GENERIC EXPERIMENTAL DESIGN FOR PRODUCT/STRATEGY EVALUATION - CRUMB RUBBER MODIFIED MATERIALS

State of California Department of Transportation
Materials Engineering and Testing Services
Office of Flexible Pavement Materials
5900 Folsom Blvd
Sacramento, California 95819

February 8, 2005

EXECUTIVE SUMMARY

This report presents the framework for a generic process to evaluate new products and/or strategies for possible use within Caltrans. The framework is the result of a collaborative effort among Caltrans, the University of California Partnered Pavement Research Center (UC PPRC) and MACTEC.

The generic experimental design process is applicable to all pavement types as well as the component materials of pavements. The framework includes various types of studies that may be used in the evaluation process — laboratory, accelerated pavement testing (APT) and field pilot studies. Additionally, it identifies other factors that must be considered in the evaluation of any new product/strategy: economic viability and environmental impact. The generic experimental design process outlined herein is considered appropriate for Caltrans operating units such as METS, Research, Maintenance and others who may be involved with evaluating paving materials.

Specific ideas/hypotheses that may broaden and expand the use of crumb rubber modifier (CRM) in pavement applications were identified as follows:

- Construction/Rehabilitation and Maintenance Applications
  - New construction
  - Thick overlays
  - Open graded-high binder mixes
  - Recycling
- Materials Studies
  - Type 1 vs. Type 2 binders
  - Binder testing
- Structural Design Studies
  - Gravel factor for RAC-G and MB mixes
  - Modification of the deflection based overlay design procedure

A collaborative effort of Caltrans, UC PPRC, and MACTEC staff, two structural design-related studies were expanded into detailed work plans which address the following:

- development of a gravel factor for RAC-G and MB mixes for use in new construction; and
- update/modification of Caltrans deflection based overlay design procedure to accommodate RAC-G and MB mixes.

It is recommended that the generic process presented in this report be reviewed by and discussed with the affected operating units and enhanced to include detailed information on data collection and testing requirements associated with each study type.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

GENERIC EXPERIMENTAL DESIGN FOR PRODUCT/STRATEGY EVALUATION – CRUMB RUBBER MODIFIED MATERIALS

1.0 INTRODUCTION

1.1 BACKGROUND

The California Department of Transportation (Caltrans) annually expends tremendous resources to evaluate new products and/or develop new strategies that would improve the performance of flexible pavements. Although there is overlapping interest and need in this evaluation process among Caltrans operating units (Materials Engineering Testing Services, Research and Maintenance), it is often undertaken independently of one another. Not surprisingly, this results in different approaches to data collection sometimes limiting the use of these data to the "sponsoring unit." Accordingly, this broad-based, generic approach to the evaluation of materials/strategies is an attempt to weave a more coordinated approach within Caltrans, one that might help to ensure that a study initiated by "materials" considers the needs of and potential effects on its "sister" operating units, i.e., design, construction, maintenance, research, etc. Since there is no standardized, consistent approach to product/strategy evaluation within Caltrans this document is offered as a first step in that direction, recognizing that this will be an iterative process.

1.2 SCOPE AND OBJECTIVE

Although the impetus for this report was the evaluation of crumb rubber modified (CRM) materials, this approach is not material-specific; i.e., it is applicable to the evaluation of new products and/or strategies regardless of pavement type and component materials. The ultimate object of developing a standardized approach is to ensure that all materials are evaluated in a uniform manner.

1.3 ORGANIZATION OF REPORT

The report is organized as follows:

- Chapter 2 presents the generic experimental design process developed in collaboration with Caltrans, the University of California Partnered Pavement Research Center (UC PPRC) and MACTEC. It is applicable to studies ranging from laboratory to full-scale field studies.
- Chapter 3 presents candidate studies of CRM materials that evolved from the literature review and discussions with Caltrans, industry, and the UC PPRC. These studies are intended to broaden and expand Caltrans usage of CRM.
- Chapter 4 presents summary and recommendations resulting from this report.

Appendices are included to provide support information as follows:

- Appendix A includes a proposed FWD deflection test scheme for all field studies.
- Appendix B contains a proposed condition survey method for all flexible pavement field studies.
- Appendix C is an example experimental design for evaluation of rubber modified asphalt mixes.
- Appendices D and E are work plans for studies that are recommended to develop gravel factor(s) for rubberized asphalt concrete (RAC-G) and modified binder (MB) mixes within the Caltrans new pavement and overlay design procedures.

2.0 GENERIC EXPERIMENTAL DESIGN PROCESS

2.1 INTRODUCTION

The generic experimental design, shown in Figure 2.1, outlines a uniform, consistent approach to evaluate a new product and/or design strategy. Each step shown in Figure 2.1 is described in this chapter.

2.2 GENERAL PROCESS OVERVIEW

The first step in the process is to develop an idea or hypothesis for the study. The idea should be developed by a project "champion" (or manager) who would be involved in and oversee the study from start to finish. This champion ensures ownership and, ultimately, responsibility for implementation. The study hypothesis also needs to be clearly defined. The hypothesis is a stated premise arising from the idea that can either be confirmed or rejected as a result of observation and testing. Once the idea and associated hypothesis are defined, an advisory committee should be established to provide technical oversight for the duration of the study and to help with implementation. The committee should include both Caltrans and industry personnel.

A review of existing information should be required as a starting point for all studies. Computer analyses or simulation studies with existing data may also be carried out if appropriate. Some products and/or strategies can be evaluated and recommended for implementation based on an evaluation of existing information or the experience of other agencies (assuming there are no economic or environmental concerns). As an example, consider Caltrans use of high binder open-graded asphalt rubber mixes that are used routinely in Arizona. These types of projects were constructed in several locations in California without extensive preliminary studies.

If the hypothesis is not confirmed as a result of the initial evaluation of available information, the project idea is usually considered invalid and discarded. However, there may be some cases where additional testing and analyses are required to confirm or reject the hypothesis. If the idea warrants further study, it may be necessary to consider various types of studies. Current technology within Caltrans allows the evaluation of new products/strategies by any or all of the following:

- Laboratory studies
- Accelerated pavement testing studies using the heavy vehicle simulator (HVS)
- Full scale field test sections (pilot studies)

Experience, research and technology development suggest that the relationship between time/resources to implementation is that shown in Figure 2.2. Among the three alternatives, laboratory studies require the least amount of time and resources to complete an evaluation. Accelerated pavement testing requires special facilities and trained personnel, thus adding more time and resources. Field pilot studies require test sections to be constructed and monitored periodically over time. These require considerably more time and money. Supplementing laboratory studies with full-scale field studies allows one to characterize the behavior of the materials/structure as a function of actual loading and environmental conditions. Logically, these studies yield data that allow one to draw definitive conclusions. A detailed discussion on three types of studies (or investigations) is presented in Section 2.3.

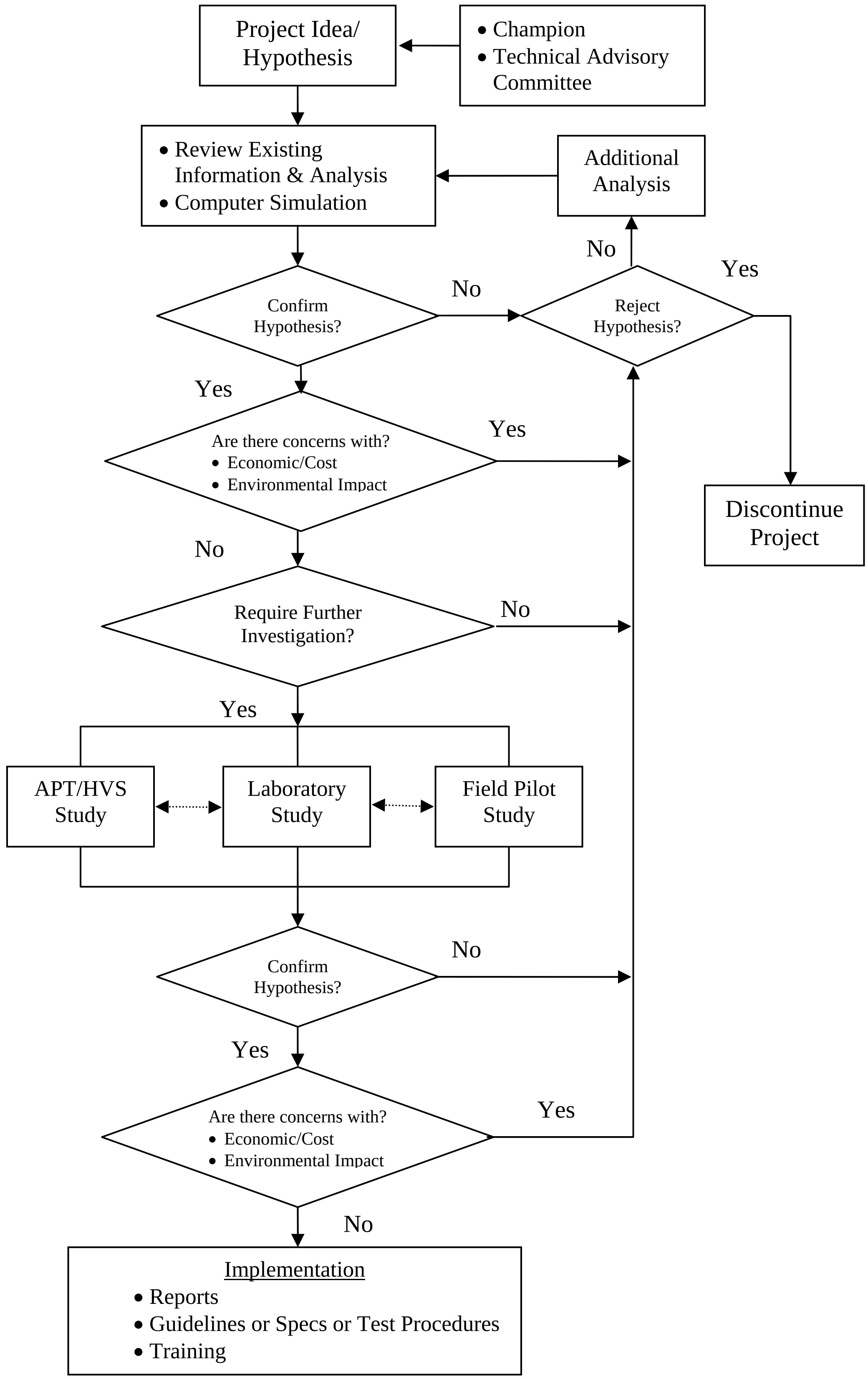


Figure 2.1 General Process for Evaluating a Product

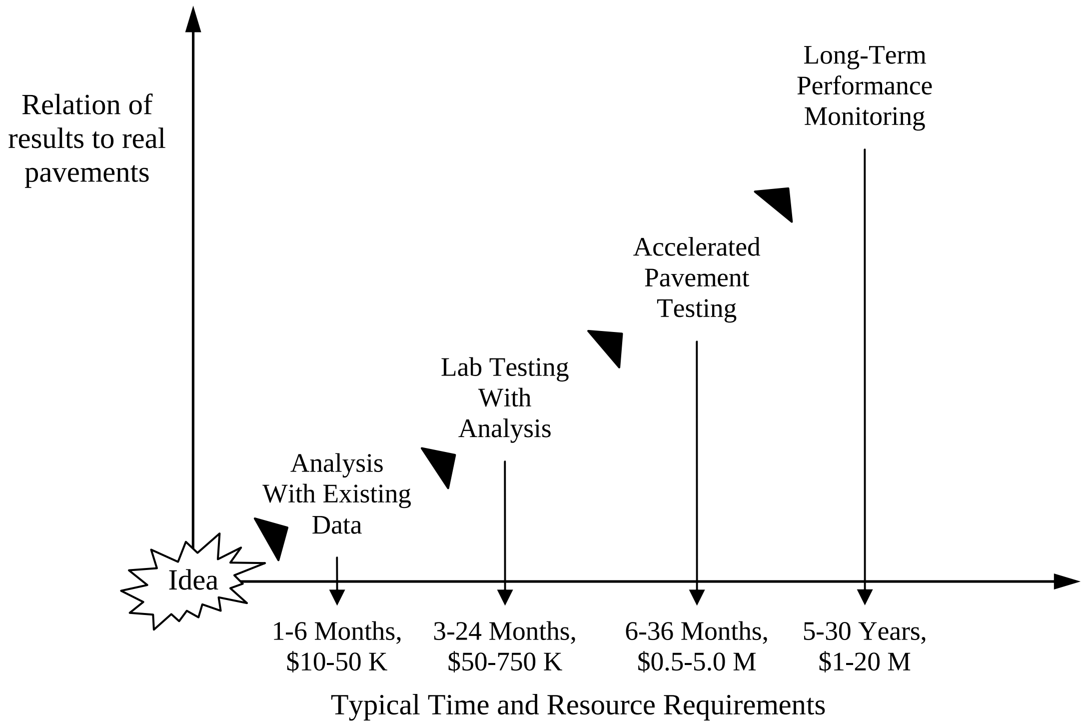


Figure 2.2 Time and Resource Requirements Associated with Various Types of Studies

The objective of conducting a study is to confirm or reject the study hypothesis. If the study results do not confirm the hypothesis, consideration should be given to rejecting the hypothesis, conducting additional analysis or using another approach for evaluation purposes. The project idea/hypothesis should be discarded if it cannot be confirmed.

The economic viability (benefit/cost ratio) and environmental impact must be assessed prior to implementation, and should be conducted as early as possible in the study.

An implementation plan should be developed after confirming the hypothesis and assessing the cost-effectiveness and environmental impact. As appropriate, the implementation plan may include the following: a report, guidelines, specifications, test procedures, and/or training materials.

Table 2.1 is a proposed project initiation form that should be completed for all studies. Items to be included are as follows:

- Proposed title
- Project champion (Member of operational unit within Caltrans who will provide oversight and lead the implementation effort)
- Background/problem statement (The background provides information on the extent and importance of the problem as well as efforts by others to solve the problem. The problem statement should provide a brief description of the problem and a clear scope of work.)
- Project objective(s)/hypotheses to be tested (This should be a concise statement of the critical issues, and if possible, the appropriate types of studies required to satisfy the project objectives.)

- Expected benefits (This should provide a clear indication of the expected monetary and operational benefits expected from the study.)
- Implementation plan (This should identify the expected deliverables, who will lead the implementation process and anticipated timetable and cost.)
- Potential partners (This should identify those who have a vested interest in the results (within Caltrans as well as industry) and could make a contribution, technical, financial or "in-kind".)

Table 2.1 Proposed Project Initiation Form

Item	Description
• Title/Idea	
• Project Champion	
• Background/Problem Statement	
• Objective/Hypothesis to be Studied	
• Expected Benefits	
• Implementation Plan	
• Potential Partners	

2.3 TYPES OF INVESTIGATIONS

Within Caltrans, specifically when evaluating products/strategies related to flexible pavements, there are three types of studies or investigation alternatives commonly used: laboratory studies, accelerated pavement testing using the HVS (heavy vehicle simulator), and field pilot studies. These alternatives may be carried out sequentially or concurrently depending upon the study hypothesis.

2.3.1 Laboratory Studies

The laboratory study may be conducted alone to evaluate a study hypothesis or in association with an accelerated pavement testing and/or field pilot study. Figure 2.3 proposes a general process for conducting the laboratory study.

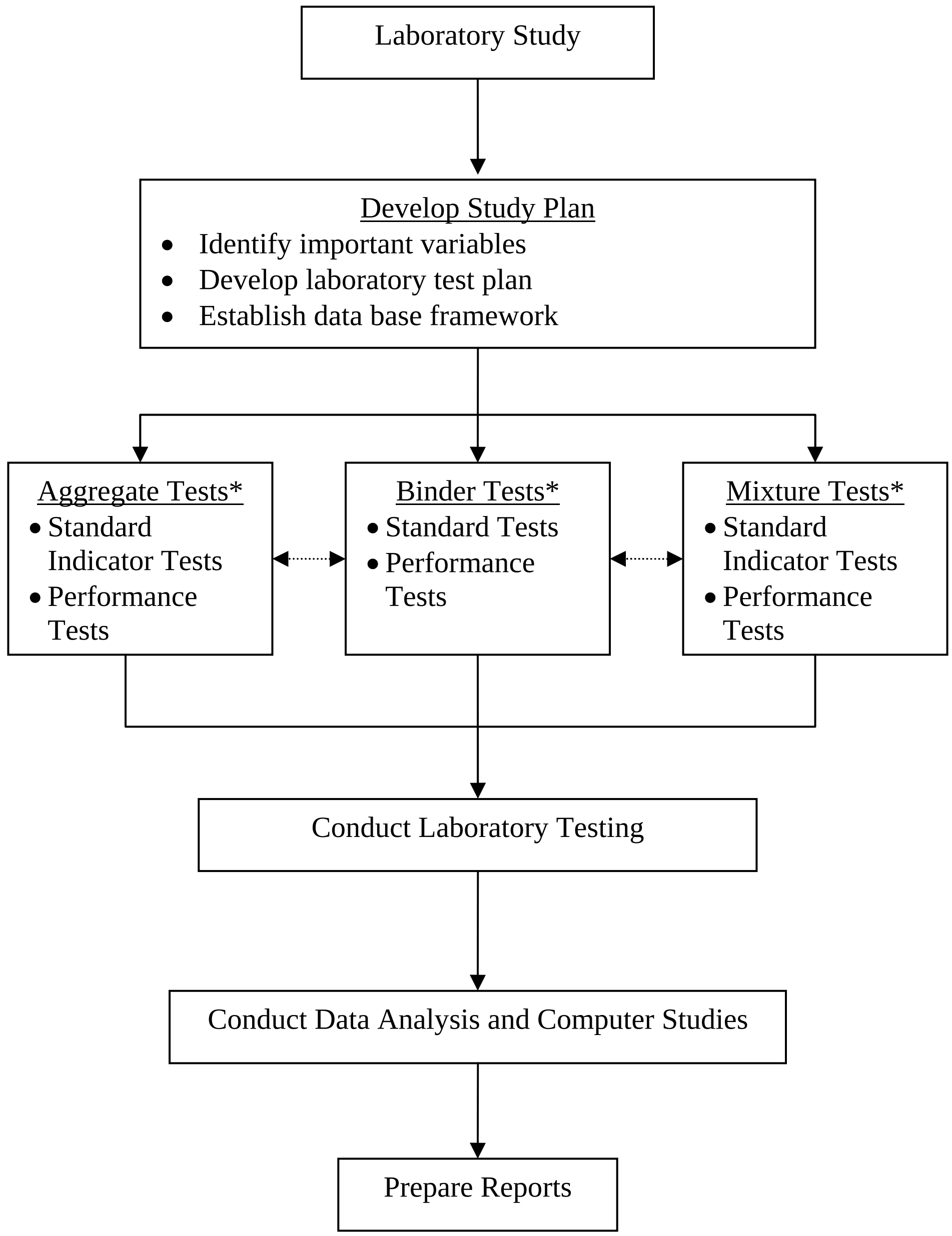
The laboratory study should begin with the development of a study plan, which includes identification of important variables to be investigated, development of a laboratory test plan (e.g., experimental design), and establishment of a database framework. The identified variables dictate the laboratory test plan and the structure of the database framework. The database should include information such as types of test performed, dates of sample preparation, testing conditions, test results, and comments related to conducting the test and test results. Laboratory tests typically include standard indicator tests and/or performance tests. The final list of tests should be determined based on the study hypothesis and recommended laboratory test plan.

Table 2.2 summarizes the types of tests that should be considered in the development of a laboratory test plan. Where feasible, performance tests should always be included to quantify the relative performance of the new product or strategy. The standard indicator tests used for a given study would vary from project to project.

The laboratory evaluation should always include a "control" product for comparison purposes. Table 2.3 shows an example experimental design matrix for the laboratory study of three mixes with two binders and two types of aggregates. The identified variables include material characteristics related to aggregate, binder and mix. A full factorial evaluation of these variables would require a minimum of 12 possible combinations. Replicate specimens could easily double or triple this number. For each combination of binder, aggregate and mix to be evaluated, a recommended set of tests should be considered. Specific testing requirements would need to be determined based on the study hypothesis. When conducting the laboratory tests, initial testing on key indicators may be carried out first for the purpose of fine-tuning the testing parameters and testing matrix defined in the original experimental design and then followed by full scale testing. If the aggregate or binder is same for all mixes, the number of specimens and tests would be proportionally reduced. More variables mean more tests.

Laboratory testing, analysis and report preparation can be accomplished as illustrated in Figure 2.3. To ensure that the laboratory study addresses the idea/hypothesis, a work schedule (including milestones for testing and reporting) should be developed. It is critical that report and "deliverable" expectations be clearly defined.

Ideally, the study should be "statistically valid and robust." Time and budget constraints will clearly affect this. Sensitivity studies of critical variables as well as design/analysis simulations are also integral parts of the laboratory study. These types of analyses, including selection of proper testing method(s) and method(s) of analysis, need to be identified in the problem statement and scope of work. Finally, a report documenting the findings of the study and including recommendations for implementation should be developed.



* Specific tests should be determined based on the study hypothesis

Figure 2.3 Proposed Laboratory Study Process for Flexible Pavement/Materials Evaluation

Table 2.2 Possible Tests for Inclusion in Laboratory Studies - Flexible Pavements

Indicator Tests	Performance Tests
a) Aggregate	
• Size and Shape • Soundness • Specific Gravity • Cleanness • Absorption	• Wear Resistance – studded tires • Polish Resistance • Durability • Adhesion
b) Binder	
• Specific Gravity • Consistency (e.g.,Viscosity, Penetration) • Safety (Flash Point)	• Rheological Properties (e.g., DSR, BBR) • Temperature Susceptibility
c) Mixes	
• Air Voids • Stability • Binder Content • Gradation • VMA, VFA, Dust to Binder Ratio	• Fatigue • Rutting • Thermal Cracking • Moisture Sensitivity • Aging Resistance

Table 2.3 Example Matrix for Laboratory Study of Mixes

Binder	Aggregate	Mix 1	Mix 2	Mix 3
Control	A			
	B			
New Product	A			
	B			

2.3.2 Accelerated Pavement Testing Study

Accelerated pavement testing (APT) using the heavy vehicle simulator (HVS) is particularly useful to evaluate factors/variables related to pavement structural properties. These types of studies typically involve construction of test sections, application of repeated loads to full scale pavement (including measuring in-place air void content with time), and monitoring the performance for rutting, cracking, and other distress modes. These studies typically include a companion laboratory testing component. Figure 2.4 presents a general process for conducting such a study.

The APT study should start with a study plan, which includes identification of important variables, development of a data collection plan, and establishment of a database framework. The identified variables dictate the data collection plan and the structure of the database framework. The database should include basic test section information such as pavement-layer geometry, materials, instrumentation (if any), types of tests and monitoring performed, testing/monitoring dates, testing conditions, testing/monitoring results, and comments related to the actual testing/monitoring as well as testing/monitoring results.

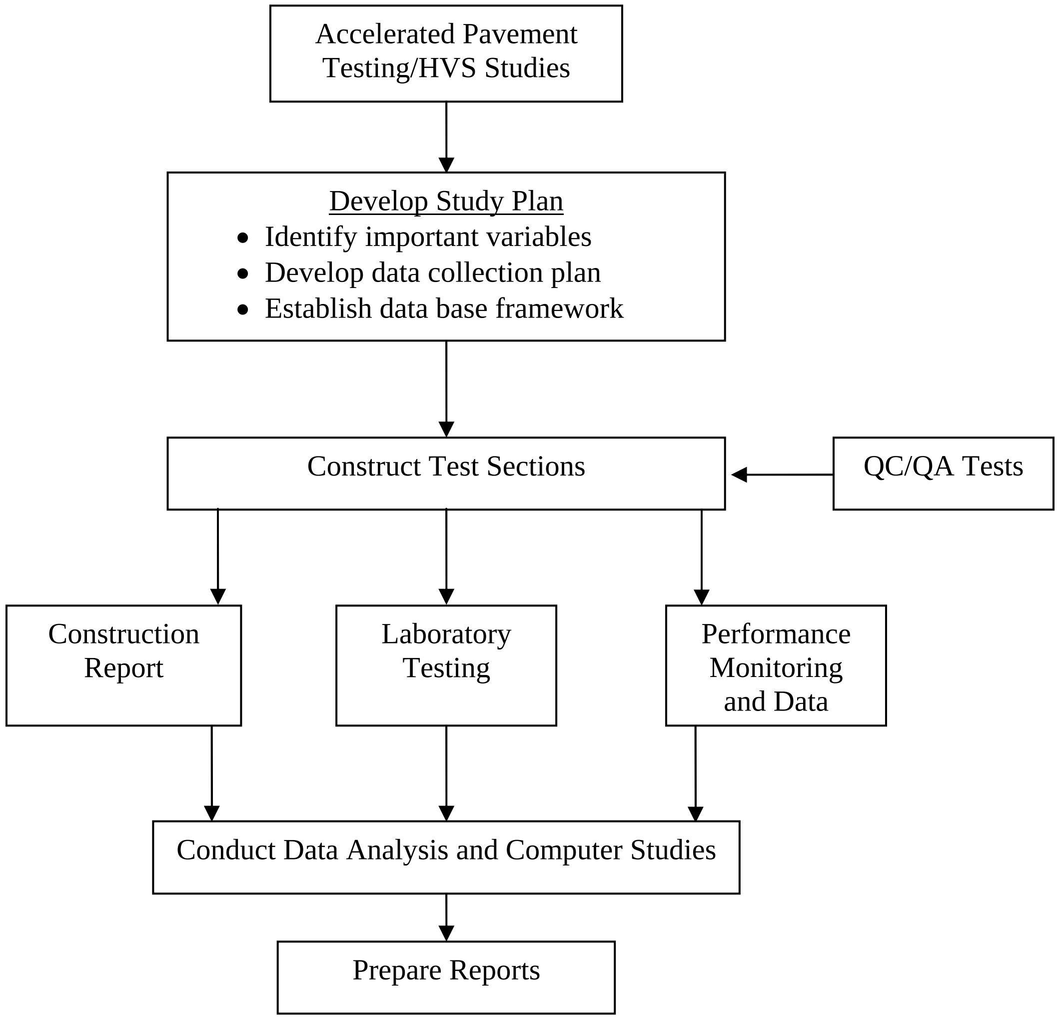


Figure 2.4 Proposed Process for APT Study

If laboratory testing is required, a specific test plan should also be included as a part of the study plan. Laboratory tests typically include standard indicator or characterization tests and/or performance tests. These tests are selected based on the study hypothesis.

Typical variables that have been considered in APT studies include the following:

- Pavement structure
  - Cross section and layer thickness
  - Base type
- Surface Materials
  - Conventional AC
  - Modified AC

Table 2.4 shows an example experimental design matrix for a study of flexible pavement overlays. Specifically, this experiment attempts to quantify the effects of the following variables: existing pavement condition, mix type, and overlay thickness. It is assumed that the same base asphalt is used. There are 16 possible combinations in this example. The overlays constructed with modified binder materials would fall into appropriate cells in the matrix. If another variable is added (e.g., roadbed soil), the number of test sections needed would double.

Table 2.4 Example Matrix for Study of Various Pavement Types and Overlay Thicknesses

		Mix Type			
Existing Pavement Condition	Overlay Thickness	Control	MB	RAC-G	RUMAC
Good	Half				
	Full				
Poor	Half				
	Full				

Prior to construction, the test section plans, specifications, and a construction quality control plan must be developed. As with other Caltrans construction projects, all equipment used to construct the test sections must be calibrated and in good working order. Quality control and assurance (QC/QA) tests should be performed during the construction of the test sections to ensure that sections are built as designed.

A construction report should be developed within 60 days after the construction. This report should address all construction-related activities: project layout including cross sections, mix design, instrumentation (if there is any), QC/QA results, etc. The construction report defines the "as-built" product serving as a baseline for evaluation purposes.

The laboratory testing should be conducted as soon as the test sections have been constructed. This may help to identify if additional tests are necessary. Performance monitoring and data collection activities should be carried out according to the schedule and requirements identified in the study plan.

The deliverable from the APT study should be a report documenting the entire effort related to the study hypothesis: construction of the test sections, analysis of the laboratory testing, performance monitoring results, and conclusions and recommendations.

2.3.3 Field Pilot Studies

Field pilot studies should be conducted only if the laboratory and accelerated pavements studies cannot accomplish the intended result or if a field study is deemed to be the best option to evaluate a product/strategy. Figure 2.5 provides a proposed process for performing field pilot studies.

The field pilot study should begin with a study plan, which includes identification of important variables, selection of candidate project (including new construction) and test section locations, development of a data collection plan, and establishment of a database framework. The identified variables dictate the selection of candidate projects, data collection plan and the structure of the database framework. The database should include basic test section information such as pavement structure and materials, pavement instrumentation (if any), test section layout, construction data, traffic data, types of tests and monitoring to be performed, testing/monitoring schedule, testing conditions, and testing/monitoring results.

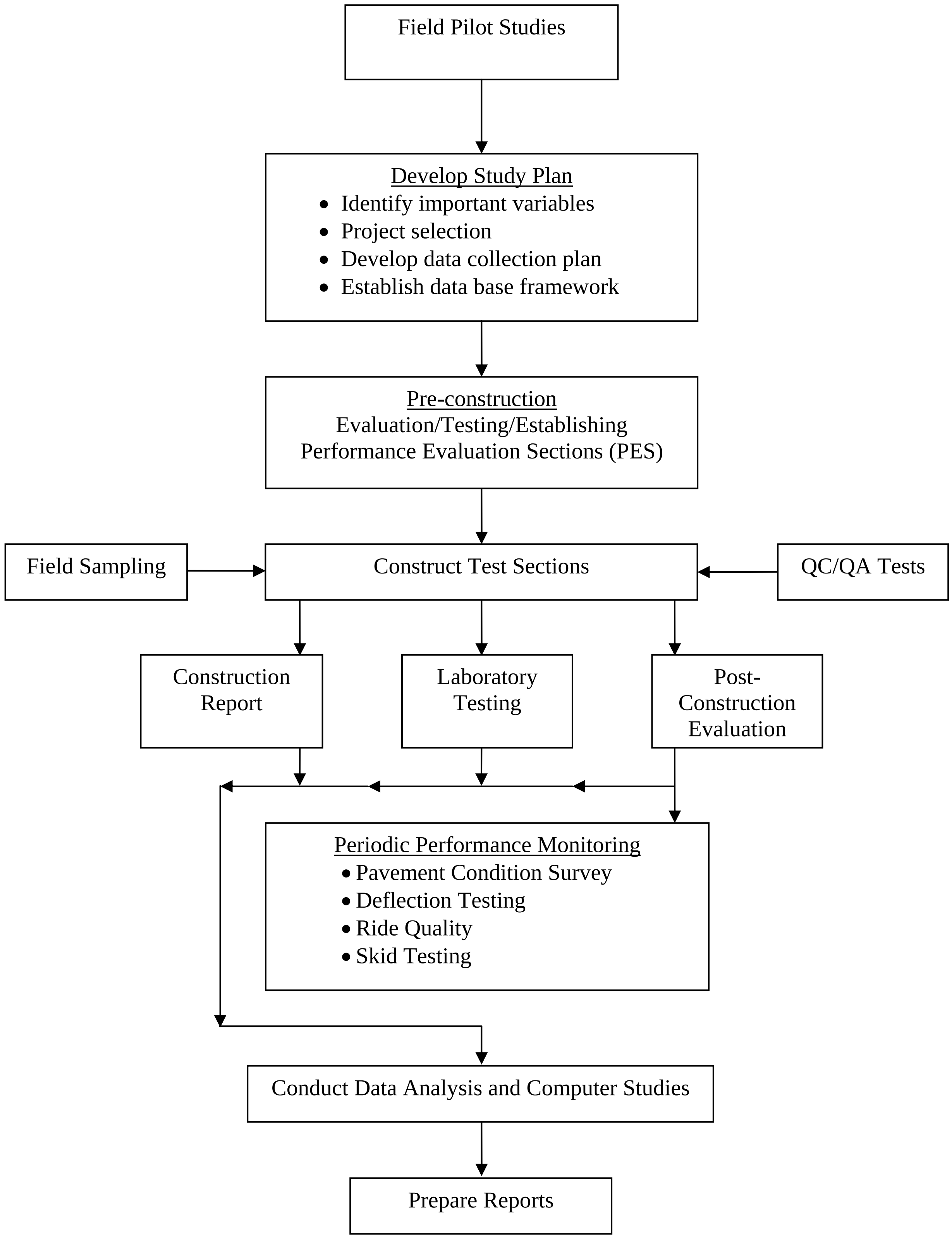


Figure 2.5 Proposed Process for Field Pilot Study

If laboratory testing is required, a specific test plan should also be included in the study plan. Laboratory tests typically include standard indicator and characterization tests and/or performance tests. These tests should be determined based on the study hypothesis and recommended and discussed in the laboratory test plan.

For flexible pavements, examples of important test variables are summarized in Table 2.5. Typical experimental design matrices for field studies are included in Table 2.6 (new construction) and Table 2.7 (rehabilitation/maintenance) projects, respectively. These designs clearly show that the number of possible sections in any field study increases greatly as the number of variables to be evaluated increases. This emphasizes the importance of careful planning when doing field studies.

The field pilot study must also consider the geometry of the roadway, cross section, and soil support condition associated with the project. Ideally, all test sections should be constructed on a uniform supporting foundation to preclude bias in the results. A list of suggestions for project selection and data collection is provided in Table 2.8. These should be similar regardless of the operational unit overseeing the project (e.g., METS, Research, Maintenance).

The field pilot study typically involves a pre-construction evaluation/testing and establishment of performance evaluation sections (PES). Specific pre-construction evaluation testing requirements are also presented in Table 2.8. The establishment of PESs should be based on existing roadway condition and support characteristics. For a rehabilitation project, FWD deflection testing is normally conducted prior to design to establish these PESs. Appendix A includes a recommended deflection testing scheme for all field studies. A consistent methodology for pavement condition survey should also be adapted. This assures all distress measurements are collected consistently and evaluated against the same criteria. Appendix B presents a proposed method for all field studies and a comparison of several methods available. Caltrans is encouraged to adopt one method for use by all operating units.

Prior to constructing test sections, plans, specifications, and a construction quality control plan must be developed. As with other Caltrans construction projects, all equipment used to construct the test sections must be calibrated and in good working order. Quality assurance and quality control (QA/QC) tests should be performed during the construction. If the study plan or the laboratory test plan requires the use of sample materials from the field, a specific sampling plan must be developed. The sampling plan should include the type of materials, quantity, sample size, sample location, and other requirements associated with the sampling activities.

A construction report should be developed within 60 days of construction. This report should address all construction-related activities: project layout including cross sections, mix design, instrumentation (if there is any), QC/QA results, etc. The construction report defines the "as-built" product serving as a baseline for evaluation purposes. It is important that the resident engineer for the project be aware of the scope and importance of the study and cooperates with the study team by providing needed information in a timely manner.

The laboratory testing should be conducted as soon as the test sections have been constructed. This may help to identify if additional tests are necessary. Post-construction evaluation should be conducted between one to six months after completion. Periodic performance monitoring should begin one year later. Periodic performance monitoring and data collection activities should be carried out according to the schedule and requirements identified in the study plan.

Data collection plans may vary with the field pilot study type, i.e., new construction, rehabilitation, and maintenance. A suggested data collection checklist for various types of field pilot studies is provided in Table 2.9. The deliverable from the field pilot study should be a report documenting the entire effort related to the study hypothesis, the construction of the test sections, the laboratory testing, performance monitoring results, conclusions and recommendations.

Table 2.5 Example of Important Variables for Flexible Pavement Studies

Variables	Considerations	New Pavement	Rehabilitation/ Maintenance
Climate	• Temperature • Rainfall	X	X
Traffic	• Low • Moderate • High	X	X
Roadbed Soil	• Good • Fair • Poor	X	X
Base Type	• Aggregate • ATPB • CTB	X	X
Existing Pavement Condition	• Good • Fair • Poor		X
Overlay Thickness	• Full • Half		X
Overlay Materials/ Surface Treatment	• Control Mix • Other Mixes • Other Materials		X

ATPB = Asphalt treated permeable base. CTB – Cement treated base
X indicates variables to be considered in field pilot studies

Table 2.6 Generic Experimental Design for New Construction

Climate	Traffic	Roadbed Soil	Pavement Types			
			AC/AB	AC/ATPB	AC/CTB	Full Depth AC
Coastal	Low	Good				
		Poor				
	High	Good				
		Poor				
Valley/Desert	Low	Good				
		Poor				
	High	Good				
		Poor				
High Desert/Mountain	Low	Good				
		Poor				
	High	Good				
		Poor				

Table 2.7 Generic Experimental Design for Rehabilitation and Maintenance Projects

Climate	Traffic	Existing Pavement Condition	Overlay Thickness/Surface Treatment			
			Control Mix	Mix 1	Mix 2	Mix 3
Coastal	Low	Good				
		Poor				
	High	Good				
		Poor				
Valley/Desert	Low	Good				
		Poor				
	High	Good				
		Poor				
High Desert/Mountain	Low	Good				
		Poor				
	High	Good				
		Poor				

Table 2.8 Suggestions for Project Selection and Data Collection – Field Pilot Studies

Data Collection Item	Considerations (MACTEC, 2002a, 2002b, 2003)
Project selection and layout considerations	
Project site and test sites	• Project length sufficient to establish performance evaluation section (PES) • Design AC layer thick enough to evaluate effect of full/half thicknesses • Uniform cross section for PES • Relatively uniform deflection profile for PES • Relatively uniform pavement condition, including drainage • Free from serious structural defects, such as pumping or base failure • Similar geometrics of roadway
Standard layout	1000 ft is preferred – 500 ft usually is not adequate to stabilize AC plant mix production or field compaction operations
Sampling location and instrumentation package	30 m or 100 ft away from each end of the test section
Pre-construction evaluation/testing	
Existing pavement profile and material properties	AC, base, subbase layer thickness, stiffness, R-value, gradation
Deflection testing data & core sampling information	For determination of location of PESs
Pavement condition survey maps and photos	Include distress type, severity, extent
Rut measurement of selected PES	Measured as part of the pavement condition survey
Traffic information	ADT, % trucks, ESALs, TI, growth rate
QC testing plan	Contractor QC plan
Mix design data	Contractor mix design and Caltrans verification
Plans and special provisions	Project specific document
Climate and environmental information	Project site information may be obtained from UCB
Maintenance history of the existing pavement	Previous repair/maintenance data
Construction monitoring/testing	
Sources of materials (binders, aggregates, modifiers)	Certificates of compliance from material suppliers
Plant type and condition (T-109 data)	Calibration data of plant and equipment
Paving dates	Start and end dates, including delays in paving operations, the reasons for them
Paving equipment used	Model, make, year
Haul distances and time	From plant to paving site
Site weather conditions	During paving, include ambient air and pavement temperatures
Mix temperatures at various locations	Upon discharge, in windrow, immediately behind screed, during breakdown, finish rolling
Compaction equipment and methods	Type, make, model, weight, vibration or static
In-place air voids	Based on core density and maximum theoretical density (CT309)
RE diaries/Inspectors notes	Copies of resident engineers and inspectors notes
Results of QC/QA tests	AC Pay data – more important for characterizing products actually supplied for study purposes
Sample requirements for laboratory tests (binders, aggregates and mixes)	Number of cores, beams, amount of aggregate, binders, respective loose mixes
Date opened to traffic	
Laboratory testing	
Refer Table 2.2	Table 2.2
Post-construction evaluation	
Pavement condition data including ride	On PESs and the entire project
Deflection data	On PESs
Additional sampling needs	If needed, 30 m or 100 ft away from each end of the test section
Periodic monitoring	
Detailed distress mapping (PES only)	On PESs
Overall condition-photo logs and distress survey	For entire project
Deflection testing	On PESs
Reporting	
Construction report	Activities associated with construction, layout, mix design
Initial performance report	Data collected during the field performance evaluation
Final report	Summary of the construction, performance, and findings

Table 2.9 Proposed Data Collection Checklist for Various Types of Study

Data Collection Item	New Construction	Rehabilitation	Maintenance
Project selection and layout considerations			
Project location and length	X	X	X
Design AC layer thicknesses	X	X	X
Cross section for PES	X	X	X
Deflection profile for PES		X	X
Pavement condition, including drainage		X	X
Description of any structural defects, such as pumping or base failure		X	X
Geometrics of roadway	X	X	X
Pre-construction evaluation/testing			
Existing pavement profile and material properties		X	X
Deflection testing data and core sampling information		X	X
Pavement condition survey maps and photos		X	X
Rut measurement of selected performance evaluation section		X	X
Traffic information	X	X	X
QC testing plan	X	X	X
Mix design data	X	X	X
Plans and special provisions	X	X	X
Climate and environmental information	X	X	X
Maintenance history of the existing pavement		X	X
Construction monitoring/testing			
Sources of materials (binders, aggregates, modifiers)	X	X	X
Plant type and condition (T-109 data)	X	X	X
Paving dates including delays in paving operations, the reasons for them	X	X	X
Paving equipment used	X	X	X
Haul distances and times	X	X	X
Site weather conditions	X	X	X
Mix temperatures at various locations (truck, paver hopper, behind paver, etc)	X	X	X
Compaction equipment and methods	X	X	X
In-place air voids	X	X	X
RE diaries/Inspectors notes	X	X	X
Results of QC/QA tests	X	X	X
Sample requirements for laboratory tests (binders, aggregates and mixes)	X	X	X
Date opened to traffic	X	X	X
Post-construction evaluation			
Pavement condition data including ride and skid	X	X	X
Deflection data	X	X	X
Additional sampling needs	X	X	X
Periodic monitoring			
Detailed distress mapping (PES only)	X	X	X
Overall condition-photo logs and distress maps	X	X	X
Deflection testing	X	X	X
Reporting			
Construction report	X	X	X
Initial performance report	X	X	X
Final report	X	X	X

X indicates data element should be collected.

2.4 Economic Analysis and Environmental Impact

As early in the project as possible, a determination should be made as to the economic viability and environmental impact of the product and/or new strategy. Environmental impact encompasses not only air and water quality, but also worker health and safety. Both initial costs and life cycle costs of implementing the product and/or strategy should also be addressed.

2.5 Implementation

The implementation plan that should address the following:

- Expected products and dissemination format.
- Responsible unit for dissemination.
- Timetable and cost for dissemination or "technology transfer."

2.6 Summary

This chapter outlined a generic process to evaluate new products and/or strategies regardless of the Caltrans operating unit (METS, Maintenance and Research). Additional work is required to evaluate the process and to refine the details for data collection and materials testing. An example of this process for the evaluation of CRM materials is presented in Appendix C.

3.0 PROPOSED CRUMB RUBBER MODIFIED MATERIAL STUDIES

This chapter outlines potential CRM studies generated from discussions with Caltrans, UC PPRC, industry, the RAC technology transfer centers, and the Caltrans-industry RAC Task Group.

3.1 CONSTRUCTION/REHABILITATION AND MAINTENANCE APPLICATIONS

3.1.1 New Construction

Caltrans use of CRM mixes has traditionally been limited to pavement rehabilitation and maintenance applications. However, this does not preclude the possibility of use in new construction as a comprehensive literature review revealed that some agencies have used CRM successfully for shoulder widening of an existing roadway or as the wearing course of a new pavement structure. For Caltrans to use CRM in new construction within its current design framework, a gravel factor (G_f) for CRM would be required.
.
Hypothesis: Asphalt rubber products can be used in new construction.

3.1.2 Thick Overlays

In California, RAC-G overlays are typically designed and constructed to 60 mm or less because of the cost differential with DGAC. Although there are concerns with the potential for shear flow and rutting of thicker sections, the 60-mm maximum is being re-evaluated in the Firebaugh project and the MB study at UC Berkeley where 90-mm overlays have been constructed. The Firebaugh and MB studies may provide some much-needed insight as to the technical and economic benefits of thicker sections, i.e., overlays thicker than 60 mm. That said, agency experience and research indicate that CRM asphalt tends to be most effective and economical when placed as a relatively thin wearing course.

Cost is a critical factor in selecting wet process binders in thick layers. RAC-G made with high viscosity binders is deemed cost effective in its current application because of the reduced thickness associated with the prevention of reflection cracking. Reduced thickness, however, may be inappropriate in other applications such as new construction.

Hypothesis: Asphalt rubber overlays can be placed at thickness greater than 60 mm without adverse effects on construction, cost and performance.

3.1.3 Open Graded-High Binder Mixes

A well-documented benefit of an open-graded asphalt concrete (OGAC) surface layer is noise reduction (ATRC, 1996; Sacramento County, 1999; Roschen, 2000; Donavan and Rymer, 2003; Carlson, 2003; MACTEC, 2004a). The tire-pavement noise reduction is attributed to the open texture and increased binder film thickness of the OGAC mix, not necessarily to the presence of CRM. Still, current studies conducted by Arizona Department of Transportation (ADOT) suggest that mixes with high viscosity binders and corresponding high binder contents (≥9% by total weight of mix) may yield greater noise reduction. Arizona has found that open-graded mixes (high viscosity binder) placed as thin (25 mm thick) overlays on portland cement concrete not only retard reflection cracking but also reduce noise (Way, 2000; Scofield and Donovan, 2003).

The Arizona Department of Transportation is a pioneer in the use of high viscosity CRM binders in paving projects for noise control (Kuennen, 2004), although that was not the original purpose for development and use of these materials. Generally, Arizona DOT uses an asphalt rubber asphalt concrete friction course (AR-ACFC) with aggregate passing the 9.5 mm sieve combined with 9 to 9.5% asphalt rubber binder for noise attenuation. A 12.5 mm lift is used on flexible pavements whereas a 25 mm lift is used on rigid pavements with high traffic volumes. Minimum noise attenuation of 4 dBA has been consistently attained using these thin open-graded surfaces, and in many cases greater attenuation has been achieved (Kuennen, 2004; Scofield and Donovan, 2003).

Similarly, a local agency study (Sacramento County, 1999) of RAC-G on Alta Arden Expressway recorded an average 4 dBA noise reduction compared to that measured on conventional asphalt concrete on Bond Road. This noise reduction continued for six years after the paving with rubberized asphalt (Sacramento County, 1999).

The use of high binder open-graded mixes has definite potential for use as a wearing course on portland cement concrete pavements or on flexible pavements. There are numerous opportunities in California to place high-binder open-graded mixes as a wearing course to achieve the twofold benefits: reducing noise and retarding reflective cracking. Extending CRM use for overlays of PCC pavements would likely improve ride quality and reduce noise.

Hypothesis: Arizona DOT's strategy of open-graded high binder mixes can be effective for Caltrans in reducing noise and retarding reflective cracking.

3.1.4 Recycling

Recycling of conventional mixes with CRM materials represents another avenue to expand the use of CRM. Currently, however, the primary concern is with recycling of RAC, an issue addressed in a companion report titled "Feasibility of Recycling Rubber Modified Paving Materials" (MACTEC, 2004b).

Hypothesis: A RAC mix can be recycled.

3.2 MATERIALS STUDIES

3.2.1 Type 1 vs. Type 2 Binders

Two types of high viscosity CRM binders have been used in California: Type 1 includes only scrap tire CRM in the asphalt cement; Type 2 includes a blend of CRM consisting of 75% scrap tire and 25% high natural CRM (typically truck tires), and an extender oil (Hicks, 2002).

Caltrans currently requires the use of Type 2 high viscosity binders and most cities and counties in California also use Type 2 binders. However, only Caltrans requires Type 2 binder. Some California cities and counties and the states of Arizona, Florida and Texas use Type 1 binders (Hicks, 2002). A study to evaluate the relative effectiveness of the Type 1 and Type 2 binders is recommended to clarify the most appropriate applications for the different binders.

The use of the extender oils in asphalt concrete mixes may help reduce the rate of age-hardening and the development of such surface distresses as thermal cracking and raveling. However, air quality complaints are reportedly related the presence of extender oils. Also, extender oil may lead to early bleeding when used in chip seals over a newly constructed asphalt pavement. Thus, the use of extender oils is an area which warrants further study. Arizona DOT does not allow extender oil in high viscosity binders; Texas and Florida DOTs allow it, but do not normally use it.

Hypothesis: Type 1 and Type 2 binders affect performance of mixes. The use of extender oil in asphalt rubber binders is unnecessary.

3.2.2 Binder Testing

Many have recognized that asphalt binder properties are critical to the control of cracking in asphalt pavements. This is particularly true for thermal cracking and, to a lesser extent, fatigue cracking. Modified binders are generally more crack resistant than "neat" binders, though performance varies considerably with modifier type and content. For high viscosity binders in California, the cracking performance is not well understood or documented. This is largely the result of the use of the aged-residue (AR) grading system that classifies asphalt cements after they have been artificially aged using the Rolling Thin Film Oven procedure and that provides little information on the properties of the unaged (or original) asphalt cement. Research has shown cold temperatures properties of the base asphalt cement govern the properties of CRM binders. Extender oil, used by refiners to soften asphalt cement and required in Type 2 binders, may enhance low temperature performance. Crumb rubber modification would provide significant increases in stiffness and elasticity at high temperatures and enhance resistance to permanent deformation or rutting and low-temperature cracking (Navarro, 2000).

To develop a better understanding of high viscosity and no agitation CRM binders, a laboratory test program should be undertaken to quantify the effect of binder type on pavement performance. This can best be achieved for some materials using the Superpave performance graded binder and mix tests. However, there are concerns as to the use of these tests with high viscosity binders. The discrete swollen rubber particles may produce highly variable dynamic shear rheometer (DSR) test results. The particulate matter may provide premature failure planes in beams for bending beam rheometer (BBR) and in direct tension specimens which are used to determine critical cracking temperature (low temperature performance tests). The outcome of this laboratory test program should provide some data for assessing the relative benefits of the different CRM (no agitation and high viscosity) binders, but due to the issues of testing two-phase materials, results may not be definitive.

Hypothesis: The properties of neat asphalt cements and CRM binders affect mix and/or field pavement performance.

3.3 STRUCTURAL DESIGN STUDIES

3.3.1 Gravel Factor(s) for RAC-G, MB-D, and MB-G

Caltrans current pavement structural design procedure (Caltrans, 2004) requires the use of R-value and Traffic Index (TI) to develop flexible pavement layer thicknesses for new and reconstruction projects. The procedure is based upon a layer equivalency approach in which the relative load-carrying capacity of individual pavement layers is related through a gravel equivalence value. The gravel factor (G_f) refers to the relative strength of a given material compared to a standard gravel subbase material. Gravel factors for dense-graded asphalt concrete and various types of base and subbase materials have been developed over the years. However, no G_f has been established for rubberized asphalt concrete (RAC) materials for use in new pavement as well as in rehabilitation designs.

Recently, Caltrans initiated an effort to develop gravel factors for RAC-G, MB-D and G mixes. Based on a meeting held with Caltrans and UC PPRC staff, a general framework for the development of the gravel factor(s) for RAC-G was developed. This framework calls for a review of the related work, especially of the laboratory test data on dense-graded AC and RAC-G materials. Interim gravel factor(s) for RAC-G may be developed based on the review of these laboratory test data and refined through mechanistic-empirical and/or finite element analysis methods. The interim gravel factor(s) may then be validated using data gathered from studies already underway: the UC PPRC HVS MB study and the Firebaugh project. Additional test sections with different thickness of RAC-G may need to be constructed and tested using the HVS to validate the interim G_f value(s). A draft work plan for this work is presented in Appendix D.

Hypothesis: The gravel equivalence approach for determining the DGAC thickness in new pavement design is valid for the thickness design of RAC-G and modified binder (MB) mixes.

3.3.2 Modification of Overlay Design Procedure

Caltrans current deflection-based flexible pavement rehabilitation design procedure (Caltrans, 2001) employs the percent reduction in deflection approach to determine the overlay thickness required for future traffic. The procedure was originally developed for the design of conventional DGAC overlays and was adapted in recent years to accommodate RAC-G overlays in lieu of (or in combination with) a standard DGAC overlay. Since its development, there has been no field validation of this design approach.

Accordingly, it is recommended that a study be undertaken to validate and calibrate the design procedure with specific emphasis on RAC-G. This may be accomplished through a combination of field and laboratory studies. Some of the needed data will be obtained from the RAC Warranty and Firebaugh projects. However, it is anticipated that more projects will be needed to provide a statistically valid data set. The experiments will require different types of RAC-G sections, including RAC-G on conventional DGAC, RAC-G on RAC-G, and conventional DGAC on RAC-G, as well as DGAC control sections. Any new sections identified will require deflection testing (before and after construction), core sampling and testing (to determine layer resilient moduli), traffic counts, and performance monitoring. A draft work plan for this work is provided in Appendix E.

Hypothesis: The deflection based approach used for determining the DGAC overlay thickness in pavement rehabilitation design is valid for the overlay thickness design of RAC-G and modified binder (MB) mixes.

3.4 SUMMARY

This chapter presented several studies that could generate data to confirm/refute the effectiveness of Caltrans currents strategies for use of CRM. Additionally, studies were suggested that might broaden or extend Caltrans current use of CRM. Also, a suggested hypothesis for each study was presented.

Caltrans is encouraged to evaluate the use of RAC and MB mixes in new construction, as thick overlays, as a wearing course for reducing noise and retarding reflective cracking, and in recycling applications. These ideas can be implemented immediately if the individual hypothesis can be confirmed and the approach is cost effective and has no adverse environmental impact. Similarly, a study on binder types (Type 1 versus Type 2) may be implemented if appropriate projects can be solicited after the confirmation of related hypotheses. Binder testing may be initiated at a later time.

The development of gravel factors for RAC-G and MB mixes requires further investigation. The work plan presented in Appendix D is the result of several meetings with Caltrans, UC PPRC and MACTEC staff. It is envisioned that the work will be performed in two phases. Phase 1 is to develop interim gravel factor and phase 2 is to validate the interim gravel factor. Phase 1 is expected to be completed by September 2005; phase 2 will require three to five years to complete, after the performance monitoring data from the various studies are collected. A draft work plan for modification of the rehabilitation design procedure, which is also the result of several meetings with Caltrans, UC PPRC and MACTEC staff, is presented in Appendix E. The work will be performed in two phases with an expected completion date for Phase 1 by September 2005.

4.0 SUMMARY AND RECOMMENDATIONS

4.1 SUMMARY

This report presents the framework for a generic process to evaluate new products and/or strategies for possible use within Caltrans. The framework is the result of a collaborative effort among Caltrans, the University of California Partnered Pavement Research Center (UC PPRC) and MACTEC.

The generic experimental design process is applicable to all pavement types as well as the component materials of pavements. The framework includes various types of studies that may be used in the evaluation process — laboratory, accelerated pavement testing (APT) and field pilot studies. Additionally, it identifies other factors that must be considered in the evaluation of any new product/strategy: economic viability and environmental impact.

The process was used to develop numerous project ideas/hypothesis that may help to broaden and expand Caltrans use of CRM in paving applications. They are listed below:

- For Construction/Rehabilitation and Maintenance Applications
  - New construction
  - Thick overlays
  - Open graded-high binder mixes
  - Recycling
- For Materials Studies
  - Type 1 vs. Type 2 binders
  - Binder testing
- For Structural Design Studies
  - Gravel factor for RAC-G and MB mixes
  - Modification of the deflection based overlay design procedure

In addition, two structural design-related studies were expanded into detailed work plans which address the following:

- development of a gravel factor for RAC-G and MB mixes for use in new construction; and
- update/modification of Caltrans deflection based overlay design procedure to accommodate RAC-G and MB mixes.

4.2 RECOMMENDATIONS

It is recommended that the generic experimental design process outlined herein be considered as a foundation for Caltrans evaluation of any new product and/or strategy, as is the case for CRM in paving applications.

Also, it is recommended that the generic process presented in this report be refined to include detailed information on data collection and testing requirements associated with each study type.

5.0 REFERENCES

AASHTO, 1993. "Guide for Design of Pavement Structures," AASHTO, Washington, D.C., 1993.

ATRC, 1996. "Asphalt Rubber Friction Course Reduces Traffic Noise," Arizona Department of Transportation Research Notes, August 1996.

Caltrans, 1979. "Asphalt Concrete Overlay Design Manual," Caltrans, Sacramento, CA, January 1979.

Caltrans, 2000. "Pavement Evaluation Manual," Caltrans, Sacramento, CA, January 2000.

Caltrans, 2001. "Flexible Pavement Rehabilitation Manual," Revised June 6, 2001. Caltrans, Sacramento, CA, June 2001.

Caltrans, 2003. "Guide to the Investigation and Remediation of Distress in Flexible Pavements," Draft Field Manual, Caltrans, Sacramento, CA, July 2003.

Caltrans, 2004. "Highway Design Manual," Caltrans, Sacramento, CA, 2004.

Carlson, D.D., H. Zhu, and C. Xiao, 2003. "Analysis of Traffic Noise Before and After Paving with Asphalt Rubber," Asphalt Rubber 2003 Conference, pp 413-428, December 2003

Donavan, P.R. and B.C. Rymer, 2003. "Measurement of Tire/Pavement Noise Sound Intensity Methodology," Asphalt Rubber 2003 Conference, pp 399-412, December 2003.

FHWA, 2003. "Distress Identification Manual for the Long-Term Pavement Performance Program (Fourth Revised Edition), Report No. FHWA-RD-03-031, McLean, VA, June, 2003.

Hicks, R.G., 2002. "Asphalt Rubber Design and Construction Guidelines: Volume 1 – Design Guidelines," $RACT^2$ Center, Sacramento, California, January 2002.

Highway Research Board, 1962. "The AASHO Road Test, Report 5, Pavement Research," Special Report 61E, , Washington, D.C., 1962.

Kuennen, T. 2004. "Asphalt Rubber Makes a Quite Comeback'" Better Road, May 2004.

MACTEC, 2002a. "Rubberized Asphalt Concrete (RAC) Warranty Pilot Projects: Information Packet for Resident Engineers Data Collection Guidelines," Prepared for Materials Engineering and Testing Services, Caltrans, Sacramento, CA, November 2002.

MACTEC, 2002b. "Rubberized Asphalt Concrete (RAC) Warranty Pilot Projects: Data Collection Guidelines," Prepared for Materials Engineering and Testing Services, Caltrans, Sacramento, CA, November 2002.

MACTEC, 2003. "Proposed Field Evaluation Plan for Asphalt Concrete Pavements with Asphalt Rubber and Rubber Modified Binders," Draft Proposed Field Evaluation Plan to CIWMB and Caltrans Partnership, September 2003.

MACTEC, 2004a. "Use of Scrap Tire Rubber – State of the Technology and Best Practices," Prepared for METS, Caltrans, Sacramento, September 2004.

MACTEC, 2004b. "Feasibility of Recycling Rubber-Modified Paving Materials", Prepared for METS, Caltrans, Sacramento, September 2004.

Navarro, J., P. Partal, F. Martinez-Boza, and C. Gallegos, 2000. "Linear Viscoelastic Properties of Ground Tire Rubber-Modified Bitumen," Asphalt Rubber 2000 Conference, pp 411-420, November 2000.

Roschen, T., 2000. "Report on the Status of Rubberized Asphalt: Traffic Noise Reduction in Sacramento County," Asphalt Rubber 2003 Conference, pp 517-539, November 2000.

Sacramento County, 1999. "Report on the Status of Rubberized Asphalt Traffic Noise Reduction in Sacramento County," Sacramento County Department of Environmental Review and Assessment, November 1999.

Scofield, L. and P.R. Donovan, 2003. "Development of Arizona's Quiet Pavement Research Program," Asphalt Rubber 2003 Conference, pp 429-452, December 2003.

University of California, Berkeley, 2003. "Comparison of MB, RAC-G and DGAC Mixes under HVS and Laboratory Testing," Draft Prepared for California Department of Transportation, University of Berkeley, July 2003.

Way, G.B., 2000. "OGFC Meets CRM Where the Rubber Meets the Rubber 12 Years of Durable Sucess," Asphalt Rubber 2000 Conference, pp 15-31, November 2000.

Appendix A

PROPOSED DEFLECTION TEST PLAN FOR PERFORMANCE EVALUATION OF MODIFIED BINDER STUDY FOR ALL FIELD PROJECTS

PROPOSED DEFLECTION TEST PLAN FOR PERFORMANCE EVALUATION OF MODIFIED BINDER STUDY FOR ALL FIELD PROJECTS

OVERVIEW

Pavement surface deflections are a structural response of the pavement system to an applied load and provide the basis for:

- evaluating pavement structural capacity,
- assessing the variability of existing support,
- characterizing the in-situ material properties of the layers, and
- developing rational rehabilitation designs.

For the purpose of performance monitoring of a test section, which has a length of 152.4 m (500 ft), the deflections should be measured at specific, pre-determined locations under certain load levels with specific sensor configurations, for a desired monitoring period. These conditions must be followed for the data to be meaningful and useful. For this study, activities associated with the FWD testing are described below. A comparison of two commonly used deflection test schemes is presented in Table A.1.

FWD TEST REQUIREMENTS

Based on an evaluation of the schemes, a proposed FWD test plan was developed following extensive discussions with Caltrans and UC PPRC. The recommended FWD test requirements are described below:

Item	Description	Comments
Sensor Configuration	1. -305, 0, 203, 305, 457, 610, 914, 1219, 1524 2. 0, 203, 305, 610, 914, 1219, 1524	Distance in mm from the center of the load plate. Plan 1 uses 9 sensors and is preferred. If seven sensors are used, then use plan 2.
Load Package	• 26.7 (Seating load, once) • 26.7 (Once, range 24.0-29.4) • 40.0 (Once, range 36.0-44.0) • 53.4 (Once, range 48.1-58.7)	Load in kN. A seating drop at 26.7 kN should be applied but not recorded. At each load level, the load should be applied once and deflections be recorded electronically.
Air & Pavement Temperatures	At each test location	Temperatures may be measured using device mounted on the FWD or manually.
Test Location	• Mid-lane, 11 deflections • Outer wheel path, 11 deflections • ~15.2 m intervals	See Figure A.1

Table A.1 Comparison of Deflection Test Schemes

Item	**CT 356 (June 2004 Version)**	**LTPP (GPS-1, 2, 6, 7, 500 ft Section)**	**Proposed Plan (Revised October 2004)**
Sensor Configuration	No description	-305, 0, 203, 305, 457, 610, 914, 1219, 1524	1. -305, 0, 203, 305, 457, 610, 914, 1219, 1524 2. 0, 203, 305, 610, 914, 1219, 1524
Load Package	• One seating load (26.7 kN) • Three drops with an applied load of 40 kN ±10% • Use average of three readings and normalized to 40 kN	• 53.4 (Seating load, 3 times) • 26.7 (4 times, 24.0-29.4) • 40.0 (4 times, 36.0-44.0) • 53.4 (4 times, 48.1-58.7) • 71.2 (4 times, 64.1-78.3)	• 26.7 (Seating load, once) • 26.7 (Once, 24.0-29.4) • 40.0 (Once, 36.0-44.0) • 53.4 (Once, 48.1-58.7)
Air & Pavement Temperatures	Record the ambient air and pavement surface temperatures		
Test Location and Frequency	Method A: o Length ≥1.6 km: 21 deflections/1.6 km; 80-m intervals outside wheel path o Length <1.6 km: determine the size of testing interval to obtain 21 deflections Method B: o Select one 300-m long test section "representative" of every 1.6 lane-km. ~15 m intervals to obtain 21 deflections o Length <300 m: determine the size of testing interval to obtain 21 deflections	• Mid-lane (21 measurements) • Outer wheel path (21 measurements) • ~7.6 m intervals	• Mid-lane (11 measurements) • Outer wheel path (11 measurements) • ~15.2 m intervals

ONSITE CORING

This activity is performed once during post-construction to verify the thickness of pavement structure after overlay. Two full depth cores should be collected at each performance evaluation section (PES). Each core should be at least 100 mm (4-inches) in diameter and be located 30.5 m (100 ft) before and after the PES (see Figure A.1). Cores should be inspected to determine its condition (e.g., stripping) and pavement layer thickness. Cores should be packaged and retained for future evaluation and/or testing.

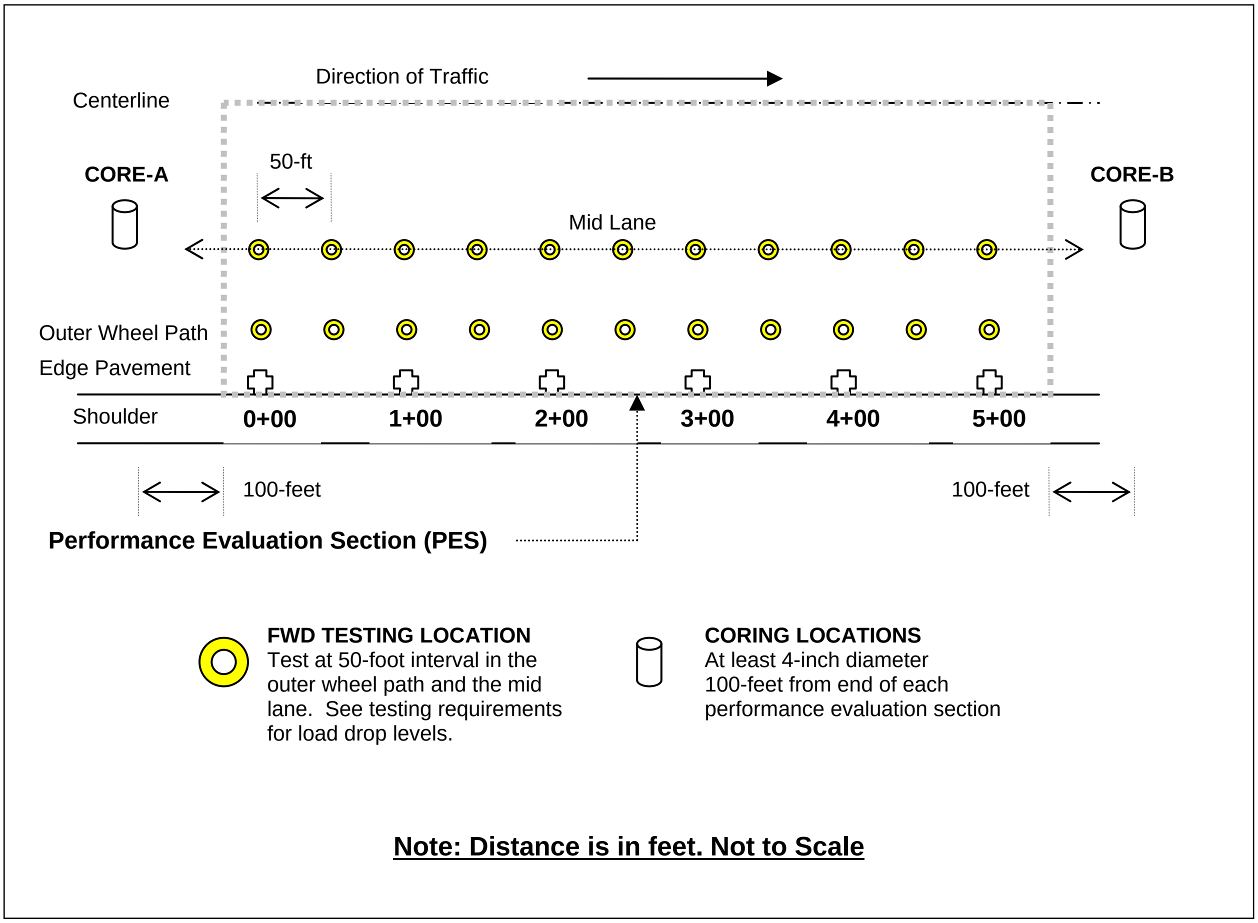


Figure A.1 FWD Test Pattern

Appendix B

PROPOSED CONDITION SURVEY METHOD FOR ALL FLEXIBLE PAVEMENT FIELD STUDIES

Table B.1 presents a comparison of several distress survey methods for flexible pavements. The method developed by Caltrans in 2003 (Caltrans, 2003) contains the majority of the distress types found on flexible pavements in California, is compatible with the procedures developed by Caltrans in 2000 (Caltrans, 2000), by LTPP (FHWA, 2003), and by AASHTO (AASHTO, 1993) and therefore is recommended for use in all field studies for condition survey on flexible pavements.

Table B.1 Comparison of Distress Survey Methods for Flexible Pavements

	Caltrans (2000)		Caltrans (2003)		LTPP		AASHTO	
Distress Type	**Severity**	**Measurement**	**Severity**	**Measurement**	**Severity**	**Measurement**	**Severity**	**Measurement**
Cracking								
Longitudinal Cracking (Non PCC Slab Joint Reflective)	1/4"	ft	L, M, H	m	L, M, H	m	L, M, H	linear ft or m
Alligator or Fatigue Cracking	A, B, C	WP/NWP	L, M, H	m or sq. m	L, M, H	sq. m	L, M, H	sq. ft or sq. m
Transverse Cracking (Non PCC Slab Joint Reflective)	1/4"	number	L, M, H	number, m	L, M, H	number, m	L, M, H	linear ft or m
Joint Reflection Cracking from PCC Slab			L, M, H	number, m	L, M, H	number, m	L, M, H	linear ft or m
Block Cracking			L, M, H	sq. m	L, M, H	sq. m	L, M, H	sq. ft or sq. m
Edge Cracking			L, M, H	m	L, M, H	m		
Deformation								
Rutting	NA	via PCS profiler	L, M, H	mm	NA	mm	L, M, H	sq. ft/m & mm
Corrugation			NA	sq. m			L, M, H	sq. ft or sq. m
Shoving	NA	yes/no	NA	number, sq. m	NA	number, sq. m		
Depression			NA	sq. m			L, M, H	sq. ft or sq. m
Overlay Bumps			NA	number, m				
Deterioration								
Delamination/Slippage Cracking			NA	sq. m				
Slippage Cracking							NA	sq. ft or sq. m
Potholes	fill/unfill	yes/no	L, M, H	number, sq. m	L, M, H	number, sq. m	L, M, H	number
Patching	NA	ft	L, M, H	number, sq. m	L, M, H	number, sq. m	L, M, H	sq. ft or sq. m
Raveling and Weathering	coarse/fine	25% or more	L, M, H	sq. m	NA	sq. m	L, M, H	sq. ft or sq. m
Stripping			NA	yes/no/unknown				
Polished Aggregate			NA	sq. m	NA	sq. m	NA	sq. ft or sq. m
Pumping and Water Bleeding	NA	yes/no	NA	number, m	NA	number, m	L, M, H	yes/no
Mat Problems								
Segregation			NA	sq. m				
Checking			NA	sq. m				
Bleeding	NA	25% or more	L, M, H	sq. m	NA	sq. m	NA	sq. ft or sq. m
Other								
Lane/Shoulder Dropoff or Heave							L, M, H	inches/100 ft
Lane Shoulder Joint Separation							L, M, H	inches/50 ft
Swell							L, M, H	sq. ft or sq. m
Re-opened Cracks	Re-open	%						
Sealed Cracks	>6 mm	%						
Settlement	NA	yes/no	NA	yes/no				

A = A single or two longtitudinal cracks in the wheel path, cracks are not spalled or sealed
B = An area of interconnected crackes in the wheel path forming a complete pattern
C = An area of moderately or severely spalled interconnected cracks outside of the wheel path forming a complete pattern

[shaded cell] Not Included

L, M, H = Low, Moderate, High. NA = Not Applicable.
WP = Wheel Path. NWP = Non Wheel Path

Appendix C

EXAMPLE EXPERIMENTAL DESIGN FOR EVALUATION OF MODIFIED ASPHALT MIXES

EXAMPLE EXPERIMENTAL DESIGN FOR EVALUATION OF RUBBER MODIFIED ASPHALT MIXES

Project Idea/Hypothesis

A generic experimental design specific to the evaluation of wet process CRM-modified binders and mixes is presented in this section. The project idea is to evaluate the performance of rubberized asphalt concrete (RAC) made with high viscosity binder, with modified binder (MB, no agitation), and a dry process CRM-modified mix (RUMAC) that Caltrans currently uses for pavement rehabilitation projects. METS is the proposed champion of this project with the RAC Task Group (RACTG) as technical advisory committee.

Review of past performance information indicates that wet process CRM mixes can result in good pavements if they are designed and constructed properly. The hypothesis for this project is that wet process mixes perform better than conventional dense-graded asphalt concrete (DGAC) and are cost effective.

Available data indicate that the initial cost per ton for using wet process mixes is significantly higher than the conventional AC. Based on overall performance to date, these products deserve further investigation. The three types of investigation alternatives described in Section 2.3 are recommended for the evaluation of RAC and MB materials. Detailed descriptions for each are provided below.

Laboratory Study

The important variables related to aggregate, binders, and mixtures were identified and described in Section 2.3.1. A dense-graded asphalt concrete (DGAC) mix should be included to serve as the control mix for comparison with other identified mixes.

The laboratory study may be conducted by itself or as a part of ATP studies and/or of field pilot studies. The laboratory testing program should include proposed tests identified in Table C.1 for aggregate and mixtures. For binders, the tests shown in Table C.1 should be run on base asphalt cements (AR-4000 and AR-8000), the high viscosity asphalt rubber binder, and the MB binders. It is suggested that the laboratory testing focus primarily on binder and mixture performance, including evaluation of volumetric property requirements for mixes made with the two different families of wet process binder (high viscosity and no agitation) and appropriate ranges of binder contents for each. (Current information from Texas and Arizona indicates that optimum binder content (OBC) for high viscosity and no agitation binder types may differ by 2%.) Performance testing of high viscosity binders may be limited due to the size of the swollen CRM particles relative to the DSR gap. Mixes should be tested for fatigue and repeated shear. The proposed mixture test program is based on work done by UC PPRC (University of California Berkeley, 2003).

Accelerated Pavement Testing Study

The important variables to be considered under APT study were identified and described in Section 2.3.2. A control AC section should be constructed along with other test sections for study. Table C.2 shows an experimental design matrix for studies of various mix types and overlay thicknesses.

Table C.1 List of Proposed Tests for Each Material

Test	Purpose	Comments
a) Aggregate		
CT 202	Combined Gradation	Indicator test
CT 205	% of crushed particles	Indicator test
CT 206	SG & Absorption - Coarse	Indicator test
CT 211	Abrasion - Coarse	Performance test
CT 214	Soundness - Coarse	Indicator test
	Soundness - Fine	Indicator test
CT 217	Sand Equivalent - Fine	Indicator test
CT 226	Moisture Content - Coarse	Indicator test
	Moisture Content - Fine	Indicator test
CT 227	Cleanness	Indicator test
CT 105	Gradings & SG - Coarse	Indicator test
	Gradings & SG - Fine	Indicator test
AASHTO T304	Uncompacted Voids	Indicator test. Index of fine aggregate angularity and texture
ASTM D4791	Flat & Elongated Particles	Indicator test
b) Binder		
AASHTO T48	Flash and Fire Points	Indicator test
AASHTO T49	Penetration	Indicator test
ASTM D217	Cone Penetration	Indicator test
AASHTO T201	Kinematic Viscosity	Indicator test
AASHTO T202	Viscosity	Indicator test
Caltrans Special	Hand-held Haake Viscosity	Indicator test
AASHTO T240	Rolling Thin-Film Oven	Indicator test
ASTM D3407	Resilience	Indicator test
ASTM D36	Softening Point	Indicator test
CT 381 and AASHTO T315	Dynamic Shear Rheometer (DSR)	Performance test. High viscosity binders may not be suitable for DSR testing due to the size of swollen CRM particles relative to DSR gap size (nominal 1 mm opening)
c) Mixture		
CT 308	Bulk Specific Gravity	Core, and lab compacted Hveem specimens
CT 309	Rice Gravity	Loose mix
CT 366	Stability Value	Lab compacted specimens
Volumetric Analysis	Air Voids Content, VMA, VFA, dust to binder ratio	Volumetric analysis of lab and field compacted mixture specimens
CT 371	Moisture Sensitivity	Lab mixed lab compacted (LMLC) mix
CT 382/CT 202	Binder Content/Gradation	Loose mix or Core
AASHTO T321 *	Fatigue Assessment, Beam	2 strains @ 20°C
	Frequency Sweep, Beam	Temps 5° and 25°C
AASHTO T320 *	Rutting Assessment, Core	Temps (40, 50, 60°C)
	Temp Freq on Stiffness, Core	Temps (20, 40, 60°C)
Long-Term Oven	Effect of Aging, Beam	3, 6 days and 2 strains
AASHTO T324	Hamburg Wheel Track	Core or lab compacted specimens
AASHTO TP10-93	Temperature Cracking Eval.	Field or lab compacted specimens

* The tests may also be run on lab mixed lab compacted mixes.

Table C.2 Matrix for Various Overlay Mixes and Thicknesses

Existing Pavement	Overlay Thickness	Mix Type				
		Control AC	RAC-G	MB-D	MB-G	RUMAC
A	Half					
	Full					

Field Pilot Studies

The important variables to be considered under field pilot studies were identified and described in Section 2.3.3. Since the idea is for pavement rehabilitation projects, the primary study variables are climate, traffic, roadbed soil, and overlay thickness and materials.

Table C.3 shows an experimental design matrix for evaluation of RAC-G and MB mixes under various study variables. For each climate, traffic, and existing pavement condition, the field pilot study includes a control mix of full thickness, RAC-G, MB-G, MB-D, and RUMAC mixes with a full thickness and/or a reduced thickness for a total of 60 possible combinations (not including the full and ½ thickness possibilities for the new products). This illustrates the importance of clearly defining the important variables so that the study is a manageable size and can be sold to upper management. For selection of projects, activities associated with various stages of construction and evaluation, guidelines (Table 2.8), sampling requirements (Table C.4), and data collection checklist (Table 2.9) should be followed.

Table C.3 Experimental Matrix for RAC-G and MB Study

Climate	Traffic	Existing Pavement Condition	Overlay Thickness				
			Control Mix	RAC-G	MB-G	MB-D	RUMAC
Coastal	Low	Good	Full	Full or Half	Full or Half	Full or Half	Full or Half
		Poor	Full	Full or Half	Full or Half	Full or Half	Full or Half
	High	Good	Full	Full or Half	Full or Half	Full or Half	Full or Half
		Poor	Full	Full or Half	Full or Half	Full or Half	Full or Half
Valley/Desert	Low	Good	Full	Full or Half	Full or Half	Full or Half	Full or Half
		Poor	Full	Full or Half	Full or Half	Full or Half	Full or Half
	High	Good	Full	Full or Half	Full or Half	Full or Half	Full or Half
		Poor	Full	Full or Half	Full or Half	Full or Half	Full or Half
High Desert/Mountain	Low	Good	Full	Full or Half	Full or Half	Full or Half	Full or Half
		Poor	Full	Full or Half	Full or Half	Full or Half	Full or Half
	High	Good	Full	Full or Half	Full or Half	Full or Half	Full or Half
		Poor	Full	Full or Half	Full or Half	Full or Half	Full or Half

Table C.4 Proposed Sampling Requirements for Each Mix

Type	Quantity	Dimension	Sample Location	Remarks
Aggregate	1000 kg		Plant	Combined gradation
Binder	40 kg/type		Plant	The quantity is for each type of binder used in project, e.g., AR-4000, wet process high viscosity, wet process no agitation (including MB),etc.
Modifier	10 kg/type		Supplier	The quantity is for each type of modifier used in project, e.g., CRM. Extender oil is also a modifier
Loose mix	250 kg		Behind paver	For making lab compacted specimens
Core	20	150 mm	10 from each end of monitoring section	Sample location should be 30 m away from each end of monitoring section
Slab	6	550 x 350 mm	3 from one end of monitoring section and 3 from the other end	Each slab is for making 4 beams

Implementation

The various studies should result in a confirmation of the project idea/hypothesis. If the hypothesis is confirmed that the RAC-G and/or MB mixes perform better than conventional AC, are cost effective, and have little or no environmental impact, an implementation plan needs to be developed. The plan should include the types of reports to be delivered as well as updated guidelines or specifications, and/or training materials. If the hypothesis is not confirmed, additional studies may be necessary or the further exploration of the idea should be discarded.

Appendix D

WORK PLAN FOR RAC-G GRAVEL FACTOR FOR USE IN STRUCTURAL SECTION DESIGN

WORK PLAN FOR RAC-G GRAVEL FACTOR FOR USE IN STRUCTURAL SECTION DESIGN

BACKGROUND

Caltrans current pavement structural design procedure (Caltrans, 2004) involves the use of R-value and Traffic Index (TI) to develop flexible pavement layer thicknesses for new and reconstruction projects. The procedure is based upon a layer equivalency approach in which the relative load-carrying capacity of individual pavement layers is related through a gravel equivalence value. The gravel factor (G_f) refers to the relative strength of a given material compared to a *standard* gravel subbase material. Gravel factors for dense-graded asphalt concrete and various types of base and subbase materials have been developed over the years based primarily on the cohesiometer tests. However, no G_f has been established for rubberized asphalt concrete (RAC) or modified binder (MB) materials for use in new pavement as well as in rehabilitation designs.

Caltrans employs several types of structural mixes in the design of asphalt concrete overlays for flexible pavements: dense-graded asphalt concrete (DGAC), MB mixes, and a gap-graded, rubberized asphalt concrete (RAC-G) mix. The thickness of the DGAC overlays needed to limit fatigue cracking is determined using an empirical relationship relating measured pavement surface deflection, TI, and the thickness of the existing pavement. The design procedure also uses an empirical relationship to determine the thickness of the overlay needed to retard reflective cracking. For a RAC-G mix, Caltrans uses equivalence ratios of 1.5 to 2.0 to reduce the thickness when fatigue cracking is the expected distress mode and 1.5 to 2.33 when reflection cracking is the expected distress mode. In cases where a greater additional structure is required, DGAC mix might be placed on the existing surface and then overlaid with RAC-G of reduced thickness. The equivalencies are based on a 10-year design life for overlays, assuming that the existing pavement is structurally adequate. Caltrans also specifies minimum and maximum RAC-G thickness of 30 mm and 60 mm, respectively (Caltrans 2001).

Other states that have significant experience with the asphalt rubber products generally treat RAC mixtures as having the same structural value as conventional DGAC. Arizona's structural design methodologies for rubber-modified asphalt concrete are the same as that for dense-graded mixture regardless of application. Texas treats gap-graded rubber-modified mixes the same as the conventional dense-graded mixes in terms of structural credit. Florida DOT does too by using AASHTO *Design Guide* layer coefficients of 0.44 for dense-graded friction course with or without crumb rubber modifier (MACTEC, 2004a).

In 2004, a literature review was conducted as a part of a study (MACTEC, 2004a) funded by California Integrated Waste Management Board (CIWMB). The results of the literature review indicate that there is no universal consensus on structural design with rubber-modified asphalt concrete mixes. However, it appears that treating RAC as a structural equivalent of DGAC has yielded reasonable results.

OBJECTIVE

The objective of this study is to develop gravel factor(s) for both RAC-G and MB mixtures for use in new pavement structural section design in accordance with Caltrans *Highway Design Manual* (Caltrans, 2004).

HYPOTHESIS

This study will be conducted as outlined in the generic experiment design described previously. The hypothesis for the experiment is that the gravel equivalence approach used for determining the DGAC thickness in new pavement design is valid for the thickness design of RAC-G and MB mixtures. This hypothesis will be tested/confirmed if analyses of existing data (and data to be collected) result in valid criteria and analytical models that accurately characterize the difference in performance among the various AC mixtures used for new pavement design.

STUDY APPROACH

Based upon the outcome of several meetings held with Caltrans and UC PPRC staff, a general framework for the development of the gravel factor(s) for RAC was outlined. This framework (graphically depicted in Figure D.1) calls for a review of the related work, especially of laboratory test data on dense-graded AC and RAC materials and supplemental testing (i.e., cohesiometer test, indirect tensile and resilient modulus tests) of DGAC, RAC-G, and MB materials. Interim gravel factor(s) for RAC-G/MB will be developed based on these test results, a review of related work, and the mechanistic-empirical (M-E) analyses. The interim gravel factor(s) will then be validated using data gathered from the current UC PPRC Heavy Vehicle Simulator (HVS) modified binder study and relevant data from other new pavement or reconstruction projects involving the use of RAC or MB mixtures. Additional test sections with different thicknesses of RAC may also need to be constructed and tested using the HVS to validate the interim G_f values. This study will be closely coordinated with a companion study to develop G_f values and associated design criteria for RAC mixtures used for overlays (see Appendix E). This study will be a joint effort of Caltrans, the UC PPRC, and MACTEC.

WORK PLAN

The study will be conducted in two phases. Phase 1 is a short-term plan, which involves the development of interim gravel factor(s) and design criteria for RAC and MB materials for use in structural design. Phase 2 is a long-term plan, which involves field validation of the interim gravel factor(s) and the collection of materials, construction, and performance data for use in the development of a future M-E design method. The short-term plan should be completed by September 2005. On the other hand, the long-term plan is anticipated to require an additional three to five years to complete, including the collection of routine field performance data from the various study sections.

Phase 1 - Short-Term Plan

The proposed short-term plan involves the following tasks:

- Review related work on gravel factors (G_f).
- Develop interim G_f based on laboratory testing of DGAC, RAC-G, and MB mixes, available laboratory test data and field performance. These data will be analyzed using M-E principles.
- Implement interim G_f values for RAC-G and MB mixtures.

The bulk of this effort will be carried out by MACTEC in consultation with Caltrans and UC PPRC staff.

Development of Gravel Factors for RAC and MB Materials

For Structural Section Design Using Caltrans Method for New Construction and Rehabilitation

↓

Short-Term Plan

- Review related work on gravel factors (G_f).
- Develop interim G_f based on laboratory tests (i.e., cohesiometer test, indirect tensile strength test, and resilient modulus test) on DGAC, RAC-G, and MB mixes, available laboratory test data, and field performance data using a mechanistic-empirical approach.
- Implement interim G_f.

↓

Long-Term Plan

- Validate interim G_f using data gathered from the UC PPRC MB study, the Firebaugh project, the RAC Warranty projects and other RAC projects.
- Construct additional experimental test sections with varying layer thickness of RAC/MB/DGAC materials and test with HVS.
- Validate interim G_f using data from the experimental test sections.
- Develop data for use in M-E design procedure.
- Finalize G_f for implementation.

Figure D.1. Study Approach for the Development of G_f for RAC and MB Materials

<u>Task 1 – Planning Meeting</u>

A one-day planning meeting will be held at the beginning of this phase to review (and finalize) the technical approach and work plan and to coordinate the data collection activities. This meeting should include key Caltrans, UC PPRC, and MACTEC staff.

<u>Task 2 – Review of Related Work on Gravel Factors</u>

This task entails a review of material related to establishing gravel equivalency factors (Caltrans method) and layer coefficients using the AASHTO method. Following is a summary from a handout on gravel factors provided by UC PPRC at the September 7, 2004 brainstorming meeting:

> Historically, Caltrans developed gravel factors for aggregate base and subbase materials and emulsion and cement treated materials based on the Brighton Test Road and laboratory cohesiometer measurements in the 1950s and 1960s. Gravel factors for other materials were established relative to that of aggregate subbase, which was assigned a gravel factor of 1.0.

Gravel factors for conventional asphalt concrete were developed based on data from the AASHO Road Test.

Examination of the AASHO Road Test data (HRB Special Report 61E, 1962) and the "layer coefficients" approach included in the original AASHO *Interim Design Guide* indicates that there is a great deal of scatter in the data. The ratios of the structural contribution factors for aggregate base, asphalt concrete and cement treated base developed from the AASHO Road Test for both the AASHO *Interim Design Guide* and the Caltrans design method are similar, but not the same. Conceptually similar, both AASHO layer coefficients and Caltrans gravel factors are used to describe the structural capacity of various materials.

The most recent gravel factor development was for asphalt treated permeable base (ATPB) materials in the 1980s by Caltrans. Test sections with and without ATPB were constructed. The gravel factor (1.4) was estimated based strictly on surface deflections measured with the Dynaflect. The performance under traffic was not considered in the development of the gravel factor. Furthermore, there was a great deal of scatter in the data.

Task 3 – Development of Interim Gravel Factor

The review of the previous work indicates that there was a significant scatter in the data and that there was no consistent method used to develop the gravel factors currently used by Caltrans. Other agencies have used either laboratory tests or accelerated pavement performance tests to develop structural layer coefficients for use in the AASHTO design procedure (MACTEC, 2004a).

In the meeting held on October 7, 2004, personnel from Caltrans, UC PPRC, and MACTEC discussed the use of a cohesiometer for determining the gravel factor G_f, for RAC and MB materials. The group acknowledged that the historical data used to develop various G_f might not be easily found in the Caltrans archives. Additionally, the group acknowledged that cohesiometer results may not relate to pavement performance. Nevertheless, the group agreed to conduct cohesiometer testing to establish baseline values for the RAC-G and MB materials. Since the utility of the cohesiometer data is unknown, it would be wise to begin with a "limited" test matrix. Should the initial test data yield meaningful results, a more comprehensive testing program can be undertaken.

Laboratory Test Plan

To assist in the development of gravel factor for rubberized asphalt concrete (RAC) materials, it was agreed that cohesiometer tests be run on dense-graded asphalt concrete (DGAC), MB, and RAC-G materials. The tests will be performed through a cooperative effort between the UC PPRC laboratory and Translab. Additionally, indirect tensile and resilient modulus testing are proposed to provide fundamental engineering properties for use in M-E analyses. The UC PPRC or Caltrans lab will conduct the indirect tensile and resilient modulus testing.

The objective of the lab test plan is to characterize the mix properties under laboratory and/or in-situ conditions. This requires both laboratory prepared samples and field cores. It should be noted that Caltrans has yet to use RAC of MB mixtures in the construction of a new pavement. Thus, development of improved gravel factors for new pavement design must rely on field data from pavement sections that have been overlaid with a RAC-G or MB mixture. These data will also be used in the development of gravel factors for overlay applications, as discussed in Appendix E.

Materials

The materials for lab prepared samples will come from the Firebaugh and/or the RAC Warranty projects. Field cores (100 mm or 4" in diameter) may be collected as necessary. The benefit of testing the field cores is obvious: their properties will reflect the "as-built" pavement condition. The proposed sampling program will provide for a valid characterization of the key mixture properties for each project. Also it helps isolate the effect of material type and environment on pavement performance.

Loose Mixes

The first part of the lab test plan involves the use of field-mixed and lab-compacted mixes. The primary benefit of testing lab compacted specimens is to capture properties of un-aged mixes.

The Firebaugh project includes four mix types: DGAC, RAC-G, MB-G, and MB-D. For each mix, six specimens will be compacted by Translab to the "as-built" air void content. These values are shown in Table D.1. Three specimens will be used for the cohesiometer test and three specimens will be used for resilient modulus and indirect tensile strength tests.

Table D.1. Target air void contents (as-built) for laboratory preparation of the different mixtures.

Mix Type	Air Void Content, %
DGAC	To be provided
RAC-G	To be provided
MB-G	To be provided
MB-D	To be provided

The air void content for each mix type is being determined by Translab based on pavement cores obtained from the project site. As a reference, the mix design information used on the Firebaugh project is summarized in Table D.2 below.

Table D.2. Mixture design information for the mixes used in the Firebaugh project.

Sieve Size (mm)	RAC-G	MB-G	MB-D	Type A
25	100	100	100	---
19	97	97	96	97
12.5	85	---	---	---
9.5	68	68	68	70
4.75	36	36	48	50
2.36	21	21	33	36
0.6	11	11	17	18
0.075	2.9	2.9	4.2	5.4
OBC, (by dry weight of aggregate), %	7.90	6.30	5.30	4.80
Maximum Density @ OBC	2.35	2.40	2.44	2.46
Asphalt Absorption @ OBC, %	0.70	0.67	0.93	0.98
Stability	37	29	39	46
VMA, %	18.31	15.43	12.80	12.09
VFA, %	83.02	82.38	79.90	76.18
Crushed Coarse, min 90%	99	99	98	100
LA Rattler: @ 100 rev max 10% @ 500 rev max 45%	4.7 24.1	5.0 23.6	4.5 22.0	4.4 24.6
Crushed Fine, min 70%	98	97	94	98
Sand Equivalent, min 47%	56	56	70	58

Cores

Lab testing of field cores is contingent upon the success of the testing and analyses of the loose mix. Table D.3 shows the number of cores needed for the proposed tests. The cores should be obtained from two different locations to account for material variability. At each location, six cores should be collected. Three cores will be used for each: the cohesiometer test and the resilient modulus and indirect tensile strength tests.

Table D.3. Core samples needed for proposed testing program.

Project/Mix Type	Number of Cores/Location	Number of Locations	Total Cores
Firebaugh/			
DGAC	6	2	12
RAC-G	6	2	12
MB-G	6	2	12
MB-D	6	2	12
Ventura/RAC-G	6	2	12
Fresno/RAC-G	6	2	12
Merced/RAC-G	6	2	12
San Diego/RAC-G	6	2	12
Lassen/MB-D	6	2	12
Total	54	18	108

Test Procedures

The cohesiometer test will be performed in accordance with ASTM D 1560-92 (Reapproved 2000) *"Standard Test Methods for Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus."*

The indirect tensile strength test will be performed in accordance with ASTM D4123-82 (Reapproved 1995) *"Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures."* The recommended testing temperature for the indirect tension strength test is 25°C. The resilient modulus test will be performed in accordance with ASTM D4123. The recommended temperatures are 5, 25, and 40°C. A destructive test, the indirect tensile strength test is conducted after the determination of resilient modulus.

Expected Outcome

The results of the cohesiometer tests from the above mixes will be reviewed, analyzed, and used to develop gravel factors. The following relationship will be used to determine a gravel factor (G_f) for each mix:

$$G_f = \left(\frac{C}{20}\right)^{0.2}$$

where: C = Cohesion value for material.
20 = Cohesion value for aggregate subbase.

It is noted that the type of aggregate subbase associated with C=20 is not documented in the literature. Since unbound aggregate performs poorly in tension, the cohesiometer test does not seem ideally suited to capture its strength properties. Since a cohesiometer value of 20 for aggregate subbase is the basis for Caltrans gravel factor design concept, it will be used as a baseline measurement. By extension, aggregate subbase should be used for calibration purposes. MACTEC will work with Translab to make specimens for this test.

The results from the DGAC mix will also be used as a baseline to allow comparison with the results from other types of mixes.

The results from the indirect tensile and resilient modulus tests have a dual purpose: 1) to support the development of gravel factors; and 2) to modify/improve the Caltrans overlay design procedure. The results from the indirect tensile strength test may be used to compute strength ratios between DGAC and RAC-G/MB mixes for comparison with the ratios determined from the cohesiometer test. Similarly, laboratory resilient modulus data will be compared to modulus generated from the analysis of deflection data.

Mechanisitic-Empirical Approach

The M-E (layered elastic) and/or the finite element approaches are rational methods for the development of gravel factors proposed for RAC and MB materials. In using the mechanistic-empirical method to develop the gravel factor, the following parameters are needed:

- Resilient modulus for conventional AC, RAC, and MB materials – These data may be obtained from deflection data through backcalculation and/or from laboratory tests. As available, UC PPRC data will be compiled for evaluation.

- Performance data for conventional AC, RAC, and MB materials – Ideally, these data should encompass conventional AC, RAC-G, and MB materials placed in similar environments and having sustained similar loading. The Firebaugh project is ideal though the final data from this project will not be available until 2009. Alternatively, the laboratory data from the fatigue and rutting tests for the conventional AC, RAC, and materials may be used. Again, UC PPRC data will be evaluated for developing preliminary performance models.

To develop interim gravel factors, pavement sections of varying thicknesses will be considered. Stresses/strains at critical locations in the pavement section will be computed and used in conjunction with performance models to quantify structural capacity. The analyses will be performed for pavements with conventional AC, RAC-G, and MB materials. Mix performance (as characterized by fatigue or rutting) may be used to develop an interim gravel factor.

The before/after deflection data from typical overlay projects will be used to estimate changes in stiffness that could, in turn, be used in the development of G_f. These data may also help develop/refine the Caltrans deflection-based overlay design procedure.

To best meet Caltrans needs on the G_f issue, it was agreed that following activities be pursued:

- Identify best use of asphalt rubber products.
- Meet with the pavement design group to identify what else is needed besides G_f for RAC projects.

- Conduct cohesiometer tests and determine G_f values.
- Obtain available materials test data (including fatigue, rutting, and stiffness/modulus) from UC PPRC Goal-3 study and other relevant information for developing interim G_f using the M-E approach.
- Develop interim guides for use and/or incorporate changes in the Caltrans *Highway Design Manual*.

To carry out these activities, on-going consultation with Caltrans, particularly from the Office of Pavement Rehabilitation (OPR), is crucial. It is recommended that key personnel from Caltrans and MACTEC participate in a one-day meeting to discuss the following:

- A critical review of existing *Highway Design Manual* (Caltrans, 2004) Chapter 600 on Pavement Structural Section and *Flexible Pavement Rehabilitation Manual* (Caltrans, 2001), specifically on the gravel factor for RAC and MB materials;
- Modifications to the aforementioned manuals to accommodate RAC and MB mixtures.
- Clarify responsibility and schedule for conducting the cohesiometer test on RAC, MB, and DGAC materials, assuming the cohesiometer and these materials are available. It may be necessary to develop an experimental matrix for this purpose.

Task 4 – Implementation of Interim Gravel Factor

It is anticipated that interim gravel factors (and other relevant design criteria) for RAC-G and MB mixtures will be developed by August 1, 2005. The implementation plan includes three primary activities.

- Report – The results of the Phase 1 (short term plan) will be thoroughly documented including a discussion of the data, analysis, and findings, and recommendations as to modifications to the Caltrans *Highway Design Manual*.

- Training – MACTEC will prepare a two-hour training module for Caltrans engineers on the application of the new gravel factors and design criteria. The training module will include a hands-on workshop to allow participants to apply the revised methodology using sample data.

Phase 2 – Long-Term Plan

The proposed long-term plan involves the following tasks:

- Construct additional experimental test sections with varying layer thickness of RAC/MB/DGAC materials and test them with HVS.
- Validate the interim G_f value using data gathered from the UC PPRC HVS MB study and any other relevant new pavement or reconstruction project involving the use of RAC or MB mixtures.
- Develop data and criteria for new Caltrans M-E design procedure.
- Implement the findings.

MACTEC will play a key role in getting this phase laid out. However, work proposed for years 2 through 5 will have to be conducted as a coordinated effort between Caltrans and UC PPRC.

Task 1 – Planning Meeting

A one-day planning meeting will be held near the end of first phase of work, probably near the completion of Task 3, to review the phase 1 results and to finalize the work plan for the long-term study.

A critical topic of this meeting will be the approach to validation of the RAC and MB gravel factors through future data collection and analyses. Another key topic will be the data needs and collection protocol for incorporating RAC and MB mixtures within an M-E design procedure.

Task 2 – Construction of Additional Experimental HVS Test Sections

Time and budget permitting additional construction of additional experimental test sections (including conventional DGAC, RAC, and MB mixtures) will be constructed for HVS testing. These will generate data for the M-E design procedure and to refine the performance models which can be used to update/refine the interim gravel factors. It is not recommended that additional full-scale experimental field projects be constructed. However, it may be possible to use information from routine construction projects.

Task 3 – Validation of Interim Gravel Factor

The ongoing studies, i.e., the UCB HVS MB study, the Firebaugh project, and the Warranty projects, will be completed in 3 to 5 years. The results from these studies should address construction, materials characterization, and laboratory and field performance for various RAC and MB materials. The data from these studies may provide valuable information related to the validation of the interim gravel factor.

Task 4 – Development of Data and Criteria for an M-E Design Procedure

Data from various projects will be gathered and analyzed. Performance data along with laboratory test results will be used to develop criteria for use in an M-E procedure.

Task 5 – Implementation

Implementation will include a report that thoroughly documents the entire effort. Conclusions and recommendations will be included. Technology transfer will be initiated at Caltrans direction.

EXPECTED OUTCOMES

The expected outcomes from this study include the following:

- From the short-term plan – establishing G_f:
  - Report documenting the development of the interim gravel factor based on lab test data and an M-E approach; and
  - Interim gravel factor for RAC/MB materials for use in Caltrans pavement design procedure.
- From the long-term plan – validating G_f:
  - Findings from the ongoing projects;
  - Construction and evaluation of additional experimental test sections;
  - Analysis and validation of the interim gravel factors using data from ongoing studies and additional experimental test sections; and
  - Data and criteria for use of RAC and MB mixtures in Caltrans M-E design procedure.

Appendix E

PROPOSED WORK PLAN FOR VALIDATION, CALIBRATION, AND IMPROVEMENT OF THE AC OVERLAY DESIGN PROCEDURE IN THE CALTRANS FLEXIBLE PAVEMENT REHABILITATION MANUAL

PROPOSED WORK PLAN FOR VALIDATION, CALIBRATION, AND IMPROVEMENT OF THE AC OVERLAY DESIGN PROCEDURE IN THE CALTRANS FLEXIBLE PAVEMENT REHABILITATION MANUAL

BACKGROUND

The Caltrans *Flexible Pavement Rehabilitation Design Manual* (Caltrans 2001) provides technical guidance for the design of a number of different rehabilitation treatments for flexible pavements. Among these are the following:

- asphalt concrete (AC) overlay (directly on the existing pavement and pre-treated with either a stress-absorbing membrane interlayer, cushion course, or a drainage layer);
- remove and replace (including mill and fill);
- cold recycled asphalt concrete (CRAC); and
- hot recycled asphalt concrete.

The primary component of the design procedure is the overlay design model. It relies on measured surface deflections to characterize the structural load-carrying capacity of the existing pavement, layer equivalence factors to define the relative strength of individual pavement layers, and the *deflection reduction* approach for thickness design. The overlay method was originally developed in 1979 (Caltrans, 1979) and has been refined over the years, including the recent adaptation to consider gap-graded, rubberized AC (RAC-G) mixtures (Caltrans, 2001). The method serves as the standard for Caltrans rehabilitation design, and is widely used by many local agencies.

OBJECTIVE

Despite its general acceptance and widespread use in the state, the Caltrans overlay design method does not readily accommodate new materials, e.g., rubber modified binder mixes. As indicated above, the design procedure was adapted to consider RAC-G mixtures based on the field performance of asphalt rubber mixtures. For AC mixtures containing crumb rubber modified binders, basic design and performance criteria need to be re-evaluated, modified as necessary and incorporated in the procedure.

The basic objective of this study is to improve to the overlay design component of Caltrans rehabilitation design procedure. This includes the following:

- validation/calibration of the RAC-G design criteria currently used by Caltrans;
- development of design and performance criteria for AC mixtures containing modified binders;
- revision of the tolerable deflection criteria for rubber modified mixtures; and
- evaluation of thickness requirements the surface layer combinations including RAC on DGAC, DGAC on RAC, and RAC on RAC.

In the case of RAC-G, special attention must be given to addressing the RAC-G maximum overlay thickness limitation and the potential problem of placing a conventional dense-graded AC overlay over an existing RAC-G surface. Also, one of the internal models for determining pavement deflection reduction as a function of overlay thickness should also be re-evaluated to account for the effect of overlay material type.

HYPOTHESIS

The objective of this study will be carried out under the general framework established in the generic experiment design described previously. The hypothesis for the experiment is that the deflection based approach used for determining the DGAC thickness overlay design is valid for the overlay thickness design of RAC-G and modified binder (MB) mixtures. This hypothesis will be confirmed if analyses of existing data (and data to be collected) result in valid criteria and analytical models that accurately characterize the difference in performance among the different AC mixtures used for overlay design.

WORK PLAN

This study will be carried out in two phases and will involve a joint effort among Caltrans, the UC PPRC, and MACTEC. The scope of the first phase will be limited primarily to the analysis of existing data from recent (and on-going) field and laboratory experiments. Its goal is to make immediate improvements to the overlay design model.

The second phase, or long-term program, will be carried out over an additional 3-5 year period and involves analysis of data from laboratory and field experiments conducted during that period, as well as data that are already available. Depending on the results of the data analyses and Caltrans transition to mechanistic-based design, the product of this program may be a completely new design procedure.

For the sake of consistency, this study should be closely coordinated with the companion study to develop RAC and MB gravel factors for use in new pavements (see Appendix D). Following is a discussion of the work tasks currently envisioned for the short-term and long-term programs.

Phase 1 – Short-Term Program

The target completion date for phase 1 is July 31, 2005.

<u>Task 1 – Planning Meeting</u>

The purpose of this meeting is to finalize the work plan for revising the current Caltrans AC overlay design methodology to accommodate the materials and performance characteristics of rubber-modified binders. This will be a cooperative effort among Caltrans, the UC PPRC, and the MACTEC project team. It is important that key staff from each organization participate in the meeting. The meeting was held in December 2004 and included the following agenda items.

- Overview of current overlay design methodology and areas of needed improvement
- Review of rubber- and polymer-modified materials characteristics and performance properties
- Approach for improvements and validation of design methodology
- Data sources for model calibration/development
- Data collection plan (associated with field sampling, field testing, and laboratory testing)
- Staff assignments
- Schedule
- Report outline
- Work plan for long-term program

The last agenda item (work plan for the long-term program) was included to take advantage of the consensus agreement reached on the short-term program and to develop consistency with the long-term program.

Task 2 – Collection and Assembly of Project Data

The short-term program will rely upon a combination of existing data and new data to improve the overlay design methodology. The bulk of the data will be gathered from existing records available from the following:

- recent laboratory and HVS studies carried out by the UC PPRC;
- Caltrans Translab field and laboratory experiments;
- RAC-G Warranty and Firebaugh projects; and
- the 1000 plus test sections that make up the Caltrans performance monitoring database, a study currently being performed for Caltrans Research by Stantec.

Some (new) field and laboratory testing will also be conducted over the next 6 to 8 months, primarily to estimate key material properties and/or laboratory properties of select rubberized- and modified-binder mixtures and to characterize the in-situ condition of certain field-test sections. The laboratory test program will include tests to determine the cohesion, stiffness, fatigue cracking, and permanent deformation properties of select AC mixtures. Because of the deflection reduction basis in the overlay design methodology, *before* and *after* overlay deflection testing is a necessary requirement for the field test program.

The data will be compiled into one or more databases that will support the development of the improved analytical models and design criteria.

Work on this task should begin in spring 2005 and be completed by July 2005.

Task 3 – Develop Effective Gravel Equivalence Factors for RAC-G and MB Mixtures

In this task, effective gravel equivalence factors will be established for RAC-G and MB mixtures based upon their "performance" relative to the standard gravel or a conventional DGAC mixture. The detailed field sampling and laboratory test plan presented in Appendix D, under section Task 3 – Development of Interim Gravel Factor - Laboratory Test Plan, addresses the sampling and testing needs for developing improved gravel factors for both new pavement and rehabilitation design. Testing included in the laboratory program are described below:.

- Cohesion Test (ASTM D1560) – This refers to the laboratory test method that was originally used to develop gravel equivalence factors for subbase and base courses, as well as the original standard DGAC mixture.

- Mix Stiffness and Strength (ASTM D4123) – Laboratory indirect tensile strength and resilient modulus offer two more alternatives for the determining the gravel equivalence factor. As fundamental engineering properties, indirect tensile strength and resilient modulus tests provide a rational basis for deriving gravel factors for asphalt concrete mixtures.

- Fatigue Resistance (AASHTO T 321) – Both laboratory and field test results for crack resistance can be used to develop gravel equivalence factors that relate RAC-G and MB mixtures to the standard DGAC mixture.

- Rut Resistance (AASHTO T320) – Both laboratory and field test results for rut resistance can also be used to develop gravel equivalence factors that relate RAC-G and MB mixtures to the standard DGAC mixture.

The fatigue and rutting tests are likely to provide more rational gravel equivalence factors if enough data can be extracted from available records or generated from field/lab testing experiments. They are the foundation for the M-E based design procedures in the second phase, long-term program. The project will rely on the staff and equipment available at METS and the UC PPRC for any lab testing.

Work on this task will be coordinated with that outlined in Appendix D to ensure consistency in the gravel factors used for new pavement and overlay design.

<u>Task 4 – Evaluate Various Structural Layer Combinations of Overlay Types on RAC-G Surface</u>

The purpose of this task is to evaluate the state of stress in two structural layer combinations that have not yet been tested in a field situation. This evaluation will be conducted using mechanistic tools based on elastic layer theory and/or finite element analysis. The alternate layer combinations include DGAC overlay on existing RAC-G surface and RAC-G overlay on existing RAC-G surface. By comparing the state of stress in these two layer combinations (as measured by critical shear and tensile strains) with the typical RAC-G on DGAC structural combination, it will be possible to identify conditions that could lead to rapid deterioration or premature failure.

<u>Task 5 – Evaluate Tolerable Surface Deflection and Maximum Thickness Criteria</u>

The current Caltrans overlay design procedure provides criteria for the conversion of a specific design thickness of DGAC overlay into an equivalent thickness of RAC-G overlay. The conversion does not directly consider the larger *tolerable surface deflection* associated with a RAC-G overlay, although it is probably inherent in the thickness conversion. The thickness reduction was based on field performance and confirmed in the HVS testing in South Africa and later at UC Berkeley.

The overlay design procedure establishes criteria for maximum and minimum thickness of the RAC-G overlay. The maximum (60-mm) thickness limitation was established to help guard against the potential for shear flow and rutting in a thicker layer. The validity of this limitation will be evaluated using data from the Firebaugh project that has test sections of 90 mm thick, in terms of both the field performance and cost effectiveness.

In this task, the Caltrans overlay design procedure will be revised to allow the direct evaluation and thickness design for RAC-G overlays. This will be accomplished by treating RAC-G overlay design as a separate, but similar process, as that for the DGAC overlay thickness design. This will require the development of a unique *tolerable surface deflection* relationship that may be appropriate for each type of combination of overlay and surface materials, e.g., RAC-G over DGAC, RAC-G over RAC-G, and DGAC over RAC-G. The tolerable deflection relationship can be developed through a two-pronged evaluation involving: 1) an analysis of laboratory fatigue and permanent deformation test results, and 2) an investigation of before and after overlay deflection measurements on RAC-G projects. It will also require an analysis of the data generated in Task 4 to determine if there is a valid maximum thickness limitation for RAC-G overlays. Performance data from the variable thickness RAC-G overlay sections in the Firebaugh project should also be helpful in this assessment.

Task 6 – Develop and Incorporate New Deflection at Milled Depth Relationship

To account for the effect of removing part of an AC surface as part of a cold recycling or mill and fill operation, the current Caltrans overlay design methodology incorporates a relatively simple model to estimate the maximum deflection at the milled depth. Because of its simplicity, the accuracy of the model is questionable.

In this task, a more accurate, yet deterministic, deflection prediction model will be developed as a replacement for the current model. Development of the new model will be based upon elastic layer theory. Potential computer programs used for the analyses include the following: LEAP2, ELSYM5, WESLEA, and EVERSTRESS. The new prediction model should be valid for the design of both DGAC and RAC-G resurfacings on milled pavements. Caltrans suggested that this approach be verified (if possible) with FWD measurements performed incrementally on milled RAC-G surface. This issue will be looked into if appropriate projects can be solicited and FWD equipment is available to perform the work.

Task 7 – Implementation

This report will document findings of the previous tasks and include recommendations as to modifications to the Caltrans *Flexible Pavement Rehabilitation Manual*. A draft of the report will be submitted in July 2005 to Caltrans for review and comment. Training materials may be developed at Caltrans direction.

Phase 2 – Long-Term Program

Task 1 – Planning Meeting

At least one but, probably, two or three planning meeting(s) will be needed to set the stage for work that will be done over the estimated five-year period of the long-term program. The first meeting should be held after collection and compilation of all the “available” data associated with the short-term program, Task 2 data collection effort. This will provide valuable information in developing the experiment designs and data collection plans for the long-term program.

Key agenda items for the planning meeting include:

- Establish framework for overlay design methodology – Caltrans and the UC PPRC have made significant strides towards establishing a mechanistic-empirical framework for overlay design. The draft framework will be reviewed in terms of its use with RAC-G and MB mixtures. It will also address the specific data needs for M-E design model development and calibration.

- Develop experiment design for laboratory and HVS experiments – A certain amount of laboratory and HVS testing will be required to “fill in the gaps” in areas related to materials characterization and performance prediction. This should be done within the framework of an overall experiment design.

- Development of experiment design for additional field sections – The experiment design will be built around existing experimental sections from the Firebaugh, Clear Lake (District 1), and RAC Warranty studies. However, it will address the need for new sections to ensure coverage of environmental zones, materials types, overlay thickness categories, existing pavement conditions, etc.

- Finalize detailed work plan – This can be done based upon the overlay design framework and the experiment designs. It will also include team/staffing assignments and a schedule.

Task 2 – Conduct Laboratory and HVS Experiments

This task provides for any laboratory and Heavy Vehicle Simulator testing that may be required to satisfy the requirements of the long-term program experiment design. It is anticipated that METS would conduct most of the routine asphalt binder and mix characterization tests, while the UC PPRC would carry out the more complex binder and mix testing. The UC PPRC would also be responsible for constructing and testing any of the HVS sections that may be required.

Task 3 – Establish and Monitor Additional Experimental Sections

The primary purpose of this task is to collect, process, and store data from the additional field experimental test sections. Most of the experimental sections will come from those represented under the current Firebaugh, Clear Lake (District 1), and RAC Warranty projects, which are already defined and programmed for data collection. However, some new test sections are likely to be identified as part of the Task 1. Accordingly, those sections will need to be laid out, sampled, tested, and monitored. MACTEC will establish these sections and oversee the field-testing and monitoring work through September 30, 2005. Beyond that date, Caltrans (or another designated contractor) must assume the field testing and performance monitoring responsibilities.

Task 4 – Compile and Analyze Data

During the 3-5 year course of the long-term program, data from the full-scale field experiments, laboratory testing, and HVS testing will be collected, processed, and stored. Some interim analyses may also be performed to evaluate trends and develop initial models. However, near the end of the period, the data will need to be compiled and then analyzed to formulate new models that relate overlay binder and mix properties for DGAC, RAC-G, and MB mixtures to performance. It is very likely that these will be mechanistic-empirical models that relate fundamental material properties of the existing pavement and overlay to pavement performance in terms of fatigue cracking, thermal cracking, and permanent deformation. The UC PPRC will be primarily responsible for the application of both mechanistic and statistical analysis techniques to develop these new Caltrans models.

Task 5 – Develop New Caltrans Overlay Design Procedure

This task represents the culmination of all the data collection, processing, analysis, and model development efforts. It will result in a new structural overlay design method that is based on mechanistic-empirical analysis techniques and operating within a fast, user-friendly microcomputer software application. The procedure will provide for the structural design of overlays consisting of DGAC, RAC-G, MB, and other asphalt mixtures. The design procedure will also allow one to evaluate overlay performance in terms of fatigue cracking, thermal cracking, and permanent deformation. This work will be carried out by the staff at the UC PPRC (or some other contractor engaged by Caltrans).

Task 6 – Implementation

As was the case for Phase 1, the two key components of implementation for the Phase 2 work include reporting and training. Both of these activities will be completed through a joint effort between Caltrans and the UC PPRC within one year after the completion of the field data collection process. The timing should coincide with the implementation activities related to the development of RAC and MB design criteria for the anticipated M-E design procedure for new pavements.

- Report – A research report will be prepared to document the analysis and development work carried out in all the previous tasks. The report will also provide recommendations on how the findings should be incorporated into a new 2010 version of the Caltrans *Flexible Pavement Rehabilitation Manual*. A draft of the report will be submitted within one year after the five-year period for review and comment.

- Training – Assuming that a training course on the new Caltrans M-E overlay design procedure will be available in 5 years (under a separate project), this effort will involve the revisions to the training course to cover the application of the new material properties and design criteria within the M-E design procedure.

EXPECTED OUTCOME

The expected outcomes from this study include the following:

- From the short-term plan – Improvements to Caltrans overlay design procedure to accommodate RAC-G and MB mixtures
  - Improved design criteria for the use of RAC and MB mixtures in the Caltrans overlay design procedure
  - A report documenting the development of the improved design criteria and recommendations.
  - Training module
- From the long-term plan – Development of design criteria for consideration of RAC and MB mixtures in a new Caltrans M-E overlay design procedure
  - Findings from the on-going projects
  - Construction of additional experimental test sections
  - Development and analysis of data from on-going studies and additional experimental test sections
  - Data and criteria for use of RAC and MB mixtures in Caltrans M-E design procedure
  - Training course improvements