California Department of Transportation

Quieter Pavement Research Summary

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Caltrans Improves Mobility Across California

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EXECUTIVE SUMMARY

Traffic noise has become a growing concern and the public is expecting 'quieter pavement' be constructed to abate traffic noise levels. Quieter pavements offer new options for minimizing the impacts of traffic noise levels on the neighborhoods adjacent to highways.

Quieter pavement is a new concept intended to reduce the impacts that tire/pavement noise has on the highway environment. This concept has received increasing attention in California and nationwide over the past several years focused on developing a better understanding of the long-term acoustic benefits of quieter pavements. The California Department of Transportation (Caltrans) has initiated several studies including the Quieter Pavement Research (QPR) proposal outlined in this document in an effort to evaluate the acoustic properties of pavements and pavement surface characteristics on tire/pavement noise levels.

Caltrans QPR plan is a systematic research proposal intended to examine the impact of "quieter pavements" on traffic noise levels and establish which pavement characteristics have the greatest impact on tire/pavement noise. The proposed research will evaluate acoustic properties and performance characteristics of both flexible and rigid pavements, and bridge decks used by the State. Additionally, the QPR study will help identify surface treatments, materials, and construction methods that will result in a quieter pavement that is also safe, durable, and cost-effective. The information gathered will be used to develop quieter pavement design features and specifications for noise abatement throughout the State. This is one of the reasons why it is necessary for Caltrans to investigate a variety of pavement surface textures and treatments.

Because of the amount of work involved, this proposal is being divided into three projects: Flexible Pavement, Rigid Pavement (including Bridge Decks), and Acoustic Correlation research studies. The purpose of the flexible pavement project is to evaluate the performance of conventional and rubberized asphalt concrete surface course treatments to establish their performance characteristics and optimal design. Similarly, the purpose of the rigid pavement and structures project is to evaluate the performance of rigid pavement and bridge deck construction methods including texturing, tining, joint widths and grooving/grinding specifications to establish their noise characteristics and develop an optimal design. The acoustic correlation project is intended to evaluate at-source and laboratory sound testing methods for measuring tire/pavement noise interaction and correlate these methods with the FHWA wayside method. This research will also quantify the benefits of quieter pavement for those who live near the highway and establish how long these benefits can be sustained.

In all, the three projects will evaluate acoustic properties and surface texture characteristics of various test sites for periods of up to 10 years for Type 3 "research grade" sites and 2 to 10 years for Type 1 "pavement evaluation" sites. The data obtained will be used to investigate the variation of design parameters (acoustic, friction, smoothness, texture, and durability) over time, and in the development of new test methods for traffic noise measurement. The data will also be used to potentially develop construction specifications for pavement surface texture, friction and smoothness that may provide a better overall design for a safer, quieter, smoother, durable, and cost-effective pavement.

To ensure adequate funding will be available for data collection and monitoring of the proposed research projects, Caltrans has identified and set aside funds from money already authorized through several ongoing research contracts (University of California Partnered Pavement Research Center (PPRC), Applied Research Associates (ARA), and Illingworth and Rodkin). Also, there is already staff identified to monitor and track each project, and task orders are in the works. Sufficient funds have been allocated for the acoustic portion of this QPR study to complete the 10-year correlation analysis for the Type 3 research grade sites. For Type 1 flexible and rigid pavement and bridge deck sites, the fund allocation is for the 2-year initial study. Any future needs or follow-up studies on Type 1 sites will be considered on a case-by-case basis for a separate funding. The need for follow-up studies and subsequent funding will be determined after the initial study is completed, and possibly as early as the first year report for each site.

SECTION I : INTRODUCTION

1. Overview Background

Quieter pavements offer new options for minimizing the impacts of traffic noise levels on the neighborhoods adjacent to highways. Quieter pavement is a new concept in the United States, and currently, the FHWA does not fund construction of quieter pavements that are to be used solely as mitigation for traffic noise impacts. Caltrans has initiated a number of studies in an effort to evaluate the acoustical properties of pavements and tire/pavement noise levels. These studies together with the proposed Quieter Pavement Research (QPR) are intended to provide answers to the following primary unknowns of quieter pavements:

a. What properties/materials in the pavement impact its noise levels and how?
b. How long can the acoustic benefits of quieter pavement last?
c. How do quieter pavements perform over time with regard to friction, smoothness, traffic loading, and maintenance needs?
d. What is the correlation between near-field (or at-source) sound measurement methods such as On Board Sound Intensity (OBSI) and traditional wayside field measurement methods?
e. What is the correlation between lab measurement methods such as impedance tubes and OBSI and wayside measurement methods?
f. Can quieter pavements be used as a more cost-effective substitute for sound barriers or allow for reduced sound barrier heights?
g. How do quieter pavements impact the noise levels from heavier vehicles such as trucks?

The proposed research is intended to provide answers to the above unknowns by evaluating acoustic properties and performance characteristics of a variety of flexible and rigid pavement treatments and textures. This QPR proposal will supplement, support, verify, and add to research being done in other states and countries.

2. Purpose

The California QPR plan is a systematic research proposal intended to examine the impact of "quieter pavements" on traffic noise levels and establish which pavement characteristics have the greatest impact on tire/pavement noise. The proposed research will examine acoustic properties and performance characteristics of both flexible and rigid pavements and bridge decks. The information gathered will be used to develop quieter pavement design features and specifications to minimize noise from tire/pavement interaction throughout the State.

3. Objectives

This QPR is divided into three components: flexible pavement, rigid pavement (including bridge decks), and acoustic correlation research. As summarized in Table I-1, these components involve evaluation of pavement surface characteristics and acoustic properties at various Type 1 "pavement evaluation" and Type 3 "research grade" sites with the objective of addressing the following primary unknowns of quieter pavement. **(See notes at the bottom of Table I-1 for the descriptions of Type 1, Type 2, and Type 3 research sites as defined in the Arizona DOT Quieter Pavement Pilot Program (QPPP))**.

The QPR findings at both Type 1 and Type 3 sites will be used to establish acoustic and performance characteristics for quieter pavements including a better understanding of the following key aspects:

a. *What properties/materials in the pavement impact its noise levels and how?*

- Test a variety of flexible and rigid pavements for noise and surface texture characteristics using OBSI. This will help determine surface texture characteristics with optimal noise reduction benefits for ultimate incorporation into design standards and construction specifications for quieter pavements in California.
- Collect material samples from each site to measure material properties such as aggregate size, void content, and other factors that may impact acoustic performance.
- Create a database for California flexible and rigid pavements to identify mixes and surface textures that may have better performance with regard to safety, durability, and long-term acoustic benefits.
- Provide best practice for selecting the optimum paving material for climate and traffic conditions based on performance trends from field measurements for noise, friction and durability.

b. *How long can the acoustic benefits of the pavement last?*

- Determine using OBSI sound measurement method the variation of the noise generated from tire/pavement interaction over time by normal surface wear of various types of pavement surface treatments and textures used or being considered for use in California. The goal of this objective is to establish acoustic based pavement performance levels for ultimate incorporation into the design standards and construction specifications for quieter pavements on the State highway system.
- Evaluate long-term acoustic performance of flexible and rigid pavements using OBSI measurement method. For the Type 1 sites, a variety of flexible and rigid pavements that are at different stages of aging will be tested using OBSI method for a 2-year period to develop initial acoustic performance curves for similar surface treatments and textures. The need for developing initial curves after two years is to establish pavement design standards and construction specifications

that can be implemented to minimize highway traffic noise. The acoustic performance curves will be verified using select Type 1 sites that could be tested for up to 5 or 10 years as needed, plus all Type 3 research sites which will be tested using both OBSI and wayside methods for a 10-year period. Modifications will be made as needed based on the 5-year and 10-year studies together with the results from national and international quieter pavement research efforts.

c. *How do quieter pavements perform over time with regard to friction, smoothness, traffic loading, and maintenance needs?*

- Collect friction, smoothness, traffic loading, pavement condition/age, and pavement maintenance data from each of the Type 1 and Type 3 sites selected for noise measurements at least on an annual basis. Performance curves will be developed for these factors in the same manner described for acoustic performance in objective b. This information will be useful in developing design standards and construction specifications as well as cost/benefit analysis for the pavement products with best overall performance characteristics.
- Determine the effect of smoothness, surface treatment and texture, and joint widths in minimizing the tire/pavement noise generated on flexible and rigid pavements. This information will be valuable in identifying which surface features have the most impact on pavement acoustic properties as well as where the greatest potential for further improvement can be made. This will help focus future research on this subject.

The following objectives will be addressed from the Type 3 "research grade" sites:

d. *What is the correlation between near-field (or at-source) sound measurement methods such as On Board Sound Intensity (OBSI) and traditional wayside measurement methods?*

- Perform OBSI and wayside measurements at research grade (Type 3) test sites over a 10-year period.
- Compare the results of OBSI and wayside measurements at select Type 3 sites to establish the correlation curve between OBSI and wayside measurements.

e. *What is the correlation between sound measurement methods such as lab impedance tubes and field measurement methods such as OBSI and wayside?*

- Conduct impedance tube tests on cores taken from the test sites of this QPR to measure sound absorption.
- Determine the correlation between laboratory sound absorption as measured by impedance tube and OBSI/wayside measurements.
- Establish correlation curves of impedance tube test results to OBSI and wayside field measurements which if successful will provide a tool for evaluating mixes for noise properties as part of mix design.

f. *Can quieter pavements be used as a more cost-effective substitute for sound barriers or allow for reduced sound barrier heights?*

- Using the performance data generated from the Type 1 and Type 3 sites, compare the life-cycle costs of various pavement types investigated and other noise abatement measures like sound barriers, to determine which have the lowest life-cycle costs.
- Develop cost-effective quieter pavement surface treatments, textures and design mixes and make proposals for possible implementation.

4. Study Approach

To accomplish the above objectives this QPR proposal will involve the following research studies and field and laboratory tests. Caltrans will review the results for the first 2 years of the QPR study and recommend further research on select Type 1 sites for up to 5 or 10 years as needed and on all Type 3 research sites for a 10-year period.

a. Perform literature search and collaborate with other states and agencies either performing or interested in performing pavement noise studies.

b. Measure pavement noise performance at recently built Type 3 research grade sites over a 10-year period using both On Board Sound Intensity (OBSI) and wayside measurement methods.

c. Measure pavement noise at various Type 1 sites of flexible and rigid pavements and bridge decks at different ages for a period of 2 to 10 years using OBSI method.

d. Evaluate pavement condition, surface characteristics, and material properties of cores taken at both research grade Type 3 sites and Type 1 sites during OBSI/wayside field measurements.

e. Use the results of Type 1 sites to obtain a snap shot of pavement performance at different ages or levels of distress to determine the correlation between acoustic benefits, safety, and other performance criteria with pavement age.

f. Perform impedance tube sound absorption measurements on Type 3 sites and select Type 1 sites. Compare with OBSI and wayside sound measurements.

g. Develop noise performance curves for various types of surface treatments for flexible and rigid pavements and bridge decks over time. For each surface type, initial curves will be developed from the 2-year data collection at a variety of Type 1 sites of different ages. The initial curves will then be verified and refined using the 10-year data collection at Type 3 sites and, as needed, 5- to 10-year data collection at select Type 1 sites.

h. Develop a matrix of various types of pavement surface treatments/textures to compare their performance with regard to noise characteristics, friction, and durability. Such a matrix will be used to update design standards and develop construction specifications as well as to focus future quieter pavement research.

i. Utilize current or previously built sound barrier projects where building a quieter pavement could have had an effect on the noise measurements to develop alternate noise abatement designs using quieter pavements. Complete life-cycle cost analysis of these alternatives to see if quieter pavements would be more cost-effective. Use life-cycle cost estimates to also compare the cost-effectiveness of different pavement types to see which would be the more cost-effective.

5. Caltrans Quieter Pavement Research Components

Because of the amount of work involved, this QPR is being divided into three components as shown in Table I-1. Each project has its own Data Acquisition Plan, which is detailed in the designated sections.

The flexible pavement project discussed in section II of this proposal is intended to evaluate the performance of dense graded asphalt concrete, open graded asphalt concrete or friction courses, and rubberized asphalt concrete surface course treatments to establish their performance characteristics and optimal design.

Similarly, the purpose of the rigid pavement QPR discussed in section III is to evaluate the performance of rigid pavement and bridge deck construction methods including texturing, tining, joint widths and grooving/grinding specifications to establish their noise characteristics and develop an optimal design. The proposed research will investigate a variation of rigid pavements and bridge decks with different surface treatments and textures to determine their optimal design with regard to noise and performance characteristics over time.

The acoustic research project discussed in section IV is intended to evaluate alternate acoustic testing methods for measuring tire/pavement noise interaction and correlating these methods with the Federal wayside testing method. This project will also quantify the benefits of quieter pavement on those who live near the highway and how long these benefits can be sustained.

6. Collaboration

As part of this QPR proposal, Caltrans will utilize research and investigations previously done (both noise and pavement performance), as well as research currently underway both in State and elsewhere, and new research to fill in gaps. Caltrans will also collaborate with other States, agencies, and industry on research to be done to provide the broadest possible database. Such collaboration will include several ongoing studies in this country and other countries to review a broad range of options and identify those mixes, textures, and other features, which can reduce tire/pavement noise and meet requirements for safety and durability. This QPR will also be used to refine modeling and guidance for quieter pavement to better understand when, where, and what quieter pavement options to use in California when building or repairing pavements. Caltrans may also work with other states to mutually test pavement surface types/textures that may not be currently available in California.

Caltrans will collaborate with FHWA on all Type 3 project sites to assure that the data collection process is agreed upon ahead of time.

7. How Results Will Be Used

The results generated by this QPR will be used primarily to accomplish the following:

- Identify flexible and rigid pavement and bridge deck surface treatments and textures that have optimum performance characteristics with respect to long-term tire/pavement noise reduction benefits, safety, durability, and cost-effectiveness.
- Improve flexible and rigid pavement mix designs, design standards/practices, and contract specifications to minimize noise levels of pavements without compromising other important pavement performance factors such as safety, smoothness, durability, and cost-effectiveness.
- Develop design standards and guidance that assures the safest, most durable, and quietest pavements are built where needed.
- Develop construction specifications to assure what is actually built meets expectations for noise, safety, and durability.
- Develop correlation between On Board Sound Intensity (OBSI) and wayside noise measurements.
- Develop correlation curves of impedance tube sound absorption test results to OBSI and wayside field measurements which if successful will provide a tool for evaluating pavement mixes for noise properties as part of mix design.

8. Conclusion

By obtaining approval for this QPR proposal, Caltrans hopes to establish agreement on the scope of conditions, criteria, and surfaces to be evaluated, and testing procedures and requirements to be used and developed. Caltrans is also seeking Federal cooperation and participation for proposed test sites to be constructed. It is hoped that through this Quieter Pavement Research plan enough data and information will be obtained to guide state and federal policy and design decisions.

Table I- 1 : Caltrans Quieter Pavement Research Components

Research Component	Lead Caltrans Unit	Test Sites *	Surface Type or Texture	See Section
Comparison of Flexible Pavement Surface Types	Division of Research & Innovation	Type 1 "Pavement Evaluation" Sites: Flexible Pavement (including flexible surface course layer over rigid pavement)	DGAC (Control) OGAC BWC RAC-G RAC-O RUMAC-GG Type G-MB Type D-MB	**II**
Comparison of Rigid Pavement and Bridge Deck Surface Types	Division of Engineering Services	Type 1 "Pavement Evaluation" Sites: Rigid Pavement	o Longitudinally tined with 1/4 inch joints (control) o Longitudinally tined with 1/8 inch joints o Longitudinally tined with no joints (continuous reinforce concrete pavement). o Burlap drag texture (no tining) o Diamond grinding	**III**
		Type 1 Sites: Bridge Decks	o Exposed aggregate texture o Polyester overlay o Diamond grinding o Grooving	
Acoustic Correlation and Verification	Division of Environmental Analysis	Type 3 "Research Grade" Sites: Flexible Pavement (including flexible surface course layer over rigid pavement)	DGAC OGAC BWC RAC-G RAC-O RUMAC-GG Type G-MB Type D-MB	**IV**
		Type 3 "Research Grade" Sites: Rigid Pavements	o Variety of groove, grind, textured new PCC o Ground existing PCC.	

Abbreviations:

BWC	Bonded Wearing Course
DGAC	Dense Graded Asphalt Concrete
OGAC	Open Graded Asphalt Concrete
PCC	Portland Cement Concrete
RAC-G	Rubberized Asphalt Concrete Type G (Gap graded)
RAC-O	Rubberized Asphalt Concrete Type O (Open graded)
RUMAC-GG	Rubber Modified Asphalt Concrete, gap-graded, dry process
Type D-MB	Dense Graded Rubber Modified Asphalt Concrete (mix blend)
Type G-MB	Gap Graded Rubber Modified Asphalt Concrete (mix blend)

*** Notes: Research Site Types Descriptions**

The following are descriptions of Type 1, Type 2, and Type 3 research sites as defined in the Arizona DOT Quieter Pavement Pilot Program (QPPP).

- **Type 1 Sites** designates pavement evaluation sites in which typical pavement management system data are collected. Air and pavement temperatures and OBSI data will also be collected at the same time as pavement performance data.

- **Type 2 Sites** designates the sites where before and after surveys are conducted to evaluate how the residences are impacted. This QPR proposal does not involve Type 2 sites because many of the test sites are not adjacent to residences and the main focus of Caltrans' QPR study is to compare different pavement types. For these reasons, it was determined that a public survey was not necessary.

- **Type 3 Sites** designates the research grade sites. These are the locations that most closely resemble the "Ideal Conditions" and will provide the highest quality field measurements for use in developing correlations between OBSI and wayside acoustic measurements. At Type 3 sites, acoustical (both OBSI and wayside), meteorological, traffic, and pavement data will be collected. Data collected at Type 3 sites will be used to evaluate the general performance of the pavement acoustical properties and to verify performance curves developed from Type 1 sites data.

SECTION II : DATA ACQUISITION PLAN FOR TYPE 1 SITES (FLEXIBLE PAVEMENT)

1. Introduction

The flexible pavement QPR study is a collaborative effort between Caltrans and the University of California Partnered Pavement Research Center (PPRC). The objectives of the flexible pavement portion of this QPR proposal are summarized in Table II-1.

As part of the proposed research study, the PPRC will conduct literature survey and summarize the state-of-the-art practices on quieter pavements. PPRC will also conduct field measurements of sound and surface friction as well as laboratory impedance tube sound absorption testing. The bulk of this effort will be spent on field data collection that will include research grade (Type 3) Caltrans noise monitoring locations plus several other Type 1 mainline highway sites with various types of surface courses including dense graded asphalt concrete (as a control), open graded asphalt concrete, open graded rubberized asphalt concrete, and gap graded rubberized asphalt concrete. The data collected will be used in trend analysis to relate pavement acoustic and performance characteristics to variables such as surface treatment type, age, traffic volume and speeds, and climate. This will allow Caltrans to develop updated pavement standards, guidance, and construction specifications for minimizing pavement noise without compromising pavement safety, durability, or other performance factors.

Types of data, test methods, and frequency of testing are described in Tables II-3 through II-6. Proposed field data collection, sampling, and testing procedures are presented in Table II-3; and planned laboratory measurements and tests on field cores collected at both Type 1 and Type 3 sites in Table II-4.

2. Site Selection

Type 1 sites selected for the flexible pavement portion of this QPR plan are presented in Tables II-2. This study will also analyze applicable data collected from Type 3 “research grade” sites shown in Table IV-1. Both Type 1 and Type 3 sites represent flexible pavements with different ages, traffic volume levels, and climatic conditions.

3. Flexible Pavement Surface Treatments

The flexible pavement surface treatments that will be investigated as part of this flexible pavement QPR project include the following *(all California mixes unless noted otherwise):*

- Dense Graded Asphalt Concrete (DGAC, control)
- Conventional Open Graded Asphalt Concrete (OGAC)
- Rubberized Asphalt Concrete Open Graded (RAC-O)
- Rubberized Asphalt Concrete Gap Graded (RAC-G)

Additional California flexible pavement surface treatments that will be tested as part of flexible pavement QPR project but not at levels from which statistical conclusions can be drawn are:

- 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
- Bonded Wearing Course

4. Cost Estimate

Project cost estimates for flexible pavement QPR study are presented in Table II-7. 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.

5. Schedule

Table II-6 summarizes data collection schedule for both Type 1 and Type 3 test sections selected for flexible pavement QPR study. The proposed research spans a period of two to ten years, with data collection at all test sections for the first two years and thereafter on a case-by-case basis for up to 8 additional years depending on Caltrans review of each year's data. A detailed work schedule for the initial 2-year period is summarized in Table II-8.

6. Coordination

The flexible pavement QPR study will coordinate with acoustic (Type 3 sites) and rigid pavement portions of this QPR proposal to ensure compatibility of OBSI and wayside sound measurements as well as other data collection methods. Caltrans will also coordinate with ongoing quiet pavement research being conducted by other states and transportation agencies, as well as with foreign countries as part of developing a broad database.

Table II- 1: Summary of Flexible Pavement QPR Objectives and Deliverables

No.	Objective	Deliverables
1	Conduct literature survey of the state-of-the-art practices for quieter pavements	A summary of the state-of-the-art literature on quieter pavement best practices with regard to materials, construction methods, surface treatment and texture types; and pavement performance with respect to noise reduction benefits, safety, durability, and cost-effectiveness.
2	Review and document as-built information and existing surface conditions for flexible pavement surface courses at all test sections	A record of as-built information including location, construction year, design life, surface course type and thickness, surface treatment and texture characteristics, and traffic data (AADT, % trucks, and TI).
3	Conduct OBSI and wayside sound measurements.	A database of OBSI and wayside sound measurements. Existing pavement surface conditions and meteorological data will be obtained whenever OBSI/wayside sound measurements are done.
3B	Perform pavement condition surveys and other field tests.	A record of existing pavement surface conditions including type and severity of surface distresses, friction, pavement profiles, smoothness (profilograph), roughness (IRI), macrotexture depth, deflection tests where specified, and obtain pavement cores for impedance tube sound absorption measurements.
4	Perform laboratory impedance tube sound absorption measurements	Impedance tube sound absorption data for possible correlation with OBSI and wayside sound measurements.
5	Develop QPR database structure	QPR database structure populated with field and laboratory data from acoustic and flexible pavement portions of the research study.
6	Perform quieter pavement acoustic and performance trend analysis and correlations.	A report of statistical analysis results for flexible quieter pavement acoustic characteristics, performance trends and correlations.
7	Publish a 2-year summary report	A report outlining all of the work completed together with the results of flexible pavement QPR project including statistical analysis and correlations of acoustic characteristics with pavement performance trends, and recommendations for additional research.

Table II- 2: Flexible Pavement QPR Project Type 1 Sites

LOCATION: DIST/CNTY/RTE/PM	EA	Surface Type	Age Category (Years)	Traffic	Rainfall
03-Pla-80-14.3/33.3	03-0A6004	RAC-O	New	High	High
01-MEN-20-R37.9/43.0	01-316104			Low	
06-TUL-99-42.0/47.0	06-493504			High	Low
06-TUL-63-19.8/R30.1	06-448004			Low	
03-Sac-50-16.10/17.30	03-3696U4		1 to 4	High	High
10-Ama-49-14.7/17.6	10-0H7304			Low	
07-LA-710-6.8/9.7	07-1384U4			High	Low
06-Tul-65-21/29	06-465104			Low	
	N/A		5 to 8	High	High
04-Nap-128-5.1/7.4	04-1R3404			Low	
04-SCl-85-1.9/4.7	04-0C1504			High	Low
08-SBD-58-R0.0/5.3	08-495004			Low	
	N/A	RAC-G	New	High	High
01-MEN-20-R37.9/43.0	01-316104			Low	
04-SCl-280-R0.0/R2.7	04-0C7704			High	Low
06-TUL-63-19.8/R30.1	06-448004			Low	
04-Mrn-101-18.9/23.1	04-0C2904		1 to 4	High	High
04-Son-1-0.0/8.4	04-0C3404			Low	
08--15-33.8/38.4	08-496404			High	Low
05-SLO-46-R10.8/R22.0	05-486704			Low	
04-Mrn-101-2.5/8.5	04-0C0404		5 to 8	High	High
10-Cal-4-0/18.8	10-1A4504			Low	
07-LA-60-R25.4/R30.5	07-115044			High	Low
07-Ven-34-4.3/6.3	07-115344			Low	
03-PLA-80-1.4/2.6	03-375604	OGAC	New	High	High
01-LAK-29-R37.3/R37.6	01-455104			Low	
04-CC-680-23.9/24.9	04-006054			High	Low
05-SCR-152-7.6/8.0	05-444804			Low	
04-Mrn-101-0.0/2.5	04-1R7104		1 to 4	High	High
04-Son-121-3.4/7.3	04-1R8204			Low	
04-SCl-237-R3.8/7.10	04-1R6704			High	Low
08-SBd-38-S0.0/R5.0	08-0A2204			Low	
04-Mrn-37-12.1/14.4	04-1R2804		5 to 8	High	High
01-MEN-1-0.1/15.2	01-350904			Low	
04-SCl-237-R1.0/2.3	04-437294			High	Low
03-Sac-16-6.9/20.7	03-0A5504			Low	

Table II- 2 : Flexible Pavement QPR Project Type 1 Sites (Continued)

LOCATION: DIST/CNTY/RTE/PM	EA	Surface Type	Age Category (Years)	Traffic	Rainfall
	N/A	DGAC	New	High	High
01-MEN-20-R37.9/43.0	01-316104			Low	
06-FRE-99-10.7/15.9	06-420304			High	Low
07-LA-138-60.2/61.6	07-127254			Low	
03-ED-50-17.3/18.3	03-1M4704		1 to 4	High	High
03-ED-50-18.5/20.3	03-1M9004			Low	
06-KER-99-R29.5/R31.0	06-421804			High	Low
04-SOL-113-0.1/18.0	04-0C6204			Low	
04-SM-280-9.6/10.8	04-252014		5 to 8	High	High
01-Men-1-20.8/38.7	01-350204			Low	
04-Ala-92-6.6/8.8	04-0R6804			High	Low
06-KER-65-R0.0/2.9	06-353704			Low	
01-Lake-20-		F-mix	New	Low	High
01-Men-101-					
01-MEN-20-16.8/17.3			1 to 4	High	High
01-MEN-20-20.5/20.6					
01-HUM-101-0.8/2.7			5 to 8	High	High
01-MEN-101-20.9/21.1					

Note:

F-mix - *Open graded mix design developed by Oregon DOT that has been placed in several locations along California's northern coast.*

Table II- 3: Proposed Field Data Collection, Sampling and Testing

Type of Data/Sample	Specific Test or Sample	Frequency of Data Collection	Comment
Pavement Condition Survey	Caltrans' Pavement Condition Survey Data	Annually	Alligator (fatigue) cracking in wheel paths Alligator (fatigue) cracking in lane [% surface] Asphalt pavement binder bleeding [% of wheel path] Severity: L,M,H Patched pavement [% of wheel path] Potholes [no. of potholes in a segment] Ravel [% surface] Rutting [mm, MEAN, STD, average on wheel paths] Shoving Delamination/slippage cracking Block cracking [% of area]
Wayside and On-board Sound Intensity[2,4] (OBSI) measurements	FHWA wayside sound measurement and Caltrans' OBSI method	Annually	OBSI measurements in both wheel paths and wayside sound measurements per FHWA's guidelines.
Pavement surface temperature	Infrared temperature gun	Annually at time of OBSI measurement	Pavement temperature profile can be estimated using equations previously developed by PPRC or BELLS equation
Air temperature	Thermocouple	Annually at time of OBSI measurement	
Friction	Dynamic Friction Tester ASTM E 1911; British Pendulum Number[1]	Annually at time of OBSI measurement	In both wheel paths
Macro texture	Circular Friction ASTM E 2157[2]	Annually at time of OBSI measurement	In both wheel paths.
International Roughness Index (IRI)	Laser profilometer	Annually at time of OBSI measurement	Either by add-on equipment to OBSI vehicle, or separately
Deflections	Falling Weight Deflectometer	Annually at time of OBSI measurement	PPRC only on SR 138[3]
Cores	Diameter: 100 mm diameter on PPE2 sections; 100 and 150 mm on other sections	Once	PPE2 sections: two cores between wheel paths, three in wheel paths, all 100 mm diameter. Other sections: eight 150 mm diameter cores between wheel paths, eight 150 mm cores in wheel paths

Notes:

1 *Specific test equipment or method will be per Caltrans recommendation.*
2 *Same test will be replicated on eight research grade Type 3 Caltrans environmental noise monitoring locations*
3 *Deflections using the Falling Weight Deflectometer will continue to be collected on SR138 as it has been since 2002. This is the only in the Caltrans environmental noise monitoring section that has an asphalt concrete overlay over flexible pavement.*
4 *On new pavement rehabilitation sections, sound intensity will be measured before and after construction.*

Table II- 4: Laboratory Measurements and Tests on Field Cores Collected at the Sites

Type of Data/Sample	Specific Test or Sample	Frequency of Data Collection	Comment
Impedance tube sound absorption	Per Caltrans Environmental	Once	Exact test procedure in development[1]
Thickness of surface course		Once	
Type and 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]

Notes:

1 *Test method will be based on NCAT procedure. Same test will be replicated on both Type 1 and Type 3 test sections.*

2 *Raw aggregate sample with gradation used on project will be 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, bin samples will be collected to batch 250 kg and binder quantity to match based on design binder content. Also, 100 kg of belt aggregate sample will be collected when QC data is not available.*

Table II- 5: Sources and Supporting Data Collection for Field Sites

Type of Data/Sample	Specific Test or Sample	Data Collection Frequency	Comment
As-Built Information	Pavement surface type and underlying structure, date of construction	Once at beginning	
Asphalt concrete mix information	Asphalt concrete mix gradation, QC/QA data on aggregate and binder, binder content	Once at beginning	May not exist for all open-graded
Traffic volume and WIM data	Annual average daily traffic (AADT)	Once at beginning	
	Percent trucks (T %)	Once at beginning	
	Traffic index (ESALs)	Once at beginning	
	Traffic speed distribution for a typical week and or level of service	Once at beginning	
Climate data	Annual rainfall	Over life	
	Freeze-thaw cycles	Over life	
	Degree-days above 30°C	Over life	
	Freezing Index	Over life	
Pavement condition survey data	Time history of types and extent of pavement distresses	Once at beginning	Since construction
	Time history of IRI or pavement rideability index	Once at beginning	Since construction

Table II- 6: Summary of Flexible Pavement QPR Data Collection Schedule

Type of test section[1]	Duration of Data Collection[2]	Data Review and Evaluation
Select Type 1 DGAC (control), OGAC, RAC-O, and RAC-G mainline highway sites of different ages	2-10 years	Annually

Notes:

1 *The number of sections being evaluated will diminish with time based on Caltrans' review of prior year's data.*

2 *Data collection after the first two years included in this plan would be a follow-on project.*

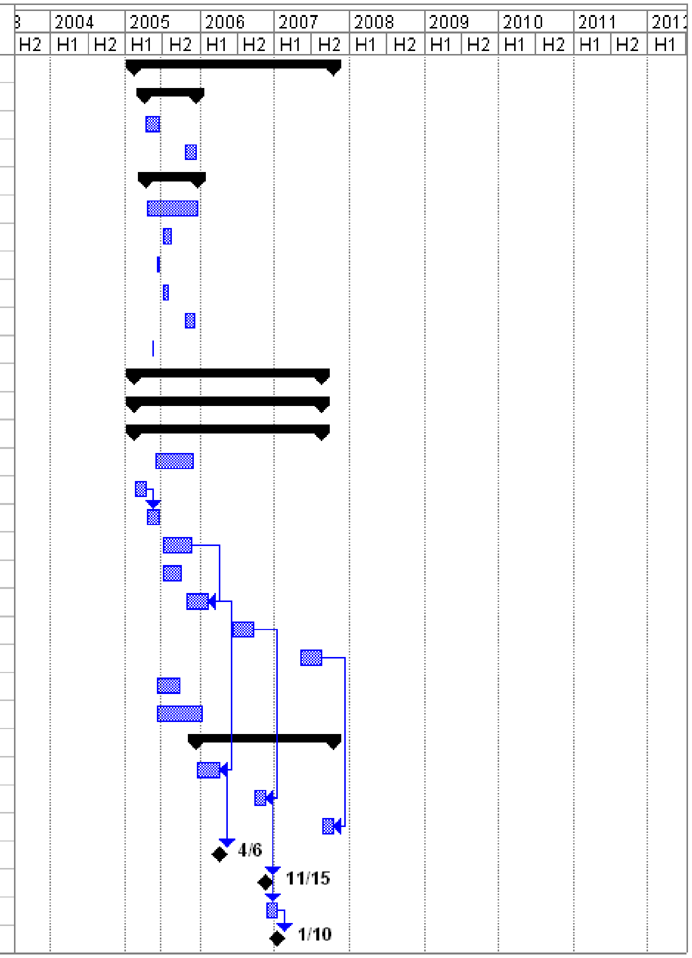
Table II- 7: Cost Estimate for Flexible Pavement QPR Project.

Estimated Costs for First Two Years
all costs are fully loaded

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
			Objective person/month assignments							
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
Staff subtotal										$ 325,491
Field Travel & expense (80 full day, 80 half)	day	$ 250				$ 30,000				$ 30,000
									Total=	**$ 355,491**
*salary portion paid by PPRC										
Equipment (including overhead)				**$ 174,900**						**$ 174,900**
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**				**$ 324,000**
** 12 DGAC sections traffic control by Stantec										
									TOTAL=	**$ 854,391**

Table II- 8: Detailed Schedule for Flexible Pavement QPR 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



SECTION III : DATA ACQUISITION PLAN FOR TYPE 1 SITES (RIGID PAVEMENT)

1. Methodology

The rigid pavement and bridge deck QPR project will be performed under the guidance of the Office of Rigid Pavement Materials and Structural Concrete, Division of Engineering Services, in collaboration with the flexible pavement and acoustics portions of this QPR study.

A literature search will be conducted to determine how similar research studies by other state agencies and foreign countries correlate to Caltrans Quieter Pavement Research goals. The literature survey will summarize the state-of-the-art on quieter pavements to ensure that all relevant data are collected. The survey will also provide sources of data that have already been analyzed and their findings to prevent repeating "research" efforts. The information obtained from literature survey will be complemented by field measurement of sound and surface friction as well as laboratory noise impedance testing.

Suitable Type 3 research grade rigid pavement sites and Type 1 pavement evaluation sites (both rigid pavements and bridge decks) will be selected to provide test sections with variations of surface features and performance characteristics to be studied. These sections will represent rigid pavements and bridge decks with different ages, traffic, mix design, texture, smoothness, joint widths and climate. Type 3 sites will be monitored for a period of 10 years and Type 1 sites for two to ten years.

The bulk of the rigid pavement QPR project effort will be spent on field data collection for Type 3 research grade Caltrans environmental noise monitoring locations and several other Type 1 mainline highway and bridge deck sites with various construction techniques. Additionally, lab tests will be conducted to determine if the results can be used to enhance or eliminate field sound measurements. The data obtained from field performance and sound measurements along with lab tests will be maintained in Caltrans QPR database for statistical analysis.

Trend analysis will be performed to relate tire/pavement noise performance levels to variables such as type of rigid pavement (i.e., doweled and non-doweled JPCP and CRCP with ¼ and 1/8 inch joints and without joints), age, surface texture (skid resistance, IRI, smoothness profile measurements), joint information (joint width and spacing), traffic volumes, and climate (Coastal, Central Valley and the Desert); and bridge deck surface types ((polyester overlay, diamond grind, transversely tined, and longitudinally tined). Each of these parameters will be correlated with OBSI and wayside noise measurements to determine their affect on highway noise. A statewide database will be established to effectively manage the data obtained from this study and maintain compatibility with the Acoustic and Flexible pavement QPR components. From this database, conclusions will be drawn to provide more complete design specifications and construction guidelines for highway noise abatement.

Table III-1 summarizes the objectives and deliverables for the rigid pavement portion of this research proposal. The actual details for each objective will be developed in the form of a task order that will involve various factors affecting noise and performance characteristics of rigid pavements.

2. Site Selection

In California, rigid pavements have been textured in the same way since the 1970's. The concrete slabs are dragged with burlap and then longitudinally tined independent of grade, traffic, climate, environment, or mix design. Therefore, this is the only texture that can be studied with the existing inventory of rigid pavements. The rigid pavement QPR project also will include newer test sections such as the Mojave site on State Route 58 (Table III-2) with both burlap drag and diamond ground textures.

Bridge decks have required resurfacing with polyester overlays when the public complains about the noise. For this reason, several bridge decks are proposed as test sections to examine the noise generated by four surface types (polyester overlay, diamond grind, transversely tined, and longitudinally tined) for high and low truck traffic highways.

Type 1 mainline highway sections and bridge sites selected for the rigid pavement QPR study are presented in Tables III-2 and III-3. Table II-2 contains various locations with alternate textures that have been constructed and may be used for comparison to traditional construction. Table III-3 shows sites that are longitudinally tined and vary in age from 2 to 40 years. These sections will be used to determine a correlation between the age of pavement and the noise generated. Existing rigid pavement research grade Type 3 sites are shown in Table IV-1.

The selected sites provide a good cross section of test sections for tined rigid pavements and bridge decks with different ages, textures, traffic volume levels and climatic conditions. Table III-4 lists the sites that need to be constructed or will be provided by another DOT as part of a pooled fund study. It is possible that some of the rigid pavement test sites can be replaced by the testing of others. However, this may require supplemental funding of projects to include measurements that were not included in their cost estimates.

To evaluate the impacts of aging and increased traffic loads, we have selected some newly constructed sections so we can get a baseline for the noise measurements that can be monitored until we see a negligible change. Increased traffic loads may create increased faulting, while pavement surface texture may change over time. Both faulting and aging effects would result in higher tire/pavement noise levels. In addition to evaluating the impacts of aging and increased traffic loads, the Mojave site on State Route 58 (Table III-2) will be used to investigate the change in noise over time for the six textures while holding the other variables constant.

3. Rigid Pavement Surface Treatments and Textures

The pavement surface treatments that will be investigated with the rigid pavements and bridge decks QPR study include:

Rigid Pavement

- Longitudinally tined with 1/4 inch joints (control)
- Longitudinally tined with 1/8 inch joints
- Longitudinally tined with no joints (continuous reinforce concrete pavement).
- Burlap drag texture (not tined)
- Diamond grinding
- Porous concrete

Bridge Decks

- Exposed aggregate texture
- Polyester overlay
- Diamond grinding
- Grooving

4. Cost Estimate

The project cost estimate for the rigid pavement portion of this QPR proposal is approximately $800,000. Nearly 40 percent of this cost is for traffic closures and 12 percent is for equipment. In addition, supplemental funding for work performed by others could cost as much as $350,000.

5. Schedule

The rigid pavement QPR study is scheduled to span approximately two years for the initial phase of the study. After two years, an assessment will be done to decide which data should be collected in a second phase. Annual decision points are needed so Caltrans can decide, after reviewing each year's data, if further testing is warranted. Rigid pavement QPR work plan and data collection schedules are summarized in Tables III-8 and III-9.

6. Coordination

Types of data, test methods, and frequency of testing as described in this section will be coordinated with acoustic and flexible portions of this QPR proposal to ensure compatibility of OBSI and wayside measurements. Additionally, the rigid pavement project will coordinate with other similar studies being conducted by NCHRP (Project HR 10-67), FHWA, and APCA to effectively manage data collection.

Table III- 1: Summary of of Rigid Pavement QPR Objectives and Deliverables

No.	Objective	Deliverables
1	Conduct literature survey of the state-of-the-art practices for quieter pavements	A summary of the state-of-the-art literature on quieter pavement best practices with regard to materials, construction methods, surface treatment and texture types; and pavement performance with respect to noise reduction benefits, safety, durability, and cost-effectiveness.
2	Review and document as-built information and existing surface conditions for rigid pavement surface courses at all test sections	A record of "as-built" information including location, construction year, design life, concrete slab thickness, surface treatment and texture characteristics, mix design, compressive and flexural strength tests, gradation and traffic data (AADT, % trucks, and TI).
3	Conduct OBSI and wayside sound measurements	A database of OBSI and wayside sound measurements. Existing pavement surface conditions and meteorological data will be obtained whenever OBSI/wayside sound measurements are done.
3B	Perform pavement condition surveys and other field tests.	Measurements of existing pavement surface texture characteristics including joint drop-offs, pavement profiles, pavement distress (degree of cracking), roughness (IRI), smoothness (profilograph), as well as macrotexture depth and spacing.
4	Perform laboratory impedance tube sound absorption measurements	Impedance tube sound absorption data for possible correlation with OBSI and wayside sound measurements.
5	Develop QPR database structure	QPR database structure populated with field and laboratory data from acoustic and rigid pavement/bridge deck portions of the research study.
6	Perform quieter pavement acoustic and performance trend analysis and correlations.	A report of statistical analysis results for quieter rigid pavement acoustic characteristics, performance trends and correlations.
7	Publish a 2-year summary report	A report outlining all of the work completed together with the results of rigid pavement/bridge deck QPR project including statistical analysis and correlations of acoustic characteristics with pavement performance trends, and recommendations for additional research.

Table III- 2: Rigid Pavement Textures for QPR Project Type 1 Sites

Section Name	Location	Surface Types	Year Constructed	Comments
San Mateo I-280	4-SM-280, PM R0.0-R5.6	Grind	2002	Urban Coastal High TI
Mojave Bypass, SR 58	8-Ker-58, PM 107.7-118	Groove, grind, Long. Tine	2003	Rural Dessert Mod TI
Santa Clara SR 85[1]	4-SCl-85, PM 14.63 to 15.51	Groove	2005	Urban Coastal High TI
Fresno Hwy 180 FRE-180	06-FRE-180 PM 0.0-3.0	Burlap	2005	Urban Central Valley Low TI
Whitmore Maintenance PLA-80	03-PLA-80	Burlap	2003	Rural Mountains High IT
San Diego South SD-905	805/905 Separation 11-091804	Long. Tine	2003	Urban Dessert High TI
San Diego North SD-8	El Cajon	Long. Tine	2004	Urban Coastal Mod TI
Placerville ED-50	Shingle Springs	Grind	2005	Rural Mountains Mod TI
Sacramento SAC-80		Groove	2005	Rural Central Valley Mod TI
West Sac YOL-80	Harbor Blvd Exit	Grind	2005	Rural Central Valley Mod TI
Tower Bridge	Sacramento	Polyester	2001	Urban Central Valley Mod TI
Sac. River Bridge	Anderson	Diamond Grind	N/A	Rural Central Valley Mod TI
Auburn-Folsom	Folsom Lake Bridge	Transverse Tine	2005	Rural Central Valley Low TI
Carquinez Bridge	San Diego	Exposed Aggregate.	N/A	Urban Coastal High TI
Sac. River Bridge	Byte Bend -Route 80	Polyester	N/A	Rural Central Valley High TI
Benicia Bridge	Bay Area	Polyester	2005	Urban Coastal High TI

Notes:

All joints shown on this table are conventional ¼ inch joints

Table III- 3: Rigid Pavements for QPR Project By Age Group.

Description	County-Route	Beg PM	End PM	Traffic	Year Constructed.
<5 Years					
Mojave Bypass	KER-58	118	119	Low	2003
San Diego	SD-905	7.9	8.7	High	2003
El Cajon	SD-8	23.4	25.1	High	2004
Baker	KER-395	11.9	13.1	Low	2005
5-10 Years					
04-N201-2	SCL-85	13.9	14.47	Low	1997
040N204-5	SCL-85	14.735	15.17	Low	1997
04-N248-9	SOL-80	18.45	19.66	High	1999
04-N251-2	SOL-80	25.58	26.85	High	1999
04-N211-2	SCL-85	15.0	15.5	Low	1997
S395-6	SLO-101	38.2	39.6	High	1998
S399-400	SLO-101	41.9	42.3	High	1998
S408-409	SLO-101	42.5	43.0	High	1998
S6A411	SD-8	55.66	55.72	Low	1998
S416-417	SLO-101	44.85	45.11	High	1998
11-20 Years					
S60602	SIS-05	15.9	16.1	Low	1992
S60662-3	SIS-05	15.4	15.6	Low	1992
S63013	RIV-15	19.96	20.05	High	1988
06-N422-3	KER-58	70.8	71.9	Low	1995
06-N426-7	KER-58	74.4	75.8	Low	1995
04-N253	SOL-80	30.8	30.9	High	1992
04-N254	SOL-80	31.9	32.1	High	1992
04-N255	SOL-80	33.5	33.7	High	1992
10-L60242	SJ-05	48.6	48.1	Low	199x
S69048	SD-10	33.4	33.6	High	1988
S63030	SHA-05	43.0	43.2	Low	1988
S63024	RIV-15	22.9	23.1	High	1988
S6A410	SD-08	55.3	55.4	Low	1990
S6A443	SD-08	55.93	55.96	Low	1990
21-30 Years					
10-L60201	MER-99	32.4	32.6	Low	NA
10-l63042					
30+ Years					
S701	RIV-60	6.3	6.5	Low	1972
S702	RIV-60	6.6	6.7	Low	1972
S703	RIV-60	6.8	6.9	Low	1972
Royal Oaks	SAC-160	9.4	10.1	Low	1966
S. Red Bluff	YOL-05	39.3	39.6	Low	1960’s

Table III- 4: Proposed Additional Rigid Pavement and Bridge Test Sections

Section Name	Surface Types [1]	Traffic Index	Location Type	Proposed Location
Struct. Section 1	Burlap	High	Coastal	TBA
Struct. Section 2	Burlap	High	Desert	TBA
Struct. Section 3	Burlap	High	Central Valley	TBA
Struct. Section 4	Burlap	Low/Med.	Coastal	TBA
Struct. Section 5	Burlap	Low/Med.	Desert	TBA
Struct. Section 6	Burlap	Low/Med.	Central Valley	TBA
Struct. Section 7	Grind	High	Coastal	TBA
Struct. Section 8	Grind	High	Desert	TBA
Struct. Section 9	Grind	High	Central Valley	TBA
Struct. Section 10	Grind	Low/Med.	Coastal	TBA
Struct. Section 11	Grind	Low/Med.	Desert	TBA
Struct. Section 12	Grind	Low/Med.	Central Valley	TBA
Struct. Section 13	Long tine 1/8" Joint	High	Coastal	TBA
Struct. Section 14	Long tine 1/8" Joint	High	Desert	TBA
Struct. Section 15	Long tine 1/8" Joint	High	Central Valley	TBA
Struct. Section 16	CRCP	High	Coastal	TBA
Struct. Section 17	CRCP	High	Desert	TBA
Struct. Section 18	CRCP	High	Mountains	TBA
Struct. Section 19	CRCP	High	Central Valley	TBA
Struct. Section 20	Porous	High	Coastal	TBA
Struct. Section 21	Porous	High	Desert	TBA
Struct. Section 22	Porous	High	Central Valley	TBA
Struct. Section 23	Porous	Low/Med.	Coastal	TBA
Struct. Section 24	Porous	Low/Med.	Desert	TBA
Struct. Section 25	Porous	Low/Med.	Central Valley	TBA
Bridge Deck 1	Grind	High	Coastal	101 - Eureka
Bridge Deck 2	Groove	High	Desert	905 San Diego
Bridge Deck 3	Exposed Aggregate	High	Mountains	I-5 Tehacapi
Bridge Deck 4	Grind	Low/Med.	Coastal	101 Oxnard
Bridge Deck 5	Groove	Low/Med.	Desert	I-15 Baker
Bridge Deck 6	Exposed Aggregate	Low/Med.	Mountains	50 - Truckee

Notes:

TBA = To Be Arranged.
1 All joints on this table are conventional ¼ inch joints unless stated otherwise

Table III- 5: Proposed Rigid Pavement Field Data Collection, Sampling and Testing

Type of Data/Sample	Specific Test or Sample	Data Collection Frequency	Comment
Condition Survey[1]	Caltrans Pavement Condition Survey	Annually	Including: % Long. Trans. and Corner Cracking, Faulting profile each joint
Sound Intensity[3,4] and wayside sound measurement	On Board Sound Intensity (OBSI) and wayside sound measurement	Annually	OBSI measurements in both wheel paths.
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 the BELLS equation
Age	N/A	Once at beginning	Records Request
Permeability	In-situ measurement	Initial + Annually	UCD can perform this test.
Air temperature	Thermocouple	At time of sound intensity measurement	
Friction	Dynamic Friction Tester ASTM E 1911; Skid test CT 342	Annually	In wheel paths
Profilograph	CT 526	Annually	In wheel paths
Macro texture	Circular Friction ASTM E 2157[2]	Annually	In wheel paths. Device will be a circular friction meter
International Roughness Index (IRI)[1]	Laser profilometer	Annually	Either by add-on equipment to sound intensity vehicle, or separately
Cores	Diameter: 100 mm	Once at beginning	Two between wheel paths, three in each wheel path, all 100 mm diameter.

Notes:

1. *Specific test equipment or method per recommendation.*
2. *Same test will be replicated on research grade Type 3 Caltrans environmental noise monitoring locations*
3. *On rehabilitation sections, sound intensity will be measured before and after construction.*

Table III- 6: Laboratory Measurements and Tests on Rigid Pavement Field Samples

Type of Data/Sample	Specific Test or Sample	Data Collection Frequency	Comment
Impedance tube noise absorption	Per Caltrans Environmental	Once at beginning	Exact test procedure in development[1]
Thickness of concrete slab		Once at beginning	
Thickness of underlying layers		Once at beginning	
Ball Penetration Test	CT 533	Once at beginning	
Flexural Strength	CT 523	Once at beginning	
Air-content	CT 543	Once at beginning	
Aggregate gradation	CT 202	Once at beginning	From aggregate after binder removal. Will be repeated where aggregate samples are collected during construction[3]

Notes:

[1] *Test method will be based on NCAT procedure. Same test will be replicated on a set of cores from research grade Type 3 Caltrans environmental noise monitoring sites.*

[2] *The aggregate gradation used on project is required.*

Table III- 7: Sources and Supporting Data Collection for Rigid Pavement Sites

Type of Data/Sample	Specific Test or Sample	Data Collection Frequency	Comment
As-Built Information	Pavement surface type and underlying structure, date of construction	Once at beginning	
Concrete slab mix information	Concrete mix gradation, QC/QA data on aggregate, cement content, water/cement ratio, and 28-day strength.	Once at beginning	May not exist for all open-graded
Traffic volume and WIM data	Annual average daily traffic (AADT)	Once at beginning	
	Percent trucks (T %)	Once at beginning	
	Traffic index (ESALs)	Once at beginning	
	Traffic speed distribution for a typical week and/or level of service	Once at beginning	
Climate data	Annual rainfall	Over life	
	Freeze-thaw cycles	Over life	
	Degree-days above 30°C	Over life	
	Freezing Index	Over life	
Pavement condition survey data	Time history of types and extent of pavement distresses	Once at beginning	Since construction
	Time history of IRI or pavement rideability index	Once at beginning	Since construction

Table III- 8: Rigid Pavement and Bridge Deck QPR Work Plan Schedule

Milestone	Target Date to Begin	Target Date to Complete
Define required data for analysis to achieve program goals	Award Date	+02 Months
Select sites to capture required data	+02 Months	+06 Months
Monitor testing sites and take samples as required	+04 Months	+22 Months
Lab test evaluation	+06 Months	+18 Months
Establish and populate database	+07 Months	+22 Months
Determine trends that indicate changes in design and const.	+21 Months	+23 Months
Determine trends that require investigation	+21 Months	+23 Months
Provide recommendations for HDM and SS and SSP's	+22 Months	+24 Months
Provide recommendations for additional study	+23 Months	+24 Months

Table III- 9: Summary of Rigid Pavement and Bridge Deck QPR Data Collection Schedule

Type of test section[1]	Duration of Data Collection[2]	Data Review and Evaluation
Research grade Type 3 Caltrans environmental noise monitoring location - Mojave	2-10 years	annually
Select Type 1 mainline highway sites of different ages	2-10 years	annually

<u>Notes:</u>

1. *The number of sections being evaluated will diminish with time depending on Caltrans' review of prior year's data.*
2. *Data collection after the first two years included in this plan would be a follow-on project.*

SECTION IV : DATA ACQUISITION PLAN FOR TYPE 3 "RESEARCH GRADE" SITES (ACOUSTIC CORRELATION)

1. Introduction

This portion of the QPR study will involve field data collection at 12 research grade (Type 3) sites that represent both flexible (8 planned sites) and rigid (4 planned sites) pavement surfaces shown in Table IV-1. Both flexible and rigid pavement sites include newly built pavements as well as aged pavements that were either recently overlaid (flexible) or ground (rigid).

The research performed at Type 3 sites will evaluate the highway traffic noise reduction benefits gained from the use of various surface treatments and/or textures. However, safety and durability remain the most important factors in surface treatment type and/or texture considerations. Accordingly, this data acquisition plan for Type 3 "research grade" sites includes the collection of data not only related to highway traffic noise characteristics but also to the safety and durability aspects of the associated pavements. The plan is intended to collect data necessary to accomplish the following:

a. Quantify the acoustic properties of various pavement surface courses currently used or being considered for use in California. (This study also provides supplemental support and verification for the Type 1 site data collections for flexible and rigid pavements in Sections II & III).
b. Quantify the variation of pavement acoustic properties with age. (This study also provides supplemental support and verification for the Type 1 site data collections for flexible and rigid pavements in Sections II & III).
c. Quantify variation of pavement acoustic properties with season.
d. Determine the correlation (if any) between physical pavement characteristics (such as macrotexture, void content, impedance) and the pavement acoustic properties, so that acoustical performance can be determined by the physical characteristics of pavement. (This study also provides supplemental support and verification for the Type 1 site data collections for flexible and rigid pavements in Sections II & III). The mean macrotexture depth for flexible pavement (Table II-1) and rigid pavement (Table III-1) test sections will be measured using laser profilometer and circular texture meter, respectively.
e. Determine the correlation between wayside, at source, and laboratory acoustical measurements, so that near-field measurements alone may be used for future pavement noise evaluations.
f. Perform life-cycle cost analysis between sound barriers and quieter pavement strategies to compare the cost-effectiveness of each option.

The data acquisition plan and evaluation of the acoustic portion of this QPR study will include the following main tasks:

1. Selection of 12 research grade (Type 3) sites
2. OBSI and wayside noise measurements for the Type 3 test sections
3. OBSI and wayside noise measurements correlation for the Type 3 test sections

The acoustic performance data collected from Type 3 and Type 1 sites will be used to establish a statewide database for both flexible and rigid pavements. The data will be analyzed to develop correlations between OBSI, wayside, and impedance tube sound absorption measurements and to corroborate any quieter pavement performance curves developed from the two-year flexible and rigid pavement studies at Type 1 sites. Additionally, the results of OBSI measurements at Type 3 sites will be used to evaluate the effectiveness of quieter pavements to minimize the impacts of tire/pavement noise, and establish how long these benefits last.

Sources and types of supporting data, test methods, and frequency of testing are described in items 2 through 14 of this Section.

2. Site Selection

The following considerations and highway features will be used to select Type 3 sites:

1. Preference of urban over rural sites. Rural sites would be acceptable if suitable urban sites are not available.
2. Free or stable traffic flow, freeway speed
3. Relatively flat; no grades 2% or greater
4. Mainline lanes only, no ramps or acceleration/deceleration lanes
5. No competing ambient noise sources – especially trains and planes, noisy structures, reflective buildings, shooting ranges, or dog kennels.
6. Project length - half mile or greater
7. Median width - less than 30 feet between inside shoulders preferred
8. Same pavement treatment on all lanes in both directions
9. Preferably, sites that provide geographic spread and/or traffic data such as volume counts (AADT) and weigh-in-motion (WIM) data.
10. Nearby Regional Weather Station (RWS) preferred but not required
11. Newly constructed or recently rehabilitated pavement sections

The proposed Type 3 sites are listed in Tables IV-1.

3. Surface Treatments and Textures

Types of flexible pavement surface treatments, and types of rigid pavements and surface textures, that will be included in this study are summarized in Table IV-1.

4. Data Collection

All data will be collected in general conformance with *ANSI S12.8-1998 and ANSI S1.13-1995 and FHWA's procedures, Measurement of Highway-Related Noise (FHWA-PD-96-046)*.

a. Measurement sites must meet Reference Energy Mean Emission Level-type (REMEL) criteria including the following:
   - i. Relatively flat terrain;
   - ii. Generally free from reflective objects; and
   - iii. Free from electromagnetic interference.

b. Types of data to be collected include the following (the specifications for each data type are presented later in the plan):
   - i. Wayside acoustical data;
   - ii. Pavement data;
   - iii. Traffic data – count vehicles and use radar gun;
   - iv. Safety data;
   - v. Meteorological data – 1 met station will be set up per site
   - vi. Near-field acoustical data using acoustic intensity method (OBSI).

     Both single probe and dual probe methods will be employed with simultaneous wayside monitoring for correlation calculations.

c. Before measurements begin, Caltrans will provide FHWA with the following information:
   - i. The location and description of all measurement sites; and
   - ii. The measurement methodology, including specific instrumentation and procedures to be used.

5. Data Analysis

All data will be analyzed in general conformance with *ANSI S12.8-1998 and ANSI S1.13-1995 and FHWA's procedures, Measurement of Highway-Related Noise (FHWA-PD-96-046)*.

a. Differences between measurement pairs (measurements made at different times at a single site, or at different sites) will be accounted for during analysis for the following:

i. Traffic composition and speeds;

ii. Meteorological conditions; and

iii. Site characteristics, such as ground cover.

b. Analysis will include sufficient data to represent typical traffic composition and speed, as well as the variation in expected meteorological conditions for the subject area.

6. Development of a Correlation Between Wayside, OBSI, and Impedance Tube Sound Absorption

a. At least one day of measurements is required to obtain enough data to calculate the correlation between OBSI and wayside for a single site under one set of conditions (this may not apply to the existing traffic pass-by method, where more than one day of pass-by measurements may be required in order to obtain a sufficient amount of data). For wayside, this requires:

i. 6 hours for continuous flow; or

ii. The number of hours it takes to collect the minimum number of clean pass-by events.

iii. Collect data at least twice per year at each test site for wayside and OBSI measurements. For impedance tube collect data from pavement cores collected from the test site.

b. To obtain an overall correlation, a minimum of three sites is needed, with data collected over 5 years minimum (10 years preferred) time and in different seasons, such that the expected ranges of conditions (for traffic composition and speeds, pavement types and conditions, meteorological conditions, and site characteristics) for the subject area are included in the measurements. Study proposes 12 sites. See Table IV-1 for candidate sites.

7. Wayside Acoustical Data

a. Measurement Methods (there are three possible types; the choice of type is made based upon the possibility of road closures, density of traffic, etc.):

i. Continuous Flow

1. Measure time-averaged sound levels (15 min.); and
2. Traffic must be constant and heavy enough for uninterrupted data blocks and must be representative of composition and speeds typical of subject area.

ii. Controlled Pass-Bys

1. Measure LAmax for each vehicle;
2. Number of pass-bys must meet the criteria for the statistical pass-by method (SPB; ISO 11819-1); and
3. Apply the SPB to get the statistical pass-by index (SPBI).

iii. Existing Traffic Pass-Bys

1. Measure LAmax for each vehicle;
2. Number of pass-bys must meet the criteria for the statistical pass-by method (SPB; ISO 11819-1); and
3. Apply the SPB to get the statistical pass-by index (SPBI).

b. Data Collection

i. Microphone Position(s)

1. Required location: distance of 50 ft from the center of the near travel lane, height 5 ft above the ground; and
2. Optional locations: distance 50 ft, height 15 ft; distance 25ft, height 5 ft.

ii. Collection Requirements

1. Sound levels (LAeq, LAmax), as specified in section 5.a (Measurement Methods);
2. One-third octave-band *data (ANSI/ISO Bands 17 through 40, nominal frequencies of 50 Hz through 10 kHz)* - a spectrum analyzer must be used either directly in the field, or later with recorded data; and
3. Acoustic data must be recorded (DAT recorder).

iii. Equipment Specifications

1. Microphones and sound level meters must conform to ANSI S1.4 Type 1,
2. Spectrum analyzers must conform to *ANSI S1.11 Type 2 (or IEC 61260 Class 2),*
3. FHWA must approve all instrumentation prior to its use, and
4. FHWA must approve any new instrumentation as needed.

8. On-Board Sound Intensity (OBSI) Acoustical Data

All data will be collected using the current AASHTO Standard Practice for Measurement of Tire Pavement Noise using On-Board Sound Intensity and AASHTO Standard Equipment Specification for System to Measure Tire-Pavement Noise using On-Board Sound Intensity, both now in draft form.

9. Impedance Tube Sound Absorption Data

a. Measurement Methods:

Impedance tube sound absorption will be measured in accordance with the method defined in ASTM E 1050 and ISO 10534–2. In this method, standing wave fields are generated in the tube using a loudspeaker. The maximum and minimum sound pressure levels are measured by two microphones, which are aligned along the length of the tube.

Standing wave ratio, which is the ratio of maximum and minimum sound pressure values, is used to determine the sound absorption coefficient of the test sample.

Work is in progress on two other methods, ISO 13472-2: "Acoustics—Measurement of sound absorbing properties of road surfaces in situ—part 2: spot method", and ISO 13472-3: "Acoustics—Measurement of sound absorbing properties of road surfaces in situ—part 3: spot method for low absorption surfaces."

b. Data Collection

i. Microphone Position(s)

The location of the two required microphones is variable and depends on the lower frequency of interest. Typical microphone locations are at 220mm, 300mm, and 350mm from the test sample.

ii. Collection Requirements

Test is planned in two cores per pavement section.

1. Sound levels (LAeq, LAmax), as specified in section 5.a (Measurement Methods).
2. One-third octave-band data (ANSI/ISO Bands 17 through 40, nominal frequencies of 50 Hz through 10 kHz) – a spectrum analyzer must be used.
3. Acoustic data must be recorded (DAT recorder).

iii. Equipment Specifications

1. Microphones and sound level meters must conform to ANSI S1.4 Type 1.
2. Spectrum analyzers must conform to ANSI S1.11 Type 2 (or IEC 61260 Class 2).

10. Pavement Data

a. Collection Requirements

i. Obtain pavement specifications for construction (construction date, mix design, pavement thickness, etc.) for:

1. Existing pavement- cores will be taken at each site - (as a minimum, identify the approximate age, general type, and texture specified for the pavement); and
2. New pavement.

ii. Measure actual pavement properties (not as stated in specifications):

1. Macrotexture (use core samples, ROSAN, or other method); document the (1) Mean Texture Depth (MTD) ASTM E-965; and (2) Mean

Profile Depth (MPD) ASTM E-2157-01 or ASTM E-1845/ISO 13473 [**Note: The CT Meter will be used to measure surface texture**];

2. Void content, if possible (use core samples or other method;
3. Pavement temperature measured periodically, at least once each hour (preferably once for each pass-by for wayside measurement when implementing one of the pass-by methods); and
4. Acoustic impedance of the pavement.

11. Traffic Data

a. Measurement Methods (type dependent on acoustical measurement type and available staff/equipment):

   i. Record all vehicles with a video camera and extract information at a later time (for continuous flow traffic or single vehicle pass-bys); or

   ii. Log all traffic information (for single vehicle pass-bys).

b. Collection Requirements -

   i. Collect the following information during all wayside acoustical measurements:

      1. Vehicle type in 5 categories (automobile, medium truck, heavy truck, bus, and motorcycle); and
      2. Vehicle speeds
         a) Pass-by method: speed for each vehicle
         b) Continuous flow method: average speeds during specified time blocks
         c) Traffic speeds will be measured using traffic cones for timing and radar.

   ii. Collect the following information during all OBSI acoustical measurements:

      1. Vehicle type in 5 categories (automobile, medium truck, heavy truck, bus, and motorcycle); and
      2. Vehicle speeds

12. Safety Data

a. Measurement Methods (may utilize one or both methods)

   i. Wet Weather Crash Performance: wet-weather and/or total vehicle crash rates at the same or similar locations.

   ii. Friction Test Results: friction test results and speed gradient when tested in conformance with ASTM E-274 (skid trailer) using the smooth tire (ASTM E-524), or International Friction Index (IFI) [ASTM E-1960].

b. Collection Requirements

   i. Duration: data collection will be of sufficient duration to demonstrate adequate long-term safety performance of pavement surfaces.

   i. Scope: safety performance indicators will be collected from each test site at time of OBSI noise measurements. Data will be combined with data collected from Type 1 sites for analysis.

13. Meteorological Data

a. Meteorological Sensor Location(s) - Will be close enough to the microphone location so that weather measurements represent conditions at the microphone used for wayside measurements.

b. Collection Requirements – we will collect the following during all wayside acoustical measurements (continuous for continuous flow traffic and during each event for single vehicle pass-bys):

   i. Air temperature;
   ii. Wind speed;
   iii. Wind direction; and
   iv. Relative humidity.

14. Life-cycle Cost Analysis

a. Use projects where sound barriers were built;

b. Design an alternative "shadow" project using quieter pavement strategies;

c. Both sound barrier and quieter pavement strategies must meet Federal requirements for noise reduction.

d. Perform life-cycle cost analysis using FHWA software RealCost on both strategies using results of acoustic performance over time from Type 1 and 3 sites.

15. Cost Estimate

The majority of the costs for this portion of QPR study will be measuring, monitoring, modeling, and documenting pavement acoustical properties. Caltrans estimates that this research will be a significant effort with short-term (1-3 year) costs of $750,000 and long-term (3-10 year) costs of $1-3 million.

16. Schedule

The project schedule spans a maximum of ten years, and is broken into short-term (1-3) year timeline and longer-term 3-10 year timeline. This study will incorporate data already collected in previous and on-going pavement studies and new sites. Decision points are included in the schedule so Caltrans with its partners annually can decide, after reviewing each year's data, if modifications of the plan are warranted.

17. Coordination

The acoustic project will be coordinated with other Caltrans' QPR projects for flexible and rigid pavements described in sections II and III of this research proposal to ensure compatibility of OBSI and wayside noise measurements, and impedance tube measurements. Caltrans will also seek partnerships with other states and agencies seeking to perform quieter pavement research. Partnerships may include sharing data to increase the size of the quieter pavement research database.

Before any measurements begin at any Type 3 site, Caltrans will provide detailed information to FHWA. This will include the location and description of all measurement sites, and specific instrumentation and procedures to be used.

Table IV- 1 : Existing and Proposed Research Grade Type 3 Sites

Section Name	Location DIST/CNTY/RTE/PM	Surface Type	Date Constructed	Age Group (Years)
Davis I-80	3-Yol-80, PM 2.9-5.8	OGAC overlay on DGAC	July 1998	5 - 8
Florin Road I-5	3-Sac-5, PM 17.2-17.9	OGAC overlay on PCC	Fall 2004	1 - 4
LA County, SR 138	7-LA-138, PM 16.0-21.0	75 mm OGAC, 30 mm OGAC, RAC-O, BWC	Spring 2002	1 - 4
SR 33 Firebaugh test section	06-Fre-33, PM 70.9-75.08	DGAC 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	Summer 2004	1 - 4
Rosemead Blvd, El Monte	07-LA-19/164-3.4/xx	Euro Gap-graded mix	May 2005	1
Additional 3 flexible pavement sites	To Be Determined	OGAC, DGAC, and/or RAC-O or RAC-G either new or overlay on existing asphalt concrete or PCC.	To Be Determined	
Mojave Bypass, SR 58	8-Ker-58, PM 107.7-118, (West end of project in eastbound lanes)	Variety of groove, grind, textured new PCC	Fall 2003	1 - 4
Santa Clara SR 85	4-SCl-85, PM 14.63-15.51	Extend test grinding of existing PCC. Scheduled for grinding in late Summer 2005	Opened in mid-1990's	8 - 10
Additional 2 rigid pavement sites	To Be Determined	One new PCC site. One grinding of existing PCC.	To Be Determined	

Abbreviations:

OGAC	Open Graded Asphalt Concrete
BWC	Bonded Wearing Course
DGAC	Dense Graded Asphalt Concrete
PCC	Portland Cement Concrete
RAC-G	Rubberized Asphalt Concrete Type G (Gap graded)
RAC-O	Rubberized Asphalt Concrete Type O (Open graded)
RUMAC-GG	Rubber Modified Asphalt Concrete, gap-graded, dry process
Type G-MB	Gap Graded Rubber Modified Asphalt Concrete (mix blend)
Type D-MB	Dense Graded Rubber Modified Asphalt Concrete (mix blend)

SECTION V : QPR STUDY REPORTS

Caltrans will issue reports on the Type 1 sites once the two-year studies are completed. During the review of the draft results, Caltrans in consultation with FHWA will determine if monitoring should be extended on any of the test sites.

Caltrans will issue reports on the Type 3 "Research Grade" sites every two years. After two years of data collection at all Type 3 sites, correlation curves will be documented between OBSI and wayside noise measurements and submitted to FHWA for review and consideration in updating Traffic Noise Model and traffic noise test practices. These correlation curves will be updated every year thereafter.