Work Plan for:
"Investigation of Noise, Durability, Permeability and Friction Performance Trends for Asphaltic Pavement Surface Types"

PPRC Strategic Plan Item 4.16

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For the California Department of Transportation
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EXECUTIVE SUMMARY

The central purpose of this research is to support the Caltrans Quiet Pavement Pilot Program. The research conforms with FHWA guidance provided to State DOTs that conduct tire/pavement noise research. The broader purpose of this research is to support the Caltrans *Quieter Pavements Road Map and Work Plan*, with goals and objectives that address quiet as well as permeable asphalt surfaces for pavements.

Results from this research will identify best practice for selecting asphaltic surfaces based on performance trends identified from field measurements for noise, permeability, friction and durability. Results will include a literature survey and creation of a database of California materials, designs, and specifications plus similar information from other states and Europe to identify potentially better mixes. Results also will determine whether there is a correlation between laboratory sound absorption as measured by impedance tube and field noise intensity, which could provide a tool for evaluating mixes for noise properties as part of mix design.

Activities within the scope of this research focus on goals and objectives approved by the Caltrans Pavement Standards Team:

1. Develop a database for lifetime performance trends to identify best practice for California open-graded and rubberized mixes.
2. Summarize information on laboratory tests that correlate with pavement performance from the stand point of noise and permeability, and gather information on mix design methods, identifying best practices that can potentially be brought to California.
3. Survey practice and research in other states and Europe on the lifetime performance of their open-graded mix types with respect to sound intensity, durability, friction, and permeability. Gather and summarize their results, identifying promising mixes.

4. Determine whether a relationship exists between a laboratory noise absorption test, the impedance tube, and field sound intensity measurements.

Potential future phases of work include conducting new laboratory tests on California mixes and those from other states and Europe for further consideration by Caltrans, and continued long-term monitoring of field sections after the two years approved in this work plan. These future phases will be reviewed by Caltrans at a later date for decisions on whether to proceed.

Deliverables for each research objective are described in the Work Plan. The literature survey by the Partnered Pavement Research Center (PPRC) will include new information from European laboratories and will summarize the state of the art on quiet and permeable pavements. PPRC will become capable of performing tests for much-needed field measurement of sound and surface friction as well as laboratory noise impedance testing. The bulk of project effort will be spent on field data collection that will include eight Caltrans Environmental noise monitoring locations plus approximately 66 mainline highway sites with various open-graded mixes, rubberized mixes, Oregon F mix, and dense-graded asphalt concrete (as a control). These sections will represent different ages, traffic, and climate. Types of data, test methods, and frequency of testing are described in this Work Plan, and PPRC will coordinate with Caltrans Environmental to ensure compatibility of sound intensity data collection. Trend analysis will relate mix performance to variables such as age, traffic, and climate, and will correlate sound measurement techniques.

Project costs and schedule are presented in this Work Plan. The total project cost is approximately $855,000. Nearly 40 percent of this cost is for traffic closures ($324,000) and 20 percent ($174,900) is for equipment. A key risk in this cost estimate is that PPRC does not have funds for required traffic closures and for some equipment.

The project schedule spans a maximum of two years, with data collection after the second year needing to be addressed in a follow-on project. Decision points are included in the schedule so Caltrans annually can decide, after reviewing each year's data, if further testing is warranted. The data collection schedule heavily depends on traffic closures, and might double if District Maintenance crews are unable to support this research effort or funds are not available for contracted traffic closures. The selection of pavement sections with open-graded and rubberized (RAC-G) surfacings also needs to be developed in cooperation with Caltrans Maintenance, who will provide lists of potential sites. Collecting data for DGAC sections is dependent on the PPE2 contractor (Stantec) schedule, so delays in their progress and contract might affect this project schedule. Delays in having the PPRC contract amendment in place by 1 July 2005 also will delay this project.

1.0 PURPOSE OF PROJECT

The central purpose of this research is to support the Department's Quiet Pavement Pilot Program (QPPP), which is meant (1) to show effectiveness of quiet pavement strategies and (2) to evaluate changes in their noise mitigation properties over time.

The broader purpose of this research is to support the goals and objectives in the Caltrans *Quieter Pavements Road Map and Work Plan*. These goals and objectives include both quiet pavement as well as permeable pavement. The objective is to provide the following results, much of which will support the Caltrans QPPP:

- Provide an indication of best practice for selecting current Caltrans open-graded mixes for climate and traffic conditions based on statistical performance trends from field measurements for noise, permeability, friction, and durability.
- Create a database and gather as much similar information from other states and Europe as possible, in order to identify mixes that may have better performance than Caltrans current mixes.
- Provide a survey of open-graded mix practice in the United States and Europe and comparison with Caltrans mixes with regard to mix specification and design.
- Determine whether there is a correlation between laboratory sound absorption as measured by impedance tube and field noise intensity, which if successful will provide a tool for evaluating mixes for noise properties as part of mix design.

2.0 BACKGROUND

The California Department of Transportation (Caltrans) has identified a need for research in the areas of acoustics, friction, and pavement performance of pavement surfaces for the state highway network. In November 2004, the Pavement Standards Team (PST) approved a new research goal for the Strategic Plan of the Partnered Pavement Research Center (PPRC), numbered 4.16. This document presents the detailed work plan for PPRC Strategic Plan Item 4.16, as approved by the PST.

The purpose of this research is to support the goals and objectives in the Caltrans *Quieter Pavements Road Map and Work Plan*.

Caltrans currently uses open-graded asphalt concrete with conventional binders, with polymer-modified binders, and with rubberized binders, and uses the Oregon F-mix, which has a different gradation, in District 1. The four most important performance measures for open-graded mixes are its acoustical properties, durability (which with cost determines its life cycle cost), permeability, and friction. Caltrans does not have good durability performance data for these mixes as a function of type, variability of aggregate gradation within the current specification, climate, and traffic. Open-graded mixes will not have the same durability as Portland cement concrete or some dense graded asphalt surfaces. Therefore, if open-graded mixes are selected as a means of reducing noise and maintaining permeability and friction, Caltrans will want to use the mix with the lowest life cycle cost, which is a function of its construction cost, and the time between renewals.

Previous work by Caltrans Environmental has shown that Caltrans open-graded mixes reduce noise, and can produce noise levels as low as those of some mixes in Europe. However, those noise measurements have not been statistically tied to variability of aggregate gradation, mix type, permeability, age, traffic, climate, or roughness. The friction and permeability performance of the current Caltrans mixes have also not been correlated with the same variables.

Caltrans is also interested in comparison of its current open-graded mixes with those of other states and European agencies with regard to noise, durability, friction, and permeability performance over time.

The results of the research will identify best practice for selecting asphaltic surfaces for climate and traffic conditions based on statistical performance trends from field measurements for noise, permeability, friction, and durability. It will create a database for this data, and gather as much similar information from other states and Europe as possible for comparison to identify mixes that may have better performance than Caltrans current mixes. It will provide a survey of open-graded mix practice in the United States and Europe and comparison with Caltrans mixes with regard to mix specification and design. It will determine whether there is a correlation between laboratory sound absorption as measured by impedance tube and field noise intensity, which if successful will provide a tool for evaluating mixes for noise properties as part of mix design.

3.0 GOALS, OBJECTIVES, AND DELIVARABLES

3.1 Goals

The goals of this research as approved by the PST are to:

1. Develop a database for lifetime performance trends to identify best practice. Trends will be determined for California open-graded and RAC-G mixes with regard to sound intensity, durability (raveling, rutting, cracking), friction, and permeability. Performance trends will be analyzed as a function of gradation, binder type, traffic

(speed, ADT, ADTT, ESALs), climate (rainfall, temperature and freezing), and roughness (IRI).

2. Gather and summarize information on laboratory tests that are correlated with these performance measures, gather information on mix design methods, and identify best practices that can potentially be brought to California.
3. Survey practice and research in other states and Europe on the lifetime performance of their open-graded mix types with respect to sound intensity, durability, friction, and permeability. Gather and summarize performance data and identify promising mixes that can be brought to California.
4. Determine whether a relation can be established between a laboratory noise absorption test, the impedance tube, and field sound intensity measurements using field cores.

As a potential future phase of work, laboratory tests identified by the survey would be performed on California mixes to check the correlation with identified performance trends, if approved by Caltrans after review of the information gathered on performance-related laboratory tests. These same tests would be performed on the promising mixes identified from the survey of other states and Europe for comparison with California mixes with known performance. Mixes showing superior performance in the laboratory would be recommended for further consideration by Caltrans.

3.2 Objectives

The deliverables of the objectives of this research will achieve the goals described above (Table 1).

Table 1 Summary of Objectives and Deliverables

Work Plan Section	Objective	Deliverables
1.2.1	Literature survey	1. Literature survey of US practice performed by PPRC. 2. Literature survey of European practice performed by EMPA.
1.2.2	PPRC test capability	PPRC operational capability to measure field sound intensity, lab noise impedance, field surface friction.
1.2.3	Database structure	Database structure. Populated database at completion of data collection objective.
1.2.4	Data collection	
	Field sections in California	Properties of as-built surfaces (sound intensity, permeability, friction, distresses) over time, with trends in data summarized annually. Continued data collection as authorized by Caltrans.
	Field and lab data from outside California	Database of measurements on outside mixes and report summarizing data collected and trends.
1.2.5	Performance trend statistical analysis	Report documenting statistical analysis results from Data Collection objective, with summary of performance trends and modeling results.
1.2.6	Two-year summary report	Report summarizing all of the work completed.

3.2.1 <u>Literature Surveys</u>

Literature surveys will be performed to evaluate current practice, and recent and ongoing research in Europe and other states on open graded mixes. The focus of the literature surveys will be on:

- Differences and similarities among California and other states and Europe with regard to open-graded mix types used, specifically: gradations, binder contents, binder types.
- Design methods for open graded mixes in use, including laboratory test methods for distress development, clogging, permeability, and acoustical properties.
- Performance of open graded mixes used by others, including identification of any published performance data with respect to long-term noise, durability (raveling, rutting, cracking), friction, and permeability. Focus will be on relating that

information to California climates and traffic and identifying potential candidate mixes from elsewhere that should be further evaluated in California.

This work will begin with a review of the recent scanning tours organized by FHWA and asphalt technical groups as well as European groups working on this issue, and the report on Noise Intensity Testing in Europe (NITE). The literature to be reviewed also will include Transportation Research Records, Proceedings of the Journal of the Acoustical Society of America, the Purdue Road Noise Study, NCAT Reports, DOT websites, and websites of European Road and Transport Institutes. It will also consider results of the following NCHRP projects:

- 1-43, *Guide for Pavement Friction* (to be completed in October 2005)
- 9-41, *Performance and Maintenance of Permeable Friction Courses* (to be completed in September 2006)
- 10-67, *Texturing of Concrete Pavements* (to be completed in February 2007)
- 1-44, *Measuring Tire-Pavement Noise at the Source* (pending)

Additional information on European mixes will also be gathered through partnership with the Road division of Swiss Federal Laboratory for Materials Testing and Research (EMPA) where a similar literature survey will be performed. Much of this literature is published in languages other than English. This literature will be summarized in English with the help of EMPA. Other recent, ongoing, and planned research being performed in Europe will be surveyed. Contacts have been established with the Danish National Roads Laboratory. The DNRL works closely with the Netherlands, another leader in Europe.

The deliverable from this objective will be the literature survey performed by the PPRC. A second deliverable will be the literature survey performed at EMPA.

3.2.2 Develop PPRC Capability for Sound Intensity, Field Friction and Texture, and Laboratory Sound Impedance Tube Measurement

The PPRC will obtain the capability to perform sound intensity measurements in the field that match or can be correlated with those performed by Caltrans Division of Environmental Analysis (Bruce Rymer) and his service providers, Illingworth and Rodkin. This will require working with Illingworth and Rodkin to identify the required equipment components and configuration, set them up, and train PPRC staff. This will also require working with Caltrans Environmental to be certain that the measurements are acceptable by performing side-by-side tests on the same field sections.

The possibility of developing a vehicle capable of simultaneously measuring noise intensity and IRI through the purchase and addition of a laser profiling bar to the sound intensity vehicle will be explored, and will be purchased if the equipment works. If this add-on IRI capability is not feasible, then IRI will be collected using a different vehicle separate from the sound intensity vehicle.

The PPRC will work with METS (Caltrans Materials Engineering and Testing Services) to identify the best testing equipment for field friction and texture measurements, and based on recommendations, will obtain that equipment.

The PPRC will work with Caltrans Environmental to develop the capability to measure noise impedance on pavement cores in the laboratory, and to ensure that the measurements are compatible with those provided to Caltrans Environmental by their service providers. This will require side-by-side testing on some cores using the PPRC equipment and the Caltrans Environmental service provider.

The deliverables from this objective will be PPRC operating ability to measure field sound intensity, laboratory noise impedance, and field surface friction.

3.2.3 Create Database Structure

The PPRC will create a database structure to be populated with the field, laboratory and other data to be collected as part of this project. The database will be in Microsoft Access, and will be capable of being loaded into Oracle. All of the data fields will be identified following Caltrans Information Technology practice. The database will be fully accessible to Caltrans, initially as spreadsheets and in Access and eventually through the web into the Oracle version. Caltrans can use and distribute the data as needed.

As the data is collected it will be checked for quality and loaded into the database on an ongoing basis.

The first deliverable of this objective will be the database structure. The second deliverable will be the populated database at the completion of the data collection objective. This work will all be performed by PPRC.

3.2.4 Collect Data on Field Sections in California

The purpose of testing field sections in California is to identify the properties of the as-built surface materials and provide time histories of sound intensity, friction, texture, permeability, surface distresses, and IRI. Details of testing to be performed are provided later in this document.

3.2.4.1 Section Selection

Field data will be collected on two sets of sections:

1. The eight Caltrans Environmental noise monitoring locations, many with several different surface type sections.
2. A set of open-graded, RAC-G, and control DGAC mainline highway sites of different ages to be identified as part of this work.

The eight Caltrans Environmental noise monitoring locations are identified in Table 2.

The set of open-graded, RAC-G, and control DGAC mainline highway sites will include sections of different ages, traffic types, and climate regions. The details of the testing for this set of sections are presented later in this document. The experiment design for the sections is shown in Table 3. The experiment will evaluate 66 sections with no replicates. The open graded sections will be selected from the list included in Appendix A. Each of these sections will need to be checked to determine if it is a viable test section. This includes checking condition, and whether constant speed of 35 or 60 mph (two standard speeds used by the Caltrans Environmental contractor) can be maintained for sound intensity measurements.

Existing dense graded RAC-G sections will be selected from the AC overlay on PCC sections in the Pavement Performance Evaluation 2 (PPE2) contract being performed by a Caltrans DRI contractor (Stantec), included in Appendix B. Some additional sections may need to be identified if there are not sufficient viable sections in the PPE2 list. This experiment design results in $5 \times 2 \times 2 \times 3 = 60$ sections, plus three to six Oregon F mix sections.

Table 2 Eight Caltrans Environmental Noise Monitoring Sites: Locations and Test Sections within Them (from Caltrans Environmental)

Section Name	Location	Surface Types	Date Constructed
Davis I-80	3-Yol-80, PM~2.9-5.8	OGAC	July 1998
Florin Road I-5	3-Sac-5, PM 17.2-17.9	OGAC	Fall 2004
LA county, SR 138	7-LA-138, PM 16-21	75 mm OGAC, 30 mm OGAC, RAC-O, BWC	Spring 2002
San Mateo I-280	4-SM-280, PM R0.0-R5.6	RAC-O on PCC, grind PCC	Fall 2002
Mojave Bypass, SR 58[1]	8-Ker-58, PM 107.7-118, west end of project in eastbound lanes	Variety of groove, grind, textured PCC	Fall 2003
Euro Gap-Graded, Rosemead Blvd, El Monte	7-LA-19/164, PM 3.4	Gap-graded mix identified in European scanning tour	May 2005
CIWMB Test Sections, Firebaugh	6-Fre-33, PM 70.9-75.08	RAC-G 45 mm RAC-G 90 mm RUMAC-GG 45 mm RUMAC-GG 90 mm Type G-MB 45 mm Type G-MB 90 mm Type D-MB 45 mm Type D-MB 90 mm DGAC 90 mm	Summer 2004
Santa Clara SR 85[1]	4-SCl-85, PM 14.63 to 15.51	Extend test grooving of PCC	Summer 2005 scheduled

Notes:

[1] These sections will be of second priority in scheduling testing because they may be monitored through a different project.

OGAC = open graded asphalt concrete

BWC = bituminous wearing course

DGAC = dense graded asphalt concrete

RAC-G = Rubber asphalt concrete Type G

RUMAC-GG = rubber modified asphalt concrete, gap-graded, dry process

Type G-MB = asphalt concrete (Type D-MB)

Table 3 Experiment Design for Mainline Highway Sections

Surface Type 5 types	**Climate Region 2 Regions**	**Traffic Type (Congestion) 2 Types**	**Age 3 Ages**
Conventional Open Graded Asphalt Concrete (OGAC)	High rainfall (North Coast, Bay Area, Low Mountain)	Mix of fast and slow, heavy	New
			1-4 years
			4 years or more
		Fast	New
			1-4 years
			4 years or more
	Low rainfall (Valley, South Coast, South Mountain, Desert)	Mix of fast and slow	New
			1-4 years
			4 years or more
		Fast	New
			1-4 years
			4 years or more
Polymer Modified Open Graded Asphalt Concrete (OGAC with PMB)	High rainfall (North Coast, Bay Area, Low Mountain)	Mix of fast and slow, heavy	New
			1-4 years
			4 years or more
		Fast	New
			1-4 years
			4 years or more
	Low rainfall (Valley, South Coast, South Mountain, Desert)	Mix of fast and slow	New
			1-4 years
			4 years or more
		Fast	New
			1-4 years
			4 years or more
Rubberized Open Graded Asphalt Concrete (RAC-O and RAC-O-HB)	High rainfall (North Coast, Bay Area, Low Mountain)	Mix of fast and slow, heavy	New
			1-4 years
			4 years or more
		Fast	New
			1-4 years
			4 years or more
	Low rainfall (Valley, South Coast, South Mountain, Desert)	Mix of fast and slow	New
			1-4 years
			4 years or more
		Fast	New
			1-4 years
			4 years or more

Table 3 (continued)

Surface Type 5 types	**Climate Region 2 Regions**	**Traffic Type (Congestion) 2 Types**	**Age 3 Ages**
Rubberized Asphalt Concrete Gap Graded (RAC-G)	High rainfall (North Coast, Bay Area, Low Mountain)	Mix of fast and slow	New
			1-4 years
			4 years or more
		Fast	New
			1-4 years
			4 years or more
	Low rainfall (Valley, South Coast, South Mountain, Desert)	Mix of fast and slow	New
			1-4 years
			4 years or more
		Fast	New
			1-4 years
			4 years or more
Dense Graded Asphalt Concrete	High rainfall (North Coast, Bay Area, Low Mountain)	mix of fast and slow	New
			1-4 years
			4 years or more
		Fast	New
			1-4 years
			4 years or more
	Low rainfall (Valley, South Coast, South Mountain, Desert)	Mix of fast and slow	New
			1-4 years
			4 years or more
		Fast	New
			1-4 years
			4 years or more
Oregon F Mix (several replicates for each cell will be sought)	District 1 (North Coast)	Fast	New
			1-4 years
			4 years or more

3.2.4.2 Data to be Collected, Tests, and Data Collection Schedule

The same type of data will be collected on both sets of field sections. The data to be collected in the field is identified in Table 4. Laboratory tests on field samples are identified in Table 5. Supporting data collection is identified in Table 6. The duration of the PPRC data collection is summarized in Table 7. The Project Schedule in Part 4 of this work plan presents the data collection schedule in greater detail, including decision points for the Pavement Standards Team to evaluate cumulative results and decide whether to continue the data collection and analysis effort in this research goal.

Table 4 Data Collection, Sampling, and Testing in the Field

Type of Data/Sample	Specific Test or Sample	Collect Annually or Once at Beginning	Comment
Condition Survey[1]	Caltrans PMS Condition Survey	Annually	Only pavement surface variables will be collected
Permeability	ASTM D 5084 falling head	Annually	Both in wheelpath and between wheelpaths
Sound Intensity[3,5]	Caltrans approved method	Annually	In wheelpath. Caltrans Environmental will perform tests until PPRC is equipped and trained
Pavement Surface Temperature at Time of Sound Intensity	Infrared temperature gun	At time of sound intensity measurement	Pavement temperature profile can be estimated using equations previously developed by PPRC or BELLS equation
Air temperature	Thermocouple	At time of sound intensity measurement	
Friction	Dynamic Friction Tester ASTM E 1911; British Pendulum Number[2]	Annually	In wheelpath
Macro texture	Circular Friction ASTM E 2157[2]	Annually	In wheelpath. Device will be loaned by Arizona DOT
International Roughness Index (IRI)[1]	Laser profilometer	Annually	Either by add-on equipment to sound intensity vehicle, or separately
Deflections	Falling Weight Deflectomer	Annually	PPRC only on SR 138[4]
Cores	Diameter: 100 mm diameter on PPE2 sections; 100 and 150 mm on other sections	Once	PPE2 sections: two between wheelpath, three in wheelpath, all 100 mm dia. Other sections: eight 150 mm diameter cores between wheelpaths, eight 150 mm cores in wheelpath

Notes:
[1] Same survey will be replicated by Stantec on PPE2 sections.
[2] Specific test equipment or method will be per METS recommendation.
[3] Same test will be replicated by Caltrans Environmental on eight Caltrans Environmental noise monitoring locations
[4] Deflections using the Falling Weight Deflectometer will continue to be collected on SR138 in the set of Caltrans Environmental sections as it has been since 2002. This is the only section in that set with an asphalt concrete pavement below.
[5] On new sections, sound intensity will also be collected before construction.

Table 5 Laboratory Measurements and Tests on Field Cores Collected at the Sites

Type of Data/Sample	Specific Test or Sample	Collect Annually or Once at Beginning	Comment
Impedance tube noise absorption	Per Caltrans Environmental	Once	Exact test procedure in development[1]
Extent of clogging test	Test to be performed by EMPA. Exact procedure to be determined.	Once	Similar research underway at FHWA and Danish National Roads Institute
Thickness of surface layer		Once	
Thickness of underlying layers		Once	
Evaluate for moisture damage		Once	Visual procedure used for PPRC Moisture Sensitivity work
Bulk specific gravity	CoreLok	Once	Will be performed by Stantec on PPE2 DGAC sections
Max theoretical specific gravity	CT 309	Once	Will be performed by Stantec on PPE2 sections
Air-void content		Once	Using bulk and max theoretical specific gravities
Binder content from core	CT 382	Once, only sections where original aggregate source and gradation available[2]	Ignition test (if raw aggregate are available)
Aggregate gradation from core	CT 202	Once	From aggregate after binder removal. Will be repeated where aggregate samples are collected during construction[3]
CT scan (tomography) for clogging	Experimental test	Once	To be performed by EMPA and maybe Texas A&M

Notes:

[1] Test method will be based on NCAT procedure. Test procedure will be determined in consultation with Caltrans Environmental (Bruce Rymer). Same test will be replicated on a set of cores by Caltrans Environmental contractor.

[2] Raw aggregate sample with gradation used on project required to calibrate ignition oven binder content measurements, which will not be available from many older projects.

[3] Where aggregate and binder can be sampled during construction, collect bin samples to batch 250 kg and binder quantity to match based on design binder content. Also collect 100 kg of belt aggregate sample when QC data not collected.

Table 6 Sources and Supporting Data Collection for Field Sites

Type of Data/Sample	Specific Test or Sample	Collect Annually or Once at Beginning	Comment
From District Office or on-line as-builts			
As-Built Information	Underlying structure, date of construction	Once	
Mix information	Job mix formula, QC/QA data on aggregate and binder, binder content	Once	May not exist for all open-graded
Traffic data	Typical traffic speed distribution across week and or level of service	Once	
	Average daily traffic	Once	
	Percent trucks	Once	
From Climate Databases (CDIM and NCDC for historical, local weather data sources for most recent data not yet in national databases)			
Climate data	Annual rainfall	Over life	
	Freeze-thaw cycles	Over life	
	Degree-days above 30°C	Over life	
	Freezing Index	Over life	
From PMS database and HQ Maintenance and HQ Design[1]			
Time history of condition survey		Once	Since construction
Time history of IRI		Once	Since construction
Traffic data	Traffic index (ESALs)	Once	
	Average Daily Traffic	Once	
	Percent trucks	Once	
From WIM database			
From WIM database	Traffic index (ESALs)	Once	Where a WIM station exists
	Average Daily Traffic	Once	Where a WIM station exists
	Percent trucks	Once	Where a WIM station exists
	Traffic speed distribution	Once	Where a WIM station exists

Notes:
[1] Condition and IRI data from the PMS database may not be useful if survey beginning and end point do not match overlay beginning and end point.

Table 7 Data Collection Schedule

Type of test section	Duration of PPRC Data Collection[1,3]	PST Evaluation Times[2]
Eight Caltrans Environmental noise monitoring locations	10 years	every year
Set of open-graded, RAC-G and control DGAC mainline highway sites of different ages	10 years	every year

Notes:
[1] the number of sections being evaluated will diminish with time as sections are overlaid or removed.
[2] PST to evaluate whether to proceed with next year's testing after reviewing every year's data collection
[3] Data collection after the first two years included in this plan would be a follow-on project.

3.2.4.3 Deliverables

The deliverable from this objective will be the databases with all measurements. A second deliverable will be a report summarizing the first two years of data collected and the trends in the data. A longer time scale than that of the PPRC measurements will be included for those sections for which valid PMS data can be found. This report will be updated annually, for as long as data collection is authorized. Periodic updates on data collection progress will be made to the PST as requested. Materials from new construction sections will be stored at the PPRC for any future work.

3.2.5 Collection of Field, Laboratory and Other Data for Open-Graded Mixes Outside California

Agencies and research organizations that are interested in partnering on this project will be asked to provide data for the variables included in the database structure. The variables will be acoustic, permeability, and surface condition distress performance for their sections with corresponding mix, climate, traffic, and IRI explanatory data, as described in the previous objective (Section 1.2.4 of this work plan). The partnering organizations will be provided with California information and access to the information produced as part of this project.

The Swiss Federal Roads Laboratory (EMPA) has already agreed to partner. Other likely partners include the other three states in the State Pavement Technology Consortium (Washington, Minnesota, Texas), Arizona, and the Danish National Roads Laboratory (DNRL, who have been working closely with their counterparts in the Netherlands).

The deliverables from this objective will be the databases with all measurements, and a report summarizing the data collected and the trends in the data. The report will also compare the results with the results from the California mixes to identify potential candidate mixes from elsewhere that should be further evaluated in California.

The extent of data gathered by the PPRC depends on the willingness and ability of partnering organizations to collect the data.

3.2.6 Performance Trend Analysis of Field, Laboratory, and Other Data for California Roadway Surfaces

The results of the first two years of data collection on California roadway surfaces described in the previous objective will be further analyzed for performance trends for the performance measures [sound intensity, permeability, friction, and surface condition (distresses)] over time and as a function of the explanatory variables. If the data permits, models will be developed for sound intensity, permeability, and surface condition as a function of the materials, climate, traffic, age, and IRI variables.

An outline of the planned trend analyses, described in more detail below, is as follows:

- Relating mix performance measures to explanatory variables

- Performance trend analysis annually on cumulative data using repeated measures analysis of variance
- After the second year's data collection, models will be developed for the performance measures using panel data analysis (time series)
- Repeat the analyses shown above if sufficient compatible data obtained from partners, once separately and once pooling with California data

- Correlations of sound measurement technologies
  - Laboratory impedance tube with field sound intensity
  - Laboratory impedance with statistical pass-by
  - Statistical pass-by with field sound intensity

For performance trend analysis, data collected annually will be evaluated by repeated measures analysis of variance (ANOVA) to evaluate permeability, texture, and friction parameters over time for pavements with different mix types, materials variables, and age, and under different climate and traffic conditions and IRI. Repeated measures ANOVA is used to examine and compare response measurement trends over time. Pavements will be grouped according to mix type (such as OGAC, RAC-O, RAC-G, DGAC, and polymer-modified OGAC), age, traffic index, and climate regions. Sound intensity, permeability, friction, and surface condition measurements will be considered as dependent variables of the experiment.

This analysis will identify the effects of the explanatory variables and their interactions, and time effects on the dependent variables.

At the end of the second year of data collection, models will be developed for each performance measure (sound intensity, permeability, friction and condition survey distresses) for which the ANOVA shows sufficiently strong statistical correlation between the performance measure and the explanatory variables. For example, the sound intensity model would predict sound intensity as a function of the potential explanatory variables of permeability/air-void content, friction, macrotexture, age, traffic variables (speed, ADT, etc.), aggregate gradation, binder type, surface distresses, IRI, layer thickness, sound absorption (from impedance tube), climate region, and pavement temperature.

Since the measurements will be conducted as time series, the information will reflect the changes in sound intensity caused by different characteristics of the pavements as well as the changes over time. Panel data regression will be conducted on the data. This analysis is used routinely by statisticians to capture long term time trends by taking measurements through time over a small number of periods.

This approach has been applied in three comparable studies describe below:

1. NCAT (D. Hanson and R.S. James) conducted a similar analysis with dense graded sections of NCAT Test Track which contains 46 different pavement surfaces. They tried to model the CPX noise levels by air-void content and fineness modulus. The coefficient of variability was found to be 0.64. NCAT also looked at the age effects on noise levels. The single event measurements were conducted on the 10 dense graded pavements in Colorado with ages from 1 to 6 years. They found that older pavements produce higher noise levels.
2. Arizona DOT studied the age effects on the noise of the ARFC mixes for their Quiet Pavement Pilot Program. During summer 2002, close proximity (CPX) measurements were conducted on ARFC surfaces in Arizona with ages of 3 to 12 years. This data suggested that there was a 5dB reduction associated with age.

3. Wisconsin DOT used linear regression to model the noise levels (close proximity) of PCC pavements in Wisconsin and some other states. Noise measurements were conducted on 25 pavements from Wisconsin, 6 from Iowa, 7 from Minnesota, 6 from Colorado, and 6 from North Dakota which had different textures. The test sections had a wide range of ages. Exterior noise levels were predicted using friction, tine depth and tine width.

If sufficient quantities of compatible data are obtained from a partner organization, it will be included in the statistical analysis. This analysis would be repeated twice, once pooling the California and outside data, and once using the outside data for comparison with the California models.

The field sound intensity measurements and laboratory impedance tube measurements for cores from same field sections will be analyzed to see if there is a statistical relationship. These two tests measure different properties, but may be dependent on the same explanatory variables to sufficient extent that laboratory impedance tube could be useful to predict sound intensity for use in mix design.

It may be possible to correlate statistical-pass-by measurements (SPB) being collected by Caltrans Environmental with the field sound intensity data and the laboratory impedance tube data (noise absorption) from cores from the same Caltrans Environmental sections (Table 2). This approach is being tried in the United Kingdom at this time. This would permit prediction of SPB, which is the roadside noise measure, based on sound intensity and impedance tube measurements.

The deliverable from this objective will be a report documenting the statistical analysis results and summarizing the performance trends and modeling results. The ANOVAs indicating the correlation of the performance variables with the explanatory variables will be reported after analysis of each round of testing.

3.2.7 Summary Report

At the end of the second year's activities (or the first year's activities if PST decides to terminate work after the first year of data collection), a report summarizing all of the work completed will be prepared.

4.0 POTENTIAL FOLLOW-ON PROJECTS

4.1 Open Graded Asphalt Concrete Mix Laboratory Test Methods and Design

The deliverables of the work described in Section 3 will provide Caltrans with information regarding the performance of current California open graded mixes, promising mix designs from outside California, and mix design methods and tests from outside California.

It is proposed that at the end of the second year of field testing and analysis, the PST will decide whether to authorize two additional objectives which are roughly outlined below.

The goal of the two follow-on objectives would be to develop a mix design procedure for open graded asphalt concrete materials and would include performance related laboratory tests for acoustics, pavement surface performance, permeability and friction.

4.1.1 Update Developments in Mix Design Testing

The literature search would be updated to examine findings from ongoing developments in open graded mix design procedures and any performance-related laboratory tests being developed in the US (particularly by NCAT) and in Europe. The deliverable would be a report summarizing the findings.

4.1.2 Laboratory Evaluation of Mix Design Procedures and Laboratory Tests

The results of the previous objective would be evaluated by applying them to typical Caltrans mixes and comparison with the results of field performance evaluation of Caltrans and promising candidate mixes identified from outside California. It is anticipated that at most three mix design procedures would be applied to three mixes with two variables in each, such as aggregate gradation, resulting in at most 3 mix design procedures × 3 mixes × 2 variables = 18 mix designs. These results would be evaluated for implementation by Caltrans. The deliverable for this project will be a report with the recommended mix design method for open graded mixes.

4.2 Continued Long-Term Monitoring of Field Sections

A potential follow-on project to be reviewed by the PST at the end of this project would be continued annual monitoring of the field sections following the plan laid out in Table 4.

5.0 TEST METHODS

The test methods to be used in this research are summarized as follows:

- *Air-void Content:* Air-void content of the mixes will be determined by using bulk specific gravities from the CoreLok Method and Maximum Theoretical Specific Gravities following Caltrans procedure CT 309.
- *Permeability:* Permeability will be measured in the field by falling head permeameter following ASTM D 5084. Falling head test measures the amount of head loss through a given sample over a given time.
- *Friction:* Friction will be measured by Dynamic Friction Tester following ASTM Standard E 1911-98. The Dynamic Friction Test is a portable instrument which measures dynamic coefficient of friction.
- *Macrotexture:* Macrotexture will be measured by Circular Texture Meter (ASTM E 2157-01). The Circular Texture Meter is a road surface macrotexture profiler, in which a CCD (Charged Coupled Device) Laser Displacement Sensor is used. It is designed to measure the macrotexture on the same circular track on which the Dynamic Friction Tester measures the dynamic coefficient of friction. The Circular Texture Meter reports the MPD (Mean Profile Depth) as well as the RMS (Root Mean Square). International Friction Index (IFI) can be computed using the Circular Texture Meter together with the Dynamic Friction Tester.
- *Age:* Age of the pavements will be obtained from pavement management systems database and district office records.
- *Traffic Index:* Traffic Index or Average Daily Traffic will be obtained from pavement management systems database.

- *Aggregate Gradation:* Aggregate samples will be obtained from cores after subjecting them to binder content removal by the Ignition Oven Method (CTM 382) and then sieve analysis (CTM 202).
- *Binder Type:* Specified binder types will be obtained from pavement management systems database or construction and design records, where available.
- *IRI (International Roughness Index):* Roughness of the pavements will be measured by an IRI laser bar mounted on the sound intensity vehicle.
- *Layer Thickness:* Layer thickness will be determined from the cores obtained.
- *Noise levels:* Noise levels of pavement will be measured by Sound Intensity Method.
- *Sound Absorption:* Sound absorption will be measured by impedance tube. Standing wave fields are generated in the tube using a loudspeaker. The maximums and minimums of the sound pressure are measured by two microphones aligned along the length of the tube. Standing wave ratio, which is the ratio of sound pressure maximums and minimums, is used to determine the sound absorption coefficient of the test sample. The working frequency of the measurement is usually between 125 to 2000 Hz depending of the tube diameter. (ASTM E1050-98 Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones, and a Digital Frequency Analysis System.)
- *Climate Data:* to be collected from local data sources, or National Climate Data Center if available in time.
- *Air and Pavement temperature:* Air and pavement temperature will be measured during sound intensity measurements.

6.0 COST

The cost estimate is shown in Figure 1. The primary risk in the cost estimate is that the PPRC does not have sufficient funds to pay for the traffic closures and some of the equipment. Efforts must be made to identify additional funds for those two items.

7.0 SCHEDULE

The primary risks in the schedule (Figure 2) are:

1. The PPRC does not have sufficient funds to pay for the traffic closures. If traffic closures must be performed by District Maintenance forces without having a Caltrans EA to charge to the time to complete each year's data collection will likely double. If District Maintenance does not have sufficient resources to perform traffic closures, the data collection time and the staff time necessary to arrange closures will also increase. An alternative for Caltrans is to provide additional funds for contracted traffic closures. Expeditious handling of district lane closure encroachment permits will be required if contracted traffic closures are used.
2. The PPRC is relying on Caltrans Maintenance to provide lists of pavement sections with open-graded asphalt and RAC-G surfacings in the various age categories. Delays in obtaining those lists (found by searching project records for appropriate item codes) will delay identification of sections for the factorial and field data collection.
3. Collection of data from other agencies is dependent on those agencies supplying the data to the PPRC in a timely manner.
4. Collection of data for DGAC sections is dependent on the PPE2 data collection schedule. The PPE2 contractor (Stantec) is expediting data collection on sections of importance to this project. However, any problems with that contract would require

the PPRC to do extra work to collect that data, which might delay the data collection schedule.

5. Any delay in the PPRC contract amendment being in place by 1 July, 2005 will delay the project.

Estimated Costs for First Two Years

all costs are fully loaded — Objective person/month assignments

Cost Item	unit	$/unit	Literature Surveys	PPRC Test Capability	Create Database	Collect Field, Lab, Other Data	Collect Data from Outside	Analysis of Data	Summary Report	TOTAL
PPRC										
Princ Investigator*	mo	$ 8,580	0.1	0.25		1	1	0.5	0.25	$ 26,598
Project Engineer (Phd)	mo	$ 9,240		0.5		2		0.5	0.5	$ 32,340
Grad Student	mo	$ 2,888	2	3	0.07	15	1.5	4	0.5	$ 75,268
Staff Engineers	mo	$ 7,828		1		9				$ 78,283
Editor	mo	$ 7,828	0.1						0.25	$ 2,740
Database engineer	mo	$ 7,828			0.1	0.5	0.2			$ 6,263
Lab tests crew	mo	$ 8,000				4				$ 32,000
Student Field Crew	mo	$ 8,000				9				$ 72,000
<u>Staff subtotal</u>										$ 325,491
Field Travel & expense (80 full day, 80 half)	day	$ 250				$ 30,000				$ 30,000
									<u>Total=</u>	**<u>$ 355,491</u>**
*salary portion paid by PPRC										
Equipment (including overhead)				**$ 174,900**						**<u>$ 174,900</u>**
Equipment details w/o overhead										
sound intensity incl vehicle				$ 60,000	including training & calibration					
circular friction test				loan from Ariz DOT						
dynamic texture meter				$ 29,000						
Impedance Tube				$ 10,000						
IRI laser profilometer bar				$ 60,000						
British Pendulum Test				loan from Caltrans						
Traffic closures (80 full day, 80 half)**	**day**	**$ 3,000**				**$ 324,000**				**<u>$ 324,000</u>**
** 12 DGAC sections traffic control by Stantec										
									TOTAL=	**$ 854,391**

Figure 1. Cost estimate for project.

ID	Task Name	Duration	Start	Finish	Predecessors
1	**PPRC 4.16**	**695 days?**	**Tue 2/15/05**	**Mon 10/15/07**	
2	**Literature survey**	**181 days?**	**Fri 4/1/05**	**Fri 12/9/05**	
3	US	54 days?	Fri 4/1/05	Wed 6/15/05	
4	Europe	40 days	Mon 10/17/05	Fri 12/9/05	
5	**PPRC testing capability**	**182 days?**	**Mon 4/11/05**	**Tue 12/20/05**	
6	sound intensity	182 days?	Mon 4/11/05	Tue 12/20/05	
7	dynamic friction	1.5 mons	Fri 7/1/05	Thu 8/11/05	
8	circular texture	2.2 wks	Wed 6/1/05	Wed 6/15/05	
9	IRI	1 mon	Fri 7/1/05	Thu 7/28/05	
10	impedance tube	1.7 mons	Mon 10/17/05	Thu 12/1/05	
11	Create database	1 wk	Tue 5/10/05	Mon 5/16/05	
12	**Collect field, lab, other data**	**655 days?**	**Tue 2/15/05**	**Mon 8/20/07**	
13	**Collect field data**	**655 days?**	**Tue 2/15/05**	**Mon 8/20/07**	
14	**OGAC, RAC, DGAC sections**	**655 days?**	**Tue 2/15/05**	**Mon 8/20/07**	
15	Stantec sections	138 days?	Mon 5/23/05	Wed 11/30/05	
16	get section list from Maint	39 days?	Tue 2/15/05	Fri 4/8/05	
17	identify sections	2.5 mons	Mon 4/11/05	Fri 6/17/05	16
18	first year collection	5 mons	Fri 7/1/05	Thu 11/17/05	
19	preliminary database populati	66 days?	Fri 7/1/05	Fri 9/30/05	
20	Perform lab tests	4 mons	Fri 10/21/05	Thu 2/9/06	18FF+3 mons
21	*second year collection**	4 mons	Thu 6/1/06	Wed 9/20/06	
22	*third year collection***	4 mons	Tue 5/1/07	Mon 8/20/07	
23	Collect other data (PMS, climate, etc.)	4 mons	Wed 6/1/05	Tue 9/20/05	
24	Collection of data from outside CA	8 mons	Wed 6/1/05	Tue 1/10/06	
25	**Data analysis**	**477 days**	**Fri 12/16/05**	**Mon 10/15/07**	
26	first year data	4 mons	Fri 12/16/05	Thu 4/6/06	20FF+2 mons
27	*second year data**	2 mons	Thu 9/21/06	Wed 11/15/06	21FF+2 mons
28	*third year data***	2 mons	Tue 8/21/07	Mon 10/15/07	22FF+2 mons
29	PST decision point 1st year data*	0 days	Thu 4/6/06	Thu 4/6/06	26
30	PST decision point 2nd year data**	0 days	Wed 11/15/06	Wed 11/15/06	27
31	Summary report first two years	2 mons	Thu 11/16/06	Wed 1/10/07	27
32	First two years work complete	0 days	Wed 1/10/07	Wed 1/10/07	31

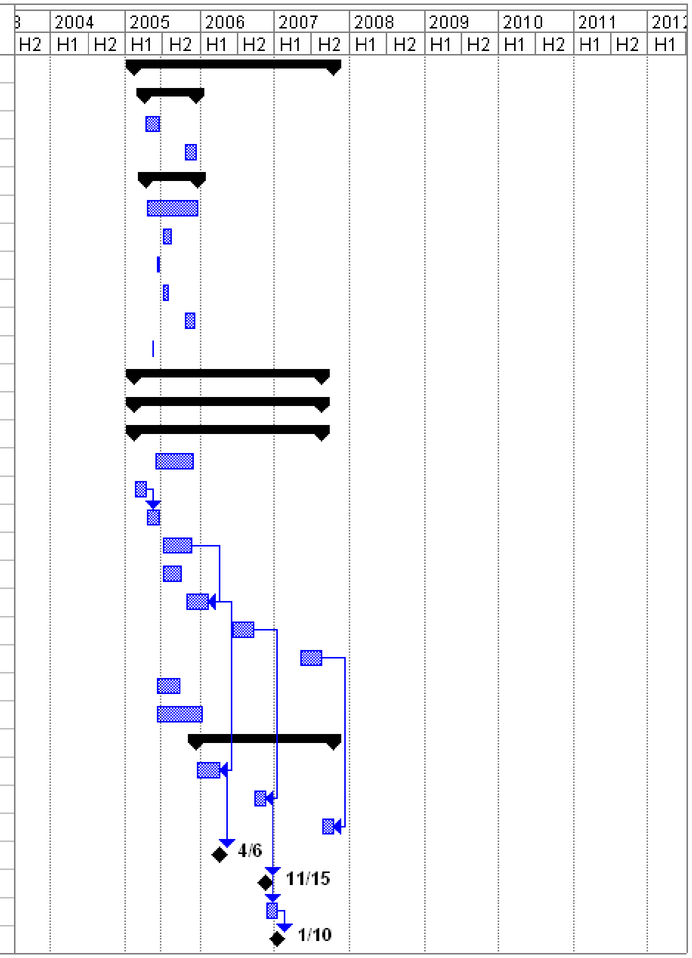

Figure 2. Project schedule.

APPENDIX A: LIST OF JOBS FROM WHICH OPEN-GRADED AND RAC-G CALIFORNIA SECTIONS (TABLE 3) WILL BE SELECTED

Summary of locations from which OGAC and RAC-G sections to be selected.

District 1: 68 Open graded Asphalt Concrete

District 2: 11 Open Graded AC, 4 RAC-G

District 3: 52 Open Graded AC, 1 polymer modified AC, 5 RAC-O, 3 RAC-G

District 4: 57 Open Graded AC, 2 polymer modified AC, 1 RAC-O, 25 RAC-G

District 5: 17 Open Graded AC, 1 polymer modified AC, 0 RAC-O, 2 RAC-G

District 6: 10 Open Graded AC, 1 polymer modified AC, 1 RAC-O, 12 RAC-G

District 7: 3 Open Graded AC, 3 polymer modified AC, 1 RAC-O, 29 RAC-G

District 8: 35 Open Graded AC, 0 polymer modified AC, 1 RAC-O, 5 RAC-G

District 9: 4 Open Graded AC, 6 polymer modified AC, 0 RAC-O, 0 RAC-G

District 10: 4 Open Graded AC, 0 polymer modified AC, 2 RAC-O, 8 RAC-G

District 11: 0 Open Graded AC, 0 polymer modified AC, 1 RAC-O, 15 RAC-G

District 12: 7 Open Graded AC, 0 polymer modified AC, 1 RAC-O, 10 RAC-G

Complete list in separate excel file

APPENDIX B: LIST OF SITES FROM WHICH CONTROL DENSE GRADED ASPHALT CONCRETE SECTIONS (TABLE 3) WILL BE SELECTED (PPE2 SITES)

Summary of locations from which DGAC sections to be selected.

District 2: 14 sections

District 4: 3 sections

District 5: 23 sections

District 6: 6 sections

District 10: 10 sections

Complete list included in separate excel file.

DGAC sections for which data is available from the PPRC Moisture Sensitivity field study (PPRC 4.9) and which did not show moisture damage, and the pilot segmentation study (PPRC 3.2.4) will also be considered for selection for this experiment. Coring and office data will already have been collected on these sections