# TABLE of CONTENTS

<table>
<thead>
<tr>
<th>Research Objective</th>
<th>Objective Title</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Introduction, 1</td>
</tr>
</tbody>
</table>

1 Verification of Empirical Design Models For Various Types of New Pavements; 2

1-A Aggregate Surfaced Pavements, 3
1-B Flexible Pavements, 5
1-C Rigid Pavements, 7
1-D Chip Seal Surfaced Pavements, 9

2 Development of Mechanistically Based Design Methods For Various Surfaced Roads; 11

2-A Aggregate Surfaced Roads, 11
2-B Flexible Pavements, 14
2-C Rigid Pavements, 17

3 Development of Improved Mechanistic Models For Various Surfaced Roads; 20

3-A Aggregate Surfaced Roads, 20
3-B Flexible Pavements, 23
3-C Rigid Pavements, 26

4 Verification/Improved Frost Action Prediction Methodology, 29

5 Influence of Axle Load Magnitude Upon Pavement Performance Under Critical Spring Thaw Conditions, 31

6 Development of Vehicle Load Damage Factors For Various Pavements; 33

6-A Aggregate Surfaced Roads, 33
6-B Flexible Pavements, 35
6-C Rigid Pavements, 37

7 Influence of New Vehicle Gear Configurations and Tire Systems Upon Pavement Performance, 39
8 Influence of AC Mixture Properties Upon Performance/Distress, 41

9 Influence of Unbound Granular Base/Subbase Properties Upon Flexible Pavement Performance/Distress, 46

10 Influence of Unbound Granular Base/Subbase Properties Upon Rigid Pavement Performance/Distress, 48

11 Influence of Subgrade Type Upon Pavement Performance, 50

12 Improved Roadway Instrumentation Techniques, 52

13 Influence of Special Design Variables upon Rigid Pavement Performance; 54
   13-A Edge Drains, 56
   13-B Contraction Joints, 59
   13-C Paving Width, 61
   13-D Joint Spacing, 63
   13-E Trapezoidal Cross Sections, 66
   13-F Cement Type and Content, 68
   13-G Aggregate Class, 70

14 Influence of Pavement Variability Upon Reliability Based Performance Models, 72

Appendix A, 75
INTRODUCTION

The Minnesota Road Research Project (Mn/Road) site is a new pavement research facility which is presently under construction and is located in Wright County 40 miles northwest of the metro area. Construction began in 1989 with the installation of a Weigh-in-Motion (WIM) scale and a fully Automated Weather Station (AWS). The construction completion date is scheduled for the fall of 1991. One of two test roads will be located adjacent to westbound I-94, between Albertville and Monticello. Upon completion freeway traffic will be deviated on to it. The other test road will be a low volume loop built next to the site, specifically designed as a test track. This facility will enable the Minnesota Department of Transportation to evaluate pavement performance under actual existing conditions. The end result will be improvement of pavement design methods, increasing pavement performance.

Through the collaborating efforts of the Minnesota Department of Transportation and the University of Minnesota a plan has been devised which will investigate 14 major pavement research objectives. These 14 objectives are based on consultant work performed by Matthew W. Witczak. Each objective deals with the effects on pavement performance due to design procedures, materials, traffic loadings, and the elements of nature. In order to more fully understand how these different parameters affect the structural stability and performance of pavements extensive research will be required.

The Mn/Road facility will be made up of 40 different pavement designs each incorporating the parameters of interest to the researcher. The mainline test road will have built into it 23 sections (14 asphalt and 9 concrete surface) and the low volume road will contain 17 test sections (8 asphalt, 5 concrete, 2 treated aggregate, and 2 aggregate surface). Theses test sections (or cells) have been designed using various thicknesses and materials (see Appendix A). The low volume road is designed for a service life of about three years while 9 mainline sections are designed for five years and 14 mainline sections for ten years. Each section will be approximately 500 feet in length with tapered transitions separating the sections.

These sections will be heavily instrumented, sampled, and tested. A large portion of the data will be collected through sensor implants within the different pavement layers at specified locations. Both the collection and recording of this data will be automated through computer hardware and software.

This report describes the 14 Mn/Road research objectives. Although, each objective still needs to be expanded into one or more individual research projects. The majority of these projects will each require 5-10 years of research to complete. Each project will be assigned to a principal investigator who will conduct the research and complete interim and final reports.
Research Objective #1

Verification of Empirical Design Models For Various Types of Pavements

David E. Newcomb

BACKGROUND

Existing design procedures for new pavements are based on empirically defined relationships which were developed up to 40 years ago. The standard performance models for rigid and flexible highway pavements were those which resulted from the AASHO Road Test in the early 1960's. It is questionable whether these models hold the same validity as they did at the time of their development because the materials for pavements and the traffic conditions under which they must perform have changed dramatically. The availability of information on traffic, weather, and materials at the MRRP will allow researchers to examine the adequacy of the current performance models.

PURPOSE

This research project is meant to ascertain the value of current design procedures and performance models for rigid, flexible, and aggregate surfaced pavements. For the immediate future, the results should indicate whether pavements in general are being underdesigned or overdesigned. In the long term, it is expected that improved performance models could be developed which would more accurately reflect pavement behavior in Minnesota's climate and traffic conditions. These performance models should be such that they may be incorporated into whatever empirical or mechanistic-empirical design procedure is in use at the time of their development. The greatest benefit which could result from this project would be a rationally determined performance model.

APPROACH

Standard traffic and materials information used in the current design methodologies for the three surface types should be collected for input to the design/performance equations. These should indicate what pavement life can be expected from a given section. A comparison can then be made between the expected and actual values of pavement life.
Research Objective #1-A

Verification of Empirical Design Models For New Aggregate Surfaced Pavements

11/19/89
David E. Newcomb

BACKGROUND

The 1986 AASHTO Guide for the Design of Pavement Structures provides a method for the design of aggregate surfaced roads. This procedure is based on the loss of serviceability of the road and the depth of rutting expected for a given level of traffic on different quality materials in various climates. This approach is one of the few available to the practicing engineer which incorporates structural considerations into low volume road design. The problem with implementing this procedure is that there is very little data to validate it with essentially no data being available in cold climates such as Minnesota.

PURPOSE

The purpose of this research would be to provide data for the validation or modification of the AASHTO design approach for aggregate surfaced pavements. The result of this effort would be the possible implementation of the AASHTO design procedure at the local government level in Minnesota. The study would be conducted by monitoring the performance of the aggregate surfaced sections at the MRRP and comparing the actual performance to that predicted by the AASHTO method.

APPROACH

The test cells which would be suitable for this purpose would be LVR-A-1 and LVR-A-2. One of these will be constructed with a clean aggregate and the other will be built with an aggregate having a higher percentage of material smaller than the No. 200 sieve. The reason for having these two materials is to understand the contribution of plasticity of the aggregate to the performance of the pavement. It is argued that while a higher percentage of fine material will weaken the pavement system, a certain amount of fines are necessary in order to give the material some cohesion.

Rut depth and serviceability would be measured periodically as traffic was applied to the sections. The relationships of these performance measurements to traffic levels and aggregate material properties would be determined through regression analysis. Since there will only be one climate and subgrade type available, these variables will have to be evaluated through results of satellite studies in Minnesota and other states. One of the problems to be surmounted in the conduct of this research will be to determine a
method for measuring the serviceability (rideability) of aggregate surfaces. Serviceability was a concept which has been well tested for asphalt and portland cement concrete surfaces, but not for aggregate surfaces.

Samples will be taken during construction in order to characterize the resilient moduli of the subgrade and aggregate surface materials as input required for the AASHTO design procedure. These should be tested in the saturated condition in frozen and thawed states as well as at optimum moisture content. To coincide with this, nondestructive testing with the falling weight deflectometer should be done periodically with subsequent backcalculation of layer moduli.

Instrumentation is not necessary to perform this study, but the importance of measuring temperature and moisture contents at different depths (as a minimum) will be discussed in subsequent work plans. The need for placing response sensors in the roadway will also be discussed.

Specifications need to be prepared for the production of the material and placement during construction. It is expected that Mn/DOT standards with a few modifications will suffice for this purpose. The MRRP manager will be responsible for the collection of the construction and periodic performance data.

RESOURCES

The PI must have a basic understanding of how to apply statistics in the analysis of performance data. The completion of this work should require 100 to 300 hours of technician and engineer time. The cost should mainly be associated with the labor involved in collecting and analyzing the data.
Research Objective #1-B

Verification of Empirical Design Models For New Flexible Pavements

11/19/89
David E. Newcomb

BACKGROUND

The 1986 AASHTO Guide for the Design of Pavement Structures and the Mn/DOT Road Design Manual provide methods for the design of asphalt surfaced roads. These procedures are based on the expected loss of serviceability of the road for a given level of traffic on different quality materials. They rely heavily on the performance data collected at the AASHO Road Test which was conducted in the late 1950's in Ottawa, Illinois. Over the course of time, changes have been made to the Minnesota design method based on observations of performance in the state; however, the basic relationships have been maintained. In the time since the Road Test, several changes have occurred in traffic characteristics. For instance, there is a greater frequency of trucks, carrying heavier loads with higher tire pressures. While it is obvious that changes should be made in the approach to pavement design, engineers have lacked the data to ascertain the effects of traffic changes.

PURPOSE

The purpose of this research would be to provide data for the validation or modification of the AASHTO and Mn/DOT design approaches for flexible pavements. The result of this effort would be the possible implementation of the updated design procedures at the state and local level in Minnesota. The study would be conducted by monitoring the performance of the asphalt surfaced sections at the MRRP and comparing the actual performance to that predicted by the AASHTO and Mn/DOT methods.

APPROACH

The test cells which would be suitable for this purpose would be LVR-F-8 to -15, ML5-F-1 to -4, and ML10-F-14 to -23. Different quality materials for surfacing and base courses will be incorporated into both the mainline and low-volume road experiments. The low-volume road will have two types of subgrade materials. There will be different traffic levels for the mainline 5- and 10-year experiments and the low-volume road. The mainline sections will be subjected to the mixed traffic of an actual Interstate, and the low-volume road will have fixed traffic of known loads.

Surface distress and serviceability would be measured periodically as traffic was applied to the sections. The relationships of these performance measurements to traffic levels and material qualities
would be determined through regression analysis. Since there will only be one climate, the effect of climatic variables will have to be evaluated through results of satellite studies in Minnesota and other states.

Samples of asphalt mixtures, aggregate base and subbase materials, and subgrade materials will be taken for characterization by resilient modulus testing during construction. These values will be used in determining the structural coefficients and effective roadbed resilient modulus as they are used in the AASHTO performance equation. Nondestructive deflection testing and the backcalculation of layer moduli will be done on a periodic basis in order to understand how changes in material properties affect the performance of flexible pavements.

Instrumentation is not necessary to perform this study, but the importance of measuring temperature and moisture contents at different depths (as a minimum) will be discussed in subsequent work plans. The need for placing response sensors in the roadway will also be discussed.

Specifications should be prepared for the production of the material and placement during construction by the Bituminous Engineer. It is anticipated that the requirement for specific levels of air voids in the asphalt mixtures will necessitate the several construction of several test strips. The MRRP manager will be responsible for the collection of the construction and periodic performance data.

RESOURCES

The PI must have a basic understanding of how to apply statistics in the analysis of performance data. The completion of this work should require 500 to 1000 hours of technician and engineer time. The cost should mainly be associated with the labor involved in collecting and analyzing the data.
Research Objective #1-C

Verification of Empirical Design Models For New Rigid Pavements

11/20/89
David E. Newcomb

BACKGROUND

The 1986 AASHTO Guide for the Design of Pavement Structures and the Mn/DOT Road Design Manual provide methods for the design of portland cement concrete surfaced roads. These procedures are based on the expected loss of serviceability of the road for a given level of traffic on different quality materials. They rely heavily on the performance data collected at the AASHO Road Test which was conducted in the late 1950's in Ottawa, Illinois. Over the course of time, changes have been made to the Minnesota design method based on observations of performance in the state; however, the basic relationships have been maintained. In the time since the Road Test, several changes have occurred in traffic characteristics. For instance, there is a greater frequency of trucks, carrying heavier loads with higher tire pressures. While it is obvious that changes should be made in the approach to pavement design, engineers have lacked the data to ascertain the effects of traffic changes.

PURPOSE

The purpose of this research would be to provide data for the validation or modification of the AASHTO and Mn/DOT design approaches for rigid pavements. The result of this effort would be the possible implementation of the updated design procedures at the state and local level in Minnesota. The study would be conducted by monitoring the performance of the portland cement concrete surfaced sections at the MRRP and comparing the actual performance to that predicted by the AASHTO and Mn/DOT methods.

APPROACH

The test cells which would be suitable for this purpose would be LVR-R-3 to -6, ML5-R-5 to -9, and ML10-R-10 to -13. Different quality materials for subbases will be incorporated into both the mainline and low-volume road experiments. Different schemes for subsurface drainage will be tried on the mainline experiment. The low-volume road will have two types of subgrade materials. There will be different traffic levels for the mainline 5- and 10-year experiments and the low-volume road. The mainline sections will be subjected to the mixed traffic of an actual interstate, and the low-volume road will have fixed traffic of known loads.

Surface distress and serviceability would be measured periodically
as traffic was applied to the sections. The relationships of these performance measurements to traffic levels and material qualities would be determined through regression analysis. Since there will only be one climate, the effect of climatic variables will have to be evaluated through results of satellite studies in Minnesota and other states.

Samples of portland cement concrete will be taken in order to test the modulus of rupture and modulus of elasticity as input to the AASHTO performance equation. Aggregate subbase and subgrade materials will be taken for characterization by resilient modulus testing during construction in order to determine the effective composite k-value. Measurements of drainage effectiveness will be made during the experiment in order to estimate the coefficient of drainage. Nondestructive deflection testing and the subsequent backcalculation of layer moduli will be done on a periodic basis in order to understand how changes in material properties affect the performance of rigid pavements. This testing will also indicate what value of load transfer factor is appropriate for Minnesota conditions.

Instrumentation is not necessary to perform this study, but the importance of measuring temperature and moisture contents at different depths (as a minimum) will be discussed in subsequent work plans. The need for placing response sensors in the roadway will also be discussed.

Specifications should be prepared for the production of the material and placement during construction by the Concrete Engineer. The MRRP manager will be responsible for the collection of the construction and periodic performance data.

RESOURCES

The PI must have a basic understanding of how to apply statistics in the analysis of performance data. The completion of this work should require 500 to 1000 hours of technician and engineer time. The cost should mainly be associated with the labor involved in collecting and analyzing the data.
Research Objective #1-D

Verification of Empirical Design Models For New Chip Seal Pavements

11/19/89
David E. Newcomb

BACKGROUND

The 1986 AASHTO Guide for the Design of Pavement Structures provides a method for the design of aggregate surfaced roads. This procedure is based on the loss of serviceability of the road and the depth of rutting expected for a given level of traffic on different quality materials in various climates. This approach is one of the few available to the practicing engineer which incorporates structural considerations into low volume road design. A variation on the idea of aggregate surfaced roads is the provision for placing a chip seal surface over the aggregate in order to waterproof the underlying materials. Currently there is very little data to indicate the effectiveness of this approach to low volume road design.

PURPOSE

The purpose of this research would be to provide data for the validation or modification of the AASHTO design approach for aggregate surfaced pavements protected by chip seal surfaces. The result of this effort would be the possible implementation of the AASHTO design procedure at the local government level in Minnesota. The study would be conducted by monitoring the performance of the chip seal sections at the MRRP and comparing the actual performance to that predicted by the AASHTO method.

APPROACH

The test cells which would be suitable for this purpose would be LVR-A-3 and LVR-A-4. One of these will be constructed with a clean aggregate base and the other will be built with an aggregate base having a higher percentage of material smaller than the No. 200 sieve. Thus, the base materials should have two distinct levels of strength. Also, the chip seals would incorporate two types of aggregate; one of which would be a pea rock (rounded material) and the other which would be a crushed material. In both sections the surface application would be a double chip seal.

Surface distress and serviceability would be measured periodically as traffic was applied to the sections. The relationships of these performance measurements to traffic levels, aggregate material properties, and surface aggregate characteristics would be determined through regression analysis. Since there will only be one climate and subgrade type available, these variables will have
to be evaluated through results of satellite studies in Minnesota and other states.

Samples will be taken during construction in order to characterize the resilient moduli of the subgrade and aggregate base materials as input required for the AASHTO design procedure. These should be tested in the saturated condition in frozen and thawed states as well as at optimum moisture content. To coincide with this, nondestructive testing with the falling weight deflectometer should be done periodically with subsequent backcalculation of layer moduli. Chip seal characteristics should be measured by Vialeet or other appropriate test method.

Instrumentation is not necessary to perform this study, but the importance of measuring temperature and moisture contents at different depths (as a minimum) will be discussed in subsequent work plans. The need for placing response sensors in the roadway will also be discussed.

Specifications need to be prepared for the production of the material and placement during construction. It is expected that Mn/DOT standards with a few modifications will suffice for this purpose. The MRRP manager will be responsible for the collection of the construction and periodic performance data.

RESOURCES

The PI must have a basic understanding of how to apply statistics in the analysis of performance data. The completion of this work should require 100 to 300 hours of technician and engineer time. The cost should mainly be associated with the labor involved in collecting and analyzing the data.
Research Objective #2-A

Development of Mechanistically Based Design Methods For Aggregate Surfaced Roads

12/11/89
David E. Newcomb

BACKGROUND

Approaches to the structural design of aggregate surfaced roads range from those based purely upon engineering judgement to those derived from empirical relationships. While these design practices have the force of history to support them, there is very little data to suggest that they are appropriate over a wide variety of conditions. The 1986 AASHTO Guide for the Design of Pavement Structures provides a method which is partially based on the distribution of stresses in the aggregate and soil layers. In this procedure, the primary parameters are the moduli of elasticity of the subgrade and the aggregate materials. The AASHTO approach accommodates seasonal changes in material properties, and uses the depth of rutting and loss of serviceability as failure criteria. While the AASHTO method is an advancement in the development of design procedures for aggregate surfaced roads, there is very little performance data to substantiate the failure criteria.

PURPOSE

The purpose of this research would be to provide the necessary data to validate and improve the AASHTO approach to the design of aggregate surfaced roads. Such data would include the measurements of stresses and deflections under loads in different seasons of the year. The results of this study would be the improvement of the existing AASHTO design equations or the development of new design criteria based on Minnesota conditions. The research would be performed by monitoring the load responses of aggregate surfaced sections at the MRRP, and analyzing these with respect to the performances of the pavement sections.

APPROACH

The test cells which would be suitable for this purpose would be LVR-A-1 through LVR-A-4. Two of these sections will have aggregate surfaces and the other two will have chip seal surfaces. The rationale for including the chip seal sections is that they may be treated mechanistically in the same manner as the aggregate surfaced pavements. The primary differences expected are that the chip seal sections will not have seasonal changes to the same degree as the aggregate surfaced sections, and that the chip seal sections will have a greater resistance to the shearing action of vehicle tires. Two types of aggregate materials will be used on both the aggregate surfaced and the chip seal surfaced sections.
One of these will be a clean aggregate with very little fine (minus No. 200) material and the other will have a moderate amount of fine material.

Rut depth and serviceability would be measured periodically as traffic was applied to the sections. One of the problems to be surmounted in the conduct of this research will be to determine a method for measuring the serviceability (rideability) of aggregate surfaces. Serviceability was a concept which has been well tested for asphalt and portland cement concrete surfaces, but not for aggregate surfaces.

Samples will be taken during construction in order to characterize the resilient moduli of the subgrade and aggregate surface materials. These should be tested in the saturated condition in frozen and thawed states as well as at optimum moisture content. To coincide with this, nondestructive testing with the falling weight deflectometer should be done periodically with subsequent backcalculation of layer moduli.

Instrumentation is necessary to perform this study with the primary emphasis on measuring temperature and moisture contents. The response of the pavements to load could be ascertained by measuring vertical deflections and stresses at various depths in the pavement structure. One possible instrumentation configuration is shown below.
Specifications need to be prepared for the production of the material and placement during construction. It is expected that Mn/DOT standards with a few modifications will suffice for this purpose. The MRRP manager will be responsible for the collection of the construction and periodic performance data.

RESOURCES

The PI must have a basic understanding of soil mechanics and of how to apply statistics in the analysis of performance data. The completion of this work should require 1000 to 1500 hours of technician and engineer time. The cost should mainly be associated with the labor involved in collecting and analyzing the data.
BACKGROUND

The primary means of designing flexible pavements for roadways are based upon empirical relationships between material properties, traffic, layer thicknesses, and performance. These relationships were valid for conditions which existed at the time of their development. The most famous of these came from the AASHO Road Test in the late 1950's. This performance equation has served to design most of the roadway pavements in this country for the last 30 years. Conditions have changed in the intervening time period and there has been no adjustment in the performance equation. For instance, only single and tandem axles were used at the Road Test and now tridem and drop axles are becoming more prevalent. Tire pressures used at the Road Test were on the order of 70 psi; whereas they are now on the order of 100 psi. Also, only conventional asphalt concrete surfaces were used at the AASHO Road Test and now modifiers are being used increasingly in mixtures. More rational approaches to thickness design are needed in order to readily accommodate future changes in traffic conditions and material types. Such approaches would have to be based on the physical response of the pavement (i.e., stress, strain, or deflection) as opposed to an empirical relationship.

PURPOSE

This research would result in the development of a mechanistic or empirical-mechanistic design procedure in which physical responses of the roadway such as stresses, strains, or deflections would be used along with some means of accounting for cumulative damage to the structure. The ultimate goal would be to incorporate models for stochastic processes such as changes in environmental conditions (moisture and temperature) and traffic loading into mechanistic analyses of pavement response.

APPROACH

The test cells which would be suitable for this purpose would be LVR-F-8 through LVR-F-15, ML5-F-1 through ML5-F-4, and ML10-F-14 through ML10-F-23. These pavements represent a range from thin conventional asphalt concrete surface over aggregate base to full-depth asphalt concrete. The traffic levels would vary from light truck traffic on the low volume sections to heavy interstate traffic over a 10-year period. Additionally, there would be two types of subgrades present; an AASHTO A-6 loam and an A-7 clay.
visual surveys and ride quality measurements would be taken periodically as traffic was applied to the sections. These will serve as measures of roadway performance to which the mechanistic parameters will be related. In other words, the visual surveys and ride quality measurements will serve to define the pavement failure.

Samples will be taken during construction in order to characterize the resilient moduli of the subgrade, aggregate materials, and asphalt concrete mixtures. The unbound subgrade and aggregates should be tested in the saturated condition in frozen and thawed states as well as at optimum moisture content. To coincide with this, nondestructive testing with the falling weight deflectometer should be done periodically with subsequent backcalculation of layer moduli.

Instrumentation is necessary to perform this study with the primary emphasis on measuring temperature and moisture contents. The response of the pavements to load could be ascertained by measuring vertical deflections, vertical stresses, and horizontal strains at various depths in the pavement structure. One possible instrumentation configuration is shown below.

![Instrumentation for LVR Conventional Sections](image-url)
Specifications need to be prepared for the production of the material and placement during construction. It is expected that Mn/DOT standards with a few modifications will suffice for this purpose. The MRRP manager will be responsible for the collection of the construction and periodic performance data.

RESOURCES

The PI must have a basic understanding of elastic analysis and of how to apply statistics in the analysis of performance data. The completion of this work should require 2000 to 2500 hours of technician and engineer time. The cost should mainly be associated with the labor involved in collecting and analyzing the data.
Researc::h Objective #2-C
Development of Mechanistically Based Design
Methods For Rigid Pavements

12/22/89
David E. Newcomb

BACKGROUND

Rigid pavements have historically been designed by quasi-mechanistic means. These approaches have their theoretical basis in work done by Westergaard and others in the time period of the 1920's to the 1940's. Over time, the mechanics have been integrated into empirical equations which describe the performance due not only to loading, but also to external factors such as drainage and load transfer capability. The AASHTO performance equation is an example of the combined empirical and mechanistic approach. However, it can be noted that neither stress, strain, nor deflection are considered directly in the relationship. Instead, parameters such as the concrete modulus of elasticity, modulus of rupture, and subgrade modulus of reaction are fitted to the observed performance of pavements at the AASHO Road Test (late 1950's). Conditions have changed in the intervening time period and no adjustment to the performance equation has been made to account for them. For instance, only single and tandem axles were used at the Road Test and now tridem and drop axles are becoming more prevalent. Also, only conventional PCC mixtures were used there; whereas now flyash is commonly used and other types of admixtures and additives are appearing with increasing frequency. More rational approaches to thickness design are needed in order to readily accommodate future changes in traffic conditions and material types. Such approaches would have to be based on the physical response of the pavement as opposed to an empirical relationship.

PURPOSE

This research would result in the development of a mechanistic or empirical-mechanistic design procedure in which physical responses of the roadway such as stresses, strains, or deflections would be used along with some means of accounting for cumulative damage to the structure. The ultimate goal would be to incorporate models for stochastic processes such as changes in environmental conditions (moisture and temperature) and traffic loading into mechanistic analyses of pavement response.

APPROACH

The test cells which would be suitable for this purpose would be LVR-R-3 through LVR-R-7, ML5-R-5 through ML5-R-9, and ML10-R-10 through ML10-R-13. These pavements represent a range from thin
Portland cement concrete surface over dense aggregate subbase to thick PCC surface over an open-graded drainage layer. A variety of design details are also represented such as dowel diameters, paving widths, panel lengths, and cross-section geometry. The traffic levels would vary from light truck traffic on the low volume sections to heavy interstate traffic over a 10-year period. Additionally, there would be two types of subgrades present: an AASHTO A-6 loam and an A-7 clay.

Visual surveys and ride quality measurements would be taken periodically as traffic was applied to the sections. These will serve as measures of roadway performance to which the mechanistic parameters will be related. In other words, the visual surveys and ride quality measurements will serve to define the pavement failure.

Samples will be taken during construction in order to characterize the subgrade, aggregate materials, and concrete mixtures. The unbound subgrade and aggregates should be tested in the saturated condition in frozen and thawed states as well as at optimum moisture content. To coincide with this, nondestructive testing with the falling weight deflectometer should be done periodically with subsequent backcalculation of layer moduli and joint efficiency calculations.

Instrumentation is necessary to perform this study with the primary emphasis on measuring temperature and moisture contents. The response of the pavements to load could be ascertained by measuring vertical deflections, vertical stresses, and horizontal strains at various depths in the pavement structure. One possible instrumentation configuration is shown below.

![Instrumentation Diagram](image-url)
Specifications need to be prepared for the production of the material and placement during construction. It is expected that Mn/DOT standards with a few modifications will suffice for this purpose. The MRRP manager will be responsible for the collection of the construction and periodic performance data.

RESOURCES

The PI must have a basic understanding of elastic analysis and of how to apply statistics in the analysis of performance data. The completion of this work should require 2000 to 2500 hours of technician and engineer time. The cost should mainly be associated with the labor involved in collecting and analyzing the data.
Research Objective #3-A
Development of Improved Mechanistic Models
For Aggregate Surfaced Roads
1/24/90
David E. Newcomb

BACKGROUND

Mechanistic models are mathematical representations of systems as explained by physical laws and theories. Models currently used in pavement analysis fall into two categories: continuum mechanics and finite elements.

Layered elastic theory is a special case of continuum mechanics which has its origins in Boussinesq analysis; widely applied in soil mechanics. As the names of the theory (elastic) and the approach (continuum) suggest, there are restrictions on the consideration of material behavior and geometry. Whatever deformation occurs in the system is assumed to be fully recoverable and the layers are assumed to extend infinitely in the horizontal direction. Furthermore, this approach is restricted to static loads only.

The finite element method allows for a closer approximation of actual system behavior since irregular geometry, unusual boundary conditions, and anisotropy can be accommodated. FEM is also well suited to considering dynamic loading conditions both in terms of material properties and boundary conditions. As applied to pavement analysis, the FEM is normally restricted to static loads and elastic materials. However, there have been efforts to incorporate nonlinear material responses such as stress sensitivity of granular materials.

In pavements, there is a great deal of interaction between the materials present in the system, the traffic loads being supported, and the environmental conditions. In order to accurately simulate the system as it behaves in fact will require substantially more complicated models.

PURPOSE

The purpose of this research is to develop a comprehensive model to describe the behavior of aggregate surfaced roadways. Considering that the predominant mode of failure in aggregate surfaced roads is permanent deformation, the resulting mechanistic model would probably be an elastic-plastic analysis with dynamic loading.

APPROACH

The test cells which would be suitable for this purpose would be
LVR-A-1 through LVR-A-4. Two of these sections will have aggregate surfaces and the other two will have chip seal surfaces. The rationale for including the chip seal sections is that they may be treated mechanistically in the same manner as the aggregate surfaced pavements. The primary differences expected are that the chip seal sections will not have seasonal changes to the same degree as the aggregate surfaced sections, and that the chip seal sections will have a greater resistance to the shearing action of vehicle tires. Two types of aggregate materials will be used on both the aggregate surfaced and the chip seal surfaced sections. One of these will be a clean aggregate with very little fine (minus No. 200) material and the other will have a moderate amount of fine material.

Samples will be taken during construction in order to characterize the subgrade and aggregate surface materials. These should be tested in the saturated condition in frozen and thawed states as well as at optimum moisture content. To coincide with this, nondestructive testing with the falling weight deflectometer should be done periodically with subsequent backcalculation of layer moduli. These results will be used as input for material characteristics in the models.

Instrumentation is necessary to perform this study with the primary emphasis on measuring temperature and moisture contents. The response of the pavements to load could be ascertained by measuring vertical deflections and stresses at various depths in the pavement structure. These measurements will serve as a means of verifying the results of the model. One possible instrumentation configuration is shown below.

Instrumentation for LVR Aggregate Surface Sections

Legend
- Thermocouple
- LVDT
- Pressure Cell
- Sine Stress Gage
- Embankment Stress Gage
- Moisture Sensor
- Thermocouple

Plan

Crossection

Profile

21
Specifications need to be prepared for the production of the material and placement during construction. It is expected that Mn/DOT standards with a few modifications will suffice for this purpose. The MRRP manager will be responsible for the collection of the construction and periodic performance data.

RESOURCES

The PI must have an understanding of mathematical modeling techniques and pavement design and performance. The completion of this work should require 1000 to 1500 hours of technician and engineer time. The cost should mainly be associated with the labor involved in developing the model and verifying the results.
Research Objective #3-B
Development of Improved Mechanistic Models For Flexible Pavements
1/24/90
David E. Newcomb

BACKGROUND

Mechanistic models are mathematical representations of systems as explained by physical laws and theories. Models currently used in pavement analysis fall into two categories: continuum mechanics and finite elements.

Layered elastic theory is a special case of continuum mechanics which has its origins in Boussinesq analysis; widely applied in soil mechanics. As the names of the theory (elastic) and the approach (continuum) suggest, there are restrictions on the consideration of material behavior and geometry. Whatever deformation occurs in the system is assumed to be fully recoverable and the layers are assumed to extend infinitely in the horizontal direction. Furthermore, this approach is restricted to static loads only.

The finite element method allows for a closer approximation of actual system behavior since irregular geometry, unusual boundary conditions, and anisotropy can be accommodated. FEM is also well suited to considering dynamic loading conditions both in terms of material properties and boundary conditions. As applied to pavement analysis, the FEM is normally restricted to static loads and elastic materials. However, there have been efforts to incorporate nonlinear material responses such as stress sensitivity of granular materials.

In pavements, there is a great deal of interaction between the materials present in the system, the traffic loads being supported, and the environmental conditions. In order to accurately simulate the system as it behaves in fact will require substantially more complicated models.

PURPOSE

The purpose of this research is to develop a comprehensive model to describe the behavior of flexible pavements. Considering that the predominant modes of load related failure in flexible pavements are permanent deformation and fatigue cracking, the resulting mechanistic model would probably be a viscoelastic analysis with dynamic loading.
The test cells which would be suitable for this purpose would be LVR-F-8 through LVR-F-15, ML5-F-1 through ML5-F-4, and ML10-F-14 through ML10-F-23. These pavements represent a range from thin conventional asphalt concrete surface over aggregate base to full-depth asphalt concrete. The traffic levels would vary from light truck traffic on the low volume sections to heavy interstate traffic over a 10-year period. Additionally, there would be two types of subgrades present; an AASHTO A-6 loam and an A-7 clay.

Samples will be taken during construction in order to characterize the subgrade, aggregate materials, and asphalt concrete mixtures. The unbound subgrade and aggregates should be tested in the saturated condition in frozen and thawed states as well as at optimum moisture content. To coincide with this, nondestructive testing with the falling weight deflectometer should be done periodically with subsequent backcalculation of layer moduli. These results will be used as input for material characteristics in the models.

Instrumentation is necessary to perform this study with the primary emphasis on measuring temperature and moisture contents. The response of the pavements to load could be ascertained by measuring vertical deflections, vertical stresses, and horizontal strains at various depths in the pavement structure. These measurements will serve as a means of verifying the results of the model. One possible instrumentation configuration is shown below.
Specifications need to be prepared for the production of the material and placement during construction. It is expected that Mn/DOT standards with a few modifications will suffice for this purpose. The MRRP manager will be responsible for the collection of the construction and periodic performance data.

RESOURCES

The PI must have an understanding of mathematical modeling techniques and pavement design and performance. The completion of this work should require 1000 to 1500 hours of technician and engineer time. The cost should mainly be associated with the labor involved in developing the model and verifying the results.
BACKGROUND

Mechanistic models are mathematical representations of systems as explained by physical laws and theories. Models currently used in pavement analysis fall into two categories: continuum mechanics and finite elements.

Layered elastic theory is a special case of continuum mechanics which has its origins in Boussinesq analysis; widely applied in soil mechanics. As the names of the theory (elastic) and the approach (continuum) suggest, there are restrictions on the consideration of material behavior and geometry. Whatever deformation occurs in the system is assumed to be fully recoverable and the layers are assumed to extend infinitely in the horizontal direction. Furthermore, this approach is restricted to static loads only.

The finite element method allows for a closer approximation of actual system behavior since irregular geometry, unusual boundary conditions, and anisotropy can be accommodated. FEM is also well suited to considering dynamic loading conditions both in terms of material properties and boundary conditions. As applied to pavement analysis, the FEM is normally restricted to static loads and elastic materials. However, there have been efforts to incorporate nonlinear material responses such as stress sensitivity of granular materials.

In pavements, there is a great deal of interaction between the materials present in the system, the traffic loads being supported, and the environmental conditions. In order to accurately simulate the system as it behaves in fact will require substantially more complicated models.

PURPOSE

The purpose of this research is to develop a comprehensive model to describe the behavior of rigid pavements. Considering that the predominant modes of load related failure in rigid pavements are slab cracking and joint faulting, the resulting mechanistic model would probably be an elastic analysis with dynamic loading.

APPROACH

The test cells which would be suitable for this purpose would be
LVR-R-3 through LVR-R-7, ML5-R-5 through ML5-R-9, and ML10-R-10 through ML10-R-13. These pavements represent a range from thin portland cement concrete surface over dense aggregate subbase to thick PCC surface over an open-graded drainage layer. A variety of design details are also represented such as dowel diameters, paving widths, panel lengths, and cross-section geometry. The traffic levels would vary from light truck traffic on the low volume sections to heavy interstate traffic over a 10-year period. Additionally, there would be two types of subgrades present: an AASHTO A-6 loam and an A-7 clay.

Samples will be taken during construction in order to characterize the subgrade, aggregate materials, and concrete mixtures. The unbound subgrade and aggregates should be tested in the saturated condition in frozen and thawed states as well as at optimum moisture content. To coincide with this, nondestructive testing with the falling weight deflectometer should be done periodically with subsequent backcalculation of layer moduli and joint efficiency calculations. These results will be used as inputs for the model.

Instrumentation is necessary to perform this study with the primary emphasis on measuring temperature and moisture contents. The response of the pavements to load could be ascertained by measuring vertical deflections, vertical stresses, and horizontal strains at various depths in the pavement structure. These measurements will serve as a means of verifying the results of the model. One possible instrumentation configuration is shown below.

**MRP SECTION ML10-R-10 - STRAIN GAGES**

<table>
<thead>
<tr>
<th>Cell A</th>
<th>6 permanent plus 16 periodic embedment gages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell B</td>
<td>16 periodic embedment gages</td>
</tr>
<tr>
<td>Cell C</td>
<td>16 periodic embedment gages</td>
</tr>
<tr>
<td>Cell D</td>
<td>16 vibrating wire strain gages</td>
</tr>
<tr>
<td>Joints AB/BE</td>
<td>10 steel strain gages</td>
</tr>
</tbody>
</table>

(a) Plan View

(b) Side View
Specifications need to be prepared for the production of the material and placement during construction. It is expected that Mn/DOT standards with a few modifications will suffice for this purpose. The MRRP manager will be responsible for the collection of the construction and periodic performance data.

RESOURCES

The PI must have an understanding of mathematical modeling techniques and pavement design and performance. The completion of this work should require 2000 to 2500 hours of technician and engineer time. The cost should mainly be associated with the labor involved in developing the model and verifying the results.
Research Objective #4

Verification/Improved Frost Action Prediction Methodology

10/5/89
David M. Johnson

BACKGROUND

One of the most critical transportation engineering issues to be dealt with in Minnesota's climate is the effect of the freezing and thawing of moisture in pavement structures and roadbeds. Freezing can cause heaving of the pavement structures, yet frozen materials can be stronger than the same material unfrozen. The thawing process reduces the ability of base/subbases and subgrades to support loads.

Because several base/subbase aggregates, two subgrade soils, and two drainage systems will be used at the MRRP, frost behavior of a variety of materials and conditions can be measured during freeze and thaw periods. The freeze and thaw processes are made even more complex by real world conditions. For instance within a given season temperatures can fluctuate dramatically and the introduction of deicing chemicals can reduce the freezing temperature of water.

The handling of frost action by the 1986 AASHTO Guide for Design of Pavement Structures depends to a large extent on the performance of rigid and flexible pavements at the AASHO Road Test. The guide recognizes "that experience in some northern tier states and Alaska may indicate that alternative procedures can be used." In 1987 "A Freeze-Thaw Test to Determine the Frost Susceptibility of Soils", CRREL Special Report 87-1 by Edwin J. Chamberlain proposed a new method of dealing with frost action.

Fully understanding the effects of frost on pavement performance has the potential to significantly advance pavement design, rehabilitation, and analysis. As a consequence it is one of the major objectives of the MRRP experiment.

PURPOSE

The purpose of this study is to verify or modify the new CRREL methods for predicting frost heave and thaw weakening. This will lead to the real time prediction of aggregate and soil moduli relative to the environmental regime they are exposed to. This will be useful in establishing load restrictions and limits.

APPROACH

Both field and laboratory testing will be conducted to support the study. Potentially all MRRP cells may be used for field testing of thaw weakening. All flexible and rigid pavement cells could be
used to test frost heaving.

A column of moisture and temperature sensors will be placed in each MRRP cell as part of an overall instrumentation scheme. Also sensors will be installed to measure moisture resistivity, an indication of the true freezing point of water. These sensors will be monitored to determine critical frost conditions in the pavement structure and roadbed when accelerated damage occurs. In addition vertical pavement surface heaving will be determined using precise surveying measurements from frost free benchmarks, LVDT's, or frost heave plates. The non-destructive strength measurements will be made using an FWD.

Laboratory testing will be conducted on base/subbase aggregates and soil samples acquired from MRRP cells in accordance with the new CRREL freezing test.

The analysis will consist of correlating field results to laboratory results and comparing this model to the one CRREL obtained.

A report will be written after the MRRP cells have been tested through one winter (freeze) and one spring (thaw). At that point in time it will be determined what (if any) additional testing, analysis, and reporting should be done.

RESOURCES

About 500 hours will be required to complete the initial testing, analysis, and reporting. Moisture, temperature, resistivity, and heave instrumentation and data collection will be provided through MRRP resources. Additional resources will be available from CRREL to conduct the laboratory testing.
Research Objective #5

Influence of Axle Load Magnitude Upon Pavement Performance Under Critical Spring Thaw Conditions

10/16/89
Harris B. Baker

BACKGROUND

The development of this research objective occurred during several meetings with Minnesota local road representatives who discussed and ranked their pavement research needs. This objective was ranked most important due to the lack of information regarding the effects of heavier allowable axle loads (9 to 14-ton), particularly during the critical spring thaw period. Spring load restrictions are generally applied more extensively by local government agencies because of lower ADT's, thus weaker designs. However, both primary and secondary flexible trunk highways experience the same problem when constructed over frost susceptible clay or silt subgrades. The current practice for imposing spring weight restrictions varies with each agency. It usually is determined by experience or political pressure. General guidelines have been developed to estimate load reduction magnitude and when to apply and remove load restrictions based on air temperature data. However, these guidelines- are rarely used due to the wide range of in-situ conditions. There is a need to refine current practices and evaluate new options to make guidelines more applicable to any given site. An easily implemented procedure is needed to help in the load restriction decision making process and give documented support to decisions made. Local agencies need their maintenance money for work other than fixing structural failures caused by heavy loads during spring thaw each year. State agencies also need a more absolute method of determining spring load restriction needs.

PURPOSE

The purpose of this research objective is to improve the current practice of establishing where and when to apply spring load restrictions as well as the duration and magnitude of the load reduction.

APPROACH

The performance of all of the Low Volume Road (LVR) cells will be incorporated into this study. Damage during spring thaw is proportional to axle weight and number of axle load repetitions. Specific single axle load repetitions (10 and 15-ton) will be induced on the LVR segment of the MRRP facility. Instrumentation including moisture, temperature, and salinity sensors, strain gauges, pressure cells, and linear variable displacement
transducers (LVDT's) will be installed in each cell. The effects of the heavy axle loads will be monitored and evaluated in several simultaneous studies, each with a different objective. Specific inferences will be drawn regarding damage done during spring thaw. NDT applied to the cells will include FWD's and the profilometer. Visual surveys of pavement condition will be conducted frequently during the critical spring thaw period. Weather data will be incorporated in the analysis.

The preliminary emphasis will be an attempt to relate FWD and weather data to structural failures. Percentage decreases in FWD measurements from summer to spring will be noted as each cell is driven to failure.

As cells fail, different pavement sections will be constructed and loaded to failure with the same load magnitudes or vice versa, thus perpetuating the load restriction refining process and revealing the most cost effective designs for problem areas. An interim report will be written in 2 years and a final report in 5 years.

RESOURCES

The principal investigator will be performing complex analyses of datum relationships between as-built design, load magnitude and repetitions, instrument and NDT measurements, and weather. Including report writing, it will take an estimated 2000 hours to complete this study. The instrumentation (temperature, moisture, and salinity sensors, strain gauges, LVDT's, and pressure cells) will be purchased and installed under a MRRP contract and will coincide with other studies. The only unique monitoring required by this study may be an increase in the frequency of FWD testing and visual surveys during the critical spring thaw period.
Research Objective #6-A
Development of Vehicle Load Damage Factors
For Aggregate Surfaced Roads
1/25/90
David E. Newcomb

BACKGROUND

Load equivalency factors provide a means for equating the damage done by various vehicle weights and tire configurations to that of a standard weight and configuration. In the AASHTO pavement design procedure, this is the 18,000-lb equivalent single axle load (ESAL). As the name suggests, this is a single axle with dual tires inflated to 70 psi at a weight of 18,000 lbs. This concept originated at the AASHO Road Test where single axles and tandem axles with dual tires were used to load the pavements. In the pavement design process, the load equivalency factors are listed for pavements of the same structural capacity and terminal serviceability index. While these are widely used in the design of pavements, there are some deficiencies inherent in them. First, the loads considered are for static weights and thus, the contribution of different suspension systems cannot be included. Second, the tire type used at the AASHO Road Test was a bias ply tire, and the current trend is toward radial tires which have different pressure distributions. The inflation pressure used for the ESAL was 70 psi, while most trucks use about 100 psi today. A dual tire configuration of standard size tires was used in the development of the ESAL; whereas now such configurations as super singles and high-cube (small tires, high pressure) tires are appearing. Lastly, the axle configurations now include tridem axles and drop axles.

PURPOSE

The purpose of this research would be to provide estimates of damage caused by different vehicle loading systems. This could be done by driving vehicles over instrumented pavements and monitoring the reactions to the loads. These experiments could be done on an as-needed basis using the low-volume road sections. By knowing the response of the pavement to the load, a mechanistic analysis could be performed to ascertain the effect of the load on pavement life.

APPROACH

The test cells which would be suitable for this purpose would be LVR-A-1 through LVR-A-4. Two of these sections will have aggregate surfaces and the other two will have chip seal surfaces. The rationale for including the chip seal sections is that they may be treated mechanistically in the same manner as the aggregate surfaced pavements. The primary differences expected are that the
chip seal sections will not have seasonal changes to the same degree as the aggregate surfaced sections, and that the chip seal sections will have a greater resistance to the shearing action of vehicle tires. Two types of aggregate materials will be used on both the aggregate surfaced and the chip seal surfaced sections. One of these will be a clean aggregate with very little fine (minus No. 200) material and the other will have a moderate amount of fine material.

The primary concern about vehicle loading systems on aggregate pavements would be in terms of how the measured responses correlated to rut depth and corrugations in the surface. This may require the use of existing failure criteria since there will not be enough time to fail the pavements in this study. Instrumentation is necessary to perform this study with the primary emphasis on measuring temperature and moisture contents. The response of the pavements to load could be ascertained by measuring vertical deflections and stresses at various depths in the pavement structure. One possible instrumentation configuration is shown below.

RESOURCES

The PI must have a basic understanding of soil mechanics and of how to relate the measured pavement responses to the expected performance of the pavement. The completion of this work could require 200 to 1000 hours of technician and engineer time. The cost should mainly be associated with the labor involved in collecting and analyzing the data.
Research Objective #6-B  
Development of Vehicle Load Damage Factors  
Flexible Pavements  

1/25/90  
David E. Newcomb  

BACKGROUND  

Load equivalency factors provide a means for equating the damage done by various vehicle weights and tire configurations to that of a standard weight and configuration. In the AASHTO pavement design procedure, this is the 18,000-lb equivalent single axle load (ESAL). As the name suggests, this is a single axle with dual tires inflated to 70 psi at a weight of 18,000 lbs. This concept originated at the AASHO Road Test where single axles and tandem axles with dual tires were used to load the pavements. In the pavement design process, the load equivalency factors are listed for pavements of the same structural capacity and terminal serviceability index. While these are widely used in the design of pavements, there are some deficiencies inherent in them. First, the loads considered are for static weights and thus, the contribution of different suspension systems cannot be included. Second, the tire type used at the AASHO Road Test was a bias ply tire, and the current trend is toward radial tires which have different pressure distributions. The inflation pressure used for the ESAL was 70 psi, while most trucks use about 100 psi today. A dual tire configuration of standard size tires was used in the development of the ESAL; whereas now such configurations as super singles and high-cube (small tires, high pressure) tires are appearing. Lastly, the axle configurations now include tridem axles and drop axles.

PURPOSE  

The purpose of this research would be to provide estimates of flexible pavement damage caused by different vehicle loading systems. This could be done by driving vehicles over instrumented pavements and monitoring the reactions to the loads. These experiments could be done on an as-needed basis using the low-volume road sections. By knowing the response of the pavement to the load, a mechanistic analysis could be performed to ascertain the effect of the load on pavement life.

APPROACH  

The test cells which would be suitable for this purpose would be LVR-F-8 through LVR-F-15. These pavements represent a range from thin conventional asphalt concrete surface over aggregate base to full-depth asphalt concrete. Additionally, there would be two types of subgrades present: an AASHTO A-6 loam and an A-7 clay.
The primary concern about vehicle loading systems on flexible pavements would be in terms of how the measured responses correlated to rut depth and fatigue cracking. This may require the use of existing failure criteria since there will not be enough time to fail the pavements in this study. Instrumentation is necessary to perform this study with the primary emphasis on measuring temperature and moisture contents. The response of the pavements to load could be ascertained by measuring vertical deflections, vertical stresses, and horizontal strains at various depths in the pavement structure. One possible instrumentation configuration is shown below.

**Instrumentation for LTP Conventional Sections**

<table>
<thead>
<tr>
<th>Cross-section</th>
<th>Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="" alt="Instrumentation Diagram" /></td>
<td></td>
</tr>
</tbody>
</table>

**RESOURCES**

The PI must have a basic understanding of layered elastic theory and of how to relate the measured pavement responses to the expected performance of the pavement. The completion of this work could require 200 to 1500 hours of technician and engineer time. The cost should mainly be associated with the labor involved in collecting and analyzing the data.
Research Objective #6-C
Development of Vehicle Load Damage Factors For Rigid Pavements

1/25/90
David E. Newcomb

BACKGROUND

Load equivalency factors provide a means for equating the damage done by various vehicle weights and tire configurations to that of a standard weight and configuration. In the AASHTO pavement design procedure, this is the 18,000-lb equivalent single axle load (ESAL). As the name suggests, this is a single axle with dual tires inflated to 70 psi at a weight of 18,000 lbs. This concept originated at the AASHO Road Test where single axles and tandem axles with dual tires were used to load the pavements. In the pavement design process, the load equivalency factors are listed for pavements of the same structural capacity and terminal serviceability index. While these are widely used in the design of pavements, there are some deficiencies inherent in them. First, the loads considered are for static weights and thus, the contribution of different suspension systems cannot be included. Second, the tire type used at the AASHO Road Test was a bias ply tire, and the current trend is toward radial tires which have different pressure distributions. The inflation pressure used for the ESAL was 70 psi, while most trucks use about 100 psi today. A dual tire configuration of standard size tires was used in the development of the ESAL; whereas now such configurations as super singles and high-cube (small tires, high pressure) tires are appearing. Lastly, the axle configurations now include tridem axles and drop axles.

PURPOSE

The purpose of this research would be to provide estimates of rigid pavement damage caused by different vehicle loading systems. This could be done by driving vehicles over instrumented pavements and monitoring the reactions to the loads. These experiments could be done on an as-needed basis using the low-volume road sections. By knowing the response of the pavement to the load, a mechanistic analysis could be performed to ascertain the effect of the load on pavement life.

APPROACH

The test cells which would be suitable for this purpose would be LVR-R-3 through LVR-R-7. A variety of design details are represented in these pavements such as the presence of dowels, panel lengths, and cross-section geometry. Additionally, there would be two types of subgrades present: an AASHTO A-6 loam and an A-7 clay.
The primary concern about vehicle loading systems on rigid pavements would be in terms of how the measured responses correlated to mid-panel and corner cracking. This may require the use of existing failure criteria since there will not be enough time to fail the pavements in this study. Instrumentation is necessary to perform this study with the primary emphasis on measuring temperature and moisture contents. The response of the pavements to load could be ascertained by measuring vertical deflections, vertical stresses, and horizontal strains at various depths in the pavement structure. One possible instrumentation configuration is shown below.

RESOURCES

The PI must have a basic understanding of layered elastic theory and of how to relate the measured pavement responses to the expected performance of the pavement. The completion of this work could require 200 to 1500 hours of technician and engineer time. The cost should mainly be associated with the labor involved in collecting and analyzing the data.
Research Objective #7

Influence of New Vehicle Gear Configurations and Tire Systems on Pavement Performance

10/9/89
David M. Johnson

BACKGROUND

New heavy vehicle designs are coming down the road faster than we can fully understand the effects of the current designs on our pavements. Under empirical pavement design methods traffic loadings are generalized (ESALs and CESALs). However as we develop the mechanistic approach to pavement design we require more specific knowledge about the effects of traffic loadings on pavement structures. In addition there has been increasing pressure from the trucking industry to permit new and heavier vehicles on our roadways. For these reasons the MRRP facility with its strong emphasis on pavement instrumentation will be used to perform thorough analyses of the effects of new and heavy traffic loadings on concrete, bituminous, and aggregate surfaced roads.

PURPOSE

The 2 purposes of this study are to:

(1) determine the effects of various permitted gear-tire-load systems on pavement structures as part of the development of a mechanistic method for pavement design.

(2) test gear-tire-load systems that are not currently permitted in order to determine the cost of their effects on pavement structures.

APPROACH

(1) Real world gear-tire-load systems will be monitored on the mainline cells and specially configured systems will be tested on the low volume road cells. The measurement of the strains and deflections of the well instrumented cells under a variety of conditions will lead to a basic mechanistic understanding of the effect of heavy traffic loadings on pavement structure. This knowledge will support MRRP objective #2, the development of mechanistically based pavement design methods.

(2) Non-permitted gear-tire-load systems will be driven on the low volume road test cells. Some of these cells will be heavily instrumented to capture strains and deflections in the pavement structures under various conditions. These responses will undergo a mechanistic analysis to predict the effect of the systems on pavement life. This will allow realistic costs to be associated
with permits.

RESOURCES

(1) Because this part of the study supports other MRRP studies it is important that it be completed early on. An interim report will be completed after 1 year and a final report will be written at the conclusion of this 2 year study. A person with a strong understanding of the mechanistic performance of pavement structures will spend about 2000 hours on this part of the study.

(2) A person with a strong understanding of the mechanistic performance of pavement structures will spend an additional 2000 hours during the life of the low volume road cells evaluating about 15 basic non-permitted gear-tire-load systems. A cost analysis report will be written at the completion of each system evaluation. A final report will be written at the completion of this 3 year study.

Several MRRP cells will be heavily instrumented under a MRRP contract to support both parts of this study. MRRP will provide resources to support the collection of relevant data.
Research Objective #8

Influence of Asphalt Concrete Mixtures Properties Upon Distress/Performance

BACKGROUND

Asphalt concrete mixture properties can do much to dictate the performance of a pavement. Deficiencies in mixture parameters or properties can lead to early failure and, thus, expensive repairs. It is known, for example, that fatigue life decreases by about 10 percent for each one percent increase in air voids. Low air voids and high asphalt content are responsible for rutting in bituminous pavements. High air voids and the use of temperature susceptible asphalt cement can lead to a mixture with a tendency toward frequent thermal cracking. While these general rules serve to remind one of the implications of mixture parameters, they do not allow for the quantification of their effects.

PURPOSE

The purpose of this research project is to examine the impact of mixture properties on pavement performance. The mixture properties which will be varied include:

1) asphalt cement type,
2) asphalt cement temperature susceptibility,
3) air voids in the mixture, and
4) mixture asphalt content.

The types of distress which will be of primary concern include:

1) permanent deformation,
2) fatigue cracking,
3) thermal cracking,
4) aging, and
5) stripping/moisture susceptibility.

The goal of this project should be the quantification of pavement life reduction due to deficiencies in mixture parameters. At some point in the research, it is conceivable that pay adjustment factors might be developed to reimburse the agency for reduced pavement life.

APPROACH

The work plan for various cells is divided according to the specific type of distress. In order to properly ascertain the effects of mixture parameters on performance, it will be necessary to monitor the performance over a range of traffic. Thus, elements of all three roadways will be used.
1) Permanent Deformation: Rutting can result from the permanent displacement of the surface or any of the pavement sublayers. If the permanent deformation occurs primarily in the surface, then it is due to material movements brought about by excessive shear strains. These are difficult to measure and the methods for measuring them are not proven except for materials such as metals. Another method for measuring permanent displacement in asphalt concrete is to use an inclinometer. The use of the multidepth deflectometer (MDD) to measure the vertical permanent strain is also a possibility. It would be best to restrict the shear strain measurements to the Low Volume Road experiment, specifically:

LVR-F-9
LVR-F-10

Transient deflection measurements could be made by means of geophones on the mainline section:

ML5-F-4
ML10-F-14
ML10-F-15

2) Fatigue Cracking: Failure in the fatigue mode is the result of repeated tensile strains at the bottom of the surface layer. These strains can be caused by conditions which make the surface to base interface vulnerable, such as a spring thaw condition in which the subgrade is frozen and the base course is saturated. The measurement of tensile strains can be accomplished by embedment strain gages placed in the wheelpaths. These gages are oriented perpendicular to the direction of traffic. Vertical deflections may be used to indirectly infer the fatigue behavior of pavements. When selecting sections for this study, it would be important to consider differences in traffic levels, asphalt concrete thickness, and material properties. Sections which would be suitable for fatigue cracking studies include:

ML5-F-1
ML5-F-4
ML10-F-14
ML10-F-16
ML10-F-21
ML10-F-22
LVR-F-9
LVR-F-10
LVR-F-11
LVR-F-12
LVR-F-13
LVR-F-14

3) Thermal Cracking: Transverse, block, or thermal cracks appear in pavements when the cycle of daily temperature is such that thermal stressed produced is greater than the tensile strength of the asphalt mixture. The appearance of these cracks does not indicate a structural failure of the pavement. Rather, they are
related to the rate of deterioration of pavement layers due to weakening caused by moisture infiltration into the asphalt concrete layer or the sublayers. The factors which may influence the amount and severity of thermal cracking are: a) properties of asphalt cement, b) voids in the asphalt mixture, c) type of subgrade, d) thickness of the surface layer, and d) traffic level. Electrical resistance tape could be used to monitor the time of cracking in pavements and LVDT's could be used for measuring crack openings. As a back-up device, gage points set in the pavement surface could also be used. Sections suitable for instrumentation include:

ML5-F-1
ML5-F-2
ML5-F-4
ML10-F-14
ML10-F-15
ML10-F-16
ML10-F-18
LVR-F-8
LVR-F-9
LVR-F-10
LVR-F-11
LVR-F-12

4) Aging: The embrittlement of asphalt cement over time is referred to as aging. This is primarily due to the oxidation of some of the polar chemical fractions in the asphalt. The detriment from this behavior is that asphalt mixtures will tend to be more susceptible to temperature and load related cracking. Factors which can contribute to the aging process include: a) the temperature susceptibility of the asphalt, b) the percent air voids in the mixture, and c) the original consistency of the asphalt cement. The only sure method of tracking the aging process is to take samples from the pavement at given intervals, extract and recover the asphalt cement, and measure the viscosity and/or penetration. Sections suitable for a study on aging include:

ML5-F-1
ML5-F-2
ML5-F-3
ML5-F-4
ML10-F-17
ML10-F-18
ML10-F-19
ML10-F-20
ML10-F-14
ML10-F-15
LVR-F-14
LVR-F-10

5) Stripping/Moisture Susceptibility: The moisture sensitivity of mixtures is important in that it can lead to a loss of cohesion in the surface material. This lack of cohesion can translate to a number of types of distresses, including: 1) fatigue cracking, 2) rutting, and 3) ravelling. The potential for
stripping is usually assessed prior to construction by means of water conditioning laboratory compacted samples and testing the material before and after conditioning. The loss of strength or resilient modulus is then related to the water sensitivity. Contributing factors in the stripping potential of mixtures include: a) high air voids, b) low-viscosity asphalt, c) temperature susceptible asphalt, d) absorptive aggregate, and e) siliceous aggregate. In-situ instrumentation is not suited to measuring this type of problem. Sections which might be used in this study include:

ML5-F-1
ML5-F-2
ML5-F-3
ML5-F-4
ML10-F-17
ML10-F-18
ML10-F-19
ML10-F-20
ML10-F-14
ML10-F-15
LVR-F-14
LVR-F-10

RESOURCES

1) Permanent Deformation
   a) Personnel: 1 Engineer @ 30%
      1 Technician @ 30%
   b) Time: 5 years
   c) Equipment: 20 strain gages
      5 inclinometers
      10 MDD's with 3 LVDT's each
      20 Accelerometers
   d) Funding: $200,000

2) Fatigue Cracking
   a) Personnel: 1 Engineer @ 30%
      1 Technician @ 30%
   b) Time: 5 years
   c) Equipment: 75 strain gages
      10 MDD's with 3 LVDT's each
      20 Accelerometers
   d) Funding: $250,000
3) Thermal Cracking
   a) Personnel: 1 Engineer @ 20%
                  1 Technician @ 30%
   b) Time: 3 years
   c) Equipment: 1000 ft. electrical resistance tape
   d) Funding: $100,000

4) Aging
   a) Personnel: 1 Engineer @ 5%
                  1 Technician @ 15%
   b) Time: 10 years
   c) Equipment: None
   d) Funding: $50,000

5) Stripping/Moisture Sensitivity
   a) Personnel: 1 Engineer @ 20%
                  1 Technician @ 40%
   b) Time: 5 years
   c) Equipment: None
   d) Funding: $150,000
Research Objective #9
Influence of Unbound Granular Base/Subbase Properties Upon Flexible Pavement Performance/Distress
10/10/89
Harris B. Baker

BACKGROUND

At the MPRP facility, a wide variety of untreated aggregate base/subbase types have been selected for use in both the LVR and Mainline bituminous surfaced experimental cells. These materials range from "open graded" to a "dirty sand gravel". A wide range of performance is expected from the different aggregates relative to strength, modulus, drainage, and frost susceptibility. A great deal of information can be obtained regarding the influence of the different base/subbase layers on each pavement system.

PURPOSE

The purpose of this research objective is to gain a deeper insight into the properties of materials used for base/subbase so that we may establish:
1. Better characterizations of material strength, response to stress/strain, and frost susceptibility, which should lead to more accurate predictive pavement models,
2. More confidence relating field NDT to laboratory testing, and
3. Further categorization of aggregate types.

APPROACH

All flexible pavement cells with base/subbase (3 ML5 + 8 ML10 + 6 LVR = 17 cells) will be monitored to evaluate base/subbase performance. Materials will be inspected and tested extensively prior to and at the time of placement (gradation, maximum density and moisture content, liquid limit, plasticity index, CBR, R-value, repeated triaxial load (resilient modulus), abrasion, permeability, etc.). Instrumentation including moisture, temperature, and salinity sensors will be installed in each cell. Cells ML10 F-18 & F-23 will need tipping buckets to monitor outflow from edge drains. NDT applied to the cells will include FWD's and the profilometer. Visual surveys of pavement condition will be conducted. After the life of the cell the pavement will be removed and the base/subbase will be inspected and tested.

Traffic and weather data will be incorporated in the analysis.

An interim report will be written in 5 years and a final report in 10 years.
RESOURCES

The principal investigator will be performing complex analyses of the soil-aggregate mixtures which, along with report writing, will take an estimated 2000 hours. About 102 moisture sensors, 102 temperature sensors, 2 tipping buckets, and a not-yet-determined amount of salinity sensors will be purchased and installed under a MRRP contract.
Research Objective #10

Influence of Unbound Granular Base/Subbase Properties Upon Rigid Pavement Performance/Distress

10/5/89
David M. Johnson

BACKGROUND

Granular materials are given less attention in rigid pavement design than in flexible design. This is partially due to the stiffer nature of the surfacing material. A "granular material" can range anywhere from a dirty sand gravel to an open graded drainable material. In addition construction, traffic, and environmental variability will affect the performance of granular materials in terms of strength, modulus, frost behavior, and drainability.

PURPOSE

The purpose of this study is to better understand the influence of granular base/subbase material properties and design on the performance of rigid pavements so granular base/subbase specification and design parameters can be verified or refined.

APPROACH

At the MRRP facility, a wide range of unbound granular base/subbase types have been selected for use in both the low volume and mainline rigid pavement cells. All rigid cell bases and subbases will be monitored to evaluate base/subbase design performance. Data will be collected from these cells by the following methods:

1. Testing and inspecting material properties and placement procedures during cell construction.

2. Applying FWD and ride tests to the rigid pavement.

3. Surveying visible pavement distress.

4. Conducting an inspection of the base/subbase materials after the life of a cell to inventory loss, segregation, or degradation of material.

LVR-R-3 through 5, ML5-R-5 through 7, and ML10-R-10 through 12 represent various base/subbase designs under different loading conditions, but are somewhat uniform in pavement design. These will be instrumented to track subsurface environmental conditions. One set of 6 moisture sensors and 6 temperature sensors will be placed vertically 6 inches apart in the base/subbase of each of
these 9 cells. Supplemental data from other MRRP instrumentation of drainage, pumping, and frost action will be used as well.

This data will be considered along with traffic and surface environmental conditions in the analysis of base/subbase performance. Interim reports will be written after 3 years and 5 years and a final report in 10 years.

RESOURCES

The PI must have the capability of performing complex base/subbase structural and drainage analysis. About 2000 hours of work will be required to complete this project. About 54 moisture sensors and 54 temperature sensors will be purchased and installed under a MRRP contract.
Research Objective #11
Influence of Subgrade Type Upon Pavement Performance
9/29/89
David M. Johnson

BACKGROUND

The two components of any roadway were built in very different ways but are expected to work in concert. The pavement structure is designed, specified, manufactured, and tested while the subgrade soil is much more random in nature. In addition the subgrade is farther from the surface which makes it more difficult to test under insitu conditions and more likely to be saturated. Finally the subgrade soil typically has a lower structural stability and is more susceptible to frost action. For these reasons we are better able to predict the strength and performance of pavement structures than of subgrade soils.

On high volume roads economics dictate a strong pavement structure that may bridge subgrade problems but on low volume roads the structural stability of the subgrade material becomes more critical. Although subgrade characteristics will be considered as part of other MRRP objectives (particularly #1, #2, #4, and #14) the unique problems with predicting subgrade structural stability require an in depth analysis.

PURPOSE

The purposes of this study are:

(1) to revise (or confirm) current design methods for low volume roads over subgrades with low structural stability so better pavement performance results without increasing cost.

(2) to more fully define and understand the parameters that affect the structural stability and performance characteristics of subgrade soils under high volume roads so design models can be verified, modified, or developed. As such this study will supplement and enhance other MRRP studies.

APPROACH

This project will be approached:

(1) by comparing the response and performance of various low volume road designs over two low stability subgrade soils ($R_-$ values of 5 and 12). Two traffic and various environmental loadings will be considered. This approach will focus on all MRRP low volume road cells.
(2) by evaluating the impact of the characteristics and variability of low stability soils on the response and performance of rigid and flexible pavements under various environmental loadings. All MRRP cells will be looked at under this approach.

Since this project is related to other MRRP projects it will share instrumentation with these projects. Data related to frost action, drainage, mechanistic performance, and empirical performance will be obtained in this manner. However extensive additional sampling and testing of the subgrades and subgrade material will be required for this project. A post mortem analysis of the subgrade will also provide valuable data.

RESOURCES

The PI(s) must be knowledgeable about the influence of subgrade soils on the performance of pavement in a cold climate.

(1) About 1000 hours of work will be required to complete the low volume road portion of this study. An interim report will be prepared after one year and a final report will be prepared after 3 years.

(2) About 1500 hours of work will be required to complete the remainder of this study. Reports will be published after 3, 5, and 10 years.
Research Objective #12

Improved Roadway Instrumentation Techniques

10/24/89
Steven M. Lund

BACKGROUND

Instrumentation will play a key role in the success of the Minnesota Road Research Project.

In the past, most pavement research has been empirically based. Although this type of evaluation is valid, pavement condition or performance is measured without always knowing how or why distress occurs.

The current trend in pavement design is toward the mechanistic approach. These designs are based on characterizing and modeling material properties and behavior using such theories as elastic layer and finite element analysis.

Instrumentation will play the primary role in measuring the required inputs for these models. Many sensors will be installed in the pavement structure. These sensors will monitor the pavement as it responds to the forces induced by traffic loadings and the environment. Instrumentation will also help resolve the different views and perspectives shared by researchers from the same technical area.

Although the best instrumentation known will be installed at the MRRP, pavement instrumentation is still an evolving technology. Much still needs to be learned about the installation and long term performance of pavement instrumentation.

PURPOSE

The primary objective of this research will be to conduct an overall evaluation of pavement instrumentation. This includes sensors directly installed in the pavement structure as well as sensors and instruments used to support pavement research.

This evaluation will address two key parts:

The installation procedure(s) will be evaluated. At this time the exact installation specifications have not been determined; however, when possible, any multiple installation procedures will be compared.

The second part of the evaluation will involve the evaluation of instrumentation reliability and durability. Multiple sensors will be installed whenever possible to compare instrumentation readings. Also, sensors will be compared should different brand
names of the same type of sensor be installed.

APPROACH

Detailed documentation during sensor installation will be crucial to the success of this research. This documentation will be the primary method of evaluating the installation procedure, as well as assuring the success of the other research by proper sensor location.

Readings from redundant instrumentation will be the used as the primary method of determining the reliability and durability of the sensors. When applicable, and if possible, alternative non-destructive measurements will be used in this evaluation.

A limited amount of instrumentation has already been installed at the Test Facility site. This includes thermocouples, thermistors and neutron access tubes (moisture sensing). Instrumentation is also directly used to produce the traffic information from the in-place Weigh-In Motion scales and the environmental data from the Automated Weather Station (AWS, installation completed by November 1, 1989). At this time other sensors being considered for installation at the MRRP include pressure cells, strain gauges, LVDT’s, accelerometers, inclinometers, tipping buckets, crack detectors, and different moisture sensors.

It is expected that much will be learned about instrumentation during MRRP construction and shortly thereafter. Therefore the primary report will be written on year after MRRP construction. Follow-up reports will be written as instrumented cells come out of service at 3, 5, and 10 years.

RESOURCES

The principal investigator (PI) for this study must have a strong instrumentation background and some understanding of pavement structural performance. Since instrumentation installation is a key part of this study, a PI must be identified before the construction of MRRP begins. Instrumentation will be installed under a MRRP contract. About 1000 hours of work will be required during the first year of the study. After that only about 100 hours per year will be required to evaluate the performance of existing instrumentation. Obviously this rate could increase if new instrumentation is installed at MRRP.

Note: As the instrumentation plan is finalized, this work plan will be updated.
Research Objective #13
Influence of Special Design Variables
Upon Rigid Pavement Performance

10/11/89
David M. Johnson

BACKGROUND

As with any structure, the design details of rigid pavements can be critical in determining their performance. Thus, such issues as load transfer mechanisms, supplemental reinforcement, drainage, and pavement geometry should be investigated. These investigations will rely heavily on electronic instrumentation for collection of pavement data. This approach should lead to a mechanistic understanding of the performance of various designs. Two investigations that provide an excellent background in pavement instrumentation are the FHWA's Experimental Project 88-621, Pavement Instrumentation, James K. Cable, Iowa State University and Mn/DOT's Assessment of Pavement Response Instrumentation, David E. Newcomb, University of Minnesota.

PURPOSE

Various cells within MRRP have been established to support the investigation of these various design details. It is hoped that this will lead to the optimization of rigid pavement design variables for Minnesota roadway conditions.

APPROACH

This objective will be accomplished by conducting 5 research projects that address the various rigid pavement design elements individually. Each of these research projects will be associated with 2 or more MRRP cells where the design element in question is varied. Data to evaluate design performance will be collected from these cells by the following methods:

1. Inspecting materials and procedures during cell construction.
2. Monitoring sensors in or under the pavement.
3. Applying test equipment to the surface of the pavement, i.e. FWD.
4. Surveying visible pavement distress during the life of a cell.
5. Conducting an autopsy of the pavement after the life of a cell.
This data will be considered along with traffic and environmental loadings in the analysis of design element performance.

Each research project will have a principal investigator who will be responsible for conducting the research and reporting on its results.
Research Objective #13-A

Influence of Special Design Variables Upon Rigid Pavement Performance Regarding Edge Drains

10/11/89
David M. Johnson

BACKGROUND

Water in rigid pavement structures or subgrade materials is associated with a multitude of pavement performance problems. Erosion, pumping, freeze/thaw deterioration of pavement structures, frost heave, reduced subgrade strengths, and concrete deterioration can lead to corner cracks, panel cracks, joint failure, and faulting. Mn/DOT has installed many new or retrofit edge drains in rigid pavement structures, although not all pavement structures are drained. Mn/DOT has two basic edge drain designs:

(1) an open graded permeable base design with a course aggregate in the drain trench and no geotextile wrap on the drain pipe.

(2) a dense graded traditional base with a fine filter aggregate in the trench and a geotextile wrap on the drain pipe.

Rudy Ford of Mn/DOT is an excellent resource in this area.

PURPOSE

The primary purpose of this research is to compare the influence of Mn/DOT's two edge drain designs on rigid pavement performance. This will lead to the establishment of guidelines for selecting subsurface drainage alternatives for rigid pavements.

APPROACH

Heavy instrumentation will allow complex moisture and flow patterns to be described and analyzed. Mainline road cells ML10-R-10 (open graded base with drain), ML10-R-11 (dense graded base with no drain), and ML10-R-12 (dense graded base with drain) will be the primary focus of this research project. These 3 cells are the same except for base material, edge drain design, and panel length. Mainline cells ML5-R-6 (dense graded base with no drain) and ML5-R-7 (open graded base with drain) will be the secondary focus of this research project. Except for base material, edge drain design, and panel length these 2 cells are the same. Although there are basic design differences between the 5 year and 10 year mainline designs, some comparison may be possible. Two contraction joints in each of the 5 cells will be instrumented as shown in the INSTRUMENTATION DIAGRAM below. Instrumented tipping buckets will be installed at edge drain
outlets to continuously measure outflow rates. Ride levels, faulting, and joint efficiency ratings using the FWD will be established throughout the life of these cells. At the end of the life of these cells an autopsy will be performed in the area of the instrumented joints to determine the condition of the pavement structure and subgrade materials.

The principal investigator (PI) is unknown at this time. An interim report analyzing the performance of edge drains will be written at the end of the life of the 5 year mainline. After 10 years a final report will be written.

**INSTRUMENTATION DIAGRAM**

**CONTRACTION JOINT**

**SHOULDER JOINT**

**CENTERLINE JOINT**

**SHOULDER JOINT**

**RIGID PAVEMENT**

**BASE MATERIAL**

**SUBGRADE MATERIAL**

\[ M = \text{moisture sensor (24 per joint)} \]

\[ P = \text{water pressure gauge (2 per joint)} \]

\[ T = \text{temperature sensor (6 per joint)} \]
RESOURCES

The PI must have the capability of performing complex subsurface drainage analysis. About 1500 hours of work will be required to complete this project. About 240 moisture sensors, 60 temperature sensors, 20 pressure gauges, and 10 tipping buckets will be purchased and installed under a MRRP contract. The funding for the PI is unknown at this time.
Research Objective #13-B

Influence of Special Design Variables Upon Rigid Pavement Performance Regarding Contraction Joints

10/11/89
David M. Johnson

BACKGROUND

Under ideal conditions contraction joints are designed to transfer all of the vertical loadings (traffic) and none of the longitudinal (temperature) loadings between rigid pavement slabs. Unfortunately Minnesota roadway conditions are far from ideal and as a result the performance of contraction joints diminish with time. Construction conditions, maintenance operations, weather, and real-world traffic all contribute to the deterioration and possible failure of these joints. The most pressing performance issue is how to establish and maintain good vertical load transfer so pumping and faulting at contraction joints are minimized. Two basic designs rely on dowel bars or aggregate interlock to accomplish vertical load transfer.

Temperature Differential Effect on the Falling Weight Deflectometer Deflections Used for Structural Evaluation of Rigid Pavements by Gustavo E. Morales-Valentin from the University of Texas at Austin and Joint Shear Transfer Effects on Pavement Behavior by T. Krauthammer of the University of Minnesota provide more background.

PURPOSE

The primary purpose of this research is to identify optimum contraction joint design parameters under insitu Minnesota roadway conditions. Mn/DOT design standards will be modified if they do not reflect the optimum parameters confirmed by this research project. A secondary purpose of this research is to develop a method for non-destructive testing of deteriorated contraction joints that will sufficiently characterize their condition so appropriate repair actions can be recommended.

APPROACH

Low volume road cells LVR-R-3 (1 inch dowels) and LVR-R-4 (no dowels) as well as ten year mainline cells ML10-R-11 (1.25 inch dowels) and ML10-R-13 (1.5 inch dowels) will be the focus of this research project. Two outside lane contraction joints in each of the 4 cells will be instrumented as shown in the INSTRUMENTATION DIAGRAM below. Radar will be used to verify the correct placement of dowels during construction. Ride levels and joint efficiency ratings using the FWD will be established throughout the life of these cells. At the end of the life of these cells an autopsy will be performed on the instrumented joints to
determine their condition.

Contraction joints in the widened pavement area (5 year mainline) will be monitored visually during their life and at the time of their autopsy for additional supportive information.

The principal investigator (PI) is unknown at this time. An interim report analyzing the performance of contraction joints will be written at the end of the life of the low volume road cells. After 10 years a final report will be written.

**INSTRUMENTATION DIAGRAM**

```
WHEEL PATH-->
SP----S-----PS
|   L   |
|   T   |
|   L   |
SP----S-----PS
V|   V   |
```

**RESOURCES**

The PI must have the capability of performing complex structural analysis of rigid pavement with and without dowels. About 2000 hours of work will be required to complete this project. About 88 strain gauges, 32 temperature sensors, 32 pressure gauges, 32 vertical displacement sensors, and 16 longitudinal displacement sensors will be purchased and installed under a MRRP contract. The funding for the PI is unknown at this time.
Research Objective #13-C

Influence of Special Design Variables Upon Rigid Pavement Performance Regarding Paving Width

10/11/89
David M. Johnson

BACKGROUND

Current Mn/DOT practice limits the width of rigid paving to 30 feet without supplemental reinforcement or 36 feet with supplemental reinforcement steel. Pavements of greater width must be constructed with a longitudinal L3 butt joint. This type of construction often results in separation and faulting at the butt joint. The rigid pavement committee feels that because of today's increasing traffic loadings and with proper pavement design, 3 lanes tied together with widened edges are constructible and will perform better. At this time no literature search has been conducted to identify other research on this problem. Mn/DOT Investigation 209 reports describe the performance of widened lane edges.

PURPOSE

The purpose of this research is to either confirm or modify the current Mn/DOT practices that restrict rigid paving widths to 36 feet without butt joints. This will be done by comparing the performance of a 40 foot widened edge design pavement without butt joints to a standard 27 foot widened edge design. If 40 foot wide tied paving does not show deterioration due to stress then it should be adopted as a standard design practice that eliminates longitudinal butt joints and associated separation and faulting.

APPROACH

The work associated with this research project will be carried out at these 3 rigid pavement cells in the 5 year design area of the MRRP mainline: ML5-R-7, ML5-R-8, and ML5-R-9. ML5-R-7 is the control for this study having a standard 27 foot wide pavement with bituminous shoulders. ML5-R-8 is a cell with 40 foot wide rigid paving. Starting from the outside the ML5-R-8 cross section will be a bituminous shoulder, a 14 foot rigid widened lane, a 12 foot rigid lane, and a 14 foot rigid widened lane (NOT open to traffic). NOTE: The non-traffic lane allows traffic and environmental loadings to be evaluated separately. Tied longitudinal joints will be constructed between lanes. Panels in ML5-R-8 will include supplemental reinforcing steel in the center lane. ML5-R-9 will be similar to ML5-R-8 except it will have NO supplemental reinforcing steel. Base design, panel lengths, and dowels are the same for these 3 cells.
Adjacent panels in each of the 3 cells will be constructed with embedded strain gauges at the top and bottom of the panel at these locations:

```
          X          X
          X          X
          X          X
          X          X
          X          X
          X          X
          X          X
20 feet
```

14 feet (this lane does NOT exist on ML5-R-7)
12 feet (13 feet on ML5-R-7)
14 feet

Each instrumented panel will also contain at least one set of temperature sensors at the top and bottom of the panel. Strains will be measured under various loading and temperature conditions in order to develop a strain profile. This profile will be used to predict pavement performance. Actual pavement performance will be measured periodically with visual surface distress surveys, ride measurements, and deflection and joint efficiency surveys using an FWD. An interim report will be written after 2 years. After 5 years a pavement autopsy will be conducted to detect subsurface pavement distress and the final report will be written.

The concrete engineer will be responsible for designing the placement of supplemental reinforcement steel in cell ML5-R-8 before 11/1/89. The principal investigator (PI) is unknown at this time. The MRRP manager will be responsible for periodically collecting strain and temperature data from instruments. The PI will be responsible for requesting real-time data collection and joint efficiency surveys. The PI will conduct annual and final distress surveys.

RESOURCES

The PI must have the capability of performing complex structural analysis of rigid pavement. About 1000 hours of work will be required to complete this project. About 96 strain gauges and 16 temperature gauges will be purchased and installed under a MRRP contract. The funding for the PI is unknown at this time.
Research Objective #13-D

Influence of Special Design Variables Upon Pavement Performance Regarding Joint Spacing

10/11/89
David M. Johnson

BACKGROUND

Rigid pavement reinforcing steel is expensive and can corrode causing pavement distress. This corrosion is accelerated in a pavement where a lot of deicing salt is used. One alternative is to use a non-reinforced rigid pavement design, but then a shorter joint spacing is required which raises costs. What design factors dictate the optimum joint spacing of a non-reinforced rigid pavement in a cold regions environment? How are cost and performance balanced?

PURPOSE

The purpose of this research is to compare the performance of various length slabs of non-reinforced rigid pavement having different designs and traffic loadings in a cold regions environment. If the optimum joint spacing considerations determined by research is different than existing design standards, Mn/DOT standards will be modified or expanded.

APPROACH

Non-reinforced pavement slab lengths of 12, 15, 20, and 24 feet exist at MRRP. One of the rigid cells has a 12 foot panel length, five have 15 foot lengths, seven have 20 foot lengths, and one has a 24 foot length. Obviously there is an abundance of cells with 15 foot and 20 foot panel lengths. Because MRRP contains many pavement and base design parameters at various values many cells need to be monitored for this research project. However, some cells are not unique in design that their analysis can only confound the results of this research project. The following cells are of a unique design, have a panel length of 15 or 20 feet, and thus will NOT be part of this research.
Two panels in each of the 10 remaining rigid cells will be instrumented as follows:

**INSTRUMENTATION DIAGRAM**

<table>
<thead>
<tr>
<th>S</th>
<th>S</th>
</tr>
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<tbody>
<tr>
<td>S</td>
<td></td>
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<tr>
<td>ST</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td></td>
</tr>
</tbody>
</table>

**PLAN VIEW**

**PROFILE VIEW**

S = strain gauge (10 per panel)
T = temperature sensor (2 per panel)

Visual and ride surveys will be done periodically on the ten remaining rigid cells in this research project. At the end of the life of an instrumented panel it will be excavated to look for additional signs of distress. If distress is found or if the visual examination of the panel indicates the need for repair, it will be instrumented as necessary to study this panel. The principal investigator (PI) is unknown at this time. Interim reports that analyze and compare the performance of different panel lengths will be written at the end of the life of the low volume road cells and the end of the life of the 5 year mainline cells. A final report will be written at the end of the life of the 10 year mainline cells.

**RESOURCES**

The PI must have the capability of performing complex structural
analysis of rigid pavement. About 2000 hours of work will be required to complete this project. About 200 strain gauges and 40 temperature sensors will be purchased and installed under a MRRP contract. The funding for the PI is unknown at this time.
Influence of Special Design Variables Upon Rigid Pavement Performance Regarding Trapezoidal Cross Sections

10/11/89
David M. Johnson

BACKGROUND

The Minnesota Highway Department used to build rigid traffic lanes with trapezoidal cross sections. However, this standard was abandoned in the 1950's. In 1988 the final report from Mn/DOT Investigation 209 recommended that rigid pavements be paved wider than the 12 foot traffic lanes to reduce the higher pavement deflections at the outside edge of traffic lanes. The old trapezoidal cross section design for traffic lanes seems to offer another method of reducing deflections at lane edges.

PURPOSE

The purpose of this research is to determine if a trapezoidal cross section is an efficient and effective design option to reduce maximum deflections in rigid low volume traffic lanes and thus extend their performance life. If this is what is determined by research, low volume traffic design standards will be modified or expanded.

APPROACH

Low volume road rigid pavement cells LVR-R-5 (6 inches thick) and LVR-R-7 (7 inches thick at the outside edges and 5 inches thick at centerline) will be the focus of this research project. Three panels in each of the cells will be instrumented as shown in the INSTRUMENTATION DIAGRAM below. Actual constructed thicknesses of instrumented panels will be verified by non-destructive methods. If this is not feasible thickness verification will be done by coring adjacent panels. Periodic-FWD testing will be done to determine deflections. All panels in these 2 cells will be surveyed for ride as well as visually for signs of distress. At the end of the life of these cells an autopsy will be performed on the instrumented panels to look for stress related deterioration.

The principal investigator (PI) is unknown at this time. A final report analyzing and comparing the performance of the two cells will be written at the end of the life of the low volume road cells.
RESOURCES

The PI must have the capability of performing complex structural analysis of rigid pavement. About 500 hours of work will be required to complete this project. About 60 strain gauges and 12 temperature sensors will be purchased and installed under a MRRP contract. The funding for the PI is unknown at this time.
Research Objective #13-F
Influence of Special Design Variables Upon Rigid Pavement Performance Regarding Cement Type and Content

10/11/89
Harris B. Baker

BACKGROUND

The two turnaround loops on the Low Volume Roadway at the MNROAD facility were not originally planned to contain test sections. They were designed with twelve-inch-thick reinforced PCC pavement to minimize the need for repair. It was recently decided that test sections may be incorporated in the loops as long as the strength of the pavement is not reduced. This research objective will use one of the loops. Alterations to the PCC pavement as a result of this research objective should only serve to strengthen the PCC pavement.

MN/DOT uses high-early strength concrete in PCC pavements where the roadway must be opened for traffic as quickly as possible. The Department's normal procedure for making high-early strength concrete is to increase the cement content of the standard mix by 30%. The added cement increases the cement-void ratio, cohesiveness, plasticity, and strength, and results in the mix attaining sufficient compressive strength with less cure time. The decreased workability caused by the additional cement is partially compensated for by increasing the water content, which should not be increased more than 5%, as explained in section 694.214 of the Mn/DOT Concrete Manual. The workability of high-early strength concrete decreases rapidly if it is not placed soon after being mixed. Construction delays during placement sometimes result in concrete being placed with a very low slump value, which makes it difficult to achieve sufficient consolidation and a smooth finished surface.

PURPOSE

The purpose of this research objective is to measure the differences between Type I 3A21, Type I 3A21 HE, and Type III 3A21 as related to constructibility, performance, and roughness of the finished pavement.

APPROACH

Both loops will contain 1850' of 12" reinforced concrete pavement. One loop will be long enough for 3 test sections, each over 600' long. Samples will be taken of the mixes for modulus of rupture and compressive strength tests. Other comparisons will be made by means of the profilometer, visual surveys, and cores.
Traffic data will be included in the analysis.

No instrumentation will be installed in the test sections.

An interim report will be written within a year of construction and a final report when significant distress occurs.

RESOURCES

The principal investigator will be performing analyses of the test results, cores, and visual surveys, which, along with report writing, will take an estimated 300 hours.
Research Objective #13-G

Influence of Special Design Variables Upon Rigid Pavement Performance Regarding Aggregate Class

10/11/89
Harris B. Baker

BACKGROUND

The two turnaround loops on the Low Volume Roadway at the MNROAD facility were not originally planned to contain test sections. They were designed with twelve-inch-thick reinforced PCC pavement to minimize the need for repair. It was recently decided that test sections may be incorporated in the loops as long as the strength of the pavement is not reduced. This research objective will use one of the loops. Alterations to the PCC pavement as a result of this research objective should not decrease the strength of the PCC pavement.

Aggregates used in concrete mixtures are classified A through E. Class A is quarried granite, trap rock, or quartzite. Class B is all other quarried rock. Class E is a mixture of two or more of the other classes. Symptoms of D Cracking have recently been observed in some PCC pavement mixtures containing Class A aggregate and in others with Class E, which in this case is a mixture of Class A 3/4"+ and Class B 3/4"-.

PURPOSE

The purpose of this research objective is to evaluate the performance of PCC pavement mixtures with different percentages of Class A and Class B aggregate.

APPROACH

Both loops will contain 1850' of 12" reinforced concrete pavement. One loop will be long enough for 3 test sections, each over 600' long. The PCC mix in one test section will contain all Class A aggregate. Another section will use 50% Class A 3/4"+ and 50% Class B 3/4"-. The other section will have 35% Class A 3/4"+ and 65% Class B 3/4"-. All three sections will use Type I 3A21 cement.

Comparisons will be made using visual surveys and cores.
Traffic data will be included in the analysis.
No instrumentation will be installed in the test sections.
An interim report will be written within a year of construction and a final report when significant distress occurs.
The principal investigator will be performing analyses of the cores and visual surveys, which, along with report writing, will take an estimated 300 hours.
Research Objective #14
Influence of Pavement Variability Upon Reliability Based Pavement Performance Models
9/25/89
David M. Johnson

BACKGROUND
One of the major changes in the 1986 AASHTO Pavement Design Guide was the introduction of a reliability based analysis procedure. The design level of reliability selected by the Engineer is probably the most significant factor influencing the design and hence performance of any roadway structure. Design reliability is important because it reflects the collective variability of all pavement design parameters influencing performance.

PURPOSE
The purpose of this study is to determine the effect of the variation of each pavement design parameter on the reliability of pavement performance. It is hoped that more control over some appropriate pavement variables will yield more predictable pavement performance and perhaps less control over others will not significantly reduce predictability.

APPROACH
At the MRRP facility, a well planned testing and sampling program is envisioned for each pavement cell. Because of this, the distribution (mean and variance) of pavement variables will be available. Also, pavement loadings and performance will be known precisely. This presents an ideal opportunity to correlate the variability in pavement design parameters to the variability in pavement performance. Flexible pavements, rigid pavements, and aggregate surfaces will undergo this statistical scrutiny.

For flexible pavements the following pavement design variables influence pavement performance in the AASHTO model:

- Effective roadbed soil resilient modulus
- Structural layer coefficients
- Structural layer thicknesses
- Drainage coefficients for base and subbase layers
For non-reinforced jointed rigid pavements the following pavement design variables influence pavement performance in the AASHTO model:

- Effective modulus of subgrade reaction
- Concrete elastic modulus
- Modulus of rupture of concrete
- Drainage coefficient
- Load transfer coefficient
- Thickness of pavement layers

For aggregate surfaces the following design variables influence performance in the AASHTO model:

- Length of the seasons
- Seasonal resilient moduli of the roadbed soil
- Elastic moduli of aggregate base and subbase layers

The performance of the flexible and rigid pavements is measured in terms of serviceability. The performance of aggregate surfaces is measured in terms of serviceability, surface rutting, and surface aggregate loss.

The principal investigator must:

1. Select the MRRP cells that conform to the AASHTO design guide.
2. Document the AASHTO design parameters for each of these cells.
3. Establish a testing program to determine the mean and variance of design parameters. Most of this testing will be done at the time of construction, however variables such as drainage and seasonal effects will be measured periodically and other variables such as loss of support will be measured at the end of the life of the cells.
4. Establish a testing program to document the performance of the selected cells.
5. Perform the analysis necessary to determine the effect of the variation of each pavement design parameter on the reliability of pavement performance.
6. Write interim reports at the end of cell construction, the end of the low volume road test, and the end of the life of the 5 year mainline cells. A final report will be written at the end of the life of the 10 year mainline cells.
RESOURCES

The PI must understand the pavement design process and must have the capability of performing complex statistical analysis. About 3000 hours of work will be required to complete this project. The extensive amount of inspection, sampling, and testing required to accomplish this objective will be done as part of an overall MRRP effort as will the period measurements of pavement performance. No additional sensors will be required for this study.
### 5-Year Mainline Experimental Sections

<table>
<thead>
<tr>
<th>Depth Below Pavement Surface (Inches)</th>
<th>West</th>
<th>Flexible Pavement</th>
<th>Rigid Pavement</th>
<th>Begin 5-year test sections</th>
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<tbody>
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**Flexible Pavement**

- ML5-F-1
  - AC (5.75)
  - cl6sp(1) (4.0)
- ML5-F-2
  - AC (5.75)
  - cl5sp(1) (4.0)
- ML5-F-3
  - AC (5.75)
  - cl3sp(1) (33.0)
- ML5-F-4
  - AC (8.75)
  - cl4sp(1) (3.0)
  - no edge drain (5.0)

**Rigid Pavement**

- ML5-R-5
  - PCC (JPC) (7.5)
  - cl4sp(1) (3.0)
- ML5-R-6
  - PCC (JPC) (7.5)
  - OGB(1) (4.0) w/drain
- ML5-R-7
  - PCC (JPC) (7.5)
  - OGB(1) (4.0) w/drain
- ML5-R-8
  - PCC (JPC) (7.5)
  - OGB(1) (4.0) w/drain
- ML5-R-9
  - PCC (JPC) (7.5)
  - cl4sp(1) (3.0)

**Legend**

- R=12, all
- PVN = Low, all
- 85/100 Pen Type, all
- AC Content-Target, all
- Air Void-Target, Wear
- TB-Target Air Voids, Base

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<th>d-Dowel Diam</th>
<th>w-Panel Width</th>
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*Supp steel*
### Minnesota Road Research Project

**10-Year Mainline Experimental Sections**

#### Rigid Pavement

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#### Notes:
- *PCC:* Portland Cement Concrete
- *AC:* Asphalt Concrete
- *OGB:* Organic Geosynthetic Barriers
- *HVPN:* High VG, Portland Type
- *LVPN:* Low VG, Portland Type
- *TB:* Target Air Voids
- *HB:* High Air Voids, Base
- *LB:* Low Air Voids, Base

---

**Version 2.0 Final**

**Revised 9-18-89**
### Minnesota Road Research Project
#### Version 2.0 Final
##### Low Volume Road Experiment

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- **Panel Width** = 24, all
- **Panel Length**
- **Pen Type** = all
- **Air Voids** = Target, all
- **AC Content** = Target, all

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**Notes:**
- 120/150 Pen Type, all
- PVB-Low, all Base and Wearing
- Double Chip Seal