued the use of full-depth designs in 1995 due to poor performance and lack of rehabilitation options. Mn/DOT does not recommend design and construction of full depth HMA pavements. Now modified and termed deep-strength design, the design procedure is based on the full-depth design chart coupled with a requirement for a 0.75-meter (30-in.) granular structure. The soil R-Value is increased to account for the benefit provided by the added thickness of the granular layer needed to attain the 0.75-meter (30-in.) depth.

Some cities and counties use deep strength design where there is limited vertical clearance or where there is a severe aggregate shortage. For the deep strength design it is very important that the subgrade be compacted well and uniformly to adequately support construction equipment and the design traffic. Special consideration of HMA durability in poorly drained conditions is also required.

1.2.3. MnPAVE Procedure

A mechanistic-empirical design procedure (MnPAVE) is now available for thickness design in Minnesota. Transfer functions based on the structural performance of Mn/ROAD pavement sections and Mn/DOT experience statewide are used to estimate pavement life. The HMA pavement structure is simulated using layered elastic analysis. To calculate stresses and strains in the structure, an elastic modulus and thickness for each layer must be known. The elastic modulus is defined as the resilient modulus (M_r), which is the ratio of deviator stress over recoverable strain for particular conditions. The resilient modulus can be determined by:

1. Direct laboratory measurements using a repeated load triaxial test
2. Estimation of M_r from a standard lab test such as the R-Value
3. Estimation of M_r from the AASHTO or Unified soil classification

Resilient moduli can also be estimated from field measurements using either the falling weight deflectometer (FWD) or the dynamic cone penetrometer (DCP). Other devices have also been developed for this purpose.

Mn/ROAD sections have been used to determine how the moduli will vary throughout the year. For MnPAVE the year is divided into five seasons with lengths that can be adjusted based on location or for special situations. This makes MnPAVE much more versatile than the Soil Factor and R-Value design procedures.

The resilient moduli (M_r) of the pavement layers vary seasonally. The variations used in the current version of MnPAVE are based on in-place measurements at Mn/ROAD and testing around the state. Currently, laboratory triaxial testing has only been performed on very few Minnesota soils. Table 1.1 can be used to estimate the resilient modulus and R-Value from the AASHTO and Unified classifications. The high values for each layer in the winter represent frozen conditions.

Transfer functions are used to estimate pavement life based on HMA fatigue cracking and subgrade rutting. Fatigue cracking in the HMA is correlated with tensile strains in the bottom of the HMA layer and subgrade rutting is correlated with compressive strain on top of the subgrade soil.

Currently, the number of ESAL's in the design lane is one of the input options for traffic. The ESAL's are calculated just as for the R-Value procedure. MnPAVE converts ESAL's to a load spectrum that contains only a dual-tire single axle load configuration.

MnPAVE has three levels of data entry:

- Basic
- Intermediate
- Advanced

The Basic level uses data that are currently used for many local roads such as soil classifications, etc. The Intermediate level uses current mechanistic tests for estimating moduli. The Advanced level requires that moduli be measured for a given project. A draft of the MnPAVE operating manual is now available from the Mn/DOT Office of Materials and Road Research Section. The MnPAVE software is available on the Mn/ROAD website.

1.2.4. Pavement Design Options for 2002

Three design procedures are available in Minnesota. More complete descriptions of the Soil Factor and R-Value procedures are given in the Mn/DOT State Aid and Geotechnical and Pavement Manuals. These procedures have been used in Minnesota on roads with all traffic levels for the past 25 plus years. The MnPAVE software beta version program now being distributed makes it possible to account for many factors that could not be directly considered previously. The potential for improved design with MnPAVE is great; however, MnPAVE will require ongoing calibration and validation. Designs with a variety of materials should be tried to see what design life is predicted from MnPAVE compared to the other design procedures and performance observed in the field. When new construction procedures or materials are used the pavement section should be evaluated using MnPAVE.

It is recommended that if a pavement is being designed using either the Soil Factor or R-Value procedures that a corresponding design also be performed with MnPAVE. A comparison of the resulting designs should be made and the Mn/DOT Office of Materials and Road Research should be informed of the results of all comparisons. A form summarizing the comparisons should be completed so that the experience with MnPAVE relative to the current designs procedures is documented.

MnPAVE will become more useful as users gain experience with it. Also, the new AASHTO Design Guide will soon be available. This national procedure will be mechanistic-empirical similar to MnPAVE, however, the AASHTO procedure will need to be calibrated in each state. Therefore, as the engineers in Minnesota gain experience with MnPAVE they will also be gaining the ability to calibrate the AASHTO design to Minnesota climate, materials and traffic conditions.

1.3. Traffic Estimates

The methods (HCADT, ESAL, and Load Spectrum) recommended for quantifying traffic for the three design procedures have been summarized. Chapter 3 presents the procedures, tables, and software available to make the estimates.

The Soil Factor Design requires an estimate of AADT and HCADT predicted 20 years into the future, or whatever design life is selected for the given roadway. To estimate current and future HCADT it is necessary to know the percentage of heavy vehicles in the traffic mix. The HCADT can be estimated from a state map or measured on specific roadways using the

technique presented in Chapter 3. For many relatively low volume roads the value from the statewide map may be appropriate; however, in any special situations such as access routes for agriculture or manufacturing, a better estimate can be made using the field measurement procedure.

The R-Value procedure currently uses design lane ESAL's to quantify traffic. ESAL estimates require an estimate of AADT, vehicle type distribution, axle weight data for each vehicle type, an estimate of growth, and design lane distribution. Methods for measuring or estimating these factors and calculating ESAL's over the design life are presented in Chapter 3.

The MnPAVE design procedure uses the design lane ESAL or load spectrum to estimate pavement life. If ESAL's are input they can be converted to a single axle load dual tire load spectrum. Load spectrum is a measure of the load distribution within each axle configuration and will be used for mechanistic design for the new AASHTO Design Guide. Eventually, MnPAVE will use load spectrum exclusively for thickness design. Mn/DOT is working on procedures to provide load spectrum data for Minnesota roadways.

1.4. Subgrade (Embankment) Soil

1.4.1. Background

The subgrade or embankment soil on which a pavement is built is the most important part of the pavement structure because:

- It is the layer on which the remainder of the structure is supported and helps resist the destructive effects of traffic and weather.
- It acts as a construction platform for building subsequent pavement layers.
- The entire pavement section would have to be removed and replaced to correct embankment performance problems created by lack of strength or uniformity.

It is imperative that the embankment be built as strong, durable, uniform and economical as possible. The most economical embankment is one that will perform well for many decades.

Chapter 4 presents methods to help achieve adequate stiffness, strength and uniformity for a given embankment soil. This starts with a good soil survey at the location so that proper design and construction procedures can be included in the project. Methods for conducting soils surveys are presented in the Mn/DOT Geotechnical and Pavement Manual. Section 4.2 presents the procedure to conduct a good soil survey at a given location.

The design factors used to evaluate the soil on a project for the three Minnesota procedures are also presented in Chapter 4 and the Mn/DOT Geotechnical and Pavement Design Manual. The Falling Weight Deflectometer (FWD) and Dynamic Cone Penetrometer (DCP) are used to determine the in-place stiffness or strength of the soils, subbase and base materials. The advantage of using field measurements is that variability can also be determined. Variability is an input for the MnPAVE design procedure.

1.4.2. Drainage

Good drainage for a pavement section and most importantly the embankment soil must be provided. Specific design considerations to achieve adequate drainage are given in the Mn/DOT Geotechnical and Pavement Manual. An important design factor is to try to keep the final grade at least 1.7 m (5 ft) above the water table. If this is not possible, a height of 1 m (3 ft) above the water table should be used.

Drains can also be used in the pavement section. However, for them to work properly it is necessary to construct a drainable base and/or subbase. Proper drainage will help maintain the strength of the pavement section, and minimize frost heave and thaw weakening.

1.4.3. Subgrade (Embankment) Soil Construction

1.4.3.1. General

To achieve the design values estimated for the actual embankment soils in the field, proper construction practices must be followed. These start with specifications that help define good construction. In Chapter 4 the specifications that pertain to embankment soil construction, general construction design considerations and some field checklists are presented.

1.4.3.2. Specifications

Mn/DOT has three specifications that pertain to the construction of embankments. These are Specifications 2105, 2111, and 2123. Specification 2105 “Excavation and Embankment” includes two types of density control. These are “Specified” (sand cone) and “Quality” (visual) compaction. Both methods state that compaction must be accomplished to the satisfaction of the engineer. For “Quality” compaction an experienced engineer or inspector must be on the project to judge if adequate compaction is achieved. For “Specified” compaction the judgment of the engineer is aided by the determination of a measured density. The density must be measured using the

representative moisture-density test for the soil being constructed. The **Specified Density Method** is recommended by Mn/DOT.

Specification 2111 presents the test rolling method for subgrade acceptance. Test rolling is a supplement to Specification 2105. Test rolling evaluates uniformity and consistency of subgrade support relative to rutting. Test rolling will detect weak/unstable areas due to inadequate compaction or high moisture content. Failed areas will require corrective measures which could include removing the unstable/unsuitable materials, reducing moisture content and recompaction of the soils.

Test rolling is not recommended for the following situations:

- Areas having less than 0.75 m (30 in.) subcut backfill in depth. These areas would probably not pass 2111 requirements.
- Areas having shallow underground utilities or structures.
- Areas having closely spaced bridges.
- Areas where geosynthetics are placed within the upper 1.7 m (5 ft) of the subgrade.

An experienced inspector can determine where soft spots occur in the constructed subgrade and make sure measures are taken to correct these. The test roller method of compaction control is recommended along with Specification 2105 because almost total coverage of the embankment grade construction is possible.

Specification 2123 lists the equipment and characteristics of the equipment required to carry out Specifications 2105 and 2111.

1.4.3.3. General Design Considerations

Based on the soil type, project conditions, structural design and specifications, certain procedures need to be established and followed to achieve good embankment construction. The goal is to provide a strong and uniform embankment for the pavement structure. Many of the procedures presented depend on the type of soil encountered on the project. As the project is started variations in the soils may be encountered and therefore the field engineer and inspector must be aware of the effect of these changes. The following recommendations are presented in Chapter 4.

- Excavation and Embankment Construction
 1. Ideally, the finished grade should be kept at least 1.7 m (5 ft) above the water

table in order to reduce capillary moisture and should be at least equal to the depth of frost penetration in order to minimize frost heave. A minimum height of 1 m (3 ft) should be maintained.

2. The existing soils and their preparation; including subgrade correction, embankment placement, and protection of the completed embankment need to be considered.

- **Soils Evaluation:** Soils must be evaluated based on whether they are suitable or unsuitable, excavated soils, salvaged materials or borrow.
- **Soils Preparation:** Proper preparation of the soils for good uniformity involves reworking, blending, mixing, and enhancing the existing materials. The mixing of existing soils will help eliminate pockets of high moisture and unstable soils. Subcutting, and/or mixing and proper compaction will help provide a uniform subgrade. Proper compaction can be verified with specified densities and test rolling. Lime or other treatments for moisture control may be considered.
- **Subgrade Correction:** Subcuts must be made to ensure uniformity of material and stability in the upper portion of the embankment. Subcuts are used to reduce or eliminate differential or pocketed high-moisture conditions, unstable materials, frost heave potential and non-uniform subgrade conditions. Typical subcut depths range from 0.6 to 1.2 m (2 to 4 ft) with a 0.3 m (1 ft) minimum. Subcuts must be used especially where there are silty type soils, which are particularly frost susceptible. In areas of the embankment that may generate frost heaves the subcut depth must extend below the frost line. The subcut should be backfilled with select granular material. If it is not practical to use select granular, then the existing soil should be mixed uniformly to a moisture content appropriate for good compaction. Drains may be needed in the bottom of the subcut to assure that water does not collect in the subcut.
- **Placement of Embankment and Backfill Materials:** As embankment materials are placed, the same soil should be used throughout each layer to prevent non-uniform moisture and drainage conditions.

- **Compaction:** Compaction must be performed in accordance with Mn/DOT Specification 2105 supplemented with 2111 using the equipment specified in Specification 2123.

1.4.3.4. Construction Notes and Procedures

The Mn/DOT Office of Construction, Technical Certification Section has published an “Inspector’s Job Guide for Construction”. This Guide gives the inspector a checklist that will help get a project started and document the parameters and procedures that need to be considered based on the specifications. One item in particular that will help keep a project under control is for the inspector to keep a good daily diary. This will help all people involved with the project feel confident that work is progressing at an appropriate rate and that the inspection work is being accomplished.

1.4.3.5. Subgrade Enhancement

Many different procedures have been used to enhance the performance of a subgrade. The methods that have been used with varying degrees of success are the following:

- Remove and replace
- Improvement of existing materials using density and moisture control
- Modification of existing materials
- Stabilization
- Reinforcement using geosynthetics

Some of the procedures have been tried by Mn/DOT and others by cities and counties. Minnesota Local Road Research Project 785 is a study of the use of various methods of modification, stabilization and reinforcement in Minnesota and surrounding states.

1.5. Pavement Section Materials

1.5.1. General

Pavement section materials are all materials that are added above the subgrade soil to more effectively withstand the traffic loads. The materials must be stronger and more durable closer to the surface. All pavement section materials must have low frost susceptibility. Chapter 5 presents many different materials that are now used in pavement sections in Minnesota and follows the same format as Chapter 4 for subgrade design and construction. Definitions of Select Granular to Hot Mix Asphalt (HMA) mixtures are given.

The granular equivalent thickness factors are related to the specifications given for the various materials. The moduli for the pavement layers that can be used for input for the MnPAVE software are also presented. The pavement moduli are varied by season just as those of the subgrade soil. As MnPAVE and its inputs are developed it will be possible to assign moduli to a variety of materials that pass a particular specification. For instance, a Specification 3138, Class 5 material with 10% passing the 0.075-mm (No. 200) sieve may have a different set of moduli than one with 5% passing the same sieve. Variations in gradation and particle angularity result in different moduli. The design factor inputs for the two HMA specification mixes used by Mn/DOT (2350 and 2360) are also presented.

1.5.2. Pavement Layer Construction

1.5.2.1. General

To obtain the design values discussed above for granular subbase, aggregate base, stabilized base and HMA, proper construction practices must be followed. Good specifications and construction methods will assure a good product. Field control procedures to help meet the specifications are presented. This includes a summary of the Inspector's Job Guide for Construction. Mn/DOT has also published a "Materials Control Schedule" in the Grading and Base Manual, which summarizes the testing frequency and quantities of materials needed to conform to the respective specifications.

1.5.2.2. Specifications

The specifications pertaining to the construction of the pavement layers include:

- Granular and Select Granular (Mn/DOT Spec. 3149.2B)
- Granular Base and Subbase Materials Gradations (Mn/DOT Spec. 3138)
- Salvaged/Recycled Materials Gradations (Mn/DOT Spec. 3138, Class 7)
- Aggregate Base/Subbase Construction (Mn/DOT Spec. 2211)
- HMA Marshall Mix Design (Mn/DOT Spec. 2350)
- HMA Superpave Mix Design (Mn/DOT Spec. 2360)

The specifications for mixtures cover the materials, mix design, and construction. The mix design for Specification 2350 uses the Marshall hammer for compaction to develop the job mix formula and construction control. Specification 2360 is the Minnesota application of the gyratory mix design that uses the gyratory compactor to compact

samples for design and field control. Both of the procedures use volumetrics including voids in the mineral aggregate (VMA) and total air voids.

Before the 2350 specification was adopted, VMA was used in the design phase of the mixture, but not checked in the field. Some mixtures were experiencing “VMA collapse” in the field; therefore, the current specifications require that VMA be controlled in the final mixture. Ride (smoothness) requirements have also been added to the 2350 and 2360 specifications. Both incentives and disincentives are included for control of ride quality and density.

Specification 2331 and 2340 mixtures are still being produced. However, asphalt absorptions are not monitored. Specifications 2331 and 2340 should not be used except for limited use on very low volume and low load facilities. Asphalt absorptions are determined in the VMA procedures. The field control procedures for the 2331 and 2340 mixtures also need to be followed carefully, especially for adequate compaction.

Currently, Mn/DOT uses Gyratory (Spec. 2360) mixes for most projects including new construction and overlays. Three levels of mix are defined for the 2350 specification. These are low volume (LV) which is defined as traffic less than 1 million ESAL’s, medium volume (MV) which is defined as traffic between 1 and 3 million ESAL’s and high volume (HV) which is defined as traffic greater than 3 million ESAL’s.

1.5.2.3. Field Control Procedures to Meet Specifications

1.5.2.3.1. General

The procedures presented in the Mn/DOT Grading and Base Manual and Geotechnical and Pavement Manual are summarized in Chapter 5. Checklists for field personnel from Field Notes for Construction Engineers and Inspectors are also presented. Recommendations are made for good field control.

1.5.2.3.2. Aggregate

The construction of aggregate bases and granular subbases involves the following procedures:

- Manufacture at a gravel pit or quarry
- Storage of materials
- Transport to the grade
- Placement

- Compaction

The material is tested for general quality, gradation, and uniformity of characteristics. Segregation must be minimized during the entire material handling and construction process. The current Schedule of Materials Control must be followed for each project. It is important that the contractor and agency use exactly the same procedures for Quality Control and Quality Assurance companion testing.

Mn/DOT specifications define three methods that can be used for compaction control of aggregate base:

- Specified Density (sand cone)
- Dynamic Cone Penetrometer (DCP)
- Quality (visual) Compaction

For the specified density method the in-place density is measured using the 150-mm (6-in.) Sand Cone Method (ASTM D 1556-90). Random sampling procedures should be followed to establish density test locations. Mn/DOT currently has specifications for Class 5, 6, and 7 aggregate base.

The DCP is a quick and easier test to measure shear strength of a granular material. The standard Mn/DOT procedure should be followed when using the DCP. The DCP must be conducted within 24 hours of compaction so that the moisture content is near standard Procter optimum moisture content.

Quality (visual) Compaction should only be used if the equipment is not available to do either sand cone or DCP testing. If quality compaction is used, the inspector and engineer must be experienced in the construction of aggregate base and embankment materials. The compaction operation must be observed continuously. It generally is only appropriate for small areas where a limited amount of granular material is being placed.

The Field Notes for Construction Engineers and Inspectors includes a section for inspection of aggregate base construction. This checklist will help the field personnel implement the specifications well. Just as for the construction of embankment soils, one of the most important documentation items is a good diary, which includes such things as hours, location, lift thickness, test results, quantity, yield and other events including weather that may have an effect on the work.

1.5.2.3.3. Hot Mix Asphalt

The current Schedule of Materials Control should be reviewed and used for setting up the field control for each HMA construction project. That document will establish:

- The specification applicable for the project
- The minimum required field acceptance testing rate
- Form number to use
- Minimum required sampling rate for laboratory testing
- Sample size required for laboratory testing

The construction of an HMA pavement layer includes the following operations:

Plant Operations

- Materials delivery or manufacture and storage (asphalt and aggregate)
- Materials proportioning and mixing
- HMA storage and/or transfer to trucks
- Delivery to the construction project

Paving Operations

- Laydown
- Compaction

Each step requires some Quality Control (QC) testing by the contractor and the Quality Assurance (QA) testing by the agency as defined in Specification 2350 or 2360. Testing will help assure that the material is uniform (not segregated), is placed to specification density, and that the surface passes ride as defined in Specifications 2350 and 2360. It is very important that the same standard procedures be used for both QC and QA testing and that the contractor and the agency employ certified technicians.

Compaction is the most important part of construction of an HMA mixture. Inadequate compaction and high air voids will result in a shorter life because of accelerated deterioration due to high permeability and low strength.

Two methods of compaction control are outlined in Specifications 2350 and 2360:

- Maximum Density Method (2350.6B and 2360.5B). The bulk specific gravity of field cores is compared to the maximum mixture specific gravity

representing that day's production. The maximum density required (Table 2350-8 or 2360-14) is determined by the average bulk specific gravity for each lot (2350.6B2a or 2360.5B3) divided by the average maximum specific gravity for that day's production. The tolerances permitted between QC and QA testing are listed in Table 2350-6 and 2360-13.

- Ordinary Compaction (2350.6C or 2360.5C). For Ordinary Compaction a control strip of at least 330 m² (395 yd²) of the same material, on the same subgrade and base conditions shall be compacted to determine a proper roller pattern to achieve maximum density. A growth curve of density with roller passes must be used to determine when maximum density has been obtained. If materials or conditions change a new control strip must be constructed. A given control strip can be used for a maximum of 10 construction days.

The Maximum Density Method should always be used unless otherwise indicated.

Ordinary Compaction without a control strip should only be used for very small areas or thin lifts less than 39 mm (1.5 in.). For these areas the HMA should be compacted until there is no appreciable increase in density with each pass of the roller as observed by an experienced engineer or inspector.

The type and characteristics of the roller(s) to be used for Ordinary Compaction are presented in Specifications 2350 and 2360.

The Inspector's Job Guide for Construction includes sections on both the inspection of plant and paving operations. This guide assumes that the inspector will be aware of the whole operation and make sure that a consistent, uniform quality mixture is produced and constructed and that the inspector will do much more than simply collect data and samples.

1.6. Summary and Recommendations

During the implementation process of a new design procedure, feedback is needed. It is recommended that MnPAVE be used to design flexible pavement sections in addition to your current design procedure. When developing a design for a specific project we ask that you report information on designed sections (thicknesses, inputs, source of inputs) from both the current

design and MnPAVE designs to Mn/DOT by sending the following information to the contacts listed below:

- MnPAVE design file (Windows *.mpv file) generated by executing Windows “File” and “Save”, or “Save As” commands (after running the program and saving, this file will contain all inputs that the user entered).
- Current procedure
- Any additional comments/questions on the program.

Contacts:

Gene Skok, University of Minnesota, Civil Engineering Department
(skokx003@tc.umn.edu)

Dave Van Deusen, Minnesota Department of Transportation, Pavement Design Engineer (dave.vandeusen@dot.state.mn.us)

Shongtao Dai, Minnesota Department of Transportation, Research Operations Engineer (shongtao.dai@dot.state.mn.us)

Traffic is evaluated using 20-year projections of AADT and HCADT for the Soil Factor design procedure. Design lane Equivalent Standard Axle Loads (ESAL's) are used for both the R-Value and MnPAVE procedures. ESAL predictions over a 20-year design period require an estimate of AADT, vehicle type distribution, axle weight data based on vehicle type, average effect of vehicle type on performance, a growth factor and lane distribution factor for the roadway. Tables and procedures are presented in Chapter 3 for determining these values using estimation techniques and the field procedure is presented for measuring vehicle type distribution.

The embankment is a very important part of a pavement structure. Chapter 4 presents the methods of evaluating the subgrade strength and stiffness for the three design procedures. To realize the design parameters for a given soil, good construction practices must be followed. Good construction starts with good specifications that define how the pavement structure is to be constructed and how compensation will be awarded. The Mn/DOT specifications for subgrade construction are 2105, 2111 and 2123. Chapter 4 includes summaries of these specifications and the field procedures that will most effectively implement them. The importance of well-trained knowledgeable personnel is emphasized.

Chapter 5 presents how the materials used in the pavement structure are evaluated for the three design procedures. The granular equivalent factors used for the Soil Factor and the R-Value procedures are listed in Chapter 5. The resilient moduli used in MnPAVE can be estimated using the procedures described in the MnPAVE Guide (Chadbourn, et. al, 2002). Eventually laboratory, DCP, and non-destructive field tests (the FWD) will be used with the laboratory resilient modulus tests. An advantage of mechanistic-empirical design (MnPAVE) is that seasonal variations in resilient modulus for materials in the pavement section are considered.

Mn/DOT Specifications 2350 and 2360 are recommended for HMA construction on low volume roads in Minnesota. Both specifications use volumetrics for field control and quality management. The contractor is responsible for Quality Control (QC) and the agency, Quality Assurance (QA). The specifications include requirements for material quality, mixture design, mixture variability, density (voids), voids in the mineral aggregate (VMA), moisture susceptibility, field density and smoothness of the finished surface. Construction procedures and a checklist for field engineers and inspectors are presented.

Finally it is important to remember that one of the primary goals of design and construction of the subgrade and pavement section materials is to obtain **uniformity**. Uniformity is critical to achieving good performance because uniformity reduces the differential movements caused by settlement, moisture changes and frost heave. Many of the construction methods and testing procedures presented in this report and other Mn/DOT publications are focused on achieving maximum uniformity in the final product.

CHAPTER 2

THICKNESS DESIGN PROCEDURES

2.1. Background and Introduction

There are three 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 three formal thickness design procedures are the Soil Factor Design found in the Mn/DOT State Aid Manual (4), the Stabilometer R-Value Design found in the Mn/DOT Geotechnical and Design Manual (5) and MnPAVE, which is the mechanistic-empirical design procedure currently under development. The Soil Factor Procedure was developed in the 1950's and has been modified somewhat since then. Mn/DOT adopted the R-Value Procedure in the early 1970's. The MnPAVE Procedure is in software form and is being tested against the other procedures. The Beta version is now available (6). In this Chapter the procedures are presented along with the factors needed for thickness determination.

The traffic factor for each of the procedures is presented in Chapter 3. The embankment (subgrade) factors for design and construction specifications and recommended procedures are given in Chapter 4. The thickness of the pavement section is defined using the Granular Equivalent for the Soil Factor and R-value design procedures. The Resilient Modulus (M_r) and the thickness of the layers define the structure for the MnPAVE Procedure. The required specifications and recommended construction procedures to attain the respective pavement section factors are presented in Chapter 5.

2.2. Soil Factor Design

Since 1954 some pavements in Minnesota have been designed using a table similar to Figure 2.1. This is the 2001 version from the State Aid Manual which uses English and metric units (4). The chart uses seven traffic categories based on 20-year projected two-way AADT and HCADT and eight embankment types using the AASHTO classification system. Thickness in terms of Granular Equivalent (G.E.) is determined for each level of traffic and soil type. Each design also has a specified maximum spring axle load.

The traffic factors are Average Daily Traffic (ADT) and Heavy Commercial Average Daily Traffic (HCADT). The ADT and HCADT are both two-way values. The ADT includes all

FLEXIBLE PAVEMENT DESIGN USING SOIL FACTORS Required Gravel Equivalency (G.E.) for various Soil Factors (S.F.) For new construction or reconstruction use projected ADT. For resurfacing or reconditioning use present ADT. All units of G.E. are in inches with millimeters (mm) in parenthesis.								
7 TON @ LESS THAN 400 ADT			9 TON -150-300 HCADT			9 TON - MORE THAN 1100 HCADT		
S.F.	Minimum Bit. G.E.	Total G.E.	S.F.	Minimum Bit. G.E.	Total G.E.	S.F.	Minimum Bit. G.E.	Total G.E.
50	3.0 (75)	7.25 (180)	50	7.0 (175)	14.00 (350)	50	8.0 (200)	20.30 (510)
75	3.0 (75)	9.38 (235)	75	7.0 (175)	17.50 (440)	75	8.0 (200)	26.40 (660)
100	3.0 (75)	11.50 (290)	100	7.0 (175)	21.00 (525)	100	8.0 (200)	32.50 (815)
110	3.0 (75)	12.40 (310)	110	7.0 (175)	22.40 (560)	110	8.0 (200)	35.00 (875)
120	3.0 (75)	13.20 (330)	120	7.0 (175)	23.80 (595)	120	8.0 (200)	37.40 (935)
130	3.0 (75)	14.00 (350)	130	7.0 (175)	25.20 (630)	130	8.0 (200)	39.80 (995)
7 TON @ 400 - 1000 ADT			9 TON - 300-600 HCADT			MATERIAL	TYPE OF MATERIAL	G.E. FACTOR*
S.F.	Minimum Bit. G.E.	Total G.E.	S.F.	Minimum Bit. G.E.	Total G.E.			
50	3.0 (75)	9.00 (225)	50	7.0 (175)	16.00 (400)	Superpave Hot Mix	Spec. 2360	2.25
75	3.0 (75)	12.00 (300)	75	7.0 (175)	20.50 (515)	Plant Mix Asp Pave	Spec 2350	2.25/2.25/2.00
100	3.0 (75)	15.00 (375)	100	7.0 (175)	25.00 (625)	Plant-Mix Bit.	Type 41,61	2.25
110	3.0 (75)	16.20 (405)	110	7.0 (175)	26.80 (670)	Plant-Mix Bit.	Type 31	2
120	3.0 (75)	17.40 (435)	120	7.0 (175)	28.60 (715)	Aggregate Base	(Class 5 & 6) 3138	1
130	3.0 (75)	18.60 (465)	130	7.0 (175)	30.40 (760)	Aggregate Base	(Class 3 & 4) 3138	0.75
						Select Granular	Spec 3149.2B	0.5
9 TON @ LESS THAN 150 HCADT			9 TON - 600 @ 1100 HCADT			AASHTO SOIL CLASS	SOIL FACTOR (S.F.) %	ASSUMED R-VALUE
S.F.	Minimum Bit. G.E.	Total G.E.	S.F.	Minimum Bit. G.E.	Total G.E.			
50	7.0 (175)	10.25 (255)	50	8.0 (200)	18.50 (465)	A-1	50 - 75	70 - 75
75	7.0 (175)	13.90 (350)	75	8.0 (200)	23.70 (595)	A-2	50 - 75	30 - 70
100	7.0 (175)	17.50 (440)	100	8.0 (200)	29.00 (725)	A-3	50	70
110	7.0 (175)	19.00 (475)	110	8.0 (200)	31.10 (780)	A-4	100-130	20
120	7.0 (175)	20.50 (515)	120	8.0 (200)	33.20 (830)	A-5	130 +	-
130	7.0 (175)	22.00 (550)	130	8.0 (200)	35.30 (885)	A-6	100	12
						A-7-5	120	12
						A-7-6	130	10

NOTE: If 10 ton (9.1 t) design is to be used, see Road Design Manual 7-3.
 For full depth bituminous pavements, see Road Design Manual 7-3.
 * Gravel Equivalency Factor per MNDOT Technical Memorandum 98-02-M RR-01.

Figure 2.1 Flexible Pavement Design Using Soil Factors

vehicles and the HCADT is defined as 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 into the future. Local conditions must be considered and the projected value may either be increased or decreased based on the projected future use of the road. More specific methods of determining design values are presented in Chapter 3.

As noted in Figure 2.1 a soil factor of 100% represents an A-6 or A-4 soil. Stronger soils have soil factors less than 100% and weaker soils greater than 100%. The soil factor percentage represents the percent increase or decrease in the thickness of the subbase (D_3). There are ranges of percentages shown for A-1, A-2, A-4 and A-7 soils. Therefore, it is possible to use some judgment relative to the capabilities of the soils after evaluating drainage and other design

considerations. Chapter 4 includes a discussion on the selection of these and other design parameters for the embankment soils.

The strength and stiffness of the soil supporting the pavement are very dependent on the density and moisture conditions of the constructed soil. **Uniformity** is also important to minimize differential heave during freeze up. The construction specifications and procedures presented in Chapter 4 must be followed to attain the strength and stiffnesses inferred in the given soil factors.

The Granular Equivalent (G.E.) defines a pavement section by equating the thickness of each aggregate or HMA layer to an equivalent thickness of granular base material. Equation 2.1 is used to calculate the Granular Equivalent. In Minnesota this is a Specification 3139 material, Class 5 or 6 (9). The relevant specifications for the other pavement materials are listed in Figure 2.1. Minimum bituminous and total granular equivalents are also shown for each traffic category. The total Granular Equivalent is defined using Equation 2.1.

$$\text{G.E.} = a_1D_1 + a_2D_2 + a_3D_3 + \dots \quad (2.1)$$

Where: D_1 = thickness of asphalt mix surface, in. (mm)

D_2 = thickness of granular base course, in. (mm)

D_3 = thickness of granular subbase course, in. (mm)

a_1 , a_2 , and a_3 = G.E. Factors listed in Figure 2.1.

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.

The respective specifications and construction procedures necessary to attain the material characteristics defined for the soil factor design are presented in Section 5.3.2.

2.3. Stabilometer R-Value Design

The Stabilometer R-Value is the current design procedure used by Mn/DOT to determine the design thickness of an HMA surfaced pavement. This procedure is based on research done in the 1960's using results from the AASHO Road Test. The basis of the design is limiting spring

deflections by increasing the strength (stiffness) of the soil or by increasing the strength (stiffness) of the pavement layers for a given level of traffic.

Figure 2.2 is the R-Value design chart from the Mn/DOT Design and Geotechnical and Pavement Design Manual (5). The embankment R-Value can be measured with a standard laboratory test (ASTM D-2844) or estimated from the soil type or classification. The R-Value laboratory procedure used in Minnesota is presented in Chapter 4. An exudation pressure of 1655kPa (240 psi) is used for determining a design R-Value in Minnesota. Predictions of R-Value from soil classification are also presented in Table 4.5.

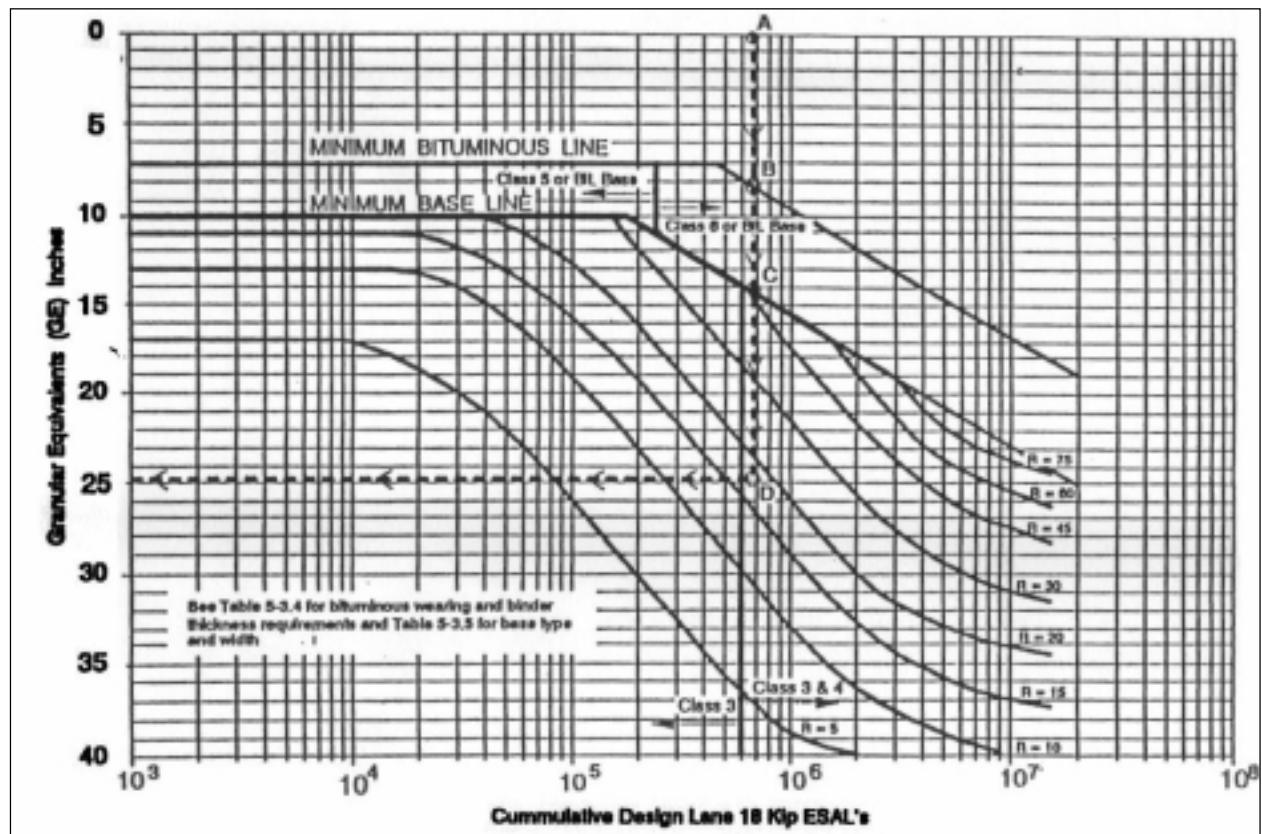


Figure 2.2 R-Value Design Chart

The traffic is evaluated in terms of 80-kN (18,000-lb) equivalent standard axle loads (ESAL's). For a particular road being designed the ESAL's are estimated for a design lane in one direction. Calculated ESAL's will be different for flexible and rigid pavements for the same traffic mix. Chapter 3 presents methods for estimating design ESAL's for flexible pavements in Minnesota.

The thickness is defined in terms of Granular Equivalent in inches. Granular equivalent factors (a_1 , a_2 , and a_3) for the R-Value design are listed in Section 5.3.2. Equation 2-1 is used to calculate the total granular equivalent in the same way as for the soil factor design. In addition to the lines for specific R-Values showing the required GE for a given number of ESAL's, lines on the R-Value design chart represent:

1. The minimum bituminous thickness GE and
2. Bituminous plus base thickness GE.

The actual thicknesses represented can be calculated using the appropriate G.E. factors.

Examples of designs using the R-Value design chart with minimum thicknesses of surface and base, plus other combinations are given in Reference 5.

2.4. MnPAVE Design

2.4.1. General

The Minnesota Department of Transportation and the University of Minnesota have developed a mechanistic-empirical (M-E) design method for flexible pavements. The procedure has been developed as a software package (MnPAVE) because of the great quantities of data and analyses used for the design. A Beta Version of the software is now available. It is still being fine-tuned somewhat.

MnPAVE predicts the structural performance of pavement sections using calculated strains in a simulated elastic layered system. To use the elastic layered system moduli and the thickness of each pavement layer must be determined for the pavement. Up to five (5) layers can be used for the calculations of:

- The tensile strain in the bottom of the surface layer and
- The compressive strain on the top of the subgrade, which is assumed to be infinite in depth.

Various combinations of material properties (moduli) are used to simulate the seasons throughout the year. Currently, five seasons are used (winter, early spring, late spring, summer and fall). MnPAVE calculates the percent of damage that occurs in each season, maximum stress, strain and displacement at the critical locations, the allowable axle load repetitions and reliability percentages. The life in years is then predicted using the predicted traffic in ESAL's or load spectra.

Fatigue cracking has been correlated with the tensile strain in the HMA surface layer and embankment rutting has been correlated with the compressive strain on the embankment. The performance equations are derived from the development of fatigue cracking and rut depth on the Mn/ROAD test sections. Moduli of the layers have been measured throughout the year using backcalculated Falling Weight Deflectometer (FWD) data or estimated from the Dynamic Cone Penetrometer (DCP) or other standard tests.

The performance equations were also checked using the performance of a number of 40-year old test sections from Investigation 183 (15). The research to develop the information to check the performance of these sections was done as part of this project and reported in Appendix A of this report.

Variability can also be incorporated into MnPAVE. Variations in the following parameters contribute to the overall variation of the pavement section.

- Layer Moduli
 - HMA Surface
 - Granular base and subbase
 - Subgrade Soil
- Layer Thicknesses
- Load Predictions
 - Vehicle class predictions
 - Vehicle weight estimates
 - Total number of vehicles

The variability of these parameters is used with the predictions equations to calculate the reliability of the performance predictions. A Monte Carlo simulation is used to calculate the reliability of the performance predictions (16). With this type of analysis it is possible to relate the variability of the thickness, material properties and traffic predictions to required thickness. More uniform construction can therefore be translated into thickness saved or increased life predictions.

MnPAVE requires that the materials be described by their stiffness (modulus) for the seasons defined. This requires that the modulus be defined for these seasons either directly or backcalculated using the FWD or DCP. Correlations with other standard tests as shown in Table 4.5 can also be used.

At this time MnPAVE should be used in conjunction with one or both of the current methods. In this way a city or county can develop confidence in the results of the MnPAVE design. Without the MnPAVE software it has not been possible to take into account the many variables that affect the performance of a pavement section.

MnPAVE has the following features:

- Three design levels based on input data quality
- Material properties adjusted seasonally
- Traffic quantified using either ESAL's or load spectra
- English or System International (S.I.) Units
- HMA modulus temperature adjustment equations that can be modified
- Reliability estimates using Monte Carlo simulations

2.4.2. Set Up

MnPAVE is designed for Windows 95/98/NT operating systems and requires 2 MB of hard drive space and a 200 MHz processor or higher.

Installation can be accomplished using the following procedure:

1. Create a new folder on the hard drive called "MnPAVE"
2. Copy the *.exe file from the floppy disk to the MnPAVE folder.
3. Run the program.

2.4.3. Start Up

2.4.3.1. Control Panel

The "Control Panel" is the first window to appear when MnPAVE is started. The control panel includes areas for input data which includes "Climate, Structure and Traffic" A button to display "Output" also appears on the window. The input must be entered in order beginning with "**Climate**" and ending with "**Traffic**", because the seasonal factors used in "**Structure**" depend on Climate and some of the ESAL calculations in Traffic depend on Structure. Changes can be made in these input windows at any time. However, for a given design check, all inputs must be completed before "**Output**" can be selected.

2.4.3.2. General Operation

MnPAVE uses the pull-down menu and window selection structures common to most software packages. The pull-down menu at the top of the screen includes, "File, Edit,

Record, View, Window and Help.” The **Output** will provide damage factors for asphalt fatigue, rutting and the percent of damage for each season. It also displays the maximum stress, strain and displacements at the critical locations, the allowable load repetitions and reliability percentages.

2.4.4. Inputs

2.4.4.1. General

MnPAVE can be operated using either S.I. or the English system of units, sometimes called Customary units. The system of units can be selected separately for the Climate, Structure and Traffic data. However, is recommended to use the same System for a given design application.

The data for each of the input parameters, Climate, Structure and Traffic are defined using three design levels, “**Basic, Intermediate or Advanced**”.

- The **Basic Level** requires the least amount of data and is intended for many low volume roads. It may also be used for preliminary design for higher volume roads.
- The **Intermediate Level** requires more specific information for a given project and is similar to the information required for that of the Soil Factor or R-Value design procedures.
- The **Advanced Level** requires detailed traffic and material property information and is intended for high volume trunk and interstate highways. It is possible for the designer to use a different design level for each type of input data.

For this manual only input for the **Basic Level** and **Intermediate Level** are considered. At this time the procedures for obtaining and using the data for the **Advanced Level** have not been developed. However, the actual moduli and other values that are used for the stress and strain calculations are shown in the **Advanced Level** window.

2.4.4.2. Climate Inputs (Seasonal Design)

The material properties used for the design levels are adjusted for seasonal changes in temperature and moisture. For example, typically the HMA modulus will be lower during the warm summer season and higher during the cooler seasons. Also, the modulus of an aggregate base will be lower during the wet spring periods. These variables cannot be taken into account with the Soil Factor and R-Value Design Procedures.

For the current version of MnPAVE the year is divided into five seasons, which reflect the major periods influencing pavement behavior as observed at Mn/ROAD. The seasons are “**Early Spring, Late Spring, Summer, Fall (standard), and Winter**”.

- **Early Spring** is defined as the period when the aggregate base or subbase is thawed, but the subgrade is still frozen.
- **Late Spring** is the period when the aggregate base has drained, but the subgrade is thawed, saturated and weak.
- During **Summer** the aggregate base has fully recovered its strength and the subgrade has only partially regained its strength.
- By **Fall**, both aggregate base and the subgrade have recovered their strength. **Fall** is considered the standard season for estimating stiffness (modulus) variations throughout the year.
- **Winter** is the season for which all the pavement layers are frozen.

The duration of the seasons will vary somewhat for different locations around the State and from year to year. A study by Ovik, et al (8) using moduli calculated at Mn/ROAD indicated that the season durations were respectively, 4, 7, 13, 13, and 15 weeks for Early Spring, Late Spring, Summer, Fall, and Winter respectively. These must always total 52 weeks and could be redistributed as more specific data are obtained for other locations. For the Advanced Level of Climatic data in MnPAVE any combination of duration and material properties during the various defined periods of the year could be used.

To estimate the seasonal modulus for the HMA the temperature at one-third the depth can be entered directly or estimated using seasonal average daily air temperatures and predictive equation developed by Witczak (17).

2.4.4.3. Structural Inputs

The structural inputs required for the MnPAVE software include the number, thickness and elastic properties (moduli) of each layer. The number and thicknesses are the design values being tried for that trial.

The moduli can be directly input if laboratory testing of the materials have been measured. If the project-specific materials have been tested, this would be considered an “advanced” determination of the moduli.

If the correlations shown in Chapter 4 for subgrade materials or Chapter 5 for the pavement section materials are used, then these would be considered Basic or Intermediate Levels of Input.

Layer 1, the surface layer can be either HMA or “Other”. The “Other” option is used to allow the designer to use materials that have moduli value outside the HMA range allowed by MnPAVE.

The **lower layers** may include “Aggregate Base, Subbase, Engineered Soil, Undisturbed Soil, Groundwater and Bedrock”.

The **Aggregate Base and Subbase** are to be constructed stiff enough to enhance HMA compaction as well as provide long term support for the HMA and help protect the subgrade.

The **Engineered Soil** is located directly below the base and/or subbase. This is the layer of soil that is excavated, blended, shaped and compacted to result in the most efficient use of that material. The construction specifications and procedures outlined in Chapter 4 must be followed to achieve the properties predicted for these materials.

The **Undisturbed Soil** is the material in-place that existed along the road alignment prior to construction. The modulus of the undisturbed soil is assumed to be one half of that of the same soil if it has been “engineered”.

The **Bedrock** and **Groundwater** layers must be included if either occurs within 2 m (6 ft) of the surface. MnPAVE uses a constant modulus of 350 MPa (50,000 psi) for both the bedrock and soil below the groundwater table because both materials behave rigidly under dynamic loads. The ditch bottom is usually assumed to be the depth of the water table. Poisson’s Ratio is assumed to be 0.15 for bedrock and 0.5 for the groundwater table. The bottom layer of the pavement structure is to be of infinite depth.

After the basic structure has been defined, a **trial thickness** for each pavement layer is entered into the boxes next to the “Materials”. The variability of thickness allowed in the respective specifications should be considered for prediction of variability of the design life. Several different materials and thicknesses can be input to develop a variety of preliminary pavement design structures.

For the **Intermediate Design Level** the structure is entered in the “Edit Structure” section of the window. The number of layers is selected by the “Material” and

“Thickness”. At the Intermediate Level a single design value of the modulus for each unbound material is used to estimate the seasonal moduli. These are listed in Table 5-2 and are backcalculated values from FWD tests at Mn/ROAD. The HMA moduli are also listed in Chapter 5.

The laboratory moduli for each material can either be entered directly or the “design” modulus can be estimated using correlations presented in Chapters 4 or 5. Currently, it is not possible to directly measure the moduli with a laboratory test. However, correlations with modulus have been made with the laboratory R-Value, or soil classification as shown in Table 4.2. The moduli determined from the correlations will appear on the **Advanced Level** screen.

Damage equations are used by MnPAVE to convert the calculated strain values from each loading into the number of allowable load applications. The allowable load applications are compared to the estimated traffic to calculate the damage factor and/or design life. The coefficients in and the format of the damage equations will be changed periodically as more performance information becomes available.

2.4.4.4. Traffic Inputs

The traffic input is quantified by selecting either “**ESAL**” or “**Load Spectra**” above the “**Traffic**” button on the **Control Panel**. At this time only ESAL’s can be used for the Traffic Input. The definition of ESAL’s and methods for predicting and calculating ESAL’s are presented in Chapter 3.

For the **Basic Design Level** the designer can obtain an estimate of ESAL’s by entering Average Annual Daily Traffic (AADT), Direction Factor, Lane Factor, and Annual Growth Rate and then can select from a number of typical Vehicle Type Distributions that have been obtained from around Minnesota.

For the **Intermediate Design Level** the AADT, Direction Factor, and Annual Growth Rate are entered along with a Vehicle Type Distribution determined for that specific location. This value may be obtained from a road with similar traffic, or be a measured distribution using the procedure presented in Chapter 3.

The **Advanced Design Level** allows the designer to enter the number of axles expected in each load class in addition to tire pressure for some special design situations.

At this time this sophistication is not recommended except for very special design situations.

It is necessary to enter information into each of the Input Windows (**Climate, Structure and Traffic**) to obtain an estimate of the life and/or damage factors for that design.

2.4.5. Outputs

The **Output** can be viewed either in a “Seasons” or “Reliability” format. Seasons output includes **Damage Factors** which are the inverse of the number of times the predicted traffic volume can be supported by the pavement before failing due to either fatigue cracking or rutting. The input traffic divided by the **Fatigue Damage Factor** gives the number of ESAL’s the pavement is able to withstand before developing fatigue failure. Fatigue failure is defined as 20% of the total lane cracked. The **Rutting Damage Factor** gives the same type of prediction for a rutting failure criteria based on a 12-mm (0.5-in.) rut depth. A damage factor of 1.00 over 20 years would be the goal for most designs.

MnPAVE provides an option for the quick recalculation of damage factors as different layer thicknesses are considered. The layer thicknesses can be altered individually or as a group until **Damage Factors** of 1.0 are obtained for both rutting and fatigue cracking.

2.5. Which Procedure Should be Used in 2001-02?

Three design procedures have been presented and summarized in this chapter. These are the Soil Factor, Stabilometer R-Value and the Mechanistic-Empirical (MnPAVE) designs. The Soil Factor and R-Value procedures are published in the Mn/DOT manuals (4)(5). They have been used for the past 25 plus years for the design of many low, medium and high volume roads. The MnPAVE procedure has been developed initially at the University of Minnesota and now is being put into useable form by Mn/DOT.

At this time it is recommended that either the Soil Factor or the R-Value Design continue to be used and that the resulting design be checked with the MnPAVE Design. The MnPAVE design takes into account many variables that the other two procedures cannot. For instance the variation of material properties for different seasons can be input to determine which is the most critical season and what effect heavier or limited loads will be. Tire pressure, different types of stabilization or other construction techniques can also be simulated.

If all of the parameters necessary to use the MnPAVE procedure are not available then the values can either be assumed or estimated from the correlations given in the respective chapters. MnPAVE is versatile and will be improved as more people use the software and compare performance predictions from the software program with field experience and designs determined from the currently used procedures. Also, in the next year (or so) nationally, the AASHTO 2002 Design Guide will be available (12). The experience with MnPAVE will make it possible for Mn/DOT and other agencies in Minnesota to calibrate the AASHTO 2002 Procedure to Minnesota climate, materials, and traffic conditions more easily.

CHAPTER 3

TRAFFIC PREDICTIONS

3.1. Background and Definitions

For design, rehabilitation and maintenance of pavement structures traffic characterization plays a crucial role. Determination of the amount and type of traffic that the roadway will be expected to carry over the design life will affect what types of materials are chosen for the pavement, the thickness design of the pavement structure and the predicted pavement performance. Traffic analysis is also an essential part of project feasibility studies, project selection, project path analysis and sizing of facilities. Therefore, it is critical that the traffic be accurately characterized so that engineers may optimize designs for the expected traffic.

Most pavement design procedures either rely on estimates of heavy commercial average daily traffic (HCADT) or equivalent single axle loads (ESAL's) for traffic loading characterization. This chapter outlines the best practices regarding calculation of these two traffic parameters. Prior to describing the various aspects of traffic characterization, it is important to define a number of terms often used in traffic collection and analysis:

1. Average Annual Daily Traffic (AADT): The estimate of daily two-way traffic on a road segment representing the total traffic on the segment that occurs in one year divided by 365. It is important to note that AADT is a volume that *may* never actually occur, but represents the average daily traffic on that segment throughout the year.
2. Average Daily Traffic (ADT): A 24-hour two-way traffic volume that must be qualified by stating a time period (e.g., average summer weekday).
3. Automated Traffic Recorder (ATR): A permanent device that continually collects and stores traffic data.
4. Axle Load: The total load transmitted by all wheels in a single, tandem or tridem axle configuration. A single axle is defined as one axle with two sets of dual tires; a super-single is one axle with two single tires. A tandem axle has two axles spaced less than 1.7 m (5 ft) apart with two sets of dual tires on each axle. A tridem axle has three spaced less than 1.7 m (5ft) apart each with two sets of dual tires on each side. Both tandem and

tridem axles can have single tires if they are wide enough to decrease the load to 200 kg (450 lb) per 25 mm (1 in.).

5. Average Daily Load (ADL): The estimate of a daily load on a roadway segment calculated from the daily vehicle types multiplied by their appropriate ESAL factors.
6. Annual Design Lane ESAL: The estimate of total ESAL damage a roadway segment will experience in one year.
7. Equivalent Single Axle Load (ESAL): The relative amount of damage imparted to a pavement structure by the passage of a standard single axle load, with dual tires. The ESAL standard is typically an 80-kN (18,000-lb) single axle and all other axle configurations and weights are equilibrated to the standard.
8. ESAL Factor: The average effect of a given vehicle type on a pavement, in terms of Equivalent Standard Axle Loads (ESAL's).
9. Heavy Commercial Traffic: All vehicles two or more axles and a minimum of six tires.
10. Heavy Commercial Annual Average Daily Traffic (HCADT): The estimate of heavy commercial daily two-way traffic on a road segment representing the total traffic on the segment that occurs in one year divided by 365. It is important to note that HCADT is a volume that *may* never actually occur, but represents the average heavy commercial daily traffic on that segment of road
11. Weigh-In-Motion (WIM): A permanent device that continually collects and stores axle weight data. This device also collects the total number of vehicles, axle spacing, length, speed and vehicle type data.
12. Vehicle Classification: The classification of traffic by vehicle type (i.e., cars, pickups, 3-axle semis, etc.)

3.2. Determination of AADT

For the Soil Factor Pavement Thickness Design Procedure described in Chapter 2 design (20-year projected, usually) AADT is one of the parameters used to categorize traffic. The design AADT can be calculated using the current value and increasing it by a growth factor depending on the projected use of that roadway. Mn/DOT maintains AADT flow maps for the County State Aid Highway (CSAH) system. These maps, which are up-dated about every two years are available on CDROM and may be obtained by contacting either the Traffic Forecast and Analysis Section or the District Traffic Engineer of Mn/DOT.

AADT can also be measured by conducting a vehicle count at the location of, or similar location to the proposed roadway.

3.3. Determination of HCADT

The other factor used to categorize traffic for the Soil Factor Pavement Thickness Design Procedure is the two-way Heavy Commercial Traffic (HCADT). The design HCADT is the value projected for the last year of the design life, which is usually 20 years. The current HCADT can be determined by:

- Using an HCADT flow map that Mn/DOT maintains throughout Minnesota. HCADT flow maps for County State Aid (CSAH) and other highways are up-dated about every two years. The HCADT flow maps are available on a CDROM that may be obtained by contacting the Mn/DOT Traffic Forecast and Analysis Section.
- Conduct a vehicle-type distribution study as outlined in Appendix 3.1. The current HCADT can be measured and the projected design value can be calculated. Again, the HCADT includes all vehicles having six or more tires, which includes all vehicles except passenger cars and pickup trucks.

3.4. ESAL Calculations

The number of Equivalent Standard Axle Loads (ESAL's) is used to define the traffic effect for the R-Value (5) and MnPAVE Design Procedures (6). The following parameters must be determined to calculate predicted ESAL's. The ESAL concept equates the damage of the measured number of various axle loads to an 80-kN (18,000-lb) axle load. The following steps outline the data collection procedure and the ESAL calculation. Determine:

- 3.4.1. AADT for project location. (Section 3.2)
- 3.4.2. Vehicle Type Distribution for the location.
- 3.4.3. ESAL factors by vehicle type.
- 3.4.4. Traffic growth factor(s).
- 3.4.5. Design lane traffic percentage.
- 3.4.6. Calculate ESALs.

3.4.1. Estimate AADT

The determination of AADT is presented in **Section 3.2**.

3.4.2. Vehicle Type Distribution

Vehicle type distribution is very important in calculating ESAL's because the axle load weights and configurations greatly affect the damage effect on the pavement very much. The most practical method of estimating the load effect is to determine the current vehicle type distribution and project that into the future. Two methods are available to predict current vehicle type distribution for a given roadway:

- Use statewide average distribution for an estimate. The statewide average for Rural CSAH and county roads for eight vehicle types are listed in Table 3.1.
- Measure the distribution at a given location using the dual hose technique developed by Mn/DOT.

Because the distribution presented in Table 3.1 represents a statewide average distribution from the 1994 Geotechnical and Pavement Manual (5) it may not be directly applicable for a given location and type of road. A comparison between the assumed and measured distributions made in 1998 and 1999 on roads in three counties indicated that significant errors could be made by using the assumed distribution. The complete study is presented in Reference 18.

Table 3.1. Vehicle Classification Percentages – Rural CSAH or County Road

Vehicle Type	Percentage in Traffic Stream
Cars and Pickups	94.1
2 Axle, 6 Tire - Single Unit	2.6
3+ Axle - Single Unit	1.7
3 Axle Semi	0.0
4 Axle Semi	0.1
5+ Axle Semi	0.5
Bus/Truck Trailers	1.0
Twin Trailers	0.0

Ref: Mn/DOT - Geotechnical and Pavement Manual, 1994 (5)

A better approach, given the deficiencies of Table 3.1, is to conduct a vehicle classification field study on the actual roadway, or similar roadway being evaluated. In doing so, many of the errors introduced by assuming a vehicle type distribution can be eliminated. Appendix B contains a field guide for conducting such a field study.

3.4.3. Determination of ESAL Factors by Vehicle Type

Each of the vehicle types specified above will impart a different amount of damage per vehicle, expressed in terms of ESAL factors. While the ESAL factors are dependent upon the type and thickness of the pavement, the default values listed in Table 3.2 may be used. A range of ESAL factors for various traffic conditions can be found in Appendix H.2 of the Mn/DOT Geotechnical and Pavement Design Manual (5).

Table 3.2. Average ESAL Factors by Vehicle Type

Vehicle Type	ESAL Factor
Cars and Pickups	.0007
2 Axle, 6 Tire - Single Unit	.25
3+ Axle - Single Unit	.58
3 Axle Semi	.39
4 Axle Semi	.51
5+ Axle Semi	1.13
Bus/Truck Trailers	.57
Twin Trailers	2.40

Ref: Mn/DOT - Geotechnical and Pavement Manual, 1994 (5).

In cases where axle weight data for a particular vehicle are available and the size and cost of the project warrant better traffic information, it is possible to calculate the ESAL factors for particular vehicles. In fact, the values shown in Table 3.2 were obtained through a method similar to that described in the 1993 AASHTO Guide (19) and requires axle weight data, an estimate of the structural number (SN) of the pavement and an estimated terminal serviceability level (p_t). Reference 19 recommends the following:

$$SN = 5.0$$

$$p_t = 2.5$$

Table 3.3 illustrates the method to calculate an ESAL factor for a hypothetical 5-axle truck with corresponding weight data from a study including 165 vehicles. The load equivalency factors were obtained from Reference 19 and are dependent upon SN and p_t . The equation at the bottom of the table demonstrates that an average ESAL factor (2.078) is calculated by dividing the total equivalent axle loads (ESAL's) by the total number of vehicles weighed. In this case the ESAL factor for these 5-axle trucks, which is somewhat higher than the value shown in Table 3.2. If a distribution of axle weights can be determined

for a given truck type the blank Table 3.3 in the appendix can be used to calculate the appropriate ESAL factor.

Table 3.3. Sample Computation of ESAL Factor

Axle Load, kips	Traffic Equivalency Factor	Number of Axles			18 Kip ESAL's
Singles					
3-5	0.002	x	1	=	0.002
5-7	0.01	x	5	=	0.05
7-9	0.034	x	15	=	0.51
9-11	0.088	x	57	=	5.016
11-13	0.189	x	63	=	11.907
13-15	0.36	x	17	=	6.12
23-25	3.03	x	3	=	9.09
Tandems					
27-29	0.495	x	50	=	24.75
29-31	0.658	x	72	=	47.376
31-33	0.857	x	85	=	72.845
33-35	1.09	x	120	=	130.8
35-37	1.38	x	25	=	34.5
Total 18 kip ESAL's				=	342.966
ESAL Vehicle Factor = $\frac{\text{Total 18 kip ESAL's}}{\text{Number of Trucks Weighed}}$ = $\frac{342.966}{165}$ = 2.078					

3.4.4. Determination of Growth Factor

The growth factor is key in determining how traffic volume will change over the life of the pavement. Two methods are available for calculating anticipated growth.

- A method is presented in the Mn/DOT Geotechnical and Pavement Design Manual (5). This method is illustrated with ESAL calculation spreadsheet (Table 3.6). This method assumes the volume of traffic will double in twenty years and that the weight of trucks will increase by about 12%.
- A growth factor table is presented in Reference 19. Table 3.4 lists these factors for 10 and 20-year lives with growth rates of 1, 2, and 4%. Growth rates are rarely greater than 4%.

These factors when multiplied by the current year estimated ESAL's yields the total ESAL's predicted for the given roadway.

Table 3.4. Growth Factors

Design Life, Years	Assumed Growth Rate, %		
	1	2	3
10	10.46	10.95	12.01
20	22.02	24.30	29.78

3.4.5. Design Lane Distribution

The “Design” ESAL’s for a given roadway are the number calculated for the lane that is expected to have the greatest loading. Lane distribution depends on the total number of lanes and traffic characteristics based on road usage. If trucks are loaded in one direction and not the other the loading distribution will be skewed.

Table 3.5 is a list of distribution factors assuming uniform directional traffic for 1, 2 and 3 lanes in each direction. Special attention must be made for turning lanes and other variations.

Table 3.5. Lane Distribution Factors

Number of Lanes in One Direction	Lane Distribution Factor	
	Single-Direction Traffic Data	Two- Direction Traffic Data
1	1	0.5
2	0.9	0.45
3	0.7	0.35

3.4.6. ESAL Calculation Spreadsheet

Once all the data have been determined as specified above, the ESALs may be determined. Mn/DOT uses a spreadsheet program, MnESALS (20). It is strongly recommended that the program be used for all ESAL calculations. The MNESAL program is available from the Traffic Forecast and Analysis Section of Mn/DOT. However, to demonstrate the essence of the program and how the above data are used, Table 3.6 illustrates an example ESAL calculation.

The second column in Table 3.6 shows the total AADT in the base year and the AADT by vehicle type. For example, cars and pickups comprise 80.47 percent of the traffic stream (1207/1500). The fifth column also shows AADT, but it has been increased by approximately 40 percent for all vehicle types to account for an increase in traffic volume over the life of the pavement. The base and design year average daily loads are simply

calculated by multiplying the ESAL factors by the AADT and summing all the vehicle classifications together.

Table 3.6. ESAL Calculation Worksheet

Vehicle Classes	Base Year AADT (two-way)		ESAL Factors		Base Year ADL	Design Year AADT (two-way)	Design Year ADL
Cars and Pickups	1207	x	.0007	=	.8	1690	1.2
2 Axle, 6 Tire - Single Unit	98	x	.25	=	24.5	137	34.2
3+ Axle - Single Unit	34	x	.58	=	19.7	48	27.8
3 Axle Semi	6	x	.39	=	2.3	8	3.1
4 Axle Semi	8	x	.51	=	4.1	11	5.6
5+ Axle Semi	120	x	1.13	=	135.6	168	189.8
Bus/Truck Trailers	25	x	.57	=	14.2	35	20.0
Twin Trailers	2	x	2.40	=	4.8	3	7.2
Total	1500				206	2100	288.9

The worksheet in Table 3.6 only yields the ADL in the base and design years. Additional calculations must be done to determine the design ESALs. The following steps must be completed to determine the total ESALs over the design life and take into account the growth of ESAL's from the initial year.

1. Determine average ADL over life.

$$\text{Average ADL} = (\text{Base ADL} + \text{Design ADL}) / 2 =$$

$$(206 + 288.9) / 2 = 247 \text{ (rounded)}$$

2. Determine total ESALs over life.

$$\text{Total ESALs} = \text{Days in N years (assume N = 20 for this example)} * \text{Average ADL} =$$

$$20 * 365 * 247 = 1,803,100$$

3. Apply design lane factor to calculate total ESALs in design lane. (Table 3.4)

$$\text{Total ESALs in Design Lane} = \text{Total ESALs} * \text{Design Lane Factor (assume 4-lane in this example)} =$$

$$1,803,100 * .45 = 811,951$$

4. Build in a 12% safety factor for the possibility of increased loads during the design.

$$\text{Adjusted ESALs} = 12\% \text{ increase factor} * \text{Total ESALs in Design Lane} =$$

$$1.12 * 811,951 = 909,385$$

5. Round off to the nearest thousand for design.

ESALs = 909,000

3.5. Summary and Conclusions

In this chapter the traffic factors needed to design an asphalt pavement have been defined and procedures have been presented for estimating the traffic factors used from the three current Minnesota Design Procedures.

For pavement thickness design the traffic factor should consider

1. The total volume of traffic,
2. The distribution of axle weights and types,
3. The distribution of vehicles and axle weights and types by lane and
4. The traffic growth at the given location.

The three Minnesota design procedures are the Soil Factor, the R-Value and the Mechanistic-Empirical (MnPAVE).

The Soil Factor Procedure uses the design year AADT and HCADT to categorize traffic as shown in Chapter 2. The methods for determining these factors are presented in Sections 3-2 and 3-3.

The R-value and MnPAVE procedures both use the summation of ESAL's over the design period for the facility. The estimation of ESAL's requires the following parameters, which are presented in the indicated parts of Section 3.4:

- | | |
|-----------------------------|-------------------------------------|
| • AADT | Section 3.4.1 |
| • Vehicle Type Distribution | Section 3.4.2 |
| | assumed (Table 3.1) |
| | measured (Appendix 3.1) |
| • ESAL Vehicle Factors | Section 3.4.3. |
| | average for local roads (Table 3.2) |
| | sample calculations (Table 3.3) |
| • Growth Factors | Section 3.4.4. (Table 3.4) |
| • Design Lane Distribution | Section 3.4.5. (Table 3.5) |
| • Sample ESAL Calculations | Section 3.4.6. (Table 3.6) |

A more comprehensive procedure for estimating ESAL's is available in a software package titled MnESAL's (20). This program considers the current and past characteristics of the traffic and predicts future trends from the recent past. MnESAL's is available from the Mn/DOT Office of Transportation Data and Analysis or the District Traffic Engineer.

At this time it is recommended that county and city engineers estimate ESAL factors and Vehicle Type distributions for typical roads in their jurisdiction. Annual ESAL calculations can then be made and for the traffic distributions experienced at specific locations.

As experience and technology in the measurement of traffic factors improves and more data are accumulated the procedures and factors presented in this chapter should be up-dated.

If the field procedure is used to determine vehicle type distribution the data should be sent by e-mail or by post to the Mn/DOT Office of Transportation Data and Analysis. The coding for a given county or city should be used so that the data from around Minnesota can be coordinated to establish realistic distributions for various areas of the State.

CHAPTER 4

SUBGRADE (EMBANKMENT) SOIL DESIGN AND CONSTRUCTION

4.1 Background and Definitions

Subgrade conditions are an influential factor on pavement performance. A stronger and stiffer subgrade will provide a more effective foundation for the overlying pavement layers. By improving the in situ soil conditions to more optimal characteristics, the pavement will be more resistant to repeated loading and environmental stresses. The in situ conditions must be considered carefully, and if there is a problem with frost-susceptible or variable soils, appropriate changes should be made. The subgrade must be strong enough to resist shear failure and have adequate stiffness to limit significant deflection. To accomplish this effectively adequate drainage is necessary. The amount of support necessary must be well understood in order to design a subgrade that will withstand the expected traffic volume and loads. Modification of the soil may be necessary depending on the in situ soil and local moisture conditions. The subgrade design should allow for construction processes with local resources that can achieve the desired support and maintain that condition for the life of the road.

The embankment soil on which a pavement is built is the most important part of the structure because:

- It is the layer on which the remainder of the structure is supported and helps resist the destructive effects of traffic and weather.
- It acts as a construction platform for building subsequent pavement layers.
- The entire pavement structure will have to be removed and replaced if there are embankment performance problems due to lack of strength or uniformity.

It is, therefore, imperative that the embankment be built as strong, durable, uniform, and economical as possible. The most economical embankment is one that will perform well for many years. Because of the many different soil and moisture conditions, which can occur along the grade on any project in Minnesota, the balance between these items is critical.

The following steps need to be followed so that adequate stiffness, strength and uniformity can be achieved most economically:

- Perform soil survey and sampling
- Determine representative design factor(s)
- Establish appropriate specifications and contract documents
- Carry out construction according to specifications

Based on the characteristics of the soil sampled on the given project, a representative design value for the soil must be established. For current pavement design methods in Minnesota this will be the Soil Factor, R-Value and/or the Resilient Modulus (M_r). These design values can be measured in the field, the laboratory, or estimated from soil classification tests and calibrations.

4.2 Soil Surveys and Sampling

A good soil survey and sampling program will provide essential information on the TYPE and EXTENT of soils to be encountered on a project. Three methods are available to conduct soil surveys:

- Local soil maps,
- Previous records of soil surveys along the same grade,
- Auger borings using techniques recommended in the Mn/DOT Geotechnical and Pavement Design Manual (5).

The soil survey will help establish where there are changes in soils, especially at transitions from one soil type to another. The different soil types will require different moisture-density and field control criteria. Standard methods should be used for classification of the soils so that meaningful decisions can be made with respect to design and construction procedures. Borehole samples should be taken, where the grade changes from cut to fill or fill to cut, a change in soil type, or a change in drainage conditions. Boreholes should generally be placed at a minimum of every 150 m (500 ft). Modification of the interval will be necessary for individual locations depending on the variability and complexity of the in situ soil conditions. For example, it would be more useful to place boreholes at smaller intervals near marshy areas while increasing the spacing to 300 m (1000 ft) in relatively uniform areas. An average spacing of 150 m (500 ft) is a reasonable rule of thumb.

In addition all borrow sources must be tested.

Generally, soils are field classified using the Triangular Textural Classification system or the AASHTO Classification presented in the Mn/DOT Geotechnical and Pavement Design Manual

(5). Use of this procedure for classifying and sampling the soils can give the design staff the information needed for preliminary thickness design and design of the grade. Sufficient quantities of each soil type from a project need to be obtained for laboratory testing of the material to determine AASHTO Classification, R-Value (measured or predicted) and Resilient Modulus (M_r) (measured or predicted).

The number of samples taken over the length of the project is imperative in determining the amount and extent of improvement necessary to ensure uniformity throughout the project. The sampling rates (Table 4.1) given are estimates and more frequent sampling in soil type transition zones is suggested to ensure that the design adequately addresses variable conditions and therefore reduces problems during construction (5).

Table 4.1 Sampling Rates (5)

Major Soil Texture	Recommended Minimum Sampling Rate	Minimum Number of Samples
Sands	0 (assume an R-value of 70 or 75)	0
Clays, Clay Loams	1 every 3 km	3
Sandy Loams (nonplastic to slightly plastic)	2 per km	5
Silt Loams	2 per km	5
Silty Clay Loams	2 per km	5
Plastic Sandy Loams	2 per km	5

4.3 Subgrade Soil Design Factors

4.3.1 General

Each of the Minnesota Flexible Pavement Design procedures classify subgrade soils in a different way:

- The Soil Factor Design uses the AASHTO Classification of the soil to select the appropriate Soil Factor (4).
- The R-Value design uses the Stabilometer R-Value laboratory test to determine a laboratory-measured stiffness. A higher R-Value indicates a higher stiffness, which will require less thickness.
- The Resilient Modulus (M_r) is the soil input for MnPAVE. Currently, only Mn/DOT and the University of Minnesota perform the Mn/DOT specified standard laboratory test for measuring resilient modulus. However, M_r has been correlated with R-Value

and AASHTO Classification (7). The results now being finalized are summarized in Section 4.3.2.3.

The correlations between Soil Factor and R-Value are based on testing and experience in Minnesota over the past 30 years. The relationships between R-Value and Resilient Modulus are also presented in the 1993 AASHTO Pavement Design Guide (19). In this section the relationships between soil classification, Soil Factor, R-Value and resilient modulus are presented. These relationships have been summarized in table form by Siekmeier and Davich (7) and also partially listed in Table 4.4.

4.3.2 Laboratory Testing

Soil tests such as resilient modulus and R-Value are used in order to estimate the stiffness properties of the soil and may be estimated from other parameters. The Mn/DOT Road Research Section has developed a comprehensive correlation table relating soil classification, soil strength tests, to seasonally varying design moduli. The seasonal factor, which relates the moduli throughout the five seasons as defined in MnPAVE (6), is determined by the change in average FWD results collected at the Mn/ROAD test site. This table has been developed to help predict appropriate and consistent resilient modulus input values for MnPAVE, for a given soil. These important design moduli for subgrade design are given in Table 4.4.

4.3.2.1 The AASHTO Soil Classification System

The AASHTO Soil Classification System was developed in the 1920's and is used to give a general idea of how well a soil will perform in a pavement system. Soils are classified based on gradation and Atterberg Limits. The classes range from A-1 through A-7. A-1 soils are very good materials for highway construction and A-7 soils are poor. Table 4.2 shows the gradation and Atterberg Limits for the various soil classes.

- Gradation for the AASHTO soil classification using the 0.425 mm (No. 40) and 0.075 mm (No. 200) sieves needs to be determined, using a washed sieve analysis as described in the AASHTO T-27 Procedure.
- Atterberg Limits – The Plastic Limit and Liquid Limit are used to define the characteristics of fine-grained soils.
- The Plastic Limit is defined as the moisture content at which the soil transforms from a friable state to a plastic state. It is determined using the

AASHTO Method T-90 for which a small sample of the soil is rolled into a 3 mm (1/8 in.) diameter.

- The Liquid Limit is defined as the moisture content of a fine-grained soil at which it transforms from a plastic state to a liquid state. It is determined using AASHTO Method T-89 for which a sample of soil about 25 mm (1 in.) thick is placed in a bronze dish, a groove is put in the sample and the number of drops of the cup is counted until the groove closes. The Liquid Limit is the moisture content that requires 25 drops of the cup.
- The Plasticity Index (PI) is defined as the difference between the Liquid Limit and the Plastic Limit. A high PI clay is more active than a low PI material.
- When run according with the standard AASHTO or ASTM Procedures the Plastic Limit and Liquid Limits are quite repeatable tests that provide a quantitative index value.
- Table 4.3 shows the conversion of AASHTO Classifications to Soil Factors according to the State Aid Manual (4).

Table 4.2 ASSHTO Soil Classification (5)

Textural Class	Identification by Feel	Ribbon Length	AASHTO Group (H.R.B. Class)	Group Index	Rating For Upper Emb.
Gravel (G)	Stones: Pass 3" sieve, Retained on #10	0	A-1-a	0	Excellent
Fine Gravel (FG)	Stones: Pass 3/8" sieve, Retained on #10	0	A-1-a	0	Excellent
Sand (S)	100% pass #10. Less than 10% silt & clay.	0	A-1-a	0	Excellent
Coarse Sand (CS)	Pass #10, Retained on #40	0	A-1-a or A-1-b	0	Excellent
Fine Sand (FS)	Most will pass #40. Gritty - non plastic	0	A-1-b or A-3	0	Excellent to Good
Loamy Sand (LS)	Grains can be felt, Forms a cast	0	A-2-4 or A-3-5	0	Excellent to Good
Sandy Loam (SL)					
a. slightly plastic	0-10% clay. Gritty	0-1/2"	A-2-6 or A-2-7	0	Excellent to Good
b. plastic	10-20% clay. Gritty	1/2"-1"	A-4	0-4	Excellent to Good
Loam (L)	Gritty, but smoother than SL	1/4"-1"	A-4	0-4	Excellent to Good
Silt Loam (SiL)	Smooth, slippery or velvety. Little resistance	0-1"	A-4	0-4	Fair to Poor
Clay Loam (CL)	Smooth, Shiny, considerable resistance.	1"-2"	A-6	0-16	Good to Fair
Silty Clay Loam (SiCL)	Dull appearance, slippery, less resistance.	1"-2"	A-6 or A-5	0-16	Fair to Poor
Sandy Clay Loam (SCL)	Somewhat gritty. Considerable resistance.	1"-2"	A-6 or A-5	0-16	Good to Fair
Clay (C)	Smooth, shiny, long thin ribbon.	2"+	A-7	0-20	Fair to Poor
Silty Clay (SiC)	Buttery, smooth, slippery.	2"+	A-7 or A-7-5	0-20	Poor
Sandy Clay (SC)	Very plastic but gritty. Long thin ribbon.	2"+	A-7 or A-7-6	0-20	Fair to Poor

Note: Where the group index is expressed as a range, such as 0-16, the lower values are the better foundation soils.

Table 4.3 AASHTO-Soil Factor Correlation (4)

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

*an A-5 soil occurs very rarely in Minnesota

4.3.2.2 Stabilometer R-Value

The Stabilometer R-Value has been used in Minnesota since 1970 to measure the stiffness of embankment soils. The laboratory procedure generally follows AASHTO-T-190. The procedure includes the use of a kneading compactor. The sample is then subjected to a final static compaction to compress the soil to the point water is exuded; called the exudation pressure. In Minnesota an exudation pressure of 1.65 MPa (240 psi) is used. This moisture and compaction correlated best with field conditions measured at projects constructed according to Mn/DOT specifications. Compacted specimens are then put in a device to measure swell pressure while being soaked over night.

The Stabilometer R-Value is then measured by placing the compacted sample in a device, which measures horizontal pressure (p_h) when a given vertical pressure is applied. A lower horizontal pressure results in a higher R-Value. Equation 4.1 is used to calculate the R-Value (21).

$$R = 100 - \frac{100}{\frac{2.5}{D} * \left(\frac{p_v}{p_h} - 1 \right) + 1} \quad (4.1)$$

Where: D = Turns displacement (Fig. 4.1)

p_h = Horizontal pressure (stabilometer gauge reading at 1103 kPa (160 psi)

vertical pressure (p_v)

Over the years Mn/DOT and others have conducted stabilometer tests on soils throughout Minnesota. The R-Value can be either used as input for the R-Value thickness design procedure or as a method to predict the resilient modulus (M_r) of the soil as input

for MnPAVE. It is important to note that for the R-Value thickness design procedure it is normal procedure to use the mean minus one standard deviation of the tabulated R-Values to establish the design value. The resilient modulus input for MnPAVE is the average value.

The R-Value has been correlated with AASHTO Soil Type in Table 5-3.2(a) of the Mn/DOT Geotechnical and Pavement Manual (5). A general correlation with Textural Class is also shown. Table 5-3.2(b) lists assumed R-Values for granular subgrade, subbase, and base courses. This table is for properly constructed AASHTO Soil Types A-1-a, A-1-b and A-3 soils.

Correlations between Soil Classification(s), R-Value and the seasonal moduli are presented in Table 4.5. This is a portion of the comprehensive table and correlations used in the MnPAVE software described in Chapter 2 (7).

The NOTES accompanying the tables in the Geotechnical and Pavement Manual are very important. To attain the stiffness indicated by the R-Value or any other procedure the soil must be constructed in a uniform manner with proper density and moisture control. Section 4.5 will cover construction control and recommended procedures more completely.

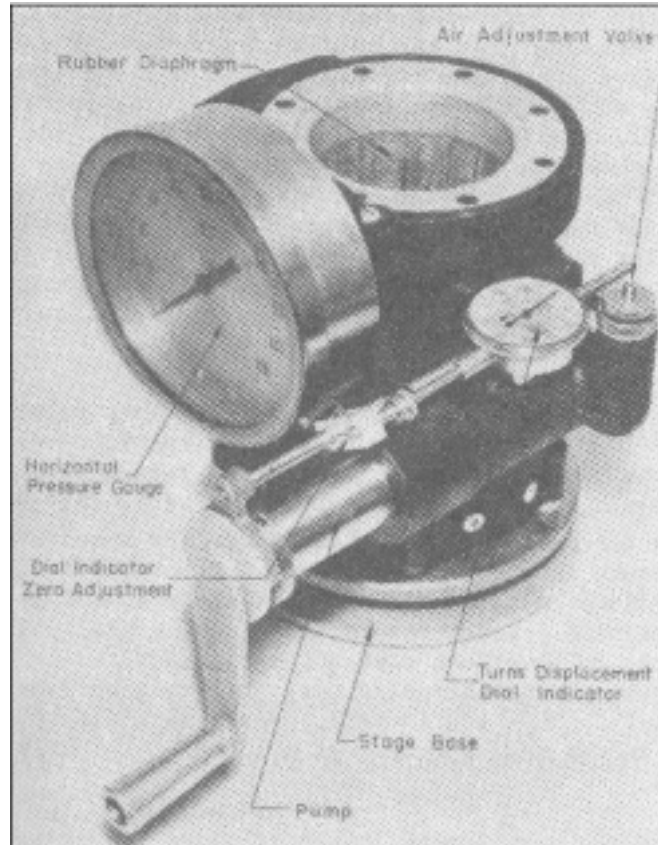


Figure 4.1 Stabilometer R-Value Testing Apparatus (22)

4.3.2.3 Resilient Modulus

The Resilient Modulus (M_r) is used to indicate the stiffness of the pavement materials including the subgrade. M_r is analogous to Young's modulus, in that it is the measurement of the recoverable elastic strain of the soil. The M_r values are used for mechanistic-empirical design procedures including MnPAVE. The M_r varies with density, moisture content, age, and position. During the SHRP Program a standard procedure, now AASHTO P46 was developed to measure M_r (22). This procedure is now being modified to more accurately measure the loading and deformation of the sample.

AASHTO P46 is a repeated load triaxial test for which a confining stress is applied and the deformation under a repeated vertical haversine stress is measured (22). The modified procedure includes a load cell and strain measurement devices inside the triaxial cell as indicated in Figure 4.2. A 0.1-sec load is applied after which a 0.9-sec rest period is used, illustrated in Figure 4.3. The recovered deformation is used for calculating M_r .

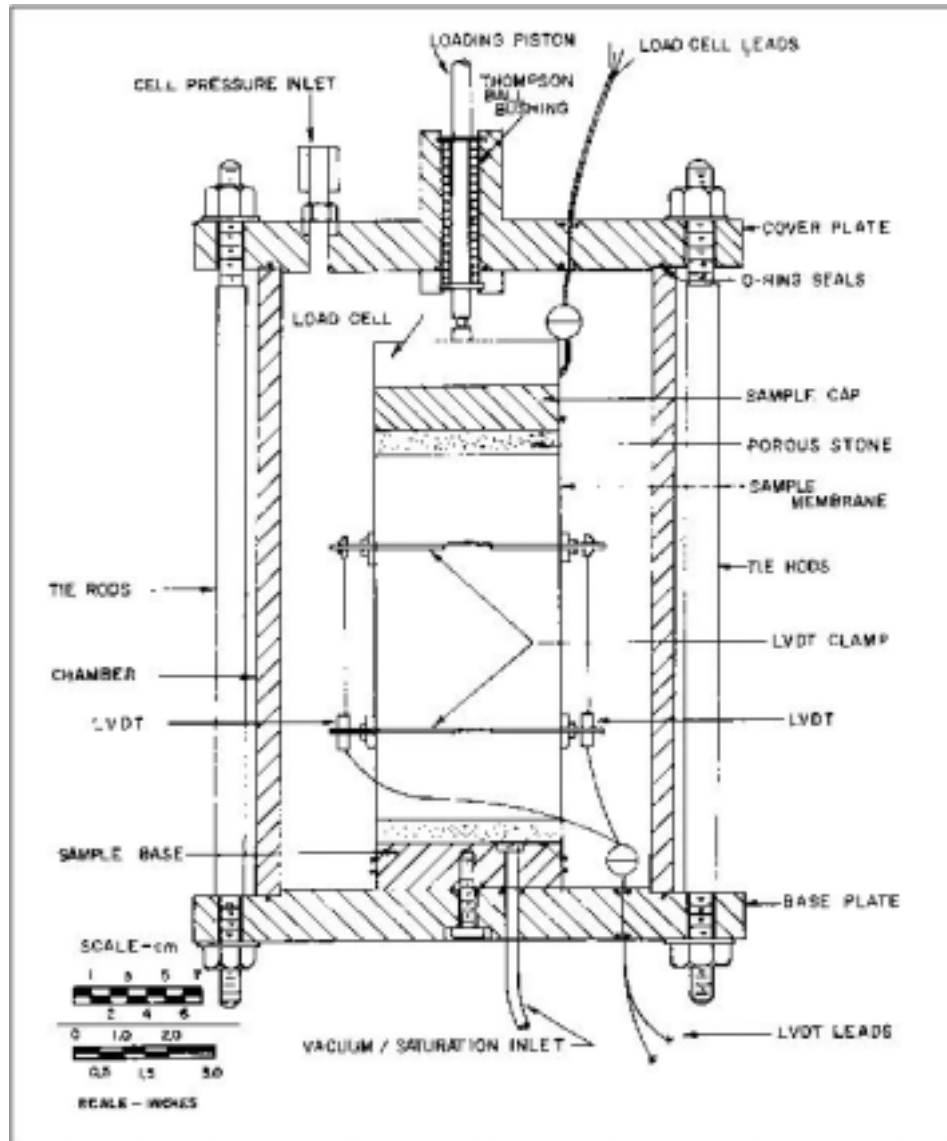


Figure 4.2 Resilient Modulus Testing Apparatus (22)

The response of the soil to repeated loadings will change throughout the year. The reason for this variation is the changing moisture and freeze-thaw conditions. When the soil mass is frozen throughout the embankment, the response will be almost entirely recovered. This can be represented by a very high R-Value.

The deviatoric stress is applied for 200 cycles, with the displacements and recovered strains recorded for the last 50 cycles. The recovered strains from the last 50 loadings are then averaged to determine the resilient modulus. The confining and deviatoric stress should be selected to reflect the expected field conditions. A confining pressure of 14 kPa (2 psi) and a deviatoric stress of 41 kPa (6 psi) are used for AASHTO P-46 (23). It is

anticipated that the modified P46 Procedure will be used for the modulus testing for the 2002 AASHTO Design Guide (12). Mn/DOT and the University of Minnesota are the only laboratories are currently setup to run the Mn/DOT modified AASHTO P46 test.

When running AASHTO P-46 the materials are defined as Material Type 1 and Material Type 2. Material Type 1 includes all unbound granular material used as subbase and base and untreated subgrade soils which meet the criteria of less than 70% passing the 2.00 mm (No.10) sieve and less than 20% passing the 0.075 mm (No. 200) sieve. Material Type 1 soils are run using a 150-mm (6 in.) diameter sample (5).

Material Type 2 includes all unbound granular base/subbase and untreated subgrade soils not meeting the Type 1 criteria. Remolded Type 2 materials are tested using a 71-mm (2.8-in) diameter specimen (5).

The resilient modulus (M_r) (Eq. 4.2) is the ratio of the amplitude of the cyclical deviatoric stress (σ) to the amplitude of the resultant recoverable axial strain (ϵ) (4-5), which is illustrated in Figure 4.3.

$$M_r = \frac{\Delta\sigma_{axial}}{\epsilon_{axial}^{re cov}} \quad (4.2)$$

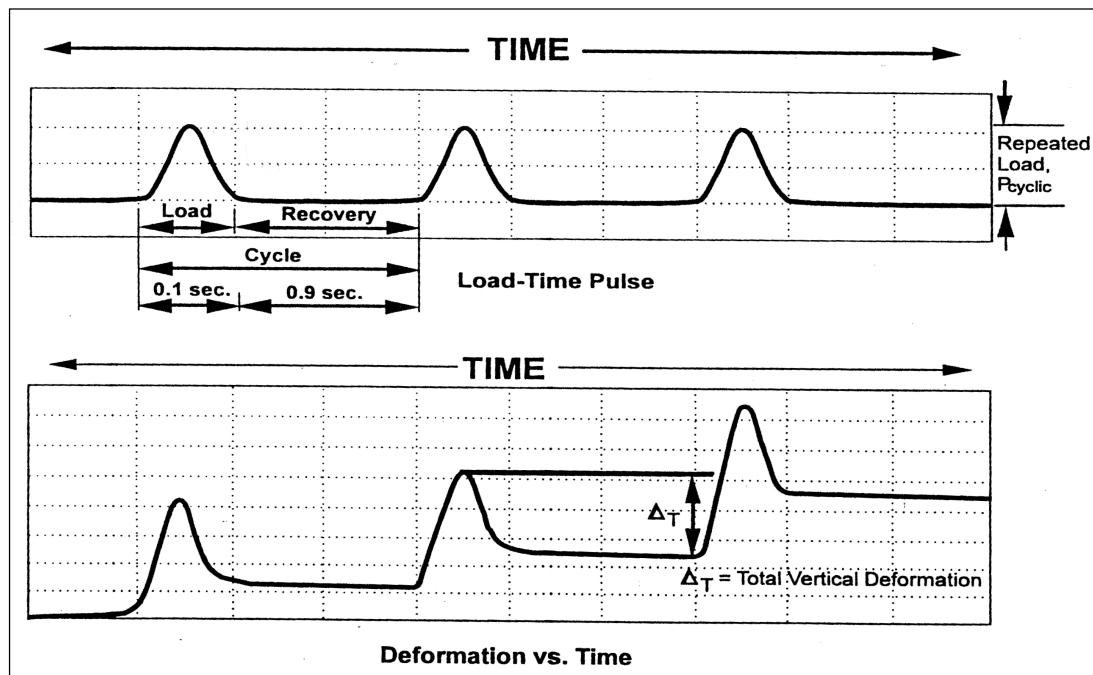


Figure 4.3 Load and Deformation vs. Time for Resilient Modulus Test (5)

4.3.3 Field Measurements of Subgrade Stiffness

4.3.3.1 General

Resilient modulus can be determined in the field, by many different methods (15). The original method for determining the modulus of the pavement and soils was the Plate Load Test (15). The primary drawback to this device is that each layer must be removed in order to test the layer below. The Falling Weight Deflectometer (FWD) and other surface devices are major improvements over the Plate Load Test because they are non-destructive, and are able to determine the moduli for the layers below the surface with a single test. They can also test the same location more than once in order to monitor change over time. One of the other advantages over the plate load test is that multiple tests at different locations can be run in a short period of time, allowing changing conditions along the road to be determined. The Dynamic Cone Penetrometer (DCP) is a device that is used to test in-situ soil conditions (24). The limit of the soil disturbance is small, approximately 100 mm (4 in). As with the FWD, the DCP can be run at many locations in a short period of time, making it very useful for determining the variation along the embankment during construction. These testing techniques allow the collection of large quantities of data, over large areas in a short period of time. The ability to collect data quickly allows for spatial variations to be measured and understood because the test is non-destructive. The changing characteristics at a particular location with the season can also be accounted for in the design procedure.

4.3.3.2 Falling Weight Deflectometer

The Falling Weight Deflectometer (FWD) is a device designed to measure the deflections produced by an impact (falling) load. The device may be hand operated or mounted in a vehicle. Mounting the FWD to a vehicle allows for rapid data collection by decreasing the travel time between measurement sites. The FWD is pictured in Figure 4.4. The deflections caused by loading are measured at distances of 0 to 1.5 m (0-5 ft) at 0.3 m (1 ft) intervals (25). The geophone and locations of measurements are shown in Figures 4.4 and 4.5. The shape of the deflection basin is indicative of the modulus of the layers (Figure 4.5). The deflection near the load plate is representative of the composite modulus of all the layers and the deflections measured further away represent the modulus of the lower layers.

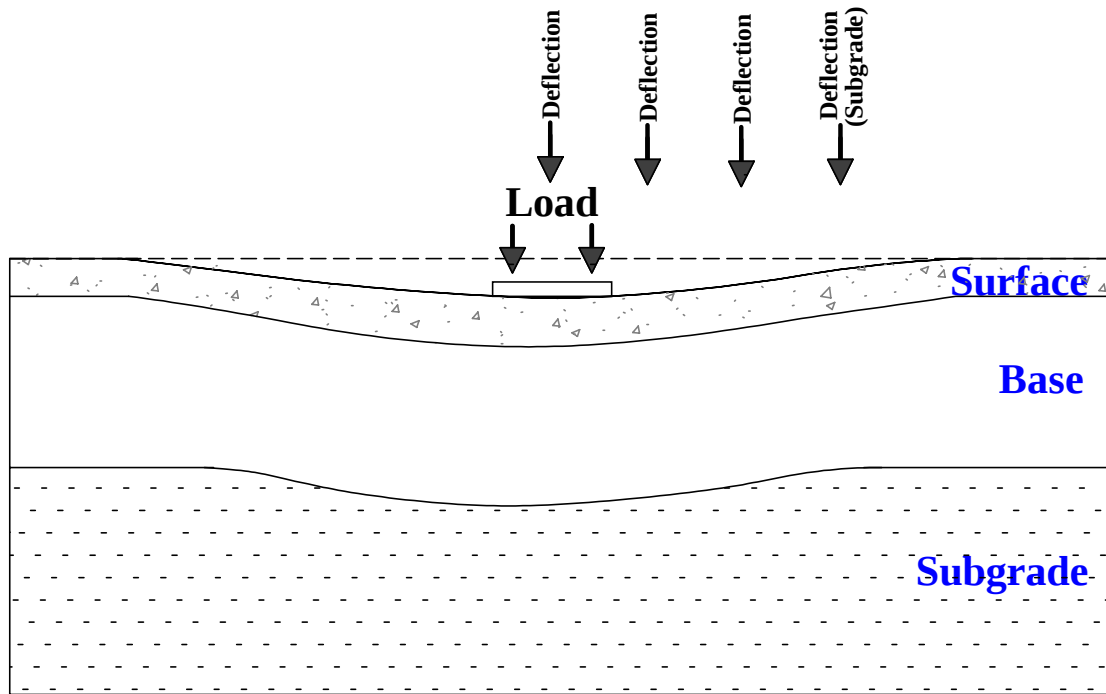


Figure 4.4 FWD Unit

The modulus of the soil is then backcalculated for the measured deflection basin. There are many algorithms commercially available, such as, EVERCALC, WESTEV, and the HOGG model. The following information must also be known about the pavement section to obtain a good estimate of the pavement moduli:

- a. Accurate determination of pavement and embankment layer thickness
- b. Determine presence and location of any near-surface stiff layer
- c. Reasonably accurate initial estimate of the moduli

Ground penetrating radar has been used successfully to determine layer thickness and the depth of the bedrock (26).



Deflection Basin Shape is a Function of:

1. Thickness of Layers
2. Elastic Modulus of Layers

Figure 4.5 FWD Deflection Basin

4.3.3.3 Dynamic Cone Penetrometer

The Dynamic Cone Penetrometer (DCP) has been in used for nearly 3 decades. The test consists of a falling mass that forces a standard cone with a diameter of 20 mm (0.8 in) and an angle of 60° into the soil being tested. The Mn/DOT standard DCP is illustrated in Figure 4.6. The amount of penetration is recorded after each blow from the hammer (24). The test is usually run until a penetration of 0.75-1.0 m (2-3 ft) is achieved. A cone with an angle of 30° can also be used for stiffer soil. The hammer has a mass of 8 kg (17 lb) and a drop distance of 575 mm (23 in.). The rate of movement into the soil with each blow is called the DCP Penetration Index (DPI), expressed in mm per blow. The DPI has been correlated to the California Bearing Ratio (CBR), unconfined compressive strength, elastic modulus, and shear strength of cohesionless granular soils (7). With this correlation the design parameters that are desired can be determined from

DCP data. This test is useful because the information can be easily converted into the form that is useful to work at a specific project.

Table 4.4 General Correlation Table for Strength and Stiffness Tests

Soil Type	CBR Range	Stiffness MPa	DCP mm/blow	R-Value 240 psi exudation pressure
Fine-grained	< 10	<40	20-30	10-30
Sand	10-30	50+	10-25	70
Gravel	20-80	100+	<10	70

4.3.3.4 Additional In Situ Factors

There are many other parameters that can be examined. Density and moisture content are two of the most common and well understood. Increasing the soil density is one of the easiest ways to improve strength and stiffness, which reduces the response to loading. If compaction is performed near optimum water content (AASHTO T-99) the maximum density can be achieved more easily yielding the stiffest condition for the material. The long term equilibrium water content in the future and short term peak water content due to precipitation and runoff must also be considered in order to limit excessive soil creep, swelling and pumping.

DCP (Mn/DOT DESIGN)

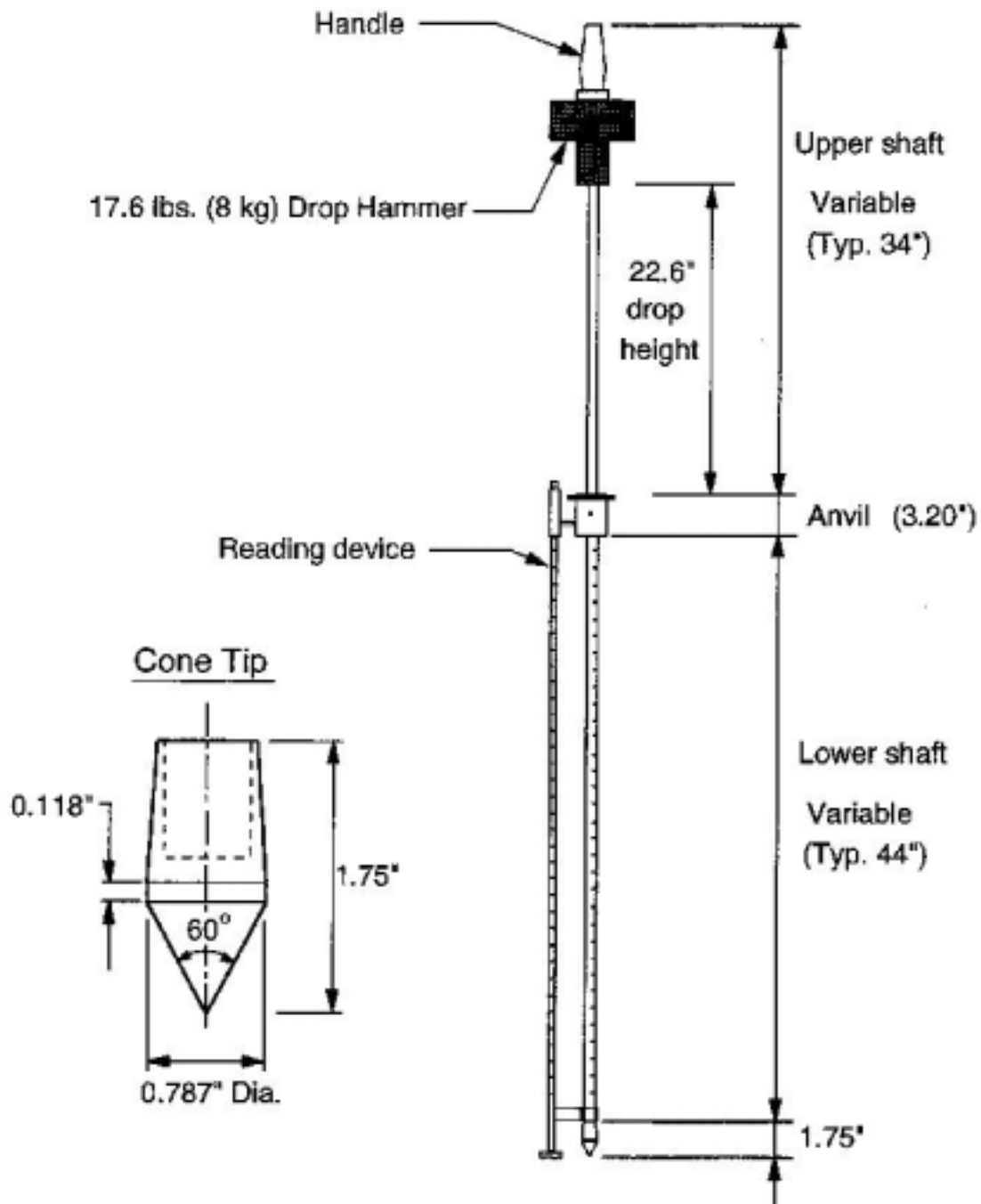


Figure 4.6 Mn/DOT DCP

4.3.4 Use of Subgrade Design Factors

4.3.4.1 General

Mn/DOT currently has three methods of flexible pavement design.

- The Soil Factor
- The R-Value
- The Mechanistic Empirical (MnPAVE)

The embankment characterization depends on the design procedure selected. Proper subcutting and mixing during construction will limit the variation of soil characteristics that have to be considered during design. Compaction to AASHTO T-99 density will increase strength and stiffness. Construction specifications are summarized in Section 4.5. Other methods of embankment stabilization can be employed to increase strength, such as the addition of lime, portland cement, or various bituminous materials.

Stabilization is covered in Section 4.6.

4.3.4.2 Soil Factor

The Soil Factor design procedure is based on the AASHTO classification system. If the soil varies over the project area then embankment construction should be specified in relation to the most critical soil type. More information can be found in the State Aid manual (4).

4.3.4.3 R-Value

The R-Value is preferred over the Soil Factor, because it provides a quantitative measure of the strength and stiffness of the soil. The current Mn/DOT design procedure is presented in the Geotechnical and Pavement Design Manual (5). The existing information for this design factor is extensive, covering most of the soil types encountered in Minnesota. A correlation has been made between R-Value, Soil Factor and AASHTO classification system. The R-Value can also be used to estimate the resilient modulus for use in the MnPAVE program (7). The design R-Value is normally the mean value minus one standard deviation

4.3.4.4 MnPAVE

MnPAVE is a computer program available through Mn/DOT for thickness design of the HMA surface, aggregate base, and subbase for a given subgrade. MnPAVE has the ability to account for seasonally changing conditions with the use of seasonal factors

(Table 4.5). The resilient modulus is varied using the seasonal factor determined at Mn/ROAD in order to account for the amount and state of water present (8). The subgrade is given a default resilient modulus of 350 MPa (50 ksi) during winter and early spring because the water in the soil is frozen creating a very stiff material. In contrast, the base is given a seasonal factor of 0.3 for the early spring verses the summer value of 1. This very low seasonal factor is used because the base and subbase are thawed and saturated, while the subgrade is frozen prohibiting water from draining. The thawed base causes the strain on the upper thawed layers to increase during the early spring. This change in stress conditions cannot be accounted for by other design factors. The application of this change in seasonal conditions to design criteria is a significant advance in embankment design since the affect of moisture freeze/thaw susceptible materials can be accounted for. MnPAVE is currently under development by Mn/DOT and is available and is available for use upon request. Table 4.5 shows the correlations developed by Siekmeier and Davich (7) relating soil classification, R-Value, and resilient modulus. In this way the stiffness characteristics of a soil can be roughly estimated from the soil classification or stabilometer R-Value. Laboratory or field measurements of the resilient modulus are always preferable.

Table 4.5 MnPAVE Design Moduli Correlation

Soil Classification			Strength Tests				MnPAVE Design Moduli							
Textural Class	AASHTO	Mn/DOT Soil Factor	R-Value (240 psi Exudation Pressure)		CBR Percentage	DCP mm/blow	Winter & Early Spring		Late Spring		Summer		Fall	
			Estimated	Measured	Estimated	Estimated	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
Gravel (G)	A-1	50-75	70	ND	21	12	350	50	62	9.0	78	11	78	11
Sand (Sa)	A-1 A-3	50-75	70	ND	21	12	350	50	62	9.0	78	11	78	11
Loamy Sand (LSa)	A-2	50-75	30	46 - 74	6.2	22	350	50	33	4.8	41	6.0	41	6.0
Sandy Loam (SaL)	A-2 A-4	100-130	30	17 - 49	4.4	27	350	50	27	4.0	34	5.0	34	5.0
Loam (L)	A-4	100-130	15	14 - 26	4.2	27	350	50	27	3.9	33	4.8	33	4.8
Silt Loam (SiL)	A-4	100-130	12	10 - 40	3.9	28	350	50	26	3.7	32	4.6	32	4.6
Sandy Clay Loam (SaCL)	A-6	100-130	17	14 - 27	4.5	26	350	50	28	4.0	35	5.0	35	5.0
Clay Loam (CL)	A-6	100-130	13	13 - 21	4.1	28	350	50	26	3.8	33	4.8	33	4.8
Silty Clay Loam (SiCL)	A-6	120-130	10	11 - 21	ND	ND	350	50	ND	ND	ND	ND	ND	ND
Sandy Clay (SaC)	A-7	120-130	14	ND	ND	ND	350	50	ND	ND	ND	ND	ND	ND
Silty Clay (SiC)	A-7	120-130	8	ND	3.4	30	350	50	24	3.5	30	4.3	30	4.3
Clay (C)	A-7	120-130	12	10 - 17	3.9	28	350	50	26	3.7	32	4.7	32	4.7

4.4 Drainage

To improve the integrity of the subgrade, it is necessary to reduce water (28). The hydrologic conditions of the construction site must be evaluated for the initial excavation proceeds.

Knowledge of the in situ conditions before construction begins is necessary to design proper drainage. In addition an interpretation of the conditions encountered during excavation should be used when implementing the intent of the design and properly construct the embankment.

Surface infiltration as well as subsurface water sources must be considered. Adequate ditches will provide sufficient drainage in most cases. Mn/DOT specifications use a standard height of 1.7 m (5 ft) of the pavement grade above the water table. In most areas in Minnesota this will allow for adequate drainage. However, in some situations additional measures may be required.

Drainage will also limit the effect of the freeze-thaw cycle. Frost heave can be limited by installing drains to lower the water table. These drains may help reduce capillary water, which is responsible for frost heave (5). Dewatering during construction is also critical. Proper remediation of unsuitable hydrologic conditions will yield a stable foundation on which to construct the remainder of the pavement section.

4.5 Construction of the Subgrade (Embankment)

4.5.1 General

In the previous sections of this chapter, methods used to establish design strength for the embankment soil have been presented. To obtain the design values indicated in the field, proper construction practices must be followed. Mn/DOT has three specifications, which apply to the construction of embankment soils: specifications 2105, 2111 and 2123 in the 2000 Mn/DOT Specification Book (9).

4.5.2 Specifications

Mn/DOT has three specifications that pertain to the construction of embankments. These are specifications 2105, 2111, and 2123 (9). Specification 2105 “Excavation” and “Embankment” includes two types of construction control. These are the “Specified Density Method” and “Quality Compaction Method” (visual inspection). The methods are similar because both specifications state that the compaction must be accomplished to the satisfaction of the Engineer. For “Quality” compaction an experienced engineer or inspector must be on the project to make sure adequate compaction is achieved. For “specified density” compaction the judgment of the engineer is aided by the determination of a measured density. The density must be measured using the representative moisture-density for the soil being constructed. Of the two methods “specified density” is recommended.

Specifications 2105, 2111, and 2123 should be used along with and support appropriate for placing and compacting the soil embankment as the first and most important step in constructing an asphalt pavement.

4.5.2.1 Mn/DOT Specification 2105 (Excavation and Embankment) (9)

Specification 2105 states how roadway excavations and embankments should be constructed within the right of way.

4.5.2.1.1 Materials

The engineer classifies excavation materials as the work progresses. The following types of excavation are defined: Common, Rock, Muck, Subgrade, Common Channel, Rock Channel and Unclassified. Common and Subgrade materials are generally the same unless otherwise specified in the proposal defining materials for a given project. Borrow materials are defined as Granular Borrow if it meets the select granular specification (3149) or Common Borrow, which can be any type of soil available near the grade. Topsoil Borrow meeting Specification 3877 may also be specified. Material salvaged from the existing project may also be used when appropriate.

4.5.2.1.2 Construction Requirements

The construction requirements are detailed in Section 2105.3 (9). The general requirements include keeping the embankments well drained at all times by maintaining surface drainage and installing planned drainage facilities as construction progresses. Existing drainage must not be interrupted as the project develops. The preparation of the embankment foundation is always important and even more critical for embankments less than 2 m (6 ft) in height because it will not be possible to construct a good embankment if the underlying materials are not stable and uniform. Before placing any embankment 1 m (3 ft) or less in height all unsuitable soil shall be removed to a depth determined by the engineer. Unstable materials must be removed from swamp areas and appropriate materials and methods used if standing water is present. Wherever possible the foundations for all embankments should be dry and compacted between shoulder lines with a tamping roller. Before placing an embankment over an old road the contractor should excavate the old road to 0.3 m (1 ft) below subgrade unless a greater depth is required by the plans.

Excavating operations need to follow plans for the project. Granular backfill must be designed to prevent trapped water in a “bath tub” created by fine-grained subgrade soils. When granular materials are uncovered, they should be placed in the uppermost portion of the embankment. The Contractor shall use disks, plows, graders or other equipment to blend and mix suitable soils to produce uniform moisture content and density. No capping of granular material with nongranular materials will be permitted

at or within 0.3 m (12 in.) of the subgrade surface. All material including bituminous and concrete waste that is considered unsuitable for use in the upper portion of the roadbed shall be placed in embankments at least 1 m (3 ft) below the top of the subgrade.

When placing the embankment material the following rules shall be followed:

- Before backfilling roadbed subcuts 0.9 m (30 in.) or less in depth, the upper 150 mm (6 in.) of soil at the bottom of the excavation should be compacted to 95 percent AASHTO T-99 maximum density.
- Embankment material should be spread in uniform layers approximately parallel to the profile grade.
- Where the foundation for the embankment (or backfill) is under water or will not support the hauling equipment without appreciable movement. The embankment may be constructed as one layer using granular material up to the lowest elevation at which the equipment can operate without excessive deformation of the underlying soils. In no case shall the top of that layer be less than 1 m (3 ft) below the top of the subgrade.
- When the embankment material is granular [less than 20 percent passing the 0.075 mm (No. 200) sieve] the thickness of the layers in the upper 1 m (3 ft) should be no greater than 0.2 m (8in.). Below 1 m (3 ft) the compacted lifts can be 0.3 m (12 in.).

When the embankment is stone of such sizes that the material cannot be compacted, that material may be placed in the embankment up to an elevation 0.3 m (1 ft) below the bottom of the grade, in layers not to exceed 0.6 m (2 ft) in thickness.

4.5.2.1.3 Compaction Requirements

Compaction is one of the most important requirements when considering the stiffness and uniformity of an embankment material. Two methods for controlling density are listed in Specification 2105. These are the Specified Density Method and Visual Inspection Method.

Even if Specified Density is being used, the inspector should be aware of the compaction as it progresses with each pass of the roller. The Visual Inspection should only be used if enough experienced inspectors are available to observe the operation.

Specification 2105 also has some requirements for Finishing Operations, Method of Measurement for Payment and finally Basis of Payment. In this section parts of 2105 are outlined below which relate primarily to the construction of a strong and uniform embankment and the Quality or Visual Inspection Method (9).

4.5.2.1.3.1 Specified Density Method

For the Specified Density Method the density is measured and related to the maximum density measured with the AASHTO T-99 (Standard Procter) Method. The laboratory method for conducting the Standard Moisture-Density test and for running the field density tests are presented in the Mn/DOT Grading and Base Manual (10). The upper 1 m (3 ft) of the subgrade must be compacted to not less than 100 percent of maximum T-99 density and the portions of the embankment placed below 1 m (3 ft) must be placed to not less than 95% T-99 density. The compaction moisture content must not be greater than 102%, nor less than 65% of Optimum Moisture Content when trying to attain 100% Maximum Density and 115% nor less than 65% moisture for 95% Maximum Density. When using specified density, the field testing and sampling shall be done at locations that confirm that the minimum specified density has been achieved everywhere.

4.5.2.1.3.2 Quality or Visual Inspection Method

For the Quality or Visual Inspection Method the contractor must be using equipment in Specification 2123. Subsequent layers must not be added until the lower layer is compacted adequately. The moisture content used for compaction must conform to the levels noted above relative to T-99 Optimum Moisture Content. In plastic soils compaction may be accomplished with pneumatic-tired, steel-wheeled, or grid rollers as specified in Mn/DOT 2123, for compacting layers 75 mm (3 in.) or less. These devices can be used for granular soil layers up to 200 mm (8 in.) thick. Compaction control using Visual Inspection is defined as determining when no more densification is occurring.

Even if Specified Density is being used the Inspector should be aware of the compaction that is progressing with each pass of the roller. The Visual Inspection should only be used if enough experienced inspectors are available to observe the operation.

Specification 2105 also has some requirements for Finishing Operations, Method of Measurement for payment and finally Basis of Payment. In this Section parts of 2105 have been outlined, which relate primarily to the construction of a strong and uniform embankment soil.

4.5.2.2 Mn/DOT Specification 2111 (Test Rolling) (9)

4.5.2.2.1 Description

Test rolling measures the bearing capacity of the soil to determine if compaction has been completed uniformly.

4.5.2.2.2 Equipment

The roller used must be pneumatic-tired and conform to Specification 2111.2:

- 2 wheels spaced not less than 1.8 m (6 ft) apart center to center transversely
- Tire size either 18 x 24 or 18 x 25. Tires should be inflated to 650 kPa (95 psi).
- Gross mass of roller not less than 13.5 metric tons (14.9 tons) and not more than 13.7 metric tons (15.1 tons) on each wheel.

4.5.2.2.3 Construction Requirements

Test rolling should be done when the grading and compaction is completed within 100 mm (4 in.) of the top of the subgrade and. should cover the entire surface. The roller speed should not be less than 4 km/hr (2.5 mph) nor more than 8 km/hr (5 mph). Care must be taken to protect culverts and other structures. The roadbed shall be considered to be unstable if under the operation of the roller, the surface shows yielding or rutting of more than 50 mm (2 in.) measured from the top of the constructed grade to the bottom of the rut. An extra 25mm (1 in.) is allowed if the granular soil is to be stabilized. In areas that are unstable the material will be removed and replaced or revised if aeration or moisture can be used to make uniform compaction possible. Failed areas should be retested with the area is less than 50 m (150 ft) in length and the Engineer is satisfied that the corrective action is adequate.

4.5.3 General Design Considerations

4.5.3.1 General

As a project is designed in the Office and then constructed, certain design considerations need to be followed to provide a strong and uniform subgrade

(embankment) for a pavement structure. Many of these depend on the type of soil encountered on the job. As discussed, a good soil survey will help establish what to expect. However, variations may occur in the field as the job progresses. Therefore, both the design and construction engineers must be aware of the general design considerations so that if changes occur in the field the Construction Engineer will know that a change may be needed. The following checklist is therefore provided for both.

4.5.3.2 Excavation and Embankment Construction

1. Finished grade elevation is kept at least 1.7 m (5 ft) above the water table.
2. The height of the finished grade above the water table including HMA, granular base, subbase and engineered soil should be greater than the depth of frost penetration to minimize frost heaving.
3. The existing soils and their preparation including subgrade correction, embankment placement, and protection of the completed embankment, all need to be considered.

4.5.3.3 Soils Evaluation

1. Suitable/Unsuitable Materials: Granular, select granular, and other soils, which will provide the required stiffness and moisture characteristics are considered “suitable”. Topsoil, organic materials, debris and other unstable materials are considered “unsuitable”.
2. Excavated Soils: Excavated soils from a given project should be used as fill on that project as much as possible.
3. Salvaged Materials: Salvaged aggregate, topsoil, and bituminous materials should be used as much as possible.
4. Borrow: Borrow material is required for embankment construction when sufficient excavated soils cannot be obtained from roadway cut sections. Borrow material should be classified as Select Granular, (Mn/DOT Spec. 3149), common, or topsoil (Mn/DOT Spec. 3877). To determine the quantities of Borrow needed a shrinkage factor must be determined. This procedure is covered in Mn/DOT Geotechnical and Pavement Design Manual Section 5-2.01.01 (5).

4.5.3.4 Soils Preparation

1. General: Proper preparation of the soils for good uniformity involves reworking and enhancing the existing materials and eliminating pockets of high moisture content and unstable soils.
2. Compaction: The most efficient way to use the existing soil on a project is to compact it well and uniformly. Good compaction will increase strength and decrease compressibility, permeability and volume changes. To obtain maximum density for a given soil it is necessary to compact it at or close to optimum moisture content. These provisions are covered in Mn/DOT Specification 2105 (9).
3. Lime Treatment: The addition of lime and fly ash are used on occasion in order to modify and stabilize embankment soils.
4. Geosynthetics: Geotextiles (geofabrics) may effectively be used for separation/stabilization in the bottom of subcuts, below culverts where soft soils make placement of the next lift difficult or density is hard to achieve. Generally, geotextiles should not be used as a substitute for portions of the required granular materials (5).

4.5.3.5 Subgrade Correction

1. Subcuts: Subcuts are made to ensure uniformity of material and maximize stability. They are used to eliminate differential conditions or pockets of high-moisture, unstable materials, frost susceptible materials, and other non-uniform conditions. Subcuts can range from 0.3 to 1.3 m (1-4 ft) depending on the soil type. Subcuts should generally be designed to the depth of frost especially when silt-type soils are encountered. In these cases the subcuts should extend below the frost depth. Tapers should be provided with each subcut to eliminate abrupt changes. The bottom of the subcut must be drainable material or with a system installed to make sure water does not collect in the bottom (5).
2. Culverts: Culverts should be placed with 0.7 m (2 ft) of aggregate bedding and 20H to 1V tapers to minimize the effects of heave and variability of the embankment soil (5).

4.5.3.6 Placement of Embankment and Backfill Materials

UNIFORMITY: To produce uniformity the following materials and procedures should be specified and followed:

- Each layer of roadbed should be constructed of uniform material.
- If variable soils are encountered over a short distance they must be blended. If available, they should be mixed.
- When different soil types are encountered in relatively largely well-defined layers 20H to 1V tapers should be used to transition from one soil to the next.
- For soft and unstable soils that will not support construction equipment, the embankment may be constructed in a single layer to the lowest elevation at which construction equipment can operate without causing the underlying soils to intrude into the upper 200 mm (8 in.) of the embankment.
- For placement of granular materials [not more than 20 percent passing the 0.075 mm (No. 200) sieve] in the upper 1 m (3 ft) of the embankment, the lift thickness may be increased to 0.3 m (12 in.) as long as proper compaction can be achieved.
- The upper 0.7 to 1.3 m (2-4 ft) of the embankment/fill should be comprised of selected earth material or granular materials. Within 0.3 m (12 in.) of the subgrade surface granular materials should not be capped with non-granular materials.
- At no time should embankment material be placed frozen or on soil that is frozen to a depth greater than 100 mm (4 in.). No frozen material exceeding 150 mm (6 in.) in dimension should be permitted in the embankment. Frozen material less than 150 mm (6 in.) can only be placed outside of a 1H to 1V slope down and outward from the subgrade point of intersection.

4.5.3.7 Compaction

Compaction must be performed to Mn/DOT Specification 2105 supplemented by 2111 using equipment specified in Specification 2123. Three methods of evaluation are presented in the specifications. These are the SPECIFIED DENSITY, QUALITY COMPACTION and PROOF-ROLLING.

Although these methods can be equally effective in evaluating the results of a Contractor's compaction work, there are circumstances when one method will be more practical and effective than another. Examples are:

- Specified Density is more appropriate if there are a limited number of inspectors.
- Specified Density is more appropriate on jobs over 38,200 cubic meters (50,000 cubic yards).
- Quality Compaction may be more appropriate if the embankment construction is less than 38,200 cubic meters (50,000 cubic yards) and the inspectors on the job are experienced in all aspects of embankment construction and there are enough inspectors to constantly observe all of the contractor's operations.
- When Specification 2111 is used, the load carrying capacity with a heavy roller defined in the Specification monitors the compaction. Test rolling should be used on projects more than 1.6 km (1 mile) in length. Areas that pump or rut excessively should be excavated and recompacted to provide adequate bearing capacity for the pavement.

4.5.4 Construction Notes and Procedures

In summary the following notes are taken from the Field Notes for Construction Engineers and Inspectors published in 2001 (11). The notes listed pertain particularly to the construction of a uniform and strong embankment soil.

1. Review the auger borings and other soils reports to ensure the best possible use is made of the soils available.
2. Monitor topsoil salvaging to ensure proper quantifiable drainage and erosion control.
3. Ensure that unstable material is identified, subcut as required and measured for final payment.
4. Confirm that existing structures and pavements near subgrade elevation are broken down as required.
5. Measure and record swamp excavation by cross sectioning prior to backfilling.
6. Monitor soil selection and blending to ensure that embankment is composed of uniform soils. Check restrictions imposed by the specifications or other contract documents. Run gradation tests on applicable soils.
7. Ensure large stones, rock and broken concrete are intermixed with soil to prevent voids. These materials are restricted to specific locations in the embankment as defined in the specifications.

8. Require embankment to be placed and compacted full width in layers not exceeding the thicknesses given in the specifications or other contract documents.
9. Maintain soil moisture control to prevent instability and keep moisture within the limits so that proper compaction can be attained.
10. Check for compaction. **Correct failing areas before application of the next layer.**
11. Ensure that hauling and leveling equipment is working over the full width of the embankment.
12. Check for yielding of the subgrade under the hauling equipment. Any soft areas due to excessive moisture should be corrected by drying and recompacting or by removing and replacing the wet yielding soils.
13. Require a well-drained and shaped work area
14. Maintain continued surveillance of erosion control throughout grading operation. Ensure temporary erosion control devices are properly constructed, anchored and maintained.
15. Make sure culverts are “bridged” with sufficient embankment thickness to prevent damage from hauling equipment and/or the Test Roller.
16. Require grading to proceed in orderly fashion with finishing carried through as work progresses.
17. Ensure that Test Roller weight, tire pressure, and dimensions specifications are met before rolling.
18. Maintain daily diary that includes location, type of work, hours, equipment, quantities, soil types and changes, layer thicknesses, relative moisture, degree of compaction, information on rutting and displacement, application and quantity of water and weather information as it impacts the grading activities. A good diary will be extremely useful to field personnel as they review events and help others determine how well a job is progressing.

Setting up a contract with these specifications and following through with the procedures and field control will help ensure the most economical use of embankment soils. A strong, stiff, and uniform embankment will result and a reliable long lasting pavement section will be constructed.

4.6 Subgrade Enhancement Summary

4.6.1 General

A common problem in the field is soil that is unsuitable for the project. One solution is replacing the soil, however this may not be economical. Improving the in situ soil by mixing and compacting is the most common method of stabilization.

Categories of Enhancement

1. Mixing and Compaction
2. Remove and Replace
3. Moisture Content Adjustment
4. Modification and Stabilization
 - i. Cementing agents
 - ii. Water-retaining agents
 - iii. Water-proofing agents
5. Geosynthetics
 - i. Geotextiles
 - ii. Geogrids
 - iii. Geocells

4.6.2 Categories of Enhancement

4.6.2.1 Improvement of Existing Materials

Compaction of granular soil is not as dependent on the moisture content. However, cohesive soils, or soils with a significant percentage of cohesive material, reach maximum compaction when the optimum amount of moisture is present. The workability of granular soils may be less if excess moisture is present. Cohesive soils are easier to work at or near optimum moisture content. Therefore, a representative moisture-density test must be run for the soil being worked.

One of the most common modifications is compaction at or slightly wetter than the AASHTO T-99 (5) optimum moisture content to the specified depth for the project. The amount of moisture necessary to reach optimum compaction is dependent on the percentages of silt and clay. The appropriate moisture content can be determined by AASHTO T-99 procedure (5). Compaction increases the shear strength and stiffness of

the soil. If it is determined that compaction alone will not be adequate, other types of remedial procedures must be implemented.

4.6.2.2 Remove and Replace

This process is also known as undercut and backfill, a process that replaces or covers the unstable soil with a layer of granular soil that can distribute the loads to the extent that the underlying soil can support the expected construction and traffic loads.

Replacement is the most direct and certain means of subgrade enhancement. It removes the uncertainty of whether improvements on the existing soil will be able to provide the necessary support for the lifetime of the road. The main drawback to this approach is the cost and the need to find a high quality replacement soil nearby.

4.6.2.3 Modification

Many types of additives are commercially available for in situ soil improvements. This procedure is usually used on soils containing a significant percentage of silt and clay, but can be used on any type of soil other than organic. The amount of improvement depends upon the original soil, the compound chosen and the concentration achieved.

1. Cementing Agents (5)
 - a. Portland cement – Sandy soils and lean clays
 - b. Flyash
 - c. Lime – Granular materials and lean clays
 - d. Bitumen – Granular soils
2. Water-absorbing Agents
 - a. Calcium Chloride – Graded aggregate
 - b. Sodium Chloride – Graded aggregate
3. Waterproofing Agents
 - a. Bitumen – Sandy soils

4.6.2.4 Geosynthetics

Geotextiles can provide separation and help stop contamination of the granular material with soil. The proper type of Geotextile will allow for the movement of water to aid in drainage of the subgrade. Geosynthetics can also dissipate loads by transferring the vertical stress over a larger area of the subgrade, limiting permanent deformation. This may decrease the amount of fill required to dissipate the expected stresses. Geosynthetics

will limit the shear stresses transferred to the subgrade, increasing the bearing capacity of the in situ soil. The shear stresses may be dissipated because of the friction developed by the geosynthetic (29).

Geogrids are used primarily for reinforcement applications because their increased aperture size reduces their effectiveness as a separator. Geogrids are used primarily to develop friction between the layers of the soil or granular base. Analyses of embankments indicate that conventional bases are initially structurally stronger than geogrid reinforced embankments, with a shallower depth of base material. However, after some time the strengths of the embankments are approximately the same. This indicates that the reinforced embankments may deteriorate slower (30).

The placement depth of the geosynthetics is critical in order to protect the geosynthetic and provide the greatest possible support. For an asphalt pavement, the burial depth for geogrids should be at the bottom of the aggregate base if the base is less than 0.25 m (10 in.). If the base layer is greater than 0.25 m (10 in.), then the geogrid should be placed at the midpoint of the base layer (30). The depth of the geosynthetic may vary for each project, because it is dependant on the fabric chosen as well as soil types and expected loading. Geosynthetics may or may not enhance the life expectancy and load carrying capacity of both paved and unpaved roads.

The 1993 AASHTO Guide for Design of Pavement Structures (19) and the Jung model developed by the Ontario Ministry of Transport, are able to account for the improvement derived from the introduction of geosynthetics.

The Minnesota Local Road Research Board and Mn/DOT are sponsoring two projects to review the performance of various methods of embankment modification, stabilization, and reinforcement. These types of embankment improvements are potentially beneficial, especially when soil or drainage conditions are poor.

CHAPTER 5

PAVEMENT SECTION MATERIALS

5.1. Background

Pavement section materials are defined as all the layers overlying the subgrade soil and can be of many different types and properties. They can vary from a granular subbase material that will enhance the properties of the subgrade soil, to a 100-percent crushed aggregate base, to a high quality asphalt mixture that can withstand many applications of very high stresses due to loading and weather. Generally, the closer to the surface a layer is located the higher the load and environmental stresses it must withstand. Therefore, layers closer to the surface must be stronger and more durable. In the previous chapter soil characteristics and embankment design were presented. The purpose of the procedures presented was to provide a uniform and stiff foundation with the existing soils. In some cases this will require stabilization and/or reinforcement. These same principles must be applied to the pavement materials so that a strong durable pavement will result.

Definitions of the various materials used are given for the three design procedures currently used in Minnesota [Soil Factor, R-Value, and mechanistic-empirical design (MnPAVE)].

The material must meet Mn/DOT specifications in order for the pavement section materials to achieve the properties assumed for design the specifications must be carried out in the field. The specifications must be implemented by knowledgeable people with proper equipment.

Section 5.2 presents definitions of materials used in the layers of a pavement section and the specifications used for construction of the materials.

Section 5.3 presents the properties used to define how the materials are input for the design procedures. In order for these properties to be obtained the section must be built according to the specifications,

Section 5.4 lists field control procedures that should be followed to meet the specifications and result in a well-constructed project.

5.2. Definitions

5.2.1. Granular Subbase and Select Granular (Mn/DOT Specification 3149-B2)

5.2.1.1. Granular

5.2.1.2. Select Granular

For special use in embankment or backfill construction Select Granular may be any pit-run or crusher-run material that is so graded from coarse to fine that the ratio of the percent passing the 0.075-mm (No. 200) sieve divided by the portion passing the 25-mm (1-in.) sieve does not exceed 12 percent by mass.

5.2.1.3. Subbase Course (Mn/DOT Specification 3138, Class 4)

The subbase course will consist of a pit run or crushed aggregate that meets the gradation specifications in Table 3138-1 of the Mn/DOT 2000 Specifications (9).

5.2.2. Aggregate Base Course

5.2.2.1. Granular (Mn/DOT Specification 3138, Class 3, 5, and 6)

A granular base course consists of any combination of screened pit-run and crushed aggregates that meet the gradation specifications of the respective columns in Table 3138-1 of the Mn/DOT 2000 Specifications (9).

5.2.2.2. Salvage Materials (Mn/DOT Specification 3138, Class 7)

- **Salvaged Concrete (C):** Crushed concrete processed to meet Class 4, 5, or 6 gradation specifications listed in Table 3138-1 when being used to substitute for Class 4, 5, or 6 materials respectively.
- **Salvaged Bituminous (B):** Crushed bituminous mixtures processed to meet Class 4, 5, or 6 gradation specifications listed in Table 3138-1 when used to substitute for Class 4, 5, or 6 materials respectively. The maximum percent residual asphalt permitted is 3 %.
- **Reclaimed Glass (G):** Up to 10 % by weight of reclaimed glass may be mixed/blended with virgin or salvaged/recycled aggregates during the crushing operation. Restrictions on sources, composition, debris content and storage are included in Specification 3138 A2. A certification procedure is also required.

5.2.3. Stabilized Base Materials.

Many materials have been used for stabilizing base courses with varied success in Minnesota. When using a stabilizing agent it is necessary to use a mix design procedure that

will result in an optimum material content. The material must then be mixed with the aggregate or salvage material uniformly to provide a consistent product.

5.2.3.1. Portland cement, lime and/or fly ash have been used in many combinations to provide a stabilized base. Mix design is very important to provide a material that will be strong and durable without excessive brittleness.

5.2.3.2. Asphalt cement, asphalt emulsions and cutbacks have been used for many years to stabilize and waterproof granular bases. Mix designs must efficiently use these materials and result in a strong durable mix. Mn/DOT Specification 2204 covers the requirements for these mixtures (9).

5.2.4. Recycling and Reclaiming

5.2.4.1. Cold In-Place Recycling: This process involves the grinding of an existing HMA surface, mixing asphalt and/or aggregate and compacting the final mixture. Mn/DOT is developing a specification for the process.

5.2.4.2. Full Depth Reclamation: This process involves the grinding and mixing of the full pavement section and compacting it in place. A Mn/DOT Specification is being developed for the use of this process.

5.2.5. Hot Mix Asphalt (HMA)

Currently, there are two types of mixtures used by Mn/DOT: the Mn/DOT 2350 Specification (Marshall Mix Design Procedure) and Specification 2360 (Gyratory Mix Design Procedure). The Gyratory mix design is used on State Highways greater than 5000 tons and project life greater than 5 years. The 2350 Specification is used for all other state roads.

5.3. Pavement Design Factors

5.3.1. General

The design factors for the Soil Factor and R-Value Design procedures are the Granular Equivalent Factors used to build up the pavement section in terms of factors a_1 , a_2 and a_3 which are for the surface, base and subbase respectively. The factors depend only on the specification which the material or mixture meets. Based on decades of experience, the relative values of these factors reflect the contribution that layer provides to the performance of the pavement structure.

The design factors for MnPAVE are the effective moduli of the respective materials. Resilient Modulus tests are now being run by Mn/DOT to develop a catalogue of moduli to use for the various combinations of materials used. For MnPAVE five moduli are used to represent the five seasons defined at Mn/ROAD (6).

5.3.2. Granular Equivalency Factors

Table 5.1 lists the Granular Equivalency Factors used for calculating the Granular Equivalent Thickness. The factors a_1 , a_2 , and a_3 relate to the surface, base and subbase respectively.

Table 5.1 Granular Equivalent (G.E.) Factors

Material	Specification	G.E. Factor
Hot-Mix Asphalt	2360	2.25
	2350	2.25
	2331	2.00
Road-mix Surface (base)	2321	1.50
Bituminous-treated Base	2204 (rich)	1.50
	2204 (lean)	1.25
Aggregate Base	Class 5 or 6, 3138	1.00
Aggregate Base	Class 3, 4, 7, 3138	0.75
Select Granular	3149.2C	0.50

Other materials and procedures do not have published factors. For procedures such as cold in-place recycling and reclamation contact the Mn/DOT Pavement Design Engineer.

5.3.3. Resilient Modulus for Pavement Materials

For MnPAVE, resilient moduli must be determined for each material for each of the five seasons. The default values listed in Table 5.2 should be used unless a Mn/DOT District Materials Engineer or the State Pavement Design Engineer has been consulted.

Table 5.2. Default Resilient Modulus Values to Use in MnPAVE

Hot Mix Asphalt Properties	Hot Mix Asphalt (HMA) Surface	MnPAVE Design Moduli									
		Early Spring		Late Spring		Summer		Fall		Winter	
		4 weeks		varied length		varied length		varied length		varied length	
		MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
	2350 Mixture* (MnDOT Spec. 2350)	11,900	1730	5000	725	1850	268	7860	1140	15,200	2200
	2360 Mixture* (MnDOT Spec. 2360)	11,900	1730	5000	725	1850	268	7860	1140	15,200	2200

*Assume PG 58-28 asphalt binder

Aggregate Base Properties	MnDOT Aggregate Base Classification	MnPAVE Design Moduli									
		Early Spring		Late Spring		Summer		Fall		Winter	
		4 weeks		varied length		varied length		varied length		varied length	
		SF = 0.5		SF = 0.5		SF = 1.0		SF = 1.0		Frozen	
		MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
	Class 7 (MnDOT Spec. 3138)	39	5.6	39	5.6	78	11	78	11	350	50
	Class 6 (MnDOT Spec. 3138)	39	5.6	39	5.6	78	11	78	11	350	50
	Class 5 (MnDOT Spec. 3138)	39	5.6	39	5.6	78	11	78	11	350	50

Granular Subbase Properties	MnDOT Granular Subbase Classification	MnPAVE Design Moduli									
		Early Spring		Late Spring		Summer		Fall		Winter	
		4 weeks		varied length		varied length		varied length		varied length	
		SF = 0.5		SF = 0.5		SF = 1.0		SF = 1.0		Frozen	
		MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
	Class 4 (MnDOT Spec. 3138)	39	5.6	39	5.6	78	11	78	11	350	50
	Class 3 (MnDOT Spec. 3138)	39	5.6	39	5.6	78	11	78	11	350	50
	Select Granular (MnDOT Spec. 3149.2B2)	39	5.6	39	5.6	78	11	78	11	350	50
	Granular (MnDOT Spec. 3149.2B1)	21	3.0	21	3.0	41	6.0	41	6.0	350	50

5.4. Construction of the Pavement Layers

5.4.1. Specification Review

5.4.1.1. Granular Materials Properties and Gradations

5.4.1.1.1. Granular Subbase (Specification 3149.2B2)

Select Granular Borrow may be any pit-run or crusher-run material that is graded from coarse to fine whose ratio of the portion passing the 0.075-mm (No. 200) sieve divided by the portion passing the 25-mm (1 in.) sieve may not exceed 12 percent by mass. The material shall not contain oversize salvaged bituminous particles or stone,

rock or concrete fragments in excess of the quantity or size permissible for placement as specified. This is a very open gradation specification. However, the material should not be very frost or moisture susceptible. To minimize frost and moisture susceptibility there should be less than seven percent passing the 0.075-mm (No. 200) sieve.

5.4.1.1.2. Aggregate Base and Subbase Materials (Mn/DOT Specification 3138)

Specification 3138 covers the gradation of surface gravel (Class 1 and 2), subbase granular materials (Class 3 and 4), and granular base materials (Class 5 and 6). The following requirements are listed:

- All unsuitable and weathered materials shall be removed from the face of the pit.
- The mixture must contain 100 percent virgin aggregate and shall consist of sound durable particles or fragments of gravel and sand except Class 2, which shall consist of 100 percent crushed quarry or mine rock. The materials should be free of sod, roots, plants and other organic matter and lumps of clay.
- The insoluble portion of carbonate rock passing the 0.075-mm (No. 200) sieve shall not exceed 10 percent. This requirement applies to materials from Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, Washington and all counties in Mn/DOT District 6.
- The gradations for each of the Classes of materials are listed in Table 3138-1.
- Crushing will be required for Class 5 and 6 aggregates for materials larger than the maximum size and smaller than a 200-mm (8-in) grizzly. If crushing causes a poor gradation it must be adjusted or some material will need to be stockpiled.
- The Los Angeles Abrasion Loss should be no more than 35 percent for Class 6 material and no more than 40 percent for all other Classes; Class 3, 4 and 5 aggregate shall contain no more than 10 percent shale as defined in the Mn/DOT Grading and Base Manual (10).

5.4.1.1.3. Stabilized Base

5.4.1.1.4. Recycled and Reclaimed Materials may be used or blended with a combination of virgin aggregates in any percentage if the resulting material meets the

requirements of the base or subbase layer being designed. These materials are covered under Specification 3138, Class 7. Three types of salvaged/recycled materials are covered:

- Salvaged Bituminous Aggregate Mixtures can be used alone or in combination with virgin aggregates such that the final mixture meets the gradation and quality requirements for the Class aggregate for which it is being substituted.
- Salvaged Crushed Concrete Aggregate has the same requirements as Salvaged Bituminous.
- Reclaimed Glass can be incorporated up to 10 percent in a granular base. Restrictions are put on the sources and types of reclaimed glass that can be used. These are listed under “composition” in Specification 3138. Restrictions on debris content and storage are also given. The source of the glass must also be certified.

5.4.1.1.5. Sampling and Testing

Specification 3138 requires the following criteria with respect to Sampling and Testing:

- All sampling of Class 1, 2 and 7 materials can be done in the stockpile.
- All other sampling for testing Class 3, 4, 5 and 6 materials should be done during placement to make sure segregation has not occurred.
- If additives such as lime or bituminous materials are being used, the sampling should be done before they are incorporated into the aggregate.
- Six test procedures are listed in Specification 3138 to be used for evaluating the aggregates. See page 827 of Mn/DOT Standard Specifications for Construction, 2000 Edition (9).

5.4.1.2. Construction of Aggregate Base (Mn/DOT Specification 2211)

The work covered under this specification includes the construction of one or more courses of aggregate base on a prepared subgrade or another base. The base will consist of granular materials graded to Specification 3138 Classes 1, 2, 3, 4, 5, 6 or 7. The gradation shall be uniform and checked with random field gradations tests as outlined in Specification 2211.3F (9).

5.4.1.2.1. Construction Requirements

5.4.1.2.1.1. General

- If the aggregate is mined from under water, it shall be stockpiled for 24 hours so as not to saturate the subgrade.
- Individual layers shall be 75 mm (3 in.) or less. Layers up to 150 mm (6 in.) with proper equipment such as heavy rollers and/or relatively clean aggregate materials can be used.
- Vibratory rollers can be used in compaction if shown to be effective.
- Higher quality material than specified can be used. However, payment will be based on the material specified.

5.4.1.2.1.2. Placing and Mixing

- Material can only be placed or windrowed on the grade a maximum of 3 km (2 mi.) in advance of construction.
- Multiple layers can be placed a maximum of 5 km (3 mi.) in advance of construction.
- A single class of aggregate must be placed and compacted along the project before another class of aggregate is placed.
- The subgrade shall be so dry during aggregate placement that no rutting will occur.
- Calcium chloride and/or water should be added for proper compaction.
- Material contaminated with subgrade material shall be replaced.
- If a surface course is in the plans the base must be covered with at least one layer of HMA over the winter. A bituminous penetration coat is not a substitute for an HMA.

5.4.1.2.1.3. Spreading

- The material must be uniformly spread so as to pass gradation specifications.
- Each layer must be completed and compacted before the next layer is spread.
- Each layer must be maintained with the surface aggregate keyed in place until the next layer is applied.

5.4.1.2.1.4. Compaction

Compaction shall be controlled using one of three methods:

- Specified Density – A full layer 75 mm (3 in.) thick shall be compacted to 100% AASHTO T-99 maximum density. The compaction moisture content shall not be less than 65% of optimum moisture content.
- Quality (Ordinary Compaction) – The material will be compacted until no further evidence of consolidation occurs under a steel-wheeled or pneumatic-tired roller defined in Specification 2123 (9). A vibratory roller may be used if approved by the Engineer. Water should be applied during compaction as needed.
- Penetration Index Method Class 5, 6, 7 shall be compacted to achieve a Penetration Index less than or equal to 10 mm (0.4 in.) per blow using a calibrated Mn/DOT Dynamic Cone Penetrometer (DCP) (24).

A layer is considered to be 75 mm (3 in.) thick unless a vibratory roller is used; then layers up to 150 mm (6 in.) can be used.

Two passing DCP tests must be obtained for each 800 cubic meters (1000 cubic yards).

If a test fails the material must be reworked compacted and retested.

The DCP testing must be completed within 24 hours of when the placing and compacting is completed. After 24 hours, the specified compaction method must be used.

Water must be applied as necessary for proper compaction.

The Penetration Index will be determined using the Mn/DOT Dynamic Cone Penetrometer (DCP) following the User Guide (24) available at the Mn/DOT Grading and Base Office (651-779-5564).

If no method of compaction is indicated, then the SPECIFIED DENSITY method shall be used. For Class 7 material only the Quality or Penetration Index Method can be used.

5.4.1.2.1.5. Workmanship and Quality

- The aggregate shall be placed to the cross-sectional dimensions shown on the plans

- The grade shall not vary by more than 15 mm (0.05 ft) from the staked grades.
- Contaminated material shall be replaced.

5.4.1.2.1.6. Aggregate in Stockpiles

When stockpile aggregate is included in the proposal the contract shall, in addition to the aggregate required for the project, stockpile aggregate of the class specified at the designated sites as directed by the Engineer.

5.4.1.2.1.7. Random Sampling Gradation Acceptance Method

- The contractor and/or producer must maintain a gradation quality control program using a random sampling acceptance procedure outlined in the Mn/DOT Grading and Base Manual (10).
- Form 24346 can be used by the contractor to certify that the material conforms to specification requirements.
- The contractor shall assume full responsibility for the production and placement of uniform and acceptable materials.
- Aggregate gradation compliance will be determined in accordance with Table 2211-A (9). Materials and workmanship shall be uniform and within the prescribed target values.
- Eleven provisions are listed in Specification 2211-F for the obtaining and testing of aggregate samples for compliance with Specification 2211 (9).

5.4.1.2.1.8. Payment

Table 2211-B lists the Aggregate Base Payment Schedule using four sublots and four samples. Table 2211-C lists the Aggregate Base Payment Schedule using individual tests.

Section 2211.4 presents the Method of Measurement for Aggregate Base placed (A) and Stockpiled Aggregate (B).

The Basis of Payment for accepted materials is presented in Section 2211.5

5.4.1.3. Hot Asphalt (HMA) Mixtures

5.4.1.3.1. General

The specifications for Hot Mix Asphalt materials cover the materials, mixture design and construction of the mixtures. Currently, there are two Specifications used

by Mn/DOT: Specifications 2350 and 2360. The 2350 mix design uses the Marshall hammer for the laboratory compaction for initial design and construction control. The 2360 mix design is the Minnesota application of the Superpave mix design that uses the gyratory compactor for compaction both for design and field control. Both of the procedures use volumetrics including Voids in the Mineral Aggregate (VMA) for design and control of the mixes. Previous to the 2350 specification, VMA was used only in the design phase; however, it was found that lower VMA's were encountered in the field in some cases. Therefore, a requirement was placed on the field-manufactured mix. Gyratory (2360) mixtures are used on roadways with greater than 5000 tons and project life greater than 5 years.

In this section, a brief review of the Mn/DOT 2350 and 2360 Specifications is given. The latest specifications are available at the Mn/DOT website address <http://www.mrr.dot.state.mn.us/pavement/bituminous/bituminous.asp>. The numbering in this section is the same as in the 2350 and 2360 Specifications.

5.4.1.3.2. Mn/DOT 2350 Specification

0.1 Description

The Specification describes mixtures appropriate for three levels of traffic (Type LV, MV and HV). The levels are defined as:

LV	Low Volume	Less than 1 million ESAL's
MV	Medium Volume	From 1 to 3 million ESAL's
HV	High Volume	Greater than 3 million ESAL's

The specification is for Hot Mix Asphalt on a prepared foundation, base course or existing surface. It is to be placed in accordance with prescribed plans or as established by the Engineer.

0.2 Materials

- Aggregate Requirements for carbonate aggregates passing and retained on the 4.76-mm (No. 4) sieve. Five broad gradation bands based are listed in Table 2350-1. The fifth gradation is for thin lift leveling.
- Additives requirements are listed. These include mineral filler, hydrated lime, liquid anti-stripping materials and coating and anti-stripping material

covered under Specification 3161 (9). These can be part of the original mix design as approved by the Bituminous Engineer or by the Construction Engineer.

- Up to 30% Recycled Asphalt Pavement (RAP) can be used in all wearing courses and 40% can be used in non-wear courses. Requirements and methods for estimating the percent crushed for the RAP are presented. Adjustments in the PG grade to use with RAP if more than 20% is used are listed in the specification. [2350.2C1;a].
- Crushed Concrete and Salvaged Aggregate. Crushed concrete can only be used for up to 50% of the aggregate in non-wear courses.
- Salvaged Aggregate can be used for up to 100% of the mixture aggregate if it meets the requirements of the mixture aggregate and is stored and proportioned into the mixture as specified.
- Scrap Shingles can be used in the mixture. The percent of shingles will be included in the percent RAP in the mixture.
- Asphalt binder material is PG graded as designated by the most recent Mn/DOT memorandum (31).
- Asphalt Mixture Requirements: Table 2350-2 lists the mixture requirements for HV, MV and LV mixtures. The HV is a 75-blow mixture whereas the others are 50-blow mixtures. A lower stability and design air voids are required for the LV mixtures. A TSR of 70% is required for all mixtures. The requirements for LV mixtures do not include any fine aggregate angularity. The VMA requirements based on maximum size of aggregate are listed in Table 2350-3 (9).

0.3 Mixture Design

A. General - Two types of mixture design are presented:

- Laboratory Mixture Design (Option 1): At least 15 days prior to the start of paving materials and a Laboratory Mixture Design are submitted to the District Materials Lab where the project is located. Mn/DOT will evaluate the materials. Then a minimum of 7 days before paving is scheduled the Contractor will submit a Job Mix

Formula. Samples of the mixture will also be submitted 7 days before paving for Mn/DOT to check Tensile Strength Ratios for the mixture. No materials in addition to those can be used in the mix. If the mix proportions change by more than 10% a new mix design must be performed. Materials to be used in the proposed mix must be submitted at least 15 working days before paving is planned.

- B. Documentation - Each proposed mix design Job Mix Formula shall include 18 items of documentation listed in Section 2350.3D.
- C. Mix Design Report – A Mn/DOT reviewed Mix Design Report includes a job-mix formula (JMF) from the composite gradation, aggregate component proportions and asphalt content of the mixture. Design air voids, VMA and aggregate bulk specific gravity values are also indicated on the paving recommendations. JMF limits will be shown for gradation control sieves, percent asphalt binder content, air voids and VMA.

A Mn/DOT reviewed Mix Design Report is required for all paving except small quantities. All materials must meet specifications before a Mix Design Report is issued. Mn/DOT will verify two trial mix designs per mix designated in the plan, per contract at no cost to the Contractor. Additional mix designs will be verified for \$2000 per design.

0.4 Construction Requirements

- A. General – The construction requirements listed in the Specification provide for the construction of all courses.
- B. Restrictions – Work can only proceed after load restrictions have been lifted in the spring. No paving can proceed if the Engineer feels damage will be caused to the subgrade or the HMA. Generally, no paving should be done after October 15 north of Browns Valley to Holyoke or after November 1 south of that line.
- C. Equipment – The Specification lays out requirements for asphalt mixing plants and placement and hauling equipment, including asphalt pavers, trucks and motor graders.

- D. Treatment of the Surface – An asphalt tack coat shall be applied to existing asphalt and concrete and all surfaces of each course or lift constructed except for the final course or lift according to Mn/DOT Specification 2357 (9).
- E. Compaction Operations – Compaction shall be accomplished with continuous operation so that all areas are compacted uniformly to the required density. Rolling with steel-wheeled rollers will not be continued if crushing of aggregates results. To secure a true surface, variations such as depressions or high areas that may develop during rolling operations and lean fat or segregated areas shall be corrected or removed.
- F. Construction Joints – Joints must be thoroughly compacted to produce a neat tightly bonded joint that meets surface tolerances. Both transverse and longitudinal joints are subject to specified density requirements. Randomly selected core locations may fall on the joint in which case the cores will be taken tangent to the joint.

0.5 Mixture Quality Management (Construction)

- A. Quality Control (QC) – The Contractor must provide and maintain a quality control program. This includes all activities and documentation including mix design, process control inspection, sampling and testing, and necessary adjustments in the process that are related to the HMA pavement which meets the requirements of the specification. This also includes the development and maintenance of a certification plan.

The Contractor is required to provide qualified personnel, a laboratory with calibrated equipment, and sampling and testing using specific procedures as listed. The test results will be documented using control charts, control limits (listed in Table 2350-4), JMF adjustments, corrective actions and failing materials. Table 2350-5 lists the Payment Schedule for the various production failures.

- B. Quality Assurance (QA) – Mn/DOT will perform QA testing as part of the acceptance process. The Engineer is responsible for QA testing, records

and acceptance. Specific operations for QC and QA are laid out in Section 2350.5.

As part of QA the Engineer will periodically witness the sampling performed by the Contractor. If the Engineer observes that the sampling and QC are not being performed properly or tests are not being done correctly the Engineer may stop production until corrective action is taken. All sampling and testing must be performed by a Certified Bituminous (QM) Technician. The agency shall calibrate and correlate all laboratory equipment in accordance with the latest version of the Mn/DOT Bituminous Manual (14).

- C. Verification Testing – Verification testing of the Contractor’s results shall be performed daily. Test result tolerances are listed in Table 2350-6 for the various items used for QC/QA. Verification testing is very important to make sure the Contractor and Agency technicians are running the QC/QA tests using the procedures within acceptable limits. Resolution procedures are also laid out.

0.6 Pavement Density

- A. General – For the 2350 Specification all mixtures are to be compacted using the Maximum Density Method unless otherwise indicated. Some mixes that would not require maximum density are lifts less than 39 mm (1.5 in.) wedge sections, patching, driveways or non-traffic areas, excluding shoulders. These exceptions will be compacted using the “Ordinary” Compaction Procedure.
- B. Maximum Density Determination – For the Maximum Density Method all courses and layers will be compacted to the values listed in Table 2350-8, which states that the mixtures shall be compacted to 91.5% of Maximum Theoretical Density. The mixture used for calculation of densities shall be a field-manufactured mixture. The requirement may be reduced by 1% if the first lift of a mix is to be placed on a yielding base. Such cases would be the first lift on a cold recycled base, aggregate base or on a PCC slab that is faulted or has mid-panel cracks or other problems. The payment

schedule for Maximum Density is presented in Table 2350-10. The Table shows that incentives can be obtained for higher densities and that the material must be removed and replaced if the percent of maximum density is less than 88.5%. The payments for density are based on cores. The resolution procedure is presented along with Table 2350-10.

The number of density lots is determined by the daily production. The payment schedule is determined by the core densities. The density is a percent of the Maximum Theoretical Density. The density of the cores is to be determined using AASHTO Method T-166. Compaction must be accomplished by eight (8) hours after the mixture is laid. Coring and traffic control during the coring operation is the Contractor's responsibility.

Density and the resulting voids are very important to the performance of an asphalt mixture. It is therefore important that specified density be used to obtain a high quality mix.

- C. Ordinary Compaction Method – In areas where the specified density method is not required, then the Ordinary Compaction Method is used. For this method a control strip is used to establish how much compaction effort is needed to densify the mixture. Construction of the control strip will be directed by the Engineer. It is to commence as soon as possible in the job. It shall be on the same base conditions and HMA layer thickness as planned for that section of the project. A growth curve of density versus roller passes shall be used to establish when no more density can be achieved. A portable nuclear density device calibrated properly can be used to establish the growth curves. Specifications for steel-wheeled and pneumatic-tired rollers to be used for Ordinary Compaction are given. Three thousand pound per wheel rollers are required for LV and MV mixtures and five thousand pound per wheel rollers are required for HV mixtures.
- D. Mixture temperature requirements are listed in Table 2350-11. The limits are based on the thickness of the lift and the air temperature.

0.7 Thickness and Surface Smoothness Requirements

The final thickness and smoothness of the HMA surface will affect the performance of the pavement quite significantly.

- A. Thickness – After compaction the thickness of each course shall be within 6 mm (0.25 in.) of the thickness shown in the plan unless automatic grade controls are used. This thickness requirement will not apply to the first course placed. If the thickness is less than the minimum specified, that course shall be replaced. If it is greater than the plans then the excess will not be included in the payment.
- B. Surface Requirements – After compaction, the finished surface shall be free of open and torn sections and true to grade and cross sections shown on the Plans using the following definitions:
 - For leveling courses a tolerance of 15 mm (1/2 in.) shall be used.
 - The surface of the non-wear and the wear course shall show no variation greater than 3 mm (1/8 in.) from the edge of a 3 m (10 ft) straightedge.
 - The transverse slope shall not vary from the planned slope by more than 0.4 percent.
 - The distance to the edge of each course and the centerline shall not be more than 75 mm (3 in.).
- C. Pavement Smoothness
 - General - Pavement smoothness is evaluated on the final mainline pavement surface because it has been shown to affect the overall performance of the pavement. Table 2350-12 lists exceptions such as turn lanes, shoulders, intersections, etc.
 - Smoothness Requirements – The smoothness requirements are based on the type of original surface, base and timing of the project. The limiting profiles are listed in Tables 2350-13 A, B, and C, showing the levels of incentive and disincentive.
 - Measurement – Smoothness will be measured with a 7.62 m (25 ft) California Type profilograph. On pass is made 2.74 m (9 ft) from the

centerline. The profilograph should be equipped with automatic data reduction capabilities. Segments of roadway are defined in the Specification.

- Profile Index – The profile index is calculated for each defined segment. A blanking band of 5 mm (0.2 in.) is used for the profile. Bumps and dips equal to or exceeding 10.2 mm in 7.62 m (0.4 in. in 25 ft) are treated separately. Bump, dip and smoothness corrections shall be done across the full width of the pavement. All corrective work shall be made by diamond grinding or approved equivalent, overlaying the area, by replacing or by inlaying.
- Payment – The cost of the smoothness testing and associated traffic control will be incidental to the cost of the wear course.

The contractor can receive incentives and disincentives for each segment. However, the total ride incentive for the surface varies by mix type of the total mix price. Also, the contractor cannot receive an incentive for ride if more than 25% of all density lots fail to meet minimum density requirements.

0.8 Method of Measurement

Each type of asphalt mixture will be measured separately by mass based on the total quantity of material hauled. Asphalt Mixture is measured by the Square Meter (Square Yard) per specified thickness, mm (in.).

0.9 Basis of Payment

Payment for the accepted quantities of asphalt mixture used in each course at the Contract prices per unit of material will be compensation in full for all costs of constructing the asphalt surfacing as specified, including the costs of furnishing and incorporating any asphalt cement, mineral filler, hydrated lime, or anti-stripping additives that may be permitted or required.

5.4.1.3.3. Mn/DOT 2360 Specification (Gyratory Mix Design)

0.1 Description

This specification covers the construction of one or more pavement courses of gyratory hot-plant mixed aggregate-asphalt mixtures on an approved prepared

subgrade and/or base course. The HMA must be placed with the lines, grades, thicknesses and cross sections laid out in the plans for the project.

A. Design Criteria

The design mixtures are divided into three levels based on Nominal Maximum Size aggregate used in the HMA. These are Types SP 9.5, SP 12.5 and SP 19.0, which represent nominal maximum sizes of 9.5 mm (3/8 in.), 12.5 mm (1/2 in.) and 19.0 mm (5/8 in.) respectively. These are further designated as Wear and Non-wear mixtures. The gyratory traffic levels are listed in Table 2360-1. The table shows categories from less than 300,000 ESAL's to greater than 100,000,000 ESAL's over a 20-year period. The PG grading system is used to select the asphalt material. The appropriate PG grade for a given project depends on the geographic location and the traffic on a given project. Mn/DOT Technical Memo (31) applies for selecting the appropriate material.

B. Minimum Lift Thickness

The following minimum lift thickness applies to the three designated mixtures.

<u>Mixture</u>	<u>Minimum Lift Thickness</u>
SP 9.5 wear	40 mm (1.5 in.)
SP 12.5 wear and non-wear	40 mm (1.5 in.)
SP 19.0 non-wear	65 mm (2.5 in.)

0.2 Materials

A. Asphalt Binder

The asphalt binder must meet all of the requirements laid out in AASHTO MP-1. The grade to be used on Minnesota projects should be established using the most current Mn/DOT Memorandum "Inspection, Sampling and Acceptance of Bituminous Materials"(33). It is important that fuel oils or other distillates not be used in the tanks used for storage of the asphalt materials. Asphalt materials are usually certified for use by the supplier. The

supplier should also provide a memo indicating appropriate mixing and compaction temperatures in the laboratory and field.

B. Additives

Additives are materials such as mineral filler, hydrated lime, and asphalt additives such as anti-strip that do not have a specific pay item. If they are required a pay item can be included. However, if additives are added at the contractor's option they will not be compensated. Any additive proposed must be approved by the Mn/DOT Bituminous Engineer.

C. Gradation Requirements

Three gradation bands are shown in Table 2360-2. These are broad bands that define the general limits of gradations for each of the mixtures. In addition restricted zones are recommended as listed in Table 2360-3. The restricted zone has been defined to help "open up" the gradation between the 2.36-mm (No. 8) and the 0.3-mm (No. 50) sieves. By missing this zone, it should make it easier to make the VMA requirements for the mixture. However, experience has shown that it is possible to accomplish the VMA requirements with gradations that pass through the restricted zone. More crushed fine aggregate and a lower percent passing the 0.75-mm (No. 200) sieve can also help the VMA level.

D. Consensus Aggregate Properties

The consensus aggregate properties are an attempt to specify characteristics that will provide for a good stable durable asphalt mixture. The properties have been found to enhance stability and stiffness in the Marshall and Hveem procedures in the past. The following aggregate properties are specified:

1. Coarse Aggregate Angularity (ASTM D 5821)
2. Fine Aggregate Angularity (ASTM C 1252)
3. Flat and Elongated Particles (ASTM D 4791) The maximum number of flat and elongated particles is 10 percent by mass for traffic Class 3 and above. The ratio of length to width used is 3:1.

4. The clay content is measured using the Sand Equivalent Test (AASHTO T-176). Higher percentages indicate a cleaner material.

E. Source-Specific Aggregate Properties

When an aggregate source is selected by the Contractor or the State the characteristics of the material must be checked to see if the material will be strong and durable. Strength and durability are important both during construction and when the mixture is in service. When materials from more than one source are used samples from each source must be evaluated. The following tests are used for source evaluation:

- Los Angeles Abrasion (Toughness Test) AASHTO T-96
- Magnesium Sulfate (Soundness Test) AASHTO T-104. Maximum loss percentages are given for specific sieve sizes. An aggregate proportion that passes the 4.75-mm (No. 4) sieve and exceeds the loss requirements listed above on the coarse aggregate fraction cannot be used in the mixture.
- Total Spall and Lumps (Deleterious Materials Test), Mn/DOT Manual No. 1209. Spall is defined as shale, iron oxide, unsound cherts, pyrite, and other similar materials. The maximum percentage of spalls and lumps for the various traffic levels are given in Table 2360-E3.
- Insoluble Residue (Soundness Test), Mn/DOT Laboratory Manual 1221. The maximum percent insoluble residue must not exceed 10%.
- Aggregate Specific Gravity shall be run on all aggregates used in the mixtures. AASHTO T-84 and T-85 as modified by Mn/DOT are to be used.
- All material passing the 0.075-mm (No. 200) sieve is classified mineral filler and all material passing the 4.75-mm (No. 4) sieve and retained on the 0.075-mm (No. 200 Sieve) is considered fine aggregate.
- A maximum of 20% recycled materials can be used in a Specification 2360 mixture. The following rules should govern the use of RAP in the mixture. The combination of RAP aggregate and virgin aggregate must comply with the consensus properties in Specification 2360.2C and

2360.2D. Specific gravities of the RAP materials must be determined. The percent asphalt binder in the RAP must be determined. RAP containing any objectionable material such as road tar, metal, glass, plastic, brick and other materials will not be permitted for use in the HMA mixture.

F. Mixture Requirements

The aggregate fractions shall be proportioned such that the composite gradation passes the grading listed in Table 2360-2.

- Aggregate Restrictions - The aggregate restrictions should also include the requirements listed in Table 2360-F1 which shows the maximum percentage of Class B carbonate aggregate that can be used.
- Gyratory Compaction - Table 2360-7 lists the Superpave Design Gyratory Compactive Effort for three levels of gyrations: N_{initial} , N_{design} and N_{maximum} . The design criteria in terms of percent of maximum density for the three levels of gyrations are given in Table 2360-8. The criteria are listed for mixes within 100 mm (4 in.) of the surface and for those greater than that depth. The table shows that initial compaction is defined at 89 to 90 percent of maximum density (10 to 11 percent air voids). The number of gyrations at design level relates to 96 to 97 percent of maximum density and the maximum levels correspond to 98 to 99 percent maximum density. These criteria would help make sure the aggregate structure is strong enough to keep the mix from densifying too much under traffic.
- Volumetric Criteria - The design air void content is 4 percent for mixes to be placed in the upper 100 mm (4 in.) of the surface and 3 percent for those at greater depths.
- Voids in the Mineral Aggregate (VMA) - The VMA criteria for Gyratory mixtures are given in Table 2360-9. The values are given for coarse and fine mixes that have the same nominal maximum size. The criteria are slightly lower as the aggregate generally gets coarser. The VMA criteria are used to make sure the mix is open enough to hold enough asphalt for a good durable mixture.

- Voids Filled with Asphalt (VFA) – The voids filled with asphalt criteria are listed in Table 2360-10. The criteria are also listed for mixes within the top 100 mm (4 in.) and those at greater depths. The values for Traffic levels 4 –7 have been increased slightly.
- Fines to Effective Asphalt Ratio – The effective asphalt content is to be estimated using the Asphalt Institute Method presented in MS-2 (34). The Fines to Effective Asphalt Content by mass shall be 0.6 to 1.2.
- Moisture Damage Susceptibility – The retained tensile strength (TSR) of the mixture using a 150-mm (6-in.) diameter specimen shall be 80 percent or greater using ASTM D-4867, Mn/DOT modified. The DOT will test the submitted mixture at least once, unless anti-strip or a different aggregate composition is submitted.

0.3 Mixture Design

A. General

The asphalt mixture designs are to be carried out by the Contractor and checked by Mn/DOT. Review and approval is done by either the District Materials or Central Office Laboratory. Once a mix design is completed the addition of other aggregates and materials is prohibited. The procedures used are AASHTO TP-4 or the Asphalt Institute Manual SP-2 (35). If any changes in proportions exceed 10% a new mix design must be done.

Three options are available for submitting and verifying each mix design.

B. Laboratory Mixture Design (Option 1)

Option 1 is for a new mix design, for which the source properties of the aggregate must be tested along with the mix design. Contractor test results and documentation as listed in Section 2360.3E are sent to the Mn/DOT Bituminous Engineer or District Materials Engineer to check conformance with the mixture requirements. Fifteen days before construction, aggregate samples are to be submitted for source, class, type and size of virgin and non-asphaltic salvage source to be used in the mixture. Aggregates requiring magnesium sulfate testing need to be submitted 30 days early. Mixture

samples are to be submitted 7 days before construction for volumetric evaluation and moisture susceptibility testing.

C. Laboratory Design / Initial Production Test Strip Verification. For a new Superpave Mixture at a particular plant placement of the mixture shall be limited to 500 tonnes (550 tons) of mixture. Two sets of mixture samples are taken for evaluation by both the Contractor and Mn/DOT. The samples are used to check gradation and consensus properties according to Tables 2360-2C and 2360-2D.

Gradation, design air voids, VMA and % asphalt binder are checked against the JMF. If any of these parameters are not met, it will result in failure of the 500 tonnes (550 tons) and require the Contractor to use Option 1 to develop a new mixture design for that project.

D. Documentation

For each of the mixture design procedures that are submitted to Mn/DOT for verification and checking, documentation of the mixture being submitted must be done in a complete and consistent manner. Fifteen (15) items needed for acceptable documentation are listed in 2360.3E. Forms are available from Mn/DOT that include all of the information required for each mixture.

E. HMA Paving Recommendations

Based on the submitted, verified and approved mixtures sent to Mn/DOT by the Contractor for a given project a Mn/DOT reviewed mix design report will be made. The mix design includes a job mix formula (JMF) from the composite gradation, aggregate component proportions, and asphalt content of the mixture. Design air voids, VMA, and aggregate specific gravity values are also indicated on the paving recommendations. JMF limits will be shown for gradation control sieves, percent asphalt binder content, air voids and VMA.

For city, county and other agencies that do not have state aid funding the Contractor shall provide the Mn/DOT District Materials Laboratory a complete Project proposal with all the materials and documents that affect the mix design.

If an initial production test strip is to be used (Option 3 above) an initial JMF for that mix must be issued. Successful verification will be done as laid in 2360.3D. If it cannot be verified, the JMF will be cancelled.

0.4 Mixture Quality Management

A. Quality Control

The Contractor is to develop and maintain Quality Control (QC) at the plant. A procedure is spelled out for certifying and maintaining certification of a plant. If proper control procedures are not followed a plant can be de-certified. If a plant is relocated it must be certified at the new location.

B. Quality Assurance

Mn/DOT will conduct some Quality Assurance (QA) tests to verify the results of the Contractor QC procedures and testing results. The QA will include sampling and testing, observation of QC sampling and testing, taking some additional samples, monitoring summary sheets and charts, checking calibration of equipment, etc.

C. Contractor's Quality Control (QC)

The Contractor's QC will include requirements for personnel (which need to be certified at a specific level) and laboratory requirements with the necessary calibrated equipment to run the tests, telephone for communication, etc.

D. Sampling and Testing

Sampling is to be at the prescribed rate using random numbers to determine the location of the samples.

E. Production Tests

Specific tests are listed for determining asphalt binder content, gyratory Bulk Specific Gravity, Maximum Specific Gravity, Air Voids-Individual and Isolated, Voids in the Mineral Aggregate (VMA), Gradation of the blended aggregate, Field Moisture Damage, Aggregate Specific Gravity, Coarse Aggregate Angularity, Fine Aggregate Angularity, and Moisture Content. Asphalt Binder Samples must also be taken in the amount of 1 liter (1 quart) for every one million liters (250,000 gallons).

F. Documentation (Records)

The Contractor shall maintain control charts and records on an on-going basis. Diaries should be kept and filed as directed and become the property of Mn/DOT.

G. Documentation (Control Charts)

The following data are to be recorded on standard control charts:

1. Blended aggregate gradation with specification sieves listed in Table 2360-2
2. Percent asphalt binder content
3. Maximum mixture specific gravity
4. Production air voids, percent Gmm @ N_{design}
5. VMA

Both individual values and moving average of four are plotted.

H. Control Limits

Control limits are set for each of the criteria used for mix evaluation and plotted on the control charts. The production Air Voids and VMA are based on the minimum specified requirements shown in Tables 2360-8 and 2360-9. Gradation and asphalt content are based on the current Department approved JMF. The control limits used for the project are the target value plus or minus the limits shown in Table 2360-11.

I. JMF Adjustment

Procedures for adjusting the JMF during construction are presented.

J. Corrective Action

The procedures for taking corrective action when the mix goes out of the specified limits are given. Testing rates are increased, and if the problem is not solved production is to stop. Table 2360-12 lists the Payment Schedule (penalties) for the various items that may be out of control beyond the time for corrective action.

K. Failing Materials

This section lays out how to handle failing materials, which are defined as materials outside of the control limits. The following situations are covered:

- Moving Average Failure – Production Air Voids

- Moving Average Failure – Percent Asphalt Binder Content, VMA and Gradation
- Individual Failure – Production Air Voids, Percent Asphalt Content, and VMA
- Individual Failure – Gradation
- Coarse and Fine Aggregate Crushing Failure

L. Quality Assurance

The Engineer will periodically witness the sampling and testing performed by the Contractor. Production may be stopped if tests are not being performed correctly. All testing and data analysis are to be performed by a Certified Level I Bituminous Quality Management (QM) Technician. The Engineer will also calibrate and correlate all laboratory equipment.

M. Verification Testing

Verification testing is to be conducted as part of QA. This testing includes one set of production tests and the taking of a companion sample once per day. A listing of the tolerances between the QC testing and QA testing is given in Table 2360-13. The following items are considered as part of Verification testing:

- Testing Methodology Verification
- Sampling Methodology Verification

If verification of test results that are used for acceptance indicate failure to comply with volumetric or densification properties, the material placed will be subject to penalties or removal and replacement as described in Tables 2360-12 and 2360-16.

0.5 Pavement Density

A. General

All pavements must be constructed in accordance with the Maximum Density Method unless otherwise specified. Construction of leveling layers less than 40 mm (1.5 in.) thick, thin lift leveling, wedging layers, patching layers, driveways, and areas which cannot be compacted with standard

highway construction equipment will be accomplished according to the Ordinary Compaction Procedure specified in 2360.5C.

B. Maximum Density Method

All courses of HMA in which the Maximum Density is used shall be compacted to a density not less than the percentage shown in Table 2360-14. The table shows that all mixes within 100 mm (4 in.) of the surface must be compacted to 92% of maximum density and non wear courses more than 100 mm (4 in.) must be compacted to 93% of maximum density. Field density is one of the most important criteria that will affect the performance of the HMA under traffic and environment. The Maximum Theoretical Density is determined as part of the JMF and then as required throughout the project.

Determination of the bulk specific gravity of cores taken after construction is to be according to AASHTO T-166, Mn/DOT modified. For coarse or open graded mixes the density is to be measured using ASTM D 1188, Mn/DOT modified.

Compaction operations must be completed within 8 hours after mixture placement. Re-rolling after this time is not permitted.

The frequency of testing is defined by dividing the day's production into equal size "lots" from which three cores are to be taken for density measurements. Two cores are to be tested and the third used as a companion sample for verification testing. If random locations fall on a joint, the core is to be taken tangent to the joint. Procedures for analyzing and evaluation of the results are presented in Section 2360.5.

The acceptance and payment schedule are listed in Table 2360-16. Density of the compacted HMA is accepted on a lot basis. Core locations have been determined by the Engineer. Cores are to be tested by the Contractor and verified by the Engineer. Density determinations are to be made by the end of the next working day after placement and compaction and prior to placement of subsequent layers.

C. Ordinary Compaction

Ordinary Compaction is defined as the determination of the level of compaction beyond which no further compaction will occur. This type of compaction can only be used in areas defined in Section 6A. Where Ordinary Compaction is to be used a control strip shall be constructed to establish a rolling pattern. The Contractor shall use a portable nuclear density or similar device to establish a density growth curve.

The size of Steel-Wheeled, Pneumatic-Tired and Trench Rollers used in Ordinary Compaction are specified in 2360.5C.

When Ordinary Compaction is used the minimum laydown temperature in all courses (measured behind the paver) of the HMA shall be as listed in Table 2360-17. The pavement temperatures required are dependent on the air temperature and the compacted mat thickness.

0.6 Thickness and Surface Smoothness Requirements

A. Thickness

After compaction the thickness of each course shall be within a tolerance of 6 mm (0.25 in.) of the thickness shown in the plans. The thickness requirements do not apply to leveling courses. Lifts that are constructed less than minimum required thickness may be removed and replaced at the discretion of the Engineer.

Any materials in the lifts greater than the thickness specified will be excluded from the payment quantities.

B. Surface Requirements

1. Measurement and Evaluation

After compaction, the finished surface of each course shall be free of open and torn sections and shall be smooth and true to the grade and cross section on the Plans with tolerances listed in 2360.6B.

Pavement smoothness is very important when considering the performance of a pavement section because of the dynamic effects of roughness. Therefore, it is measured and used to evaluate the quality of the final pavement. Exclusions to this requirement are listed in Table 2360-18.

Identification of pavement sections is given for various construction types, the criteria for which are listed in Tables 2360-19 A, B and C. Table 2360-19A is for new or pavements with three or more lifts, B is for projects with fewer lifts or curb and gutter, etc. and Table 2360-19C for construction on unmilled, single lift or BOC with two lifts on a pavement with a PSR less than 2.7. The measurement of profile is to be made with a 7.62 m (25 ft) California Type profilograph that produces a profilogram (a trace of the profiled surface). One pass is to be made in each lane 2.74 m (9 ft) from the centerline. Each lane is treated separately. The profilograph is to be operated at a speed no greater than a normal walk, 6 km/hr (4 miles/hr).

Specifics for running the profilograph and calculation of the Profile Index are given in Section 2360.6C. Individual bumps and dips are also defined. Bump, dip and smoothness correction work shall be done across the whole lane width. All corrective work shall be done by diamond grinding or approved equivalent, overlaying the area, by replacing the area or by inlaying.

2. Payment for Profile Indices

The cost of certified smoothness testing and associated traffic control will be incidental to the cost of the wear course mixture. Based on the measured profiles, the contractor may pay a penalty or receive an incentive for the work. The only limit is that the total incentive shall not exceed 5 or 10% of the total mix price. Incentives are only based on the new profile index. The Engineer may, at his discretion, assess a penalty in lieu of requiring the Contractor to take corrective action when the profile index for a segment indicates corrective action is necessary.

0.7 Method of Measurement

HMA's of each type will be measured separately by mass based on the total quantity of material hauled from the mixing plant, with a deduction made for bituminous materials. The constructed thickness must meet the requirements indicated in Section 2360.6A.

0.8 Compensation

Payment for the accepted quantities of HMA mixture used in a course at the Contract prices per unit of material will be compensation in full for all costs of constructing the HMA surfacing as specified, including the costs of furnishing and incorporating any aggregate, asphalt binder, mineral filler, hydrated lime, and any anti-stripping additives permitted or required.

5.4.2. Field Control Procedures to Meet Specifications

5.4.2.1. General

In this section, procedures in the Mn/DOT Grading and Base, Geotechnical and Bituminous Manuals (10, 5, 14) are presented. Checklists developed by the laboratory and field staff are also summarized in the Field Notes for Construction Engineers and Inspectors (11). Some discussion is also made as to which methods are the best to use for field control of either granular or HMA materials. Field control procedures for cold in-place recycling and full depth reclamation have not been finalized.

The next section reviews the procedures recommended for the QC/QA of granular bases and the following will review those considered best practices for HMA materials. As with other procedures for design and control of pavements, it is anticipated that the procedures presented here will be improved over the years and therefore, the methods presented should be up-dated periodically.

5.4.2.2. Granular Subbases and Aggregate Bases

5.4.2.2.1. General

The construction of granular subbases and aggregate bases involves the following procedures:

- Manufacture of the material from a gravel pit or quarry.
- Storage of the materials (stockpiling)
- Transport to the grade
- Placing of the material
- Compaction

The specifications require that the material be tested initially for general quality, gradation and compaction. It must be determined that the material being tested is uniform meaning that very little segregation has occurred. It is also important to make

sure the material being constructed is represented by the correct moisture-density test if specified density is being used.

5.4.2.2.2. Schedule of Materials Control

A current schedule of materials control should be reviewed before each project to establish:

- The specification applicable for that project
- The minimum required acceptance testing rate
- Form No.
- Minimum required sampling rate for laboratory testing
- Sample size required for laboratory testing

These requirements are listed for gradation, one-point density, Moisture-density, relative density, relative moisture content, pulverization testing, percent crushing, and aggregate quality testing.

The Schedule of Materials Control is Tab. A 5-692.100 in the Grading and Base Manual (10).

A standard sample identification card is also presented in the Grading and Base Manual Fig. 1 5-692.101 (10).

Standard forms to use for Independent Assurance Sampling and Testing are also presented.

5.4.2.2.3. Standard Methods of Testing

Standard methods of testing and procedures to be used by the contractor and Mn/DOT for QC and QA are presented in Section 5-296.200 of the Grading and Base Manual. It is very important that exactly the same procedures be used by both groups when quality assurance and verification testing are performed.

Methods to correctly sample and test for statistically based specifications are presented in Chapter 5-692.700 of the Grading and Base Manual. It is very important to use the principles of statistics because all pavement construction materials are variable. When a material is designed the variability is considered. Then in the field the constructed material must be placed as uniformly as possible and within the variability assumed during design. The MnPAVE Design procedure will include

variability as one of the conditions to consider in thickness design and generally will show that a thinner pavement can be designed where less variability can be measured.

5.4.2.2.4. Methods of Compaction Control for Aggregate Bases

Three methods are included for Compaction Control of aggregate bases in the Mn/DOT specifications:

- Specified Density
- Dynamic Cone Penetrometer
- Quality Compaction

Specified density is usually measured using the 150-mm (6-in.) Sand Cone Method, ASTM D 1556-90. The larger cone is used to minimize side effects of the hole. It is important to make sure that random sampling procedures are used for selecting sample locations, that the material being tested has been moisture-density tested and that the standard test procedure is used for the sand cone test.

The Dynamic Cone Penetrometer (DCP) has recently been added as a test procedure for aggregate base construction control. This procedure is quicker and easier to run than the sand cone density. Also, it gives a direct measure of the material stiffness modulus. It is important to follow the test procedure carefully and to conduct the test within 24 hours of compaction so that crusting does not occur. Statistical procedures should again be used to establish the test location and analyze the data. Quality Compaction should only be used if the equipment is not available to do either Specified or DCP testing. If quality compaction is used, the inspector and engineer should be experienced in the construction of aggregate base and embankment materials. They must also observe the compaction operation continuously. This method of compaction is appropriate only for very small areas where a limited amount of material is being placed.

5.4.2.2.5. Job Guide for Aggregate Base Construction

The Mn/DOT Office of Construction, Technical Certification Section has published Field Notes for Construction Engineers and Inspectors (11). This booklet presents many items that an inspector should use to do a quality job of construction control. The following are a portion of the checklist items presented for aggregate base construction:

1. Review the contractor/producer QC procedures and test results. Obtain the completed Certification of Aggregates (form #24346) from the contractor.
2. Review any certification of crushed glass.
3. Perform the necessary inspection and testing (bitumen content, crushing, abrasion testing, shale, etc.) before delivery of any materials.
4. Prior to placing the base, verify that the subgrade is true to required grade and cross-section. Subgrade must be free of ruts, soft spots, large stones and excess dust.
5. Monitor placement operation. Lift should not exceed 75 mm (3 in.) of thickness unless approved by the Engineer.
6. Check depth and yield (tons per station) to ensure uniform construction.
7. Obtain samples for testing gradation, moisture-density, etc. according to the Schedule of Materials Control.
8. Ensure that compaction of each lift is completed satisfactorily to required density and cross-section before starting placement of the next lift.
9. When weight tickets are required, collect, check, and initial them for each load as they arrive.
10. Maintain records (Diary) that should include such things as hours, location, lift thickness, test results, quantity, yield and other events that may have an effect on the work.

5.4.2.3. Hot Mix Asphalt (HMA) Construction

5.4.2.3.1. General

A current Schedule of Materials Control should be reviewed and used for setting up the field control for each HMA construction project. That document will establish:

- The specifications applicable for the project
- The minimum required acceptance testing rate
- Form number to use
- Minimum required sampling rate for laboratory testing
- Sample size required for laboratory testing

The construction of an HMA pavement layer can be summarized as follows:

Plant Operations

- Materials delivery or manufacture and storage (asphalt and aggregate)
- Materials proportioning and mixing
- HMA storage and transfer to trucks
- Delivery to construction project

Paving Operations

- Laydown
- Compaction

Each of these steps requires Quality Control (QC) testing by the Contractor and Quality Assurance (QA) testing by Agency as spelled out in the Specifications. The purpose of this testing is to establish that the material is uniform (no segregation) and is placed to a specified density so that the mixture will perform well. The ride is also now checked after construction. Penalties are assessed if specifications are not met and incentives make it possible to earn bonuses if specifications are exceeded.

5.4.2.3.2. Standard Methods of Testing

Standard testing methods to be used by the Contractor and Mn/DOT for QC and QA are presented in Mn/DOT 2350 and 2360 Specifications (9). It is very important that exactly the same procedures be used by both groups when QC, QA and verification testing are performed.

Procedures to correctly sample and test for statistically based specifications are presented in Chapter 5-692.700 of the Grading and Base Manual. It is very important to use the principles of statistics because all construction materials are variable. When a pavement structure is designed the variability should be considered. Then in the field the constructed material must be placed as uniformly as possible and within the variability assumed during design. MnPAVE uses variability as one of the conditions to consider in thickness design.

5.4.2.3.3. Methods of Compaction Control for HMA

Section 5-3.10 of the Geotechnical and Pavement Manual (5) presents Bituminous Mixture Compaction Guidelines. Compaction is the final stage in the placement of a bituminous mixture during the paving operation. At this stage it is possible to develop or not develop the full potential strength and durability of the mixture. Inadequate

compaction of the mixture will result in a shorter pavement life because of accelerated deterioration due to load and/or environment.

The engineer has a choice of three different compaction control methods to select from based on the 2350 and 2360 specifications for a given project. The various methods are presented in detail in the Mn/DOT Bituminous Manual. A brief description of each and when to use them are given.

- Specified Density Method (2350.6B and 2360.5B). This process involves comparing the Bulk Specific Gravity of a sample obtained from the roadway with Bulk Specific Gravity of a sample obtained from the same material prior to compaction and then compacted by the Marshall method for 2350 and the gyratory method for 2360. Maximum Theoretical Density determinations are also made on the field sample to determine if the mixture has been compacted to the minimum specified density as listed in Tables 2350-8 or 2360-14 respectively. The frequency of and variation between QC and verification testing are also presented.
- Ordinary Compaction (2350.6C or 2360.5C). For the Ordinary Compaction Method a control strip of at least 330 m^2 (395 yd^2) of the same material, subgrade and base conditions shall be compacted to determine a proper roller pattern to achieve maximum density. A growth curve of density with passes must be used to determine when maximum density is obtained. If materials or conditions change a new control strip must be constructed. A given control strip can only be used for 10 days of construction.

The Specified Density Method should be used unless otherwise indicated.

Ordinary Compaction can be used without a control strip for very small areas less than 330 m^2 (395 yd^2). For these cases the HMA should be compacted until there is no appreciable increase in density with each pass of the roller as defined by the engineer.

The type and characteristics of the roller(s) to be used for Ordinary Compaction are presented in the given sections of the 2350 and 2360 Specifications.

5.4.2.3.4. Job Guide for Plant Mix Bituminous Paving

The Mn/DOT Office of Construction, Technical Certification Section has published Field Notes for Construction Engineers and Inspectors (11). This booklet presents many items that will help an inspector be ready for working with a contractor to construct a high quality project. The quality of construction affects the performance of the pavement more than the thickness design. The items listed are for mixing plant inspection and then the paving operation. The list presented here is a selected group of items that influence the performance of the pavement most.

The development of this Guide is set on the principle that the Inspector should not just be a data and sample taker. The inspector should be aware of the whole operation to make sure that a consistent, uniform quality mixture is produced and constructed.

Plant

1. Determine under which specification the mixture(s) are to be produced and review any special provisions.
2. Review the plant certification along with the schematic of the plant. If the plant is not certified go through the procedure for certification. Have the plant inspector and Plant Authorized Agent complete and sign the Asphalt Plant Inspection Report (TP 02142-02, TP 021143-02). By signing the Asphalt Plant Inspection Report, the plant-authorized agent agrees to maintain all plant and laboratory equipment within allowable tolerances set forth in the respective specification and the Bituminous Manual.
3. Identify items to be sampled, rates of sampling and testing using the Materials Control Schedule. Determine source or access for securing samples.
4. Determine material flow controls and settings to comply with the design mixture. Review the Mix Design Report.
5. Monitor calibration of plant equipment (pumps, aggregate bins, feeders, etc.).
6. Check that appropriate QC samples are being taken and tested.
7. Check that contractor is monitoring asphalt content through required spot checks.
8. Make sure that the HMA is being mixed at the temperature recommended by the asphalt supplier.

9. Watch mixture appearance to ensure uniformity and look for any indication of plant malfunctions such as sticky feeders or other operations.
10. Watch stockpile operations so that contaminated materials are not entered into the cold feed bins.
11. Ensure that truck boxes are clean and protected against buildup and also free of excessive cleaning agents. Fuel oil or other distillates must not be used to clean the truck beds.
12. Make sure segregation is not occurring during the loading operation. Also make sure trucks are covered when necessary.
13. Weigh tickets are to be completely and properly filled out and automatic scale printer operations are to be monitored. Make sure scale calibration is being performed.
14. Monitor asphalt shipments and make sure Contractor is taking necessary asphalt samples.
15. Monitor Contractor's testing to ensure that the required number and type of tests are done and that proper procedures with calibrated equipment are being followed:
 - a. Review Contractor's on-site QC records and charts for accuracy and completeness.
 - b. Monitor agency tests and confirm that they are within allowable tolerances for Contractor and Agency checks.
16. Check that Contractor is maintaining plant diary and daily records that include hours of operation, production, asphalt delivered, shutdowns (why?), mix adjustments, temperature and any other significant events.
17. Take or observe the taking of verification samples (one per mix per day).
 - a. Retain one half of sample for Verification testing.
 - b. Provide Contractor with companion sample.
 - c. Deliver Verification sample to the Agency lab.
 - d. The Contractor must test the Verification sample(s).

Paving

1. Check paving and compaction equipment for compliance with specifications. Get acquainted with the equipment operation.
2. Check adjustments available on the paver including flow gates, auger control, tamper bar, screed angle, vibration and crown.
3. Check grade for smoothness, compactness, cross slope, grade and alignment. Make sure the surface is free of gravel, loose patches or excessive patch and joint material.
4. Identify areas of instability that require repair.
5. Establish the paving and rolling sequence with the Contractor.
6. Observe the tacking operation. It needs to be uniform and not too thick or thin.
7. Collect, check, and initial each delivery ticket.
8. Check material in each load for problems such as segregation or contamination. Check in truck and as the load is dumped.
9. Watch the paver operation for:
 - a. Maintaining of grade
 - b. Incorrect line
 - c. Malfunctioning automatic screed control
 - d. Too much starting and stopping
10. Monitor laydown temperature to make sure it is consistent and within the range recommended by the Supplier.
11. Observe the mat surface for uniformity of texture, presence of spot segregation, proper thickness, width and yield.
12. Observe breakdown roller operation for uniformity and continuity of operation with attention to speed, pattern, location of drive wheel and vibration (if used).
13. Continue observation of roller operations to ensure timely performance geared to removal of roller marks and bumps.
14. Check surface for compliance with smoothness requirements. If a profilograph is being used, make sure the settings are correct and the profilograph is calibrated.

15. Cores are to be taken and tested by the Contractor. Core locations are to be determined and marked by the Agency. Take possession of the companion cores. Monitor density tests for compliance with proper equipment and test procedure. The Contractor will schedule testing so that it can be observed by the Inspector.
16. Maintain daily records that include such things as:
 - a. Hours of operation
 - b. Stations paved
 - c. Course paved
 - d. Depth, width, tonnage and yield
 - e. Measured delivered temperature
 - f. Weather
 - g. Other events which could affect the quality and quantity of work
17. Take or observe the taking of verification samples (one per mix per day).
 - a. Retain one half the sample for Agency testing.
 - b. Provide the Verification companion sample to the Contractor for testing.
 - c. Deliver Verification sample to Agency lab.
 - d. Verification companion samples must be tested by the Contractor.
18. Obtain Summary Sheets:
 - a. Contractor Density Core Worksheets
 - b. Agency Core Worksheets
 - c. Agency's Verification results
 - d. Tonnages represented by the respective worksheets to establish density incentives and disincentives.

If there are any questions about the frequency or amount of material to sample, refer to the Materials Control Schedule.

CHAPTER 6

SUMMARY AND RECOMMENDATIONS

6.1. General

This manual presents design and construction methods recommended for Hot Mix Asphalt (HMA) pavements in Minnesota. Mn/DOT and the asphalt pavement industry are in a time of transition both for pavement thickness design construction procedures.

6.2. Thickness Design Procedures

Three procedures are now available for use in Minnesota: the Soil Factor Procedure, the Stabilometer R-Value, and the mechanistic-empirical procedure (MnPAVE). The Soil Factor Design Procedure is presented in the Mn/DOT State Aid Manual (4) and the R-Value method is presented in the Mn/DOT Geotechnical and Pavement Manual (5). The MnPAVE software Beta Version 5.009 is also available (6). A summary of the procedures is presented in Chapter 2. Currently, both the Soil Factor and R-Value procedures are being used for city and county roads. A summary of the operating manual for MnPAVE is included in Chapter 2. The manual includes a summary of Setup, Startup, Input and Output for the software.

The current procedures have been used over the past 25 plus years. It is recommended that:

- The current procedure of choice (Soil Factor or R-Value) be used to establish a thickness design or alternative designs.
- The MnPAVE software be used to establish alternate design(s).
- Send comparisons to the Mn/DOT Road Research Section using the form provided.
- If new materials or existing materials are used in a different way, set up designs using MnPAVE and report the results.

6.3. Traffic

The methods recommended for estimating traffic for the three design procedures are presented in Chapter 3.

The Soil Factor Design requires an estimate of AADT and HCADT predicted for 20 years into the future or other design life. The HCADT prediction requires an estimate of vehicle type

distribution. The distribution can be estimated from a statewide HCADT map or measured on specific roadways using the procedure presented in the appendix.

When predicting traffic for the Soil Factor Procedure, the design AADT and HCADT should be determined using:

- An estimate current AADT by conducting a vehicle count at the location of, or similar location to the roadway being designed.
- An estimate current HCADT using the field procedure with two pneumatic tubes conducted by the Mn/DOT Traffic Forecast and Analysis Section and given in the Appendix B.
- As an alternate, the current ADT and HCADT are estimated from current statewide AADT and HCADT maps, which are maintained for State Highways and County State Aid Highways (CSAH) system. The statewide AADT maps are up-dated about every two years are available on CDROM and may be obtained by contacting either the Mn/DOT Traffic Forecast and Analysis Section or the Mn/DOT District Traffic Engineer.
- The future AADT and HCADT predicted using the appropriate growth factor determined as presented in Section 3.4.4.

The R-Value and MnPAVE Design procedures currently use ESAL's for traffic load evaluations. ESAL (Equivalent Standard Axle Loads) estimates require a determination of current AADT, vehicle type distribution, ESAL factors (the average effect of a given type of vehicle in terms of ESAL's), a calculation or estimate of growth, and design lane distribution. The procedures and tables recommended for these calculations are presented in Chapter 3. The MnESALS software will result in the best estimate of ESAL's for a particular design situation. The procedure(s) are presented in Section 3.4. The procedure requires the following:

- Estimate of AADT as indicated above and in Section 3.4
- Estimate Vehicle Distribution; the procedure recommended is the method presented in Appendix B. The length of the study depends on the volume of traffic on the roadway. As an alternate the statewide average for Rural CSAH and county roads for the eight vehicle types listed in Table 3.1. If at all possible the vehicle type distribution should be measured for a given location because of the significance of the vehicle distribution shown in calculating ESAL's in Reference 18.

- Estimate ESAL Factors by vehicle type; Table 3.2 shows a list of ESAL factors for CSAH and other low volume roads. Other distributions can be assumed based on loadings determined from knowledge of the usage for the design roadway. Table 3.3 illustrates a method of estimating ESAL effect for a given vehicle type.
- Growth Factor; The growth factor to be used can be estimated using the procedure presented in Table 3.6 or the factors listed in Table 3.4.
- The Design Lane distribution for 1, 2 and 3 lanes in one direction are listed in Table 3.5.
- An ESAL calculation spreadsheet is presented in Table 3.6. This spreadsheet should be used if the MNESALS Software is not available.

Eventually, the MnPAVE procedure will use the estimated Load Spectra concept to evaluate traffic. Load Spectra yields a distribution of axle loads for various configurations of axles. For the next few years the same type of data will be required to predict Load Spectra as has been used to predict ESAL's. Therefore, it is recommended that data and information continue to be obtained as has been listed herein.

6.4. Subgrade (Embankment) Soil

For the Soil Factor Design procedure the subgrade soil is evaluated using the soil factor, which is dependent on the AASHTO classification. The AASHTO classification should be determined by testing the soil "representative" of the project being designed. The "representative" soil can only be determined using a soil survey with the procedure(s) given in Section 4.2. To determine the AASHTO classification the gradation uses a sieve analysis and hydrometer analysis for the fine-grained material. The Atterberg Limits (Plastic Limit and Liquid Limit) must be run and used for the classification.

The R-Value can be measured directly in the laboratory, or can be estimated from the AASHTO Classification. It is recommended that the R-Value for the "representative" be measured directly using the procedure as modified by Mn/DOT (5). A second choice is to estimate the R-Value using the correlated values from Reference 7.

The resilient modulus (M_r) can be estimated from either the R-Value or AASHTO soil classification using relationships developed by Siekmeier and Davich (7). A laboratory test is now being developed to measure the resilient modulus directly in the laboratory (23). Until this test is developed, the resilient modulus must be determined preferably using the R-Value correlation or else with the AASHTO classification correlation.

The resilient modulus should be varied throughout the year using the seasonal factors given in Section 4.3.4.4. More research needs to be conducted to determine how the five seasonal factors determined from Reference 8 vary with soil type.

Mn/DOT Specifications 2105, 2111 and 2123 should be used for construction of subgrades in Minnesota (9). Test rolling (2111), specified density and quality compaction are the three methods of compaction control included in these specifications. Proof rolling, which is covered in Specification 2111, is recommended. Proof rolling requires an experienced inspector for observation. Specified density as presented in Specification 2105 is the second choice. Quality compaction is recommended only if an experienced Inspector is available and/or for relatively small areas. The situations where one method is appropriate relative to the others are listed in Section 4.5.3.7.

The six items listed in Section 4.5.3. must be followed to result in a well-constructed subgrade.

The Mn/DOT Office of Construction, Technical Certification Section has published as “Inspector’s Job Guide for Construction” (11). This guide should be used so that the Inspector has a checklist which will help start and keep the project well organized and follow the specifications set up for the project.

Various methods of subgrade enhancement are presented in Section 4.6.2. As these procedures are used non-destructive field testing using the Falling Weight Deflectometer (FWD) or Dynamic Cone Penetrometer (DCP) should be used to determine the magnitude and variability of the in-place subgrade strength (stiffness). These values along with observations of performance and traffic should be used to improve the performance predictions used in MnPAVE.

6.5. Pavement Section Materials

6.5.1. General

The materials used for pavement sections range from select granular materials to high type Hot Mix Asphalt materials. Each of these materials or combination of materials is defined by specification for the Soil Factor and R-Value design procedures. Granular Equivalent factors are assigned to each specification material. These factors are considered constant throughout the year. The MnPAVE procedure requires that Resilient Modulus values be assigned to each of the materials. The resilient modulus has been found to vary

throughout the year (8) and within specifications. At this time moduli values are being used based on laboratory and field testing of Mn/ROAD materials (7). The recommendations in this section are for the specifications to use, the design factors, construction procedures and specific procedures within the specifications that will result in a good performing pavement.

6.5.2. Specifications and Design Factors

The following granular equivalent factors are recommended for materials that pass the respective specifications:

Material	G.E. Factor	Mn/DOT Specifications
Select Granular	0.50	3149-2, 2211
Subbase	0.75	3138 (Class 3 & 4), 2211
Granular Base	1.00	3138 (Class 5 & 6), 2211
Plant Mix Bituminous	2.00	2331
Plant Mix Bituminous	2.25	2350, 2360

Various other G.E. factors have been applied to some stabilized bases. However, the Mn/DOT District Materials Engineer or Pavement Section should be contacted for advice on these materials.

For MnPAVE default seasonal moduli have been developed based on in-place non-destructive and laboratory testing of the Mn/ROAD materials. The moduli have been related to the specifications used at Mn/ROAD and the temperature and moisture conditions measured. Table 5.2 lists the default moduli used now in MnPAVE. The variation of modulus throughout the year for pavement materials in other locations must be monitored for MnPAVE input. Documentation of these values must be an on-going project for the next few years. At this time the correlation of moduli to specifications shown in Section 5.3 should be used.

6.5.3. Construction of Granular Bases

For aggregate base and subbase materials construction should follow the procedures and criteria listed in Specification 2111. The construction requirements for placing and mixing, spreading, and compaction must be followed. Three methods of compaction control are listed; specified density, quality (ordinary) compaction and penetration index using the DCP. The recommended procedures are:

1. Use of the penetration index with the DCP.
2. Specified density.

These procedures indicate that the granular material has been compacted to a level where the construction of the next layers can be accomplished and that the material has the strength needed to support the design traffic.

Quality or ordinary compaction should only be used for small areas and/or an experienced Inspector is available to observe the construction continuously.

The “Schedule for Materials Control” must be setup and followed for each project so that the required sampling and testing are accomplished.

Standard methods of testing whether it be for density or DCP testing must be followed. The Inspector’s Guide for Construction (11) should be used as a checklist to determine what materials and procedures will help the Engineer, Inspector and Contractor efficiently carry out the project specifications.

6.5.4. Construction of Hot Mix Asphalt Materials

Specifications 2350 or 2360 should be followed for construction of HMA surface mixtures. All HMA mixtures in Minnesota use PG graded asphalts. The cities and counties should use the PG graded asphalt specified for their region. Laboratory compaction is accomplished with a standard Marshall hammer that applies blows to each side of the specimen.

The 2350 LV, MV and HV mixtures are based on strength criteria measured with the Marshall Stability test and design air voids which are listed in Table 2350-2 (8). Moisture susceptibility as measured with the modified Lottman test strength ratios is also specified along with the coarse and fine aggregate angularity.

The 2360 (Superpave) specification does not have a strength or stiffness requirement. The primary difference in the two specifications is the method of compaction. The 2360 specification uses the gyratory compactor both in the lab and in the field.

Table 2350-3 lists the minimum VMA for the mixture as compacted in the field. Also the compaction percent of maximum theoretical density is listed in Table 2350-8 and 2360-14.

The mixture design for both procedures is accomplished using Quality Management procedures; that is the Contractor provides the mix design and Quality Control and the Agency does check testing or Quality Assurance testing to check the work done by the

Contractor. The procedures laid out in Specifications 2350 and 2360 should be followed carefully to result in a good stable and durable mixture. Section 5.4.2.3.3. presents the methods of compaction control available. These are:

1. Specified Density – Measurement of density for comparison with maximum theoretical density.
2. Ordinary compaction with a control strip
3. Ordinary compaction without a control strip.

Specified density should be used unless otherwise indicated. The only reasons would be lack of equipment or people to run the tests. The second option is Ordinary compaction with a control strip. The control strip indicates when maximum compaction was achieved and gives a measure of consistency. The roller requirements for use with ordinary compaction are given in Section 2350-6 and 2360-5 for the respective specifications. Ordinary compaction without a control strip should only be used for very small areas and when an experienced Inspector is on the job to observe the operations continuously. The incentives and disincentives listed for density control in Table 2350-10 and 2360-6 should be used.

Also, the incentives and disincentives for ride in Tables 2350-13 and 2360-6C should also be followed. A road built smoother will perform better than one using the mixture and pavement section built rougher.

The Schedule for Materials Control should be setup and followed for the specifications on the given project. The listings are for both plant and paving operations. Each of these requires Contractor (QC) testing and Agency (QA) testing. The specifications lays out the differences allowable between the tests.

The Inspector's Job Guide for Plant Mix Bituminous Paving (11) should also be consulted to help setup and run the project efficiently.

A good diary will help all people involved with the project maintain a good schedule of construction and field control.

One of the major goals of presenting the specifications and recommended field procedures for constructing the subgrade and pavement section materials is so that the available materials are used as effectively as possible. The procedures should also result in the construction of the materials so that a uniform product will be obtained. The most uniformly constructed materials will perform the best.

REFERENCES

1. Van Cauwelaert, F.J., Alexander, D.R., White, T.D., and Barker, W.R., “Multilayer Elastic Program for Backcalculating Layer Moduli in Pavement Evaluation”, Nondestructive Testing of Pavements and Backcalculation of Moduli, ASTM STP 1026, A.J. Bush, III and G.Y. Baladi, Editors, American Society for Testing Materials, Philadelphia, PA., 1989, pp. 171-188.
2. Roadent Reference
3. Skok, Eugene L., Newcomb, David E., Timm, David H., “Minnesota Low Volume Road Design – 1998”, Mn/DOT Project 74708, TOC#55, Report No. 1999-34
4. Mn/DOT State Aid Manual, Mn/DOT Division of State Aid for Local Transportaton, July, 1998.
5. Mn/DOT Geotechnical and Pavement Manual, April, 1994.
6. Chadbourn, Bruce A., Dai, Shongtau, Davich, Peter A., Siekmeier, John A., Van Deusen, David A., “Pavement Designer’s Guide for Mn/DOT Flexible Pavement Design, MnPAVE Beta Version 5.0, DRAFT, Mn/DOT Office of Materials and Road Research, July, 2001.
7. Siekmeier, John A., and Davich, Peter A., “Correlation Table for Predicting Resilient Modulus from other Soils and Aggregate Characteristics”, DRAFT, 2001.
8. Ovik, Jill M., Birgisson, and Newcomb, David E., “Characterizing Seasonal Variations in Pavement Material Properties for Use in a Mechanistic-Empirical Design Procedure”, Final Report, Mn/DOT Report 2000-35.
9. Standard Specifications for Construction – 2000 Edition, Mn/DOT
10. Mn/DOT Grading and Base Manual, June, 1998.
11. “Inspector’s Guide for Construction”, Mn/DOT Office of Construction Technical Certification Section, 2001.
12. “AASHTO Guide for Design of Pavement Structures – 2002”, American Association of State Highway and Transportation Officials, NCHRP Project
13. Chadbourn, Bruce A., Skok, Jr., Eugene L., Newcomb, David E., Crow, Benita L., and Spindler, Samantha, “The Effect of Voids in the Mineral Aggregate (VMA) on Hot-Mix Asphalt Pavements”, Mn/DOT Contract 74581, W.O. 202, Mn/DOT Report 2000-13.
14. Mn/DOT Bituminous Manual, March, 1935.

15. Kersten, Miles S., Skok, Eugene L., “Application of AASHO Road Test Results to the Design of Flexible Pavements in Minnesota”, Final Report, Minnesota Department of Highways Investigation 183, Final Report, 1968.
16. Timm, David A., Newcomb, David E., and Birgisson, Bjorn, “Mechanistic-Empirical Flexible Pavement Thickness Design: The Minnesota Method”, Mn/DOT Report No. MN/RC – P99-10, January 1999.
17. Witczak, M.W., “Temperature Distribution Prediction Equations.”
18. Skok, Eugene L., Timm, David A., Clyne, Timothy, “Traffic Supplement to Low Volume Road Best Practices Manual”, Mn/DOT Project 74708, Work Order No. 180, Final Report Draft, 2001.
19. AASHTO Pavement Design Guide, American Association of State Highway and Transportation Officials, 1993.
20. MnESAL’s Manual, Mn/DOT Traffic Data Collection and Analysis Section.
21. Soils Manual, The Asphalt Institute, Manual Series No. 10, Fourth Edition, USA, 1986.
22. Kupferman, M., Pinciotti, R.D., “Use of a Micro-Computer for Control, Data Acquisition and Evaluation of the Resilient Modulus Test, Resilient Modulus of Soils: Laboratory Conditions, Elton, D.J., Ray, R.P., Geotechnical Special Publication No. 24, American Society of Civil Engineers, New York, NY, October, 1989.
23. Brodsky, Nancy S., Resilient Modulus Measurements of Cohesive Soils: Laboratory Conditions”, Elton, D.J., Rat, R.P., Geotechnical Special Publication No. 24, American Society of Civil Engineers, New York, NY, October, 1989.
24. User Guide for the Dynamic Cone Penetrometer (DCP), Minnesota Department of Transportation, 1999.
25. Uzan, J., “Dynamic Linear Backcalculation of Pavement Material Parameters, Journal of Transportation Engineering, Vol. 120, No. 1, American Society Of Civil Engineers, January/February, 1994.
26. Uzan, J., “Advanced Backcalculation Techniques, Nondestructive Testing of Pavements and Backcalculation of Moduli”, Second Volume ASTM STP 1198, Harold L.VonQuintos, Albert Bush, III, and Gilbert Baladi, Editors, ASTM, Philadelphia, PA, 1994.
27. Nazarian, S., Tandon, V., Crain, K., and Yuan, D., “Use of Instrumented Dynamic Cone Penetrometer in Pavement Characterization, Nondestructive Testing of Pavements and Backcalculation of Moduli”, Third Volume, ASTM STP 1375, S.D. Tayabji, S., Lukanen, E.O., Editors, ASTM, West Conshohocken, PA, 2000.

28. Yoder, E.J., Witczak, M.W., "Principles of Pavement Design", Second Edition, 1975, John Wiley & Sons, Inc., New York, NY,
29. Bearden, J.B., and Labuz, J.F., "Fabric Reinforcement and Separation in Unpaved Roads", Mn/DOT Report No. MN/RC-1994-04, St. Paul, MN December, 1998.
30. Huntington, G., and Ksaibati, K., "Evaluation of Geogrid-Reinforced Granular Base, Recent Advances in the Characterization of Transportation Geo-Materials" Tutumluer, E., and Papagiannakis, A.T., Geotechnical Special Publication No. 89, American Society for Civil Engineers, Virginia, 1999.
31. Mn/DOT Technical Memo on the use of PG graded asphalt in Minnesota., 2001.
32. "Superpave Asphalt Mixture Design", AASHTO Method MP-1, 1997.
33. Mn/DOT Technical Memo on Inspection Sampling and Acceptance of Bituminous Mixtures, 2000
34. Asphalt Mixture Design Manual, The Asphalt Institute Manual Series No. 2 (MS-2)
35. Asphalt Superpave Mixture Design Manual, The Asphalt Institute Special Publication Series No. 2 (SP-2), 1999.

APPENDIX A

**USE OF INVESTIGATION 183 AND 195 TEST SECTIONS
AS A LONG TERM PERFORMANCE COMPARISON
WITH THE MINNESOTA M-E DESIGN PROCEDURE**

March 13, 2002

David H. Timm
Eugene L. Skok
Erland O. Lukanen

INTRODUCTION

A mechanistic-empirical design procedure (ROADENT) has been developed to determine appropriate design thicknesses of hot-mix asphalt pavements in Minnesota (1,2). Calculated strains in the pavement section are used with transfer functions to predict the amount of traffic, in ESALs, the section will support before deterioration in the form of fatigue cracking or critical rut depth. To make these predictions, field performance must be observed and related to measured or calculated strains in the pavement. The first performance prediction equations were developed based on performance of sections at the Minnesota Road Research Project (Mn/ROAD) after four years of service (3,4).

Since the Mn/ROAD project represents only a portion of conditions encountered in Minnesota, it is necessary to expand the calibration data set to a wider range of conditions. To validate and/or calibrate the performance equations for other traffic levels, soil types and pavement sections, performance records of some of the Investigation 183 and 195 test sections (5,6) were reviewed, some of which are over 40 years old. The properties of the soils and pavement layers were measured during the course of the research studies and included in References (5) and (6). Strain levels for the pavements were simulated mechanistically and damage factors were calculated for each season and totaled for each of the years to rehabilitation for the test sections and observed performance was compared to the predicted performance.

Mr. Tom Nelson and Mr. Mark Levenson of the Mn/DOT Data Management Services Section made the traffic predictions necessary for comparison. The condition of the 50 test sections from 1964 through 1977 was reported by Lukanen (7). The Mn/DOT

Pavement Management Section provided information on conditions from 1977 to the present. The conditions of the sections were observed on videos from 1992 to the present. Elaine Miron and Erland Lukanen located the sections using the video station at Mn/DOT and it was necessary to locate the original test sections using historical stationing and current reference points. This information was retrieved from historical records and files that had been stored for the past 25 years. The locations using current reference points were determined using logbooks provided by the Mn/DOT Pavement Design and Management Sections.

The construction histories of the 10 Investigation 183 test sections were used to relate the observed performance with the predicted damage ratios calculated from the computer simulated pavement and empirical transfer functions. The predictions were then compared to the observed performance and determined to be conservative or not conservative. This information was used to judge if the current performance prediction equations should be modified.

MINNESOTA FLEXIBLE PAVEMENT DESIGN TEST SECTIONS

In 1963 and 1964, 50 flexible pavement design test sections were established to help evaluate flexible pavements in Minnesota using the concepts and results from the AASHO Road Test. In addition the stabilometer, R-Value was introduced as a strength test to evaluate subgrade soils and granular bases. Each test section consisted of two 500-ft test or evaluation sections separated by a 200-ft sampling and destructive testing segment. The evaluation of the 1200-ft test sections was made using the following methods:

1. Sampling and testing of each layer was performed with plate load testing. Thickness measurements of each layer were also made as trenches were dug.
2. Condition surveys were conducted each year to document the type, severity and amount of cracking. Alligator cracking was measured in square feet per 1000 square feet as defined at the AASHO Road Test. Cold temperature cracks were counted periodically, but not always recorded because they were not considered part of a structural evaluation.
3. Longitudinal profile was measured using the Bureau of Public Roads (BPR) roughometer in units of inches per mile and was called the Roughness Index. The Roughness Index was correlated with Present Serviceability Rating (PSR). Later the PSR was also correlated with the PCA roadmeter and the Maysmeter.
4. Traffic was measured using load and vehicle type distribution studies conducted in 1964 and 1969 at each test section along with statewide data for other years. This information was used to calculate equivalent loads in ESALs for each year from the time of construction.
5. Performance was defined as the number of ESALs the pavement withstood or was predicted to withstand before the serviceability was reduced to 2.5.
6. The structural capacity of the sections was measured using the plate bearing test and the Benkelman beam test.

The information from the study of these test sections was used to develop the current Mn/DOT R-value design procedure, which has been in use since about 1971. A report summarizing the performance of the original 50 test sections was written in 1980 (7). The

distress and rideability conditions, applied traffic and strength summaries of each section were presented through 1977.

SELECTION OF PILOT TEST SECTIONS

With the advent of mechanistic-empirical (M-E) flexible pavement design and the need for a well-calibrated design system, it was decided to calibrate the mechanistic-empirical design procedure developed at the University of Minnesota using the performance and construction histories of the Investigation 183 test sections. The steps required to accomplish this were the following:

1. Locate the test sections on the trunk highway system, which required determining the reference points and stationing of the sections. These were obtained from original project files and Mn/DOT log books in the Mn/DOT design and pavement management sections.
2. Request traffic predictions for each of the test sections' reference points from original construction through the year 2000.
3. Obtain pavement condition data. The condition of each section was summarized in Reference (7) from original construction through 1977. Conditions were observed using the Pavement Management video station from 1992 to the present. Rut depths on each section were also measured.
4. Determine structural profile histories of the sections by examining pavement management records. These records were used to establish when reconstruction or significant maintenance was performed, changes in thickness were also noted.

5. Resilient moduli of each layer were estimated using the stabilometer R-value of the soils and granular materials for each test section. The moduli of the asphalt concrete layers were estimated from backcalculated moduli at the Mn/ROAD project. The moduli along with thicknesses were used to calculate strains for each of five seasons. Using these strain calculations and the traffic estimates damage factors were determined using the existing performance equations for fatigue and rut depth. Comparisons of predicted and measured performance were made to check if the predictions were less or more conservative than the observed performance over the 40-year period.

Selection of Pilot Study Test Sections

As a pilot study to evaluate whether data could be generated to review the 40-year old test sections, it was decided to develop information from nine of the Investigation 183 test sections. The fifty Investigation 183 test sections were categorized by soil type using Table 1 and by traffic using Table 2. Table 3 lists the sections along with the district, soil type and traffic level for each. Table 3 shows that there were five sections with granular subgrades, 23 semi-plastic and 22 plastic subgrades. There are 24 sections with low traffic, 17 medium and 8 high traffic sections. The following criteria were used to select the pilot test sections:

1. At least one test section from each Mn/DOT district.
2. Some test sections with Plastic, Semi-Plastic, and Granular subgrade soils using the definitions as in Table 1.

Table 1. Soil Classifications for Pilot Project.

Soil Type (Abbreviation)	AASHTO Classification
Plastic (P)	A-6, A-7
Semi-Plastic (SP)	A-4, A-5
Granular (G)	A-1, A-2, A-3

3. Test sections which had Low, Medium and High traffic. The traffic categories were based on the calculated 1966 annual ESALs using the levels as in Table 2:

Table 2. Traffic Classifications for Pilot Project.

Traffic Category (Abbreviation)	Annual ESAL Level in 1966
Low (L)	< 20,000
Medium (M)	20,000 to 100,000
High (H)	> 100,000

Table 3. Investigation 183 Pavement Sections.

Test Section	District	Soil Category			Traffic Category		
		GR	SP	P	L	M	H
1	4	X					X
2	2			X		X	
3	2			X		X	
4	1			X	X		
5	1		X		X		
6	1		X				X
7	1			X	X		
8	1			X		X	
9	1		X			X	
10	3		X		X		
11	3	X			X		
12	3			X	X		
13	3		X			X	
14	3		X			X	
15	3	X					X
16	3		X			X	
17	5		X			X	
18	5	X				X	
19	5		X				X
20	5		X			X	
21	5			X		X	
22	5		X			X	
23	9		X				X
24	6			X	X		
25	6			X	X		
26	6		X		X		
27	6		X		X		
28	6			X	X		
29	6			X	X		
30	7		X				X
31	7		X		X		
32	7			X	X		
33	8			X		X	
34	8			X			X
35	8			X	X		
36	8		X			X	
37	8			X		X	
38	8			X		X	
39	8		X		X		
40	8	X			X		
41	6		X				X
42	4		X		X		
43	4			X	X		
44	4			X	X		
45	2		X		X		
46	2		X		X		
47	7			X	X		
48	7			X	Unknown		
49	7		X			X	
50	8			X	X		

Table 4 lists the test sections selected for the pilot study to establish whether the pavement management system along with traffic and materials characterization could be used to trace performance history. One section was selected from each Mn/DOT district and a variety of soil types and traffic levels. There are four each of semi-plastic and plastic soils and one with a granular subgrade. There are four sections with low, two medium and three high traffic levels.

Table 4. Investigation 183 Sections Selected for Pilot Study of 40-Year Performance.

District	Test Section	Soil Type	Traffic
1	183-6	SP	H
2	183-3	P	M
3	183-11	G	L
4	183-43	P	L
5	183-22	SP	M
6	183-26	SP	L
7	183-47	P	L
8	183-34	P	H
9	183-23	SP	H

Location

Table 5 lists the Trunk Highway, Lane, Reference Marker (Mile Post) and stationing for the nine pilot test sections. The information was obtained from the Investigation 183 files and was necessary for locating the sections using the current referencing system in the Mn/DOT Pavement Management System. It was also necessary to establish the locations for traffic requests.

Table 5. Pilot Section Locations.

Test Section	District	Trunk Highway	Lane*	Mile Post (Mile Post Stationing)	Test Section Station Limits
6	1	2	EB	250 - 251 (372+43.7 - 424+82.3)	372 - 384
3	2	59	SB	363 - 362 (4099+52 - 4155+54)	4140 - 4152
11	3	371	SB	43 - 44 (555+92-608+63)	565-577
43	4	54	NB	4 - 5 (211+22 - 264+20)	227 - 239
22	5	55	EB	179 - 180 (1322+12 - 1374+72)	1335 -1347
26	6	76	SB	30 - 29 (682+50 - 734+79)	693-700
47	7	19	EB	121 - 122 (117+68 - 170+41)	129-141
34	8	7	EB	(116 - 117) (456+62 - 509+52)	465-477
23	9	36	EB	(13 - 14) (141+89 - 196+73)	171-183

*Lane: The direction of traffic over the test section (EB = Eastbound, WB = Westbound, NB = Northbound and SB = Southbound)

The nine test sections selected for this study were subjected to a mechanistic-empirical (M-E) analysis to assess whether the current performance transfer functions accurately predict observed pavement performance. The following subsections detail the process and findings of the M-E analysis.

PILOT TEST SECTION DATA

Prior to performing the M-E analysis it was necessary to gather information regarding the structural profiles of the sections, seasonal layer moduli, traffic and performance data. Each of these is described below.

Structural Profiles

Records from the pavement management office of Mn/DOT were examined to obtain the dates of maintenance; rehabilitation or reconstruction activities performed on each of the test sections. Of interest in this study were changes made to the structural profile of the sections. Tables 6 through 14 detail the construction histories of the test sections. It is important to note that, in some cases, sections were milled and overlaid. However, in the tables, simply total thicknesses are given since only these were needed in the M-E analysis. Additionally, except where noted, the granular base layers were constructed of Mn/DOT Class 5 material and subbase layers of Mn/DOT Class 4 material. Finally, the subgrade soil types are specified according to the AASHTO soil classification system.

Table 6. Section 183-3 Structural Profile History.

Year	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Subgrade Soil Type
1961	2.0	15.5	A-7-6
1969	6.5		
1987	8.0		
1999	10.0		

Table 7. Section 183-6 Structural Profile History.

Year	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Granular Subbase Thickness (in)	Subgrade Soil Type
1959	1.5	5.0	11.0	A-2-4
1960	6.0			
1981	7.5			

Table 8. Section 183-11 Structural Profile History.

Year	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Granular Subbase Thickness (in)	Subgrade Soil Type
1960	2.0	5.0	4.0	A-1-b
1961	5.5			
1986	4.5			

Table 9. Section 183-22 Structural Profile History.

Year	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Granular Subbase Thickness (in)	Subgrade Soil Type
1961	7.0	6.0	16.0	A-4
1973	8.5			

Table 10. Section 183-23 Structural Profile History.

Year	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Granular Subbase Thickness (in)	Subgrade Soil Type
1960	7.0	9.0	12.0	A-2-4
1987	11.75			

Table 11. Section 183-26 Structural Profile History.

Year	Asphalt Concrete Thickness (in)	Granular Base* Thickness (in)	Subgrade Soil Type
1961	3.0	14	A-4
1988	7.5		

* Mn/DOT Class 3 Material

Table 12. Section 183-34 Structural Profile History.

Year	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Granular Subbase Thickness (in)	Subgrade Soil Type
1959	9.5	3.5	4.5	A-6
1986	12.5			

Table 13. Section 183-43 Structural Profile History.

Year	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Granular Subbase Thickness (in)	Subgrade Soil Type
1959	2.0	7.0	8.0	A-6
1968	4.0			
1989	7.5			

Table 14. Section 183-47 Structural Profile History.

Year	Asphalt Concrete Thickness (in)	Granular Base* Thickness (in)	Granular Subbase Thickness (in)	Subgrade Soil Type
1954	2.0	4.0	8.0	A-6
1973	4.5			

* Asphalt stabilized base

Seasonal Layer Moduli

Asphalt Concrete

Based upon previous research at Mn/ROAD (8), the asphalt concrete layers were assigned seasonal moduli as shown in Table 15.

Table 15. Asphalt Concrete Seasonal Moduli.

Season	Modulus, psi
I (Winter)	1,987,433
II (Spring Thaw)	1,528,794
III (Spring Recovery)	993,717
IV (Summer)	290,471
V (Fall)	764,397

Granular Base and Subbase

Tests to determine the R-value of the granular bases and subbases were done in the original 183 investigation (5,7). The data were used in this project to determine the normal or summer modulus using the following relationships (9):

$$M_R = 1000 + 555 \cdot R\text{-value} \quad (R\text{-value} \leq 20)$$

$$M_R = 1000 + 250 \cdot R\text{-value} \quad (R\text{-value} > 20)$$

Seasonal multipliers, obtained from Mn/ROAD (8), were used to determine the moduli in the other four seasons as shown in Table 16.

Table 16. Seasonal Base and Subbase Moduli.

Season	I*	II	III	IV	V
Test Cell and Layer	Modulus, psi				
183-3 Base	40,000	19,200	24,100	28,650	28,940
183-6 Base	40,000	19,665	24,650	29,350	29,650
183-6 Subbase	40,000	14,070	17,600	21,000	21,200
183-11 Base	40,000	19,900	24,950	29,700	30,000
183-11 Subbase	40,000	8,880	11,100	13,250	13,380
183-22 Base	40,000	19,665	24,700	29,350	29,650
183-22 Subbase	40,000	13,400	16,800	20,000	20,200
183-23 Base	40,000	18,730	23,480	27,950	28,200
183-23 Subbase	40,000	11,200	14,100	16,750	16,900
183-26 Base	40,000	20,600	25,800	30,750	31,100
183-34 Base	40,000	13,800	17,300	20,600	20,800
183-34 Subbase	40,000	11,900	14,900	17,750	17,900
183-43 Base	40,000	18,960	23,770	28,300	28,600
183-43 Subbase	40,000	12,900	16,200	19,250	19,400
183-47 Base	40,000	19,900	24,950	29,700	30,000
183-47 Subbase	40,000	18,730	23,500	27,950	28,200

* Winter modulus assigned a maximum value of 40,000 psi.

Subgrade

Previously measured R-values, as with the base and subbase layers, were used to determine the moduli for the subgrade soils in the summer condition. The following equations converted R-value to resilient modulus (9):

$$M_R = 1000 + 555 \cdot R\text{-value} \quad (R\text{-value} \leq 20)$$

$$M_R = 1000 + 250 \cdot R\text{-value} \quad (R\text{-value} > 20)$$

Seasonal multipliers obtained from Mn/ROAD (8) were used to adjust the moduli for seasonal effects. Table 17 lists the seasonal subgrade moduli by test section. It is important to point out that soils having the same AASHTO classification typically had somewhat different R-values resulting in different seasonal moduli.

Table 17. Seasonal Subgrade Moduli.

Season	I	II	III	IV	V
Test Cell (Soil Type)	Modulus, psi				
183-3 (A-7-6)	40,000	19,020	5,740	5,550	7,760
183-6 (A-2-4)	40,000	20,800	16,000	16,000	14,550
183-11 (A-1-b)	40,000	23,400	18,000	18,000	16,360
183-22 (A-4)	40,000	31,950	9,650	9,325	13,040
183-23 (A-2-4)	40,000	15,925	12,250	12,250	11,140
183-26 (A-4)	40,000	29,980	9,055	8,750	12,236
183-34 (A-6)	40,000	28,150	8,500	8,215	11,500
183-43 (A-6)	40,000	26,250	7,930	7,660	10,700
183-47 (A-6)	40,000	29,126	8,797	8,500	11,888

Traffic Data

The test section locations were provided to the Management Data Services Section of Mn/DOT where estimates of accumulated ESALs over the 40 years were made. Original estimates were made from the initial date of construction through 1980 and then from 1980-2000. The estimates are based on weight and vehicle type distributions made periodically at the specific test section location throughout these time periods. Accumulated and yearly total ESAL values were tabulated so that accumulated ESALs could be noted at the time of rehabilitation or reconstruction. The total number of ESALs were then determined for each of the structural cross sections shown in Tables 6 through 14. Table 18 lists the relevant ESALs for each structural profile.

Table 18. ESALs by Test Section During Each Time Span.

Years	ESALs
Section 183-3	
1961-1968	109,073
1969-1986	458,126
1987-1998	504,711
1999-2001	100,858
Section 183-6	
1959	0
1960-1980	3,241,078
1981-2001	3,705,513
Section 183-11	
1960	13,463
1961-1985	477,568
1986-2001	655,432
Section 183-22	
1961-1972	258,706
1973-2001	1,771,782
Section 183-23	
1960-2001	3,833,503
Section 183-26	
1961-1987	126,198
1988-1998	113,450
Section 183-34	
1959-1985	1,541,977
1986-2001	1,139,912
Section 183-43	
1959-1967	31,730
1968-1988	112,630
1989-2001	69,730
Section 183-47	
1954-1972	565,554
1973-2001	1,422,364

Performance Data

In the original 183 study, yearly measurements of rut depth and amount of cracking were recorded; however, measurements were taken only through 1977. More recently, video records of the test sections were evaluated to assess the rutting and cracking performance of the test sections. These records were available for the years of 1996 to 1998. These two sources of data were merged to give a more complete sectional history of pavement performance. Figures A1 through A18, in Appendix A, illustrate the rutting and cracking performance of each section by year. Additionally, the total surface thickness was plotted on the graphs to give an indication of when the structural profile changed during the life of the section. It is important to note that years in which there is a profile change and zero rut depth or cracking corresponds to no performance data available for that year.

MECHANISTIC-EMPIRICAL ANALYSIS

Once all the necessary inputs had been obtained as specified above, it was possible to proceed with the M-E analysis of the test sections. The procedure consisted of four steps, detailed below:

1. Calculate strains for each pavement cross section.
2. Calculate seasonal traffic volumes.
3. Calculate seasonal expected number of allowable loads.
4. Calculate damage factors using Miner's Hypothesis.

Calculate Strains for Each Pavement Cross Section

The program, WESLEA for Windows, was used to perform the mechanistic simulation necessary to determine strains in the pavement structures. The structural inputs, specified above, were input and an 18-kip single axle load with dual tires inflated to 100 psi was applied to the pavement surface. The maximum tensile strain (ϵ_t) at the bottom of the asphalt concrete layer and the maximum compressive strain (ϵ_v) at the top of the subgrade were recorded as illustrated in Figure 1. This was done on a seasonal basis to account for changes in layer stiffnesses due to temperature and moisture changes in the different layers. The strain data may be found in Appendix B.

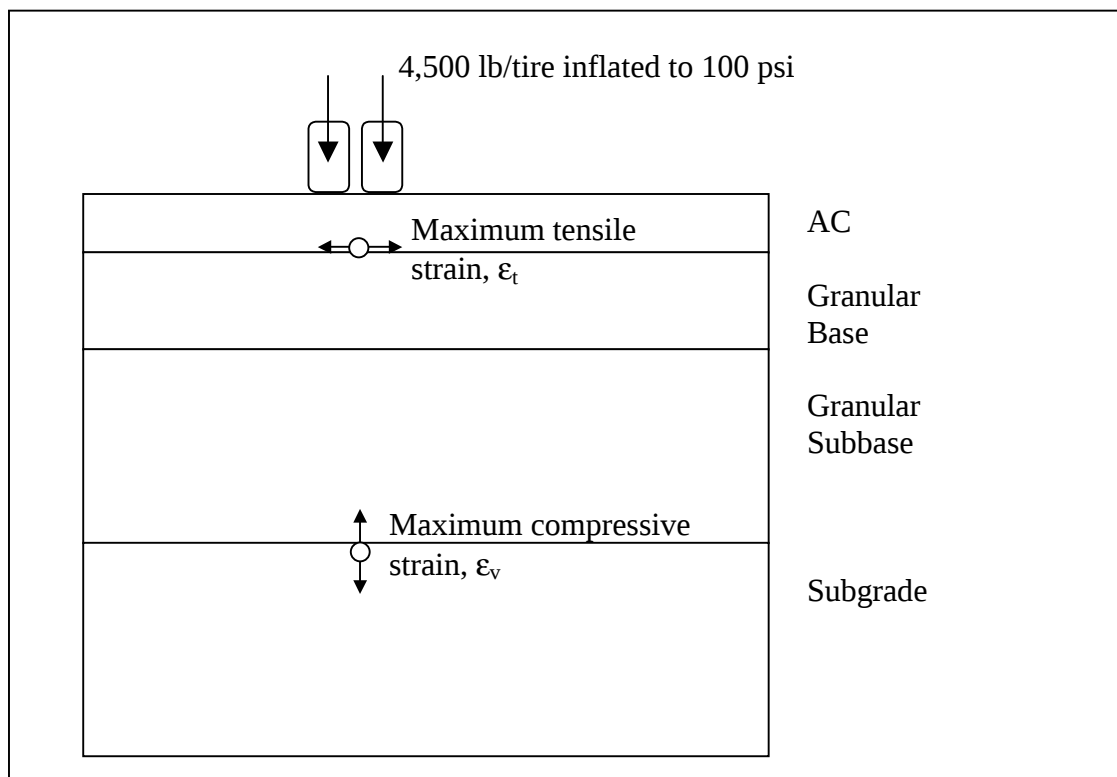


Figure 1. Mechanistic Simulation of Pavement Sections.

Calculate Seasonal Traffic Volumes

To accommodate a seasonal evaluation in Miner's hypothesis, it was necessary to distribute the ESALs over the five seasons of the analysis. The percentages shown in Table 19 were used to distribute the traffic to each season. The seasonal traffic data for each section are in Appendix B.

Table 19. Seasonal Traffic Multipliers.

Season	% of ESALs In Each Season
I - Winter	23%
II - Spring Thaw	5.8%
III - Spring Recovery	5.8%
IV - Summer	50%
V - Fall (Normal)	15.4%

Calculate Seasonal Expected Number of Allowable Loads

Transfer functions developed at the Minnesota Road Research Project (Mn/ROAD) were used to estimate the number of allowable loads for each structural cross section based on the strain data obtained from WESLEA for Windows. The number of allowable loads, by test section, season and year are listed in Appendix A. The transfer functions for fatigue and rutting life are as follows:

$$N_f = 2.83 \cdot 10^{-6} \left(\frac{10^6}{\epsilon_t} \right)^{3.206} \quad (1)$$

$$N_r = 5.5 \cdot 10^{15} \left(\frac{1}{\epsilon_v} \right)^{3.929} \quad (2)$$

where: N_f = number of allowable load repetitions until fatigue failure (approximately 10% of area fatigue cracked)

N_r = number of allowable load repetitions until rutting failure (0.5 inch rut depth)

ϵ_t = maximum tensile microstrain at bottom of asphalt concrete layer

ϵ_v = maximum compressive microstrain at top of subgrade layer

Calculate Damage Factors Using Miner's Hypothesis

Using Miner's hypothesis, which is a damage function that accounts for the cumulative effects of traffic-related pavement damage, it was possible to determine damage factors for each structural profile. The equation representing Miner's hypothesis is:

$$D = \sum_{i=1}^k \frac{n_i}{N_i} \quad (3)$$

where: D = damage factor

n_i = number of actual repeated loads in season i

N_i = number of allowable loads before fatigue or rutting failure in season i

i = Season, 1 through 5

By definition, when D exceeds unity, failure has occurred. When D is less than unity, then the pavement structure has sufficient capacity to withstand the given traffic level. The damage factors for each test section, by season and year, are listed in Appendix A.

M-E AND OBSERVED PERFORMANCE COMPARISON

A primary objective of this study was to assess whether the current pavement performance models accurately predict field performance. To this end, the damage factors obtained in the M-E analysis were compared to measured distress on the nine test sections. The comparison process and results are presented below for rutting and fatigue cracking performance, respectively.

Rutting Performance

Rut depth measurements from the nine sections were used to classify rutting distress as low, medium or high severity with corresponding rankings of 1, 2 or 3, respectively. Rutting damage factors, as calculated in the M-E analysis, were classified in the same manner. Table 20 lists the classification system.

Table 20. Rutting Classifications.

Severity	Rank	Measured Rut Depth (in.)	Simulated Damage Factor
Low	1	< 0.25	< 0.5
Medium	2	0.25 - 0.5	0.5-1.0
High	3	> 0.5	> 1.0

For each pavement profile, the rut depth and damage factors were determined and assigned a rank according to Table 20. The *measured* rank was then subtracted from the *predicted* rank to give an indication of the conservative or un-conservative nature of the M-E simulation. For example, if a section had a measured rut depth of 0.2 inches (Rank=1) and the simulated damage factor was 0.65 (Rank 2), the result would be +1.0, or a conservative prediction. In other words, the M-E simulation predicted more rutting than was observed. Table 21 lists the possible outcomes of this ranking system and their interpretations.

Table 21. Possible Comparison Outcomes and Interpretation.

Outcome	Interpretation
+2.0	Very Conservative Prediction
+1.0	Conservative Prediction
0	Accurate Prediction
-1.0	Un-conservative Prediction
-2.0	Very Un-conservative Prediction

Figure 2 illustrates the rutting comparisons for all of the test sections. The following observations are made with respect to the graph:

1. Most predictions were on the conservative side, only one prediction was un-conservative.
2. Only four of the seventeen predictions were very conservative, while six were rated as accurate.
3. The majority of predictions were either off by a ranking of one or were rated as accurate.

Based on these observations, it may be stated that the rutting performance transfer function provides somewhat conservative estimates of rutting, yet not excessively so.

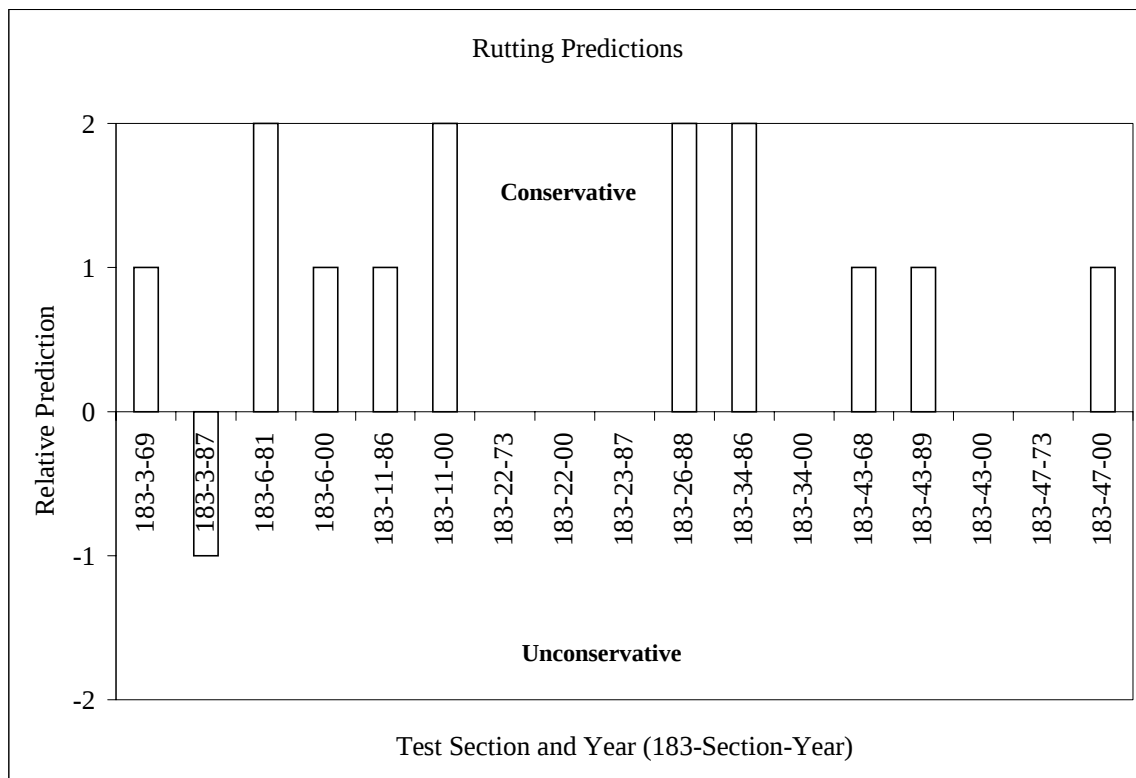


Figure 2. Rutting Performance Comparison.

Fatigue Performance

A similar procedure was used in comparing measured fatigue performance to that predicted in the M-E analysis. Table 22 lists the relative rankings for fatigue

performance. Figure 3 illustrates the relative outcome and Table 21 may be used to interpret the results.

Table 22. Fatigue Cracking Classifications.

Severity	Rank	Measured Cracking (ft ² /1000ft ²)	Simulated Damage Factor
Low	1	< 50	< 0.5
Medium	2	50 - 100	0.5-1.0
High	3	> 100	> 1.0

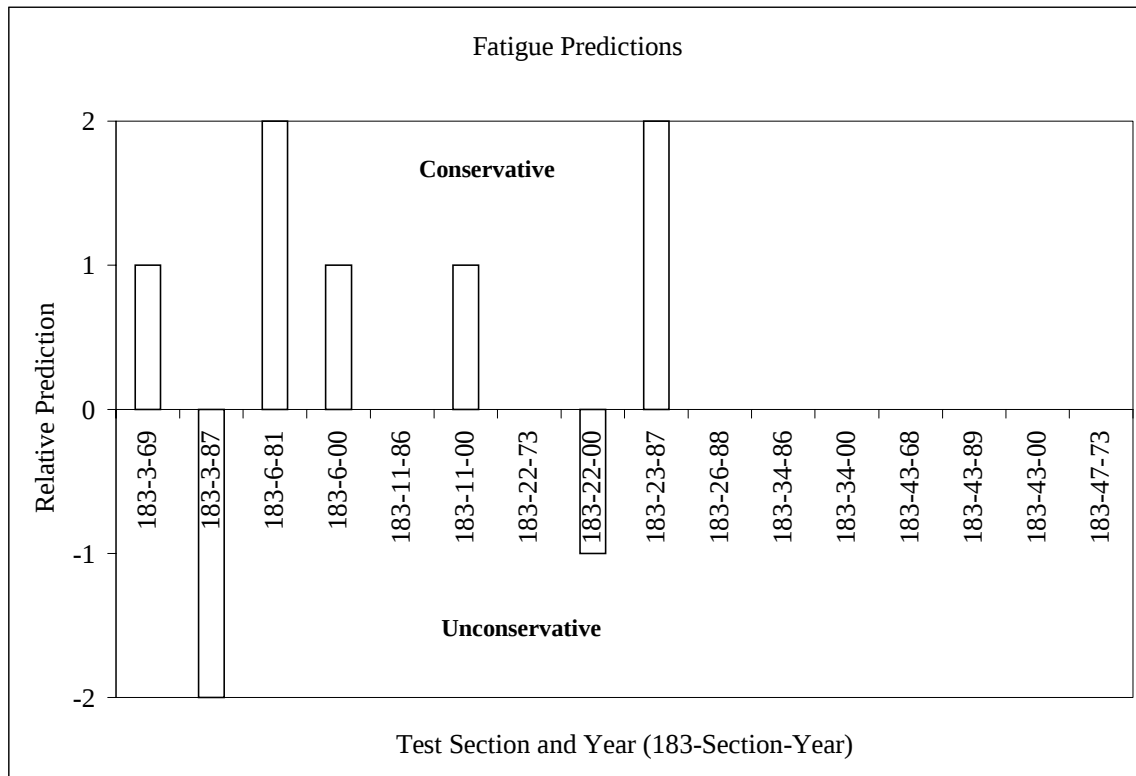


Figure 3. Fatigue Performance Comparison.

With respect to Figure 3, the following observations may be made:

1. Nine of the sixteen predictions were found to be accurate.
2. The remaining predictions tended to the conservative side, with two very conservative predictions.
3. Only two un-conservative predictions were made, one being very un-conservative.

Based on these observations it may be stated that the current fatigue prediction equation provides reasonable estimates with respect to fatigue performance.

CONCLUSIONS AND RECOMMENDATIONS

Based on the data presented in this investigation, the following conclusions may be drawn:

1. The data from Investigation 183 and 195 are sufficient and accessible enough to execute an M-E validation/calibration procedure as described in this report. As there are 41 additional sections, it is recommended that the validation/calibration procedure continue to widen the data set even further.
2. The comparison between predicted and observed rutting performance did not indicate a need to alter the rutting performance equation at this time. However, as more test sections are added to the calibration database, a modification may be necessary.
3. Likewise, the comparison between predicted and observed fatigue cracking did not warrant a change to the current transfer function. As more sections are added, it may need to be modified.

REFERENCES

1. Timm, D.H., David E. Newcomb and Theodore V. Galambos, "Incorporation of Reliability into Mechanistic-Empirical Pavement Design," Transportation Research Record, Transportation Research Board, Washington, D.C., 2000 (in press).
2. Timm, D.H., David E. Newcomb and Theodore V. Galambos, "Incorporation of Reliability into the Minnesota Mechanistic-Empirical Pavement Design Method," Final Report, MN/RC-1999-35, Minnesota Department of Transportation, St. Paul, MN, 1999.
3. Timm, D.H., David E. Newcomb and Bjorn Birgisson, "Development of Mechanistic-Empirical Design for Minnesota," Transportation Research Record No. 1629, Transportation Research Board, Washington, D.C., 1998, pp. 181-188.
4. Timm, D.H., D.E. Newcomb and B. Birgisson, "Mechanistic-Empirical Flexible Pavement Thickness Design: The Minnesota Method," Staff Paper, MN/RC-P99-10, Minnesota Department of Transportation, St. Paul, MN, 1999.
5. Kersten, M.S. and Skok, E.L., "Application of AASHO Road Test Results to Design of Flexible Pavements in Minnesota," MHD Investigation 183, Interim Report, University of Minnesota, 1968.
6. Lukanen, E.O., "Evaluation of Full-Depth Asphalt Pavements," Investigation No. 195, Interim Report, Minnesota Department of Transportation, 1977.
7. Lukanen, E.O., "Application of AASHO Road Test Results to Design of Flexible Pavements in Minnesota," Investigation No. 183, Report No. FHWA-MN-80-09, Minnesota Department of Transportation, 1980.

8. Ovik, J.M., "Characterizing Seasonal Variations in Pavement Material Properties for Use in a Mechanistic-Empirical Design Procedure," M.S. Thesis, University of Minnesota, 1998.
9. AASHTO Guide for Design of Pavement Structures, American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

APPENDIX B

VEHICLE CLASSIFICATION FIELD GUIDE FOR LOW VOLUME ROADS



Task 2

Traffic Supplement to the Low Volume Road Best Practices Manual

MARCH 13, 2002

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

INTRODUCTION

The purpose of this field guide is to give specific directions in setting up and performing a vehicle classification study on low volume roads. This guide is limited to setting up a study on a two-lane, two-direction roadway. The instructions contain provisions for a one or two data collection unit study, depending on traffic volume.

EQUIPMENT LIST

- 1 or 2 Timemark Lambda vehicle classification data collection unit (sometimes referred to as “boxes”), depending on traffic volume
- 2 pneumatic air tubes capable of spanning entire pavement width and connecting to the data collection unit.
- 4 metal stakes
- 4 anchoring brackets
- Chain(s) and lock(s)
- Sidewalk chalk
- Tape measure (capable of measuring 16 ft)
- Mallet
- Gloves to protect hands during installation and removal of equipment
- Asphalt backed roofing tape, 2” or 4” wide, available from Mn/DOT district traffic engineers

EQUIPMENT POSITIONING

Once a roadway has been selected for a classification study, it is important to consider the following factors in placing the air tubes:

- Vehicles should cross tubes in a perpendicular fashion. Avoid placing tubes on curves or in turns.
- Vehicles should cross the tubes at uniform speeds. Avoid placing tubes in zones where acceleration or deceleration is common (e.g., near stop signs or turns).
- The tubes should be placed flat against the pavement. Avoid placing tubes where curbs will prevent tubes from lying flat.
- The data collection unit should be locked to a signpost or other roadside stationary object.
- When traffic volumes exceed 3,000 AADT, it is recommended that a two-box setup be used. Otherwise one box will suffice.

EQUIPMENT SET UP

CAUTION: When working in an area that is under live traffic, exercise extreme caution. Flashing lights on vehicles, fluorescent vests and hats are required.

1. Cut eight 10” strips of roofing tape.
2. Warm up the roofing tape. On a warm day (above 55°F), this may not be necessary. Otherwise, place the tape near a car heater.
3. Unravel the pneumatic hoses and lay them side by side parallel to the roadway.
 - A. One-box setup: 60-ft hoses are used. These hoses are clamped at one end.
 - B. Two-box setup: 75-ft hose are used. These hoses are free at both ends and have a stopper in the middle so that data may be collected independently in each lane.
4. Check the hoses for any obvious holes or splits which could affect the ability to collect data.
5. Anchor one end of hose.

It is important that the hoses be of identical length so that the air pulse takes the same amount of time to travel down both tubes to the data collection box. The length can be adjusted by moving the anchor at the free end so that the hoses have equivalent length.

 - A. One-box setup: Using mallet and stake, anchor the clamped end of one tube to the side of the roadway opposite from where the data collection unit will be placed.
 - B. Two-box setup: Anchor one end of one tube to the side of the roadway near an anchoring device where the box will be placed.
6. Stretch the staked hose, perpendicular to the centerline, to the other side of the roadway. Stretch the hose about 10% of its length. For example, a 40-foot section of hose, unstretched, should be stretched about 4 ft.
7. Anchor other end of hose.
 - A. One-box setup: Using mallet and stake, anchor the free end of the stretched tube.
 - B. Two-box setup: Using mallet and stake, anchor the other end of the stretched tube. Be sure that the stopper in the hose is near the centerline of the pavement.
8. Check that the staked tube is perpendicular to the centerline.
9. Using the chalk, make three marks adjacent to the staked tube. These marks should be spaced evenly across the pavement.
10. Using the tape measure and chalk, make three parallel marks 16 ft from the first set of marks.

11. Place the second hose on top of the second set of marks.
 - A. One-box setup: Stake the clamped end on the same side of the roadway as the first tube.
 - B. Two-box setup: Stake one of the free ends on the side of the roadway.
12. Stretch the second hose about 10% (see step 2) and stake to the other side of the road.
13. Place the data collection unit(s).
 - A. One-box setup: Place the data collection unit near the anchoring device (e.g., signpost).
 - B. Two-box setup: Place the data collection units near the anchoring devices (e.g., signposts).
14. Connect the tubes to the data collection unit.
 - A. One-box setup: Tube A should be the most northbound or eastbound direction. Tube B should be the most southbound or westbound direction.
 - B. Two-box setup: Tube A should be the tube that is hit first by oncoming traffic. Tube B should be the tube hit second by oncoming traffic.
15. Continue with software setup.

SOFTWARE SETUP

Figure 1 illustrates the inside of the Timemark Lambda data collection unit. Note that the [Select] button will move between different options (indicated by flashing text) in a particular menu, while the [Enter] button will choose the option and go on to the next menu.

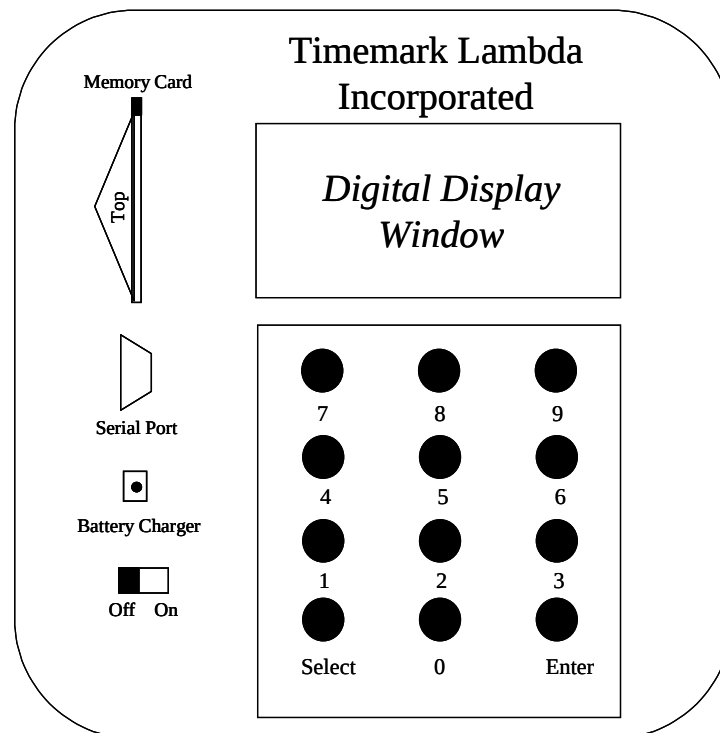


Figure 1 Data Collection Unit Controls and Display

For a one-box setup, follow these instruction exactly. For a two-box setup, follow the directions for each box.

1. Decide on Data Storage: Decide whether to use the data collection unit's internal memory or a data card to record the vehicle hits during the study. If the study will not exceed 25,000 vehicles, then the data collection unit's internal memory is sufficient. If the study will exceed 25,000 vehicles, then a data card should be used. If you decide to use a data card, insert one into the memory card slot as shown in Figure 1.
2. Turn on the data collection unit: An introductory screen will appear displaying the software version number. The screen will then proceed to *Main Menu* automatically.
3. Choose *Memory Manager*: Under the *Main Menu*, the following options appear:
Record a New Study
Monitor Traffic
Memory Manager
Use the [Select] button, if necessary, to make *Memory Manager* flash. Then press [Enter]. Select the option to clear the memory and return to the main menu. **NOTE:** Clearing the memory will erase all previously recorded data. Be sure that previously recorded data has been saved elsewhere or has already been processed.
4. Choose *Record a New Study*: Under the *Main Menu*, the following options appear:
Record a New Study
Monitor Traffic
Memory Manager
Use the [Select] button, if necessary, to make *Record a New Study* flash. Then press [Enter]. The *Tubes: Raw Data* menu will now appear.
5. Choose *Select a New Study*: Under the *Tubes: Raw Data* menu, the following options appear:
Start Recording Now
Set Start/Stop Times
Select a New Study
Use the [Select] button, if necessary, to make *Select a New Study* flash. Then press [Enter]. The *Enter Site Code* screen will now appear.
6. Enter the 12-digit filename using the following guide:
Digits 1-4 = site number (each county has been assigned a range of numbers, refer to the end of the field guide for the appropriate number)
Digit 5 = number of boxes used in study (typically 1 or 2)
Digit 6 = direction of traffic in primary direction. This is the direction of traffic crossing Tube A first. Refer to Figure 2 for directional numbers.
Digit 7 = lane number for primary direction (1 = Driving, 2 = Passing)
Digits 8-9 = route system
01=Interstate

02=US Hwy
 03=MNTH
 04=CSAH
 05=MASS
 07=County Road
 08=Township Road
 09=Unorganized Township Road
 10=City St.

Digits 10-12 = route number

Once the data filename has been input, press [Enter] and the *Study Type Menu* will appear.

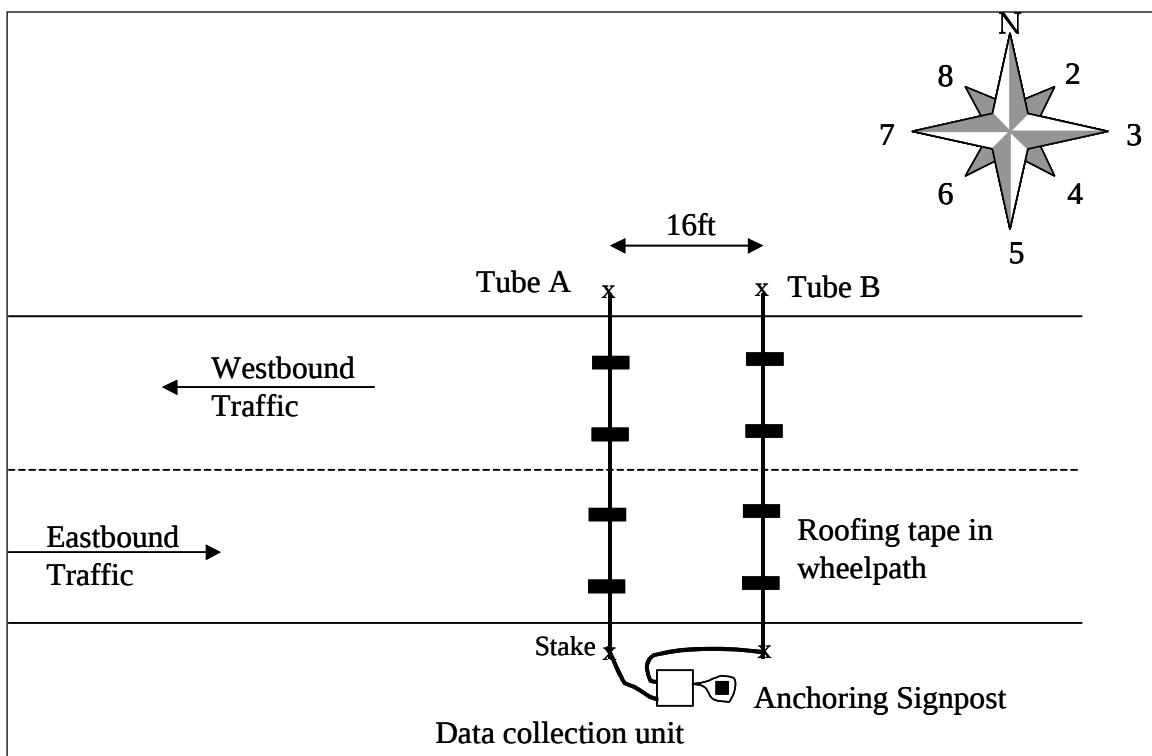


Figure 2 Final Setup (One-Box)

7. Choose Raw Data: Under the *Study Type Menu* the following options appear:
 Raw Data
 Volume
 Speed
 Use the [Select] button, if necessary, to make *Raw Data* flash. Then press [Enter].
 The *Sensor Type Menu* will appear.
8. Choose Road Tubes: Under the *Sensor Type Menu* the following options appear:
 Road Tubes

Piezos Only

Loops Only

Use the [Select] button, if necessary, to make *Road Tubes* flash. Then press [Enter]. The *Sensor Layout Menu* will appear.

9. Choose A/B, C/D Spaced: Under the *Sensor Layout Menu* the following options appear:
A,B,C,D
A/B, C/D Spaced
Use the [Select] button, if necessary, to make *A/B, C/D Spaced* flash. Then press [Enter]. The *Select Spacing Type* menu will appear.

10. Choose Set Universal Value: Under the *Select Spacing Type* menu the following options appear:
Set Universal Value
Set Individual Lanes
Use the [Select] button, if necessary, to make *Set Universal Value* flash. Then press [Enter]. The *Enter Sensor Spacing* screen will appear.

11. Enter 16-ft Spacing: On the *Enter Sensor Spacing* screen input 16-ft sensor spacing, this value will usually be there by default. Once '16' has been input, press [Enter]. The *Tubes: Raw Data* menu will appear.

12. Choose Start Recording Now: Under the *Tubes: Raw Data* menu, the following options appear:
Start Recording Now
Set Start/Stop Times
Select a New Study
Use the [Select] button, if necessary, to make *Start Recording Now* flash. Then press [Enter]. The data collection screen will now appear. The data collection screen contains a table as shown below:

Raw Tube	Time	Lane: 1
A:	0	TA
B:	0	TB

The middle column contains the number of total hits on each of the two tubes, A and B.

13. Verify that the System is Operational: Check that the tubes are recording hits, either by vehicles or by stepping forcefully on one of the tubes. If hits are not being recorded, there may be a problem with the connection of the tubes to the data collection unit or a tube may be damaged. The equipment and connections may need to be inspected. If hits are being recorded, continue with final setup.

FINAL SETUP

1. Make sure tubes are aligned with chalk marks. Adjust if necessary.
2. Using pre-cut, warm strips of tape, secure tubes in each of the wheelpaths.
3. Check that collection unit is still registering hits. If necessary, even the number of hits between each tube.
4. Close box and chain to anchoring device.

The final one-box setup is pictured in Figure 2. A two-box setup is shown in Figure 3.

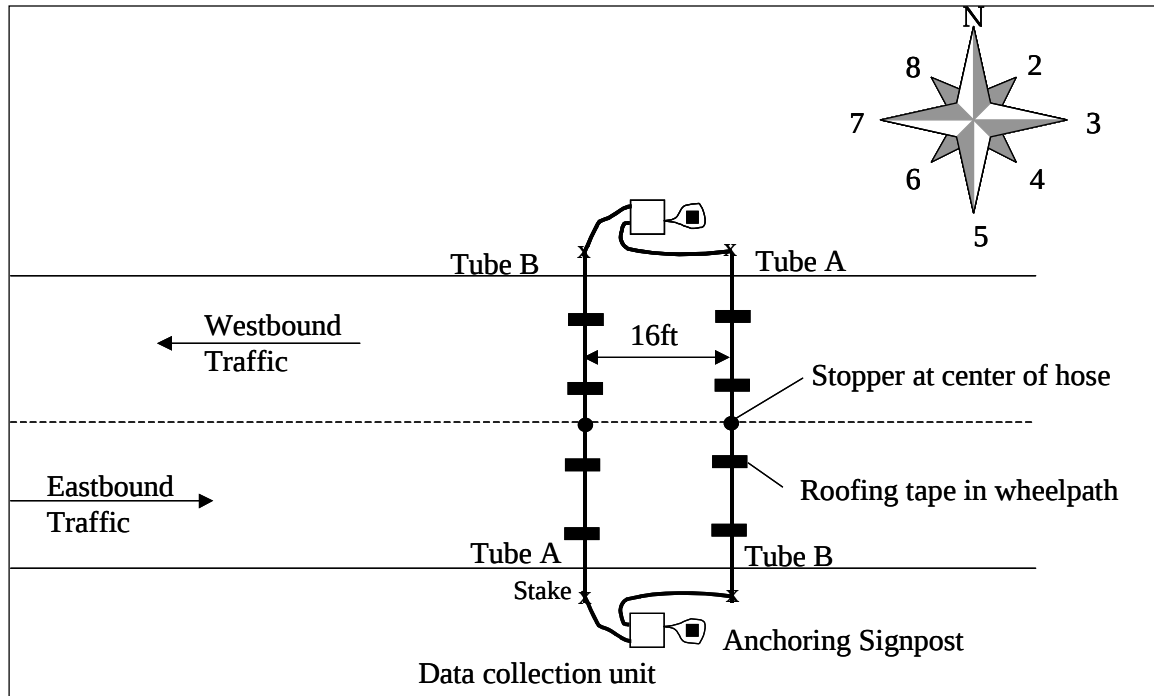


Figure 3 Final Setup (Two-Box)

LENGTH OF STUDY

The duration of the study is influenced by several factors.

1. **Capacity of data collection unit:** Each unit may store up to 25,000 vehicles over the duration of the study. In most low volume road cases, this number will not be exceeded. For higher volume (>3,000 AADT) two boxes or data cards should be used to handle the increased traffic volume.
2. **Traffic Volume:** To get an accurate classification of vehicles, it is important to collect enough data. A minimum of 48 hours should be collected. However, on lower volume roads it may be necessary to collect up to a week's worth of data. Judgement should be exercised in deciding on the length of the study. A Mn/DOT traffic engineer may be contacted for further guidance.

AFTER THE STUDY

1. Open the data collection unit and verify that data were collected and that it is still operating.
2. Manually record the number of hits on each tube. This serves as a crude backup in case the data are lost.
3. Shut off the unit.
4. If a flash card was used to record data during the study, the data have already been saved to the disk. The disk can now be removed for analysis later. If not, insert a flash card in the disk drive of the data collection unit.
5. Turn on the data collection unit and the new study will automatically be transferred to disk. After data have been transferred, remove the disk for analysis later.
6. Label the disk with the 12-digit number used to specify the study.
7. Remove equipment from roadside and roadway.

CAUTION: When working in an area that is under live traffic, exercise extreme caution. Flashing lights on vehicles, fluorescent vests and hats are required.

8. The labeled disks may be sent to the Traffic Division of Mn/DOT's Office of Data Management Services for analysis. Send to:

Melissa Thomatz
Transportation Data Section
Office of Transportation Data and Analysis
Mailstop 450
Minnesota Department of Transportation
395 John Ireland Blvd.
St Paul, MN 55155

Alternatively, the data files may be emailed to Melissa Thomatz at:
melissa.thomatz@dot.state.mn.us

IMPORTANT NOTES

1. The air hoses have an approximate life span of 2 years. They will not collect data if punctured.
2. The batteries in the data collection units typically last one month without recharging. They can be recharged overnight.
3. On the newer Timemark units, there is a power saver feature that shuts off the screen if no buttons are pushed after a period of time. However, the unit will still collect data. To reactivate the screen, press [Enter]. The screens on the older units will remain on as long as the unit is on.
4. For further assistance on running a vehicle classification study, the following people are available for contact:

Rod Heuer: rod.heuer@dot.state.mn.us
Tom Nelson: tom.nelson@dot.state.mn.us
651-297-1194

ASSIGNED COUNTY COUNT NUMBERS

COUNTY	SITE CODES	COUNTY	SITE CODES
AITKIN	4001-4025	MARSHALL	5451-5475
ANOKA	4026-4075	MARTIN	5476-5500
BECKER	4076-4110	MEEKER	5501-5525
BELTRAMI	4111-4150	MILLE LACS	5526-5550
BENTON	4151-4200	MORRISON	5551-5600
BIG STONE	4201-4225	MOWER	5601-5650
BLUE EARTH	4226-4275	MURRAY	5651-5675
BROWN	4276-4300	NICOLLET	5676-5700
CARLTON	4301-4325	NOBLES	5701-5725
CARVER	4326-4375	NORMAN	5726-5750
CASS	4376-4400	OLMSTED	5751-5800
CHIPPEWA	4401-4425	OTTER TAIL	5801-5850
CHISAGO	4426-4475	PENNINGTON	5851-5875
CLAY	4476-4525	PINE	5876-5900
CLEARWATER	4526-4550	PIPESTONE	5901-5925
COOK	4551-4575	POLK	5926-5975
COTTONWOOD	4576-4600	POPE	5976-6000
CROW WING	4601-4650	RAMSEY	6001-6025
DAKOTA	4651-4700	RED LAKE	6026-6050
DODGE	4701-4725	REDWOOD	6051-6075
DOUGLAS	4726-4750	RENVILLE	6076-6100
FARIBAULT	4751-4775	RICE	6101-6125
FILLMORE	4776-4800	ROCK	6126-6150
FREEBORN	4801-4825	ROSEAU	6151-6175
GOODHUE	4826-4875	ST. LOUIS	6176-6225
GRANT	4876-4900	SCOTT	6226-6275
HENNEPIN	4900-4925	SHERBURNE	6276-6300
HOUSTON	4926-4950	SIBLEY	6301-6325
HUBBARD	4951-4975	STEARNS	6326-6375
ISANTI	4976-5000	STEELE	6376-6400
ITASCA	5001-5050	STEVENS	6401-6425
JACKSON	5051-5075	SWIFT	6425-6450
KANABEC	5076-5100	TODD	6451-6475
KANDIYOHI	5101-5150	TRAVERSE	6476-6500
KITTSOON	5151-5175	WABASHA	6501-6525
KOOCHICHING	5176-5225	WADENA	6526-6550
LAC QUI PARLE	5226-5250	WASECA	6551-6575
LAKE	5251-5275	WASHINGTON	6576-6625
LAKE OF THE WOODS	5276-5300	WATONWAN	6626-6650
LeSUEUR	5301-5325	WILKIN	6651-6675
LINCOLN	5326-5350	WINONA	6676-6725
LYON	5351-5400	WRIGHT	6726-6800
McLEOD	5401-5425	YELLOW MEDICINE	6801-6825
MAHNOMEN	5426-5450		

Note: If the numbers for your county are insufficient, contact Tom Nelson or Rod Heuer at Mn/DOT for additional site codes.