

Work Plan for:
**“Development of Improved Mix and Structural Design and Construction
Guidelines for Deep In-Situ Recycling (DISR) of Cracked Asphalt Concrete
with Foamed Asphalt”**

PPRC Strategic Plan Element 4.12

PREPARED FOR:

Partnered Pavement Research Center (PPRC)
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UCPRC

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Abstract:

This work plan is for the research program on Deep In-Situ Recycling (DISR) with Foamed Asphalt that will be carried out for Caltrans by the University of California Pavement Research Center (UCPRC).

The research includes extensive laboratory testing and field monitoring. The laboratory testing will identify the roles of constituents of foamed asphalt mixes and select best laboratory practices and appropriate test methods, both for advanced research and routine project-level tests. UCPRC will also perform field monitoring on DISR-foamed asphalt projects built by Caltrans. Literature review and mechanistic sensitivity analysis will also be performed. Deliverables will include recommendations for improved mix design method, structural design method, and construction guidelines.

The research will be mostly completed by September 2008 except for the semi-long-term monitoring that will continue for six to eight additional years. A separate, additional work plan will be prepared if additional HVS tests are authorized by the PST.

Keywords:

foamed asphalt, DISR, CFIPR, FWD, field monitoring

Related documents:

UCPRC-TM-2005-11, UCPRC-TM-2004-06

Signatures:

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EXECUTIVE SUMMARY

The research on Deep In Situ Recycling with Foamed Asphalt (DISR-foamed asphalt) included in this plan will support the Department's (Caltrans) efforts in developing more cost-efficient and sustainable pavement rehabilitation strategies that minimize both agency and user cost. Use of the DISR-foamed asphalt strategy can improve the Department's stewardship of the state road network through in-place recycling of existing cracked road materials, thereby reducing the amount of new materials required for rehabilitation. Use of the strategy also offers the potential for reducing traffic delay through longer pavement life and shorter construction traffic closures.

This work plan includes a significant partnering effort with others doing research on DISR-foamed asphalt, which when combined with the work included in this plan, will provide the Department and local government agencies with greater flexibility in selecting appropriate rehabilitation strategies.

The results of the research in this plan are expected to provide the following benefits to Caltrans:

- Measurement and documentation of the results obtained on Caltrans projects built to date and to be built in the future, specifically fundamental data and information regarding materials and pavement structures, and their performance in the field;
- Improved criteria for selecting projects for DISR-foamed asphalt;
- Improved mix designs, appropriate to rehabilitation of existing California structures;
- Improved structural designs, accounting for California mixes, climates and traffic, and Caltrans practice;
- Improved construction practice from documentation of construction practices and their effects on materials properties and performance;
- Improved performance information, which will facilitate life cycle cost analysis comparisons of DSIR-foamed asphalt with other rehabilitation strategies; and
- Cost savings and increased recycling when rehabilitating Caltrans flexible pavements.

This technology was originally developed in the United States, but it is currently most widely used in South Africa and Australia. It has also been used to a lesser extent in Europe.

The technology was presented to Caltrans pavement engineers at the South African Pavement Technology Workshop in March 2000. Five projects have been built to date in California, on SR20, SR89, SR132, I80, and SR33.

The fact that most of the Department's DISR-foamed asphalt mixes will primarily consist of recycled asphalt pavement (RAP) separates California practice from that of other states and countries investigating and using this technology. The work performed as part of this plan will focus on parent materials composed primarily of RAP. Similar work to be undertaken soon by other researchers in other countries using parent materials composed primarily of granular layers and recycled cement-treated layers will be monitored and shared. With a decade of engineering practice and research, extensive knowledge about foamed asphalt-treated materials and pavement structures with foamed asphalt-treated layers has been gained. Projects have been successful around the world, with a few notable exceptions. However, gaps exist between current knowledge and the knowledge needed to increase the probability of success when using this technology.

The major research needs identified for DISR-foamed asphalt are summarized below, and the research in this plan addresses them. The results will not answer every question regarding use of DISR-foamed asphalt in California, but they will provide a starting point that will increase the probability of success with this technology.

- Understanding issues related to mixes with large percentages of RAP
- Quantifying field performance
- Understanding the roles of cement and foamed asphalt in controlling material properties
- Developing appropriate laboratory procedures
- Developing appropriate mix design procedures
- Developing appropriate structural design procedures
- Construction guidelines

Details regarding these research needs and a brief overview of recent work outside of California are presented in this work plan's Problem Statement.

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

- Perform laboratory tests on the constituents of DISR-foamed asphalt materials (recycled AC material, foamed asphalt, cement, etc.) and DISR-foamed asphalt mixes.
- Test DISR sections with the Heavy Vehicle Simulator (HVS) to obtain preliminary performance data.
- Evaluate and extend existing guidelines for mix design, structural design, and construction of DISR-foamed asphalt, with expected results of improving properties over the life cycle of the pavement including future rehabilitation.
- Update life cycle cost estimates with performance information.

One set of HVS tests on a DISR-foamed asphalt project on SR89 has already been performed and reported, and is not included in this work plan. Although it is uncertain at this time whether additional HVS tests will be performed, they are highly recommended, but only if testing can be carried out on the mainline highway (with a detour used by traffic) thereby ensuring that the experiment is representative of the construction. A separate additional work plan will be prepared if additional HVS tests are authorized by the PST.

The deliverables of the objectives of this research will achieve the goals described above. The Objectives and Deliverables are summarized in the following table.

Table 1. Summary of Objectives and Deliverables

Work Plan Section	Objective	Deliverables	Problems Addressed
4.2.1	Literature survey and technology and research scan	<ol style="list-style-type: none"> 1. Literature survey of worldwide practice. 2. Technology scan of current practice worldwide not published in literature 3. Technology scan of current and planned research worldwide 	Focus on large proportions of RAP; ensure not repeating completed research; coordinate with research programs
4.2.2	Mechanistic sensitivity analysis	Report on mechanistic analysis identifying key properties of DISR-foamed asphalt materials, classified as granular, asphaltic or cemented, and expected effects on pavement performance and critical values for pavement performance.	Roles of cement and foamed asphalt; mix design; critical materials property values for structural design
4.2.3	Assessment of Caltrans projects built to date based on available data	<ol style="list-style-type: none"> 1. Database of field testing results on Caltrans DISR-foamed asphalt projects built to date, and available design data. 2. Reports on measured properties, pavement performance, traffic levels, climate variables for each site, comparison between projects, and variation within projects (includes projects from 4.2.4 once except for initial measurements), and mechanistic analysis comparing performance and properties with findings of Objective 4.2.2. 	Monitoring of field sections; role of cement and foamed asphalt; relation of mix design, structural design, construction to performance
4.2.4	Measurement of properties on Caltrans DISR-foamed asphalt Projects to be built in the future	<ol style="list-style-type: none"> 1. Database of field and laboratory testing results for materials collected on each project and available design data. 2. Reports summarizing initial development in field of stiffness and other properties of DISR-foamed asphalt layers and other pavement layers, and conditions under which those properties developed and comparison with laboratory results for same materials. 3. Sampling of sufficient quantities of unmixed materials for comparison of variability within projects and for later laboratory testing. 	Monitoring of field sections; relation between laboratory and field measured properties (curing, compaction, etc); relation of mix design, structural design, construction to properties and performance
4.2.5	Laboratory testing to identify specimen preparation and test methods, and develop information for mix design, structural design and construction guidelines	<ol style="list-style-type: none"> 1. Database of laboratory test results for range of materials, mix designs, tests, specimen preparation, conditioning variables. 2. Report summarizing results and statistical analysis of results, and recommendations for best laboratory practice. 	Best laboratory practices (curing, compaction, tests, etc); effects of mix design, water, temperature, compaction on critical properties; relation between laboratory test methods
4.2.6	Mix design recommendations	Report summarizing recommended mix design practice, based on results of Objectives 4.2.1 through 4.2.5.	Mix design

Work Plan Section	Objective	Deliverables	Problems Addressed
4.2.7	Structural design recommendations	Report summarizing recommended structural design practice, based on results of previous objectives, including recommended gravel factors and performance estimates for LCCA based on mechanistic analysis and results of Objectives 4.2.1 through 4.2.5.	Structural design
4.2.8	Construction recommendations	1. Report summarizing “lessons learned” from experience to date. 2. Report with recommended construction practices based on first report and results of Objectives 4.2.1 through 4.2.5.	Construction

The risk for the deliverables of Objective 4.2.3 is that original mix design, structural design, and as-built records are not available. Delays in obtaining those data will delay the data analysis even if the field tests have been successfully performed. The UCPRC will have to rely on Caltrans staff responsible for those projects to provide all available information.

The risk for Objective 4.2.4 is that Caltrans may not have any new DISR-foamed asphalt projects go to construction in the next construction season. Contingency plans have been developed for this risk.

The risk for the deliverable of Objective 4.2.7 is that Caltrans staff from DISR-foamed asphalt projects are unavailable to be interviewed.

The total estimated cost for the work included in this test plan is \$427,245. The expected completion date for the project, except for additional long-term monitoring, is September 2008.

The risk for cost is the potential need to compensate the contractor for time lost during sampling of RAP. It is doubtful that this will be more than several thousand dollars. There is a

risk that the traffic closure will cost more than shown. Adherence to the schedule might be influenced by the following:

1. *Delays in traffic closures.* The cost of traffic closures will need to be covered with an existing expenditure account available to Maintenance, or if contracted traffic closures are used then sufficient funds will need to be found in the contract budget and permits will need to be obtained.
2. *Availability of RAP material.* The UCPRC is relying on Caltrans, local government, and contractors to cooperate in arranging sampling of sufficient unmixed RAP materials for laboratory experiments.

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1.0 PURPOSE OF THE PROJECT

The investigation into Deep In Situ Recycling with Foamed Asphalt (DISR-foamed asphalt) will support the Department's (Caltrans) efforts in developing more cost-efficient and sustainable pavement rehabilitation strategies that minimize both agency and user cost. Use of the DISR-foamed asphalt strategy can improve the Department's stewardship of the state road network through in-place recycling of existing cracked road materials, thereby reducing the amount of new materials required for rehabilitation. It also offers the potential for reducing traffic delay through longer pavement life and shorter construction traffic closures. This work plan includes a significant partnering effort with others doing research on DISR-foamed asphalt, which when combined with the work included in this plan, will provide the Department and local government agencies with greater flexibility in selecting appropriate rehabilitation strategies.

The results of the research in this plan are expected to provide the following benefits to Caltrans:

- Measurement and documentation of the results obtained on Caltrans projects built to date and to be built in the future, specifically fundamental data and information regarding the materials and pavement structures, and their performance in the field.
- Improved criteria for selecting projects for DISR-foamed asphalt.
- Improved mix designs, appropriate to rehabilitation of existing California structures.
- Improved structural designs, accounting for California mixes, climates and traffic, and Caltrans practice.
- Improved construction practice from documentation of construction practices and their effects on materials properties and performance.
- Improved performance information, which will facilitate life cycle cost analysis comparisons of DSIR-foamed asphalt with other rehabilitation strategies.
- Cost savings and increased recycling when rehabilitating Caltrans flexible pavements.

In addition, by considering a broad range of DISR material types, the mix design and structural design requirements developed in this research will help harmonize the procedures for all cold in-place recycling (CIPR) in California.

2.0 BACKGROUND

Deep in-situ recycling of damaged asphalt concrete pavement with foamed asphalt as stabilized base is an in-place pavement recycling strategy. Compared with CIPR using emulsion asphalt stabilization, its potential benefits include:

- Faster construction
- Shorter traffic closure
- Less environmental impact

This technology was originally developed in the United States but is currently most widely used in South Africa and Australia. It has also been used to a lesser extent in Europe.

The technology was presented to Caltrans pavement engineers at the South African Pavement Technology Workshop in March, 2000 in Richmond by the University of California Pavement Research Center (UCPRC) as part of the Caltrans Research sponsored Caltrans Accelerated Pavement Testing project (CAL/APT).

The first Caltrans project using this technology was the rehabilitation of a 15.3 km long section of State Route 20 in western Colusa County in 2001. Following this, at least one FHWA project, three additional Caltrans projects and several county projects were constructed in California with this technology prior to 2005 (Raffaelli, 2004), and an additional project was constructed on SR33 in 2005. Accelerated pavement tests using the Heavy Vehicle Simulator (HVS) were performed by the UCPRC on a shoulder, and deflection and other tests were performed on the mainline on a DISR-foamed asphalt project on SR89 in Sierra County in 2003 (Theyse et al 2004). Besides California, other states such as Texas, Maine, Louisiana and Kansas have reported similar projects. Both satisfactory performance and premature failures have been reported. The cause of premature failures has been typically due to poor practice (eg mix design and construction procedures) and not due to the foamed asphalt technology itself (Chen et al. 2004; Mohammad et al. 2003; Marquis et al. 2003; Romanoschi et al. 2004).

Most Caltrans low-volume and medium-volume highways and streets have asphalt concrete layers of at least 125 mm. Many have more than 200 mm of existing asphalt concrete, which is as deep as current in-place recycling equipment can reach in one pass and a practical limit for effective compaction of a single lift of recycled material. These layers consist of overlays and seal coats that have accumulated over 40 to 80 years of service. Fatigue, reflection and/or thermal cracking are the typical distresses, with some rutting of the base layers beneath if water has penetrated through the cracks.

The fact that most of the Departments' DISR-foamed asphalt mixes will primarily consist of recycled asphalt pavement (RAP) separates California practice from that of other states and countries investigating and using this technology. Pavement technology in South Africa and Australia primarily relies on granular materials of varying quality and cement treated base layers for the primary load carrying capacity of the pavement, with asphalt concrete or aggregate surface treatment layers (chip seals) at the surface that are less than 50 mm thick. Therefore, there is very little asphalt concrete recycled in their DISR-foamed asphalt layers, which is accordingly reflected in their research and experience. Use of DSIR-foamed asphalt by local agencies in California may be similar to that of either South Africa or Caltrans depending on the design and specifications at the time the road was built and subsequent rehabilitation and maintenance.

In Europe there is little use of DISR-foamed asphalt as practiced in the US or South Africa/Australia. European interest in foamed asphalt has typically consisted of mixing warmed foamed asphalt (Warm Mix Asphalt) with about 50/50 blends of RAP and granular materials. A European Community investigatory committee has been established for this technology. (COST Meeting).

3.0 PROBLEM STATEMENT

With a decade of engineering practice and research, extensive knowledge about foamed asphalt treated materials and pavement structures with foamed asphalt treated layers has been gained. Projects have been successful, with a few notable exceptions (Chen et al 2004). However, gaps exist between the current knowledge and the knowledge that is needed to increase the probability of success when using this technology.

For example, the most comprehensive technical guidelines currently available on mix design, structural design and construction are *Interim Technical Guidelines: the Design and Use of Foamed Bitumen Treated Materials*, commonly referred to as “TG2”, published by the Asphalt Academy of South Africa in 2002, based on work conducted by the CSIR, and *Wirtgen Cold Recycling Manual* published by Wirtgen. The authors at CSIR prepared background documents for California under sub-contract to the UCPRC at the same time (Theyse et al, 2004). However, in on-going studies to verify the guidelines, the same authors found that certain basic assumptions and conclusions in TG2 are not valid (Long et al 2003). Additional field investigations revealed that the performance of actual projects did not match predictions with currently available models and knowledge, leading to the conclusion that the investigation “posed more questions than answers” about current knowledge captured in TG2 (Collings et al 2004). The primary issue in the South African studies is that the projects appear to be performing much better than predicted by TG2. TG2 has been used for the mix and structural designs for projects built in California to date. Some of these concerns have been addressed in the Wirtgen guideline, with some of the work being carried out by the South African researchers who compiled TG2, however, insufficient research has been completed, to answer all of the questions. There is little additional useful information in the literature.

The major research needs identified for DISR-foamed asphalt are summarized below. The research in this plan addresses these needs. The results will not answer all of the questions regarding use of DISR-foamed asphalt in California, but will provide a starting point from which the probability of successful use of this technology will improve.

- Understanding issues related to mixes with large percentages of RAP

- Quantifying field performance
- Understanding roles of cement and foamed asphalt in controlling material properties
- Developing appropriate laboratory procedures
- Developing appropriate mix design procedures
- Developing appropriate structural design procedures
- Construction guidelines

3.1 Issues related to mixes with large percentages of RAP

If the material is predominantly RAP, the asphalt content in the DISR-foamed asphalt mixes can be as high as 6 to 8 per cent. The interaction of the aged asphalt in the RAP and the foamed asphalt is unknown. Materials with such high asphalt contents might be more susceptible to temperature; at the same time, their flexibility and resistance to water might also be improved compared to mixes with predominantly natural gravel (i.e., in South Africa and Australia). Baseline data on mixes with high percentages of RAP must be developed, together with structural designs that consider the critical properties influencing performance.

3.2 Quantifying Field Performance

Ongoing research in South Africa has revealed that the results from laboratory testing following existing protocols do not always closely relate to field performance. However, there is very little quality long-term field performance data from DISR experiments and monitoring of field sections and relating the findings back to construction data, mix design and laboratory performance is required so that procedures and protocols can be improved.

Variability needs to be understood and addressed in mix design, structural design and construction. Variability between projects and within a given project can be attributed to variability of the existing materials for the DISR-foamed asphalt layer; the other layers in the pavement (new overlay and layers beneath the DISR-foamed asphalt layer), and construction variability of proportions of cement and foamed asphalt, compaction, and aggregate gradation

from grinding in the DISR-foamed asphalt layer. Over time there is daily and seasonal variation of temperature and rainfall, curing of the DISR-foamed asphalt materials and aging of the asphalt concrete, as well as the influence of traffic.

The current mix design, structural design and construction procedures currently do not adequately consider these sources of variability within projects and differences between projects as there is very little documented quality field data. This phase of the study will address this issue.

3.3 Roles of Cement and Foamed Asphalt in Controlling Material Properties

The amount of cement and foamed asphalt in the mix design determines the properties of the DISR-foamed asphalt layer. Depending on the amounts, the same parent material may behave as a cemented material, an asphalt-bound material or a granular material. Cemented materials will have higher stiffness and little or no permanent deformation, but may crack due to shrinkage and are subject to fatigue damage. Asphalt-bound materials have less stiffness than cemented materials, little or no shrinkage, but are subject to temperature susceptibility, permanent deformation and fatigue damage. Granular materials improved by smaller quantities of cement and asphalt have no shrinkage and no fatigue damage, but have lower stiffness and greater susceptibility to water. There is overlap between these types of behavior depending on the mix design. There is very little data available regarding the properties for DISR-foamed asphalt mixes based on RAP parent material.

3.4 Developing Appropriate Laboratory Procedures

Current methods of sampling of parent materials consisting primarily of RAP from the field and preparing it for laboratory testing are not well documented and can be improved upon.

The Marshall hammer is used in current laboratory compaction procedures for DISR-foamed asphalt in TG2. However, the Marshall hammer does not induce an aggregate structure similar to that of the material in the field, and cannot produce specimens other than 100 mm (4 inch) diameter by 62 mm (2.5 inch) tall briquettes. Optimum specimen size and compaction procedures thus need to be evaluated.

Recent investigations indicate that laboratory curing procedures in TG2 do not necessarily represent the curing conditions in field, which is further complicated by the daily and seasonal fluctuation of environmental conditions. Research on curing is currently underway in South Africa, but is focused on recycled cement treated granular materials with multiple chip seal treatments. Whether their conclusions will be applicable to typical Caltrans mixes with high percentages of RAP is questionable and hence a parallel study needs be undertaken using RAP material and typical California climatic conditions to determine an appropriate curing procedure.

Tests in the current TG2 are not necessarily representative of field performance. Laboratory test methods need to be developed that measure the important properties for each of the three classes of materials. The tests must be quick and simple enough to be used routinely, or else the mix and structural designer must have available typical properties that can be estimated from surrogate tests.

The relationships between laboratory results and expected performance in the field need to be determined by analyzing laboratory test data of field-measured properties, observed field performance, and accelerated pavement testing data. This must be achieved through mechanistic analysis.

3.5 Developing Appropriate Mix Design Procedures

Current mix designs are based on research on predominantly natural or cemented materials. Mix design tests and mix design criteria must be developed for predominantly RAP materials to ensure that mixes with optimum properties are used on any given project, and that useful results for structural design and construction quality control are provided.

3.6 Developing Appropriate Structural Design Procedures

Current structural design procedures are also based on research on predominantly natural or cemented materials, mostly on roads with lighter traffic volumes than those in California. Appropriate structural design coefficients (gravel equivalence) applicable to RAP materials,

representative of California traffic and based on mechanistic-empirical analysis need to be developed for use in current Caltrans flexible design procedures.

3.7 Construction Guidelines

Available construction guidelines are based on experience from natural or lightly cemented materials and are not necessarily relevant to predominantly RAP materials. Guidelines specific to California conditions and based on “lessons learned” from construction practice in California to date need to be prepared to ensure that all relevant variables that can be controlled during construction and which have the greatest effect on performance are documented.

4.0 GOALS, OBJECTIVES AND DELIVERABLES

4.1 Goals

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

1. Perform laboratory tests on constituents of DISR-foamed asphalt materials (recycled AC material, foamed asphalt, cement, etc.) and DISR-foamed asphalt mixes.
2. Test DISR sections with the Heavy Vehicle Simulator (HVS) to obtain preliminary performance data.
3. Evaluate and extend existing guidelines for mix design, structural design, and construction of DISR-foamed asphalt, with expected results of improving properties over the life cycle of the pavement including future rehabilitation.
4. Update life cycle cost estimates with performance information.

One set of HVS tests on a DISR-foamed asphalt project on SR89 has already been performed and reported (Theyse et al 2004b), and is not included in this work plan (Goal 2 above). Although it is uncertain at this time whether additional HVS tests will be performed, they are highly recommended, but only if testing can be carried out on the mainline highway (detour is used by traffic) thereby ensuring that the experiment is representative of the construction. A separate additional work plan will be prepared if additional HVS tests are authorized by the PST.

4.2 Objectives and Deliverables

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	Problems Addressed
4.2.1	Literature survey and technology and research scan	<ol style="list-style-type: none"> 1. Literature survey of worldwide practice. 2. Technology scan of current practice worldwide not published in literature 3. Technology scan of current and planned research worldwide 	Focus on large proportions of RAP; ensure not repeating completed research; coordinate with research programs
4.2.2	Mechanistic sensitivity analysis	Report on mechanistic analysis identifying key properties of DISR-foamed asphalt materials, classified as granular, asphaltic or cemented, and expected effects on pavement performance and critical values for pavement performance.	Roles of cement and foamed asphalt; mix design; critical materials property values for structural design
4.2.3	Assessment of Caltrans projects built to date based on available data	<ol style="list-style-type: none"> 1. Database of field testing results on Caltrans DISR-foamed asphalt projects built to date, and available design data. 2. Reports on measured properties, pavement performance, traffic levels, climate variables for each site, comparison between projects, and variation within projects (includes projects from 4.2.4 once except for initial measurements), and mechanistic analysis comparing performance and properties with findings of Objective 4.2.2. 	Monitoring of field sections; role of cement and foamed asphalt; relation of mix design, structural design, construction to performance
4.2.4	Measurement of properties on Caltrans DISR-foamed asphalt projects to be built in the future	<ol style="list-style-type: none"> 1. Database of field and laboratory testing results for materials collected on each project and available design data. 2. Reports summarizing initial development in field of stiffness and other properties of DISR-foamed asphalt layers and other pavement layers, and conditions under which those properties developed and comparison with laboratory results for same materials. 3. Sampling of sufficient quantities of unmixed materials for comparison of variability within projects and for later laboratory testing. 	Monitoring of field sections; relation between laboratory and field measured properties (curing, compaction, etc); relation of mix design, structural design, construction to properties and performance
4.2.5	Laboratory testing to identify specimen preparation and test methods, and develop information for mix design, structural design and construction guidelines	<ol style="list-style-type: none"> 1. Database of laboratory test results for range of materials, mix designs, tests, specimen preparation, conditioning variables. 2. Report summarizing results and statistical analysis of results, and recommendations for best laboratory practice. 	Best laboratory practices (curing, compaction, tests, etc); effects of mix design, water, temperature, compaction on critical properties; relation between laboratory test methods
4.2.6	Mix design recommendations	Report summarizing recommended mix design practice, based on results of Objectives 4.2.1 through 4.2.5.	Mix design

Work Plan Section	Objective	Deliverables	Problems Addressed
4.2.7	Structural design recommendations	Report summarizing recommended structural design practice, based on results of previous objectives, including recommended gravel factors and performance estimates for LCCA based on mechanistic analysis and results of Objectives 4.2.1 through 4.2.5.	Structural design
4.2.8	Construction recommendations	1. Report summarizing “lessons learned” from experience to date. 2. Report with recommended construction practices based on first report and results of Objectives 4.2.1 through 4.2.5.	Construction

4.2.1 Literature Survey and Technology and Research Scan

Through a literature survey and communication with other researchers working on DISR, namely in South Africa, Australia, New Zealand and Europe, the PPRC will perform the following tasks:

- Identify the worldwide current state of the knowledge, state of the practice and key problems identified for deep in-situ recycling using foamed asphalt.
- Identify the range of applications used to date with regard to types of materials being recycled, designs and construction specifications, and applicability of the results to Caltrans rehabilitation projects.
- Identify current and planned research outside of California and how those results might be used for Caltrans.

The deliverable for this objective will be a report summarizing the literature survey and technology scans of unpublished current practice and current and planned research.

4.2.2 Mechanistic Sensitivity Analysis

The PPRC will perform mechanistic analysis of a factorial of pavement structures to identify key properties of materials from DISR with foamed asphalt affecting expected performance in typical Caltrans structures that will be rehabilitated, and expected distress mechanisms (failure modes) depending on the properties, ie cracking and rutting. The analysis will be performed for materials in the three overlapping classes of DISR-foamed asphalt materials, namely cemented, asphaltic

and granular and is expected to identify gaps in the existing knowledge with regard to properties and existing performance models.

Ranges of properties for each type of material will be considered in the analysis, simulating the effects of different mix designs, using properties and performance models for existing similar materials. The factorial will also include variables such as:

- The stiffness of underlying layers
- Thickness of the DISR-foamed asphalt layer
- Thickness and stiffness of the asphalt concrete surface layers.

The deliverable for this objective will be a report identifying the key properties effecting expected performance and expected distress mechanisms for DISR-foamed asphalt materials that behave as cemented, asphalt-bound or granular materials. The report will also present the preliminary estimation of acceptable ranges for properties of DISR-foamed asphalt materials for a range of typical Caltrans rehabilitation pavement structures.

4.2.3 Assessment and Monitoring of Caltrans Projects Built to Date

The UCPRC will perform long-term pavement performance field testing annually for 10 years to measure as-built properties of DISR-foamed asphalt materials and other pavement layers, including seasonal variation, and change over time due to traffic and the environment. The projects to be investigated are shown in Table 2.

Table 2: DISR-Foamed Asphalt projects built to date to be monitored

Section	Location	Mix Design of FTB	Date Constructed
SR20	State Route 20, PM 10-20	2.5% AR4000, 2-3 % cement	July, 2001
SR89	State Rouge 89, PM 20-30	2.5% bitumen, 1% cement	July, 2002
SR132	State Route 132, PM 13-15.	?% bitumen, 4% fly ash	August, 2003
I-80	Interstate 80, near Auburn	2.9% bitumen, 1.5% cement	July, 2005
SR33	District 5	?	Summer, 2005

The results of the field testing will be used to:

- Analyze variability of measured as-built properties to determine ranges of values

- Compare pavement performance within each project
- Compare pavement performance between projects with different DISR-foamed asphalt mix designs, structural designs, traffic levels and environmental conditions
- Relate performance back to laboratory test results and performance predictions from the mix and structural designs
- Determine whether DISR-foamed asphalt materials built to date have properties similar to those of cemented, asphalt-bound or granular materials in terms of the following:
 - Sensitivity of stiffness to curing time, temperature, season and load
 - Damage under traffic loading and environment
 - Permanent deformation

Supporting information to be collected on these projects is shown in Table 3.

Table 3: Supporting information to be collected for projects built to date

Type of Data/Sample	Specific Test or Sample	Frequency	Comment
From Caltrans headquarter or district offices or city engineer office			
Conditions before rehabilitation.	The original structural and mix design; failure modes.	Once.	Extract from as-builts, coring records and PMS database
Design information.	Structural and mix design for rehabilitation.	Once.	From project records
Design traffic	Design TI	Once	From project records
Actual traffic	Expected average monthly traffic loading.	Every two years	From Traffic database (AADT, % Trucks, TI), and assumed or actual (if WIM available) axle load spectrum
As built information.	Actual mix ratio; density achieved and other information.	Once.	From construction records
Historical FWD data		Once.	Including layer thickness information.
From climate database.			
Rainfall.	Monthly precipitation.	Annually.	Correlation to moisture content measured will be sought.

Tests to be performed on each project built to date are listed in Table 4. Laboratory tests to be performed on field collected specimens are shown in Table 5.

Table 4: Field testing and sampling for projects built to date

Type of Data	Test Method and Protocol	Frequency	Comment
Condition survey	Caltrans PMS condition survey	Twice per year.	
Actual layer thickness	Ground penetrating radar (GPR), Dynamic Cone Penetrometer (DCP) and cores.	Once.	GPR to get thicknesses and material types every 150 m. Cores for overlays and FTB if applicable; DCP for FTB and underlying layers if applicable. If coring and DCP are not applicable, nominal design values will be used for other analysis.
Penetration rate	DCP. ASTM D6951-03.	Twice, between wheel paths.	Once at the end of the dry season (September to October) and once at the end of the wet season (February to March).
Density	Nuclear gage. California test 231.	Whenever DCP is applicable. For all DCP holes.	Following DCP.
Moisture content	Nuclear gage. ASTM D3017.	Whenever DCP is applicable. For all DCP holes.	Following DCP.
Temperature	Thermocouple.	During DCP and FWD testing.	Following DCP. Measure at pavement surface; AC-FTB interface; middle depth in FTB and FTB-SB interface.
Deflection	FWD. ASTM D4694-96(2003).	Twice per year (dry and wet seasons). Performed before DCP and at the same locations as DCP if applicable.	Historical data of FWD tests by Caltrans will also be collected and analyzed. Once at the end of the dry season (August to September) and once at the end of the wet season (February to March).
Cores for laboratory testing		Several 100 or 150 mm cores to be taken once during initial FWD/DCP/density testing. 50 mm cores for DCP and density twice in first year.	Provides layer thickness, general material conditions, density, and moisture content. Historical data might be available in Caltrans.

Table 5: Laboratory testing on field cores from projects built to date

Step	Test	Comment
1	Cut off the overlays to get 100 mm diameter cylinder specimen of foamed asphalt mix.	The shape of the specimen might be a problem for triaxial test.
2	Density.	
3	Conditioning #3 (See Table A.1)	To dry the sample and also increase the temperature.
4	Dry density.	
5	P46 at 50°C	To study the temperature susceptibility of stiffness.
6	P46 at ambient temperature	After the specimen has cooled down.
7	Soaking #2	
7	P46.	To study the moisture susceptibility.
8	Conditioning #3	To dry the sample.
7	P46 at ambient temperature	To study whether the stiffness loss due to soaking is recoverable.
7	UCS	If the sample is not significantly damaged by the triaxial tests.

The deliverables for this objective are:

- Database of field and laboratory testing results on Caltrans DISR-foamed asphalt projects built to date with available supporting design and construction data.
- Report on the first two sets of measured properties, pavement condition, traffic levels, and climate variables for each site, including variation within projects and comparison between projects.
- Periodic reports on the properties and performance of each project.

The initial and periodic reports will provide information regarding the semi-long term (2 to 6 years) development and seasonal fluctuation of stiffness and strength of the treated materials and the effects of traffic, environmental (temperature and water) and structural parameters (condition of layer above and below DISR-foamed asphalt layer) on foamed asphalt mix properties. The reports will also provide information on the relation between different methods for measuring stiffness, namely back-calculation from FWD, DCP, and triaxial.

4.2.4 Measurement of Properties on Future Caltrans DISR-Foamed Asphalt Projects

On projects to be built in the next year, the UCPRC will sample mixed and unmixed materials, remove cores and beams, and perform non-destructive tests during and just after construction.

The unmixed materials will be used for the laboratory testing to be performed as part of Objective 4.2.5. The mixed DISR-foamed asphalt materials will be used to fabricate beam and cylinder specimens at the site for laboratory testing. Mixed asphalt concrete from the overlay on the DISR-foamed asphalt will be sampled for later preparation of specimens to determine stiffness, fatigue and rutting properties. Cores of asphalt concrete overlay and foamed asphalt materials will be used to assess thickness as well as other properties. After construction sampling and testing, the UCPRC will add these projects to the list of projects to be monitored as part of Objective 4.2.3. This will provide vital in-service information on the foamed asphalt layer.

Candidate projects with testing details for this objective are shown in Tables 6-9.

Table 6: Potential future DISR-Foamed Asphalt projects

Section Name	Location	Mix Design	Date Constructed
Future Caltrans site	To be determined	To be determined	To be determined
Future UCD or local government site	To be determined	To be determined	To be determined

Table 7: Field testing and sampling plan for future projects

Type of Data	Test Method and Protocol	Collect frequency and time	Comment
Sampling of DISR-foamed asphalt unmixed material	RAP without stabilizing agents. California Test 125.	10 tonnes through duration of construction;	Raw material is reserved for later laboratory testing. Test aggregate temperature before and after milling
Sampling of field mixed asphalt overlay material	Sample 240 kg of field mix (12.5-gal buckets)	Once during construction	For fatigue tests (18 beam tests; 6 frequency sweep tests)
Sampling of foamed material before compaction	RAP with stabilizing agent - 10kg	Periodically during construction	To assess variability in RAP characteristics, especially aggregate type and grading
As-built layer thickness	Ground penetrating radar (GPR) DCP Cores ASTM D6951-03.	GPR: Once after construction. DCP: Once before construction and once after construction (mainly for subbase and subgrade info.)	The thickness variability in both longitudinal and transverse directions will be investigated.
Penetration rate	DCP. ASTM D6951-03.	Same as “Actual layer thickness”.	“Actual layer thickness” and “penetration ratio” use the same data but yield different deliverables. Tests on different days are desired to be performed in approximately the same time to minimize the influence of temperature.
Density	In-situ density by nuclear gage for DISR-foamed asphalt material (California test 231). Bulk	Same as “Actual layer thickness”. Test for all DCP holes.	Following DCP.

Type of Data	Test Method and Protocol	Collect frequency and time	Comment
	density from cores for overlay		
Moisture content	Nuclear gage. ASTM D3017.	Same as “Density”. Test for all DCP holes.	Following DCP.
Temperature (pretreatment)	Infra-red gun	Test across recycling width in front (surface) and behind recycler	At time of construction
Temperature	Thermal couple.	Same as “Density”. Test for all DCP holes.	Following DCP. For each DCP hole, measure temperature at pavement surface; AC-FTB interface; middle depth in FTB and FTB-SB interface.
Deflection	FWD ASTM D4694-96(2003).	3 days and 28 days after construction if traffic closure is available. Same locations as “penetration rate” but test before DCP. Test for all DCP holes.	It is expected that on day 3, no overlay has been put; on day 28, overlay has been built. Test schedule is subjected to change according to the actual construction schedule.

Table 8: Laboratory testing for future DISR-foamed asphalt projects

Type of Data	Test Method	Collect frequency/time	Comment
Cylinder sample	152mm diameter and 300mm height. LTPP P46 Collect fresh mix before compaction; jet hammer compaction to design density.	8 specimens each day of construction or per mix composition, if more than 1 mix type per day Select 4 days if construction duration is longer than 4 days.	One sampling area should be selected for all 8 specimens. Compaction on site at the same time of recycling. All compaction should be finished within 4 hours from mixing.
Beam sample	California Test 523	6 specimens each day of construction. Select 4 days if construction duration is longer than 4 days.	Compaction on site at the same time of recycling. All compaction should be finished within 4 hours from mixing.

The beams and cylinders listed in Table 8 will be cured under different laboratory conditioning regimes. Resilient modulus (cyclic triaxial) and UCS tests will be repeated to assess temperature and moisture susceptibility. Beam samples will be subjected to a fatigue beam test and/or strain-at-break (flexural beam) tests. The laboratory strength results will be compared for the different curing regimes to assess the sensitivity of strength or strain-at-break to curing. The laboratory stiffness results will be compared with the back-calculated stiffness results from deflection testing. The UCS results will be compared with the monotonic triaxial results to establish the reliability levels of simple UCS tests. Details of laboratory testing of the beams and cylinders and the curing regimes are included in Appendix A.

Specimens will also be studied under a scanning electron microscope to better understand the roles of each constituent and to assess stabilization mechanisms and key factors at a microscopic level. Valuable information has been obtained on specifically the roles of the asphalt and cement in similar studies in South Africa. The technique has not been documented elsewhere.

Table 9: Supporting data to be collected for short term investigations

Type of Data/Sample	Specific Test or Sample	Frequency
From Caltrans headquarters, district offices or city engineer offices		
Conditions before rehabilitation.	The original structural and mix design; failure modes.	Once.
As design information.	Structural and mix design for rehabilitation.	Once.
Design traffic	Expected average monthly traffic.	Once.
As built record	Actual mix ratio; density achieved and other information.	Once.

The deliverables for this objective are:

- A database of field and laboratory test results on future Caltrans DISR-foamed asphalt projects with available supporting design and construction data.
- A report on as-built information and the measured properties for the first 28 days after construction, together with comparisons of results from previous projects and variation within each project.
- A report on the laboratory testing of sampled materials. The report will include:
 - Laboratory stiffness, strength, permanent deformation and their susceptibility to moisture, temperature and curing regime
 - Comparison of different stiffness testing methods including back-calculation from FWD deflections, DCP, and triaxial
 - Overlay fatigue and laboratory stiffness as a function of time of loading and temperature
 - Estimates of the cracking and permanent deformation life of the pavement for comparison with future performance observations.

4.2.5 Laboratory Testing to Identify Key Issues of Foam Treatments

The results obtained to date from the literature survey, mechanistic sensitivity analysis, and testing and analysis of existing field projects have been used to develop the following plan for laboratory testing. Those results indicate the following:

- Critical properties for DISR-foamed asphalt materials include:
 - Stiffness
 - Permanent deformation resistance
 - Fatigue resistance
 - Shrinkage
 - Temperature sensitivity
 - Water sensitivity
- The requirements for each of these properties depend on:
 - Design traffic
 - Stiffness of layers beneath the DISR-foamed asphalt layer
 - Presence of cemented/asphalt layers below the DISR-foamed asphalt layer
 - Thickness of DISR-foamed asphalt layer
 - Overlay thickness and stiffness
- DISR-foamed asphalt takes on the typical characteristics of a granular, asphalt-bound or cemented material depending upon the mix design, specifically the quantities and interaction of the parent material and its residual asphalt, added foamed asphalt, cement and other added materials. The importance of the critical properties listed above depends on which of these material types a given mix resembles, as shown in Table 10.

- By considering this broad range of DISR material types the mix design and structural design requirements developed in this research will help harmonize the procedures for all cold in-place recycling (CIPR).

Table 10: Summary of critical properties for different material types

Property	DISR-Foamed Asphalt Material Behavior Type		
	Granular (minimal asphalt and cement content)	Asphalt-bound (greater asphalt content)	Cemented (greater cement content)
Stiffness	Important	Important	Important (depends on thickness)
Permanent deformation resistance	Important	Important	Not Important
Fatigue resistance	None	Important	Important
Shrinkage	None	Not important for low cement contents	Important
Permeability	Important	Important	Important
Water sensitivity	Important	Important	Important
Temperature sensitivity	Not important	Important	Important

The objective of the laboratory testing plan will be to:

- Identify the most appropriate laboratory specimen preparation methods and tests to measure each of the identified properties
- Determine the relationships between the responses of each test to the mix variables
- Determine the relationships between laboratory and field measured properties
- Determine the effect of the following variables on the properties listed in Table 10 for DISR-foamed asphalt materials with RAP as the parent material:
 - Asphalt source
 - RAP gradation
 - RAP binder content and age
 - Percentages and type of active filler (cement, lime, fly-ash) and foamed asphalt
 - Aggregate (RAP) mixing temperature

- Compaction method
- Relative density
- Curing conditions
- Moisture conditioning
- Temperature
- Identify which curing conditions most closely match field cured materials in terms of stiffness

Typical procedures in TG2, the Wirtgen guideline and in mix designs commonly used by Caltrans to date are shown in Table 11.

Table 11: TG2 and Wirtgen guideline specimen preparation and testing

Test Concern	Initial configuration
Foaming property	Maximum Foamability Index (FI)
Compaction requirement	Marshall compaction for ITS and UCS, 90% maximum density or compaction energy control.
Curing condition (for short term)	24 hours ambient unsealed then 3 days at 40°C sealed in an oven.
Asphalt content	2.5%
Cement content	1%
Test method and criteria	Indirect Tensile Strength (ITS) and Unconfined Compressive Strength (UCS)
Grading	Mineral fines added to obtain 0.45 power function on <2mm fraction

4.2.5.1 Asphalt foamability characterization for California asphalts

The purpose of this objective is to characterize the foamability characteristics of the typical range of asphalts expected to be used in California. Some preliminary testing has already been performed (Saleh, 2003). The experiment design is shown in Table 12. Suppliers will be requested to supply binders with no anti-foaming agents.

Table 12: Experiment design for asphalt foamability

Variable	No of values	Values
Asphalt source	2	Valley, Coastal
Asphalt Grade	2	PG 64-10, PG 64-16
Asphalt Temperature (°C)	5	140, 150, 160, 170, 180
Water/Asphalt Ratio (%)	5	1, 2, 3, 4, 5
Replicates	1	
Total Number of Foamability Tests	100	

The deliverable for this objective will be a technical memorandum summarizing expansion ratio and half life of foam for a range of asphalts available in California.

4.2.5.2 Asphalt Binder Source

The purpose of this objective is to characterize asphalts available in California in terms of their performance in a range of tests using foamed asphalt. The experiment design is shown in Table 13.

Table 13: Experiment design for asphalt binder source and grade

Variable	No of values	Values
Asphalt Source	2	Valley, Coastal
Asphalt Grade	2	PG 64-10, PG 64-16
Temperature susceptibility of stiffness (°C)	2	20, 40
Fixed values		
Asphalt content (%)	1	2.5
RAP source and gradation	1	Mineral fines only*
Active filler	0	No active filler tested
Compaction	1	Vibrating hammer
Curing method	1	TG2
Replicates	3	
Tests		
Flexural strength and strain at break	24	
Unconfined compressive strength, stiffness & shrinkage	24	
Triaxial stiffness	24	
No of specimens		
Flexural strength	24	
Unconfined compressive strength	24	
Triaxial	24	

* Mineral fines added to obtain 0.45 power function on <2mm fraction

The deliverable for this objective will be a technical memorandum summarizing the performance of the various sources of asphalt in foamed asphalt laboratory applications.

4.2.5.3 RAP Source and Gradation

Gradation analysis will be performed on RAP parent material sampled from Objective 4.2.4 projects and used with gradation analysis from District 2 “pulverization” projects (PPRC Strategic Plan 2.4.2) to define the range of typical gradations of parent material for DISR. Five gradations will be selected from the gradation analysis, one each on the coarse, middle and fine sides of the set measured and a further two with added millings and added fines (sourced from a local crusher). The preliminary experimental design is shown in Table 14.

Table 14: Experiment design for RAP source and gradation

Variable	No of values	Values
Rap Source	2	Two different projects
Aggregate gradation*	5	coarse, medium, fine, fine + millings, fine + dust
Fixed values		
Asphalt content (%)	1	2.5
Active filler content (%)	0	No active filler tested
Binder source and type	1	From Exp 4.2.5.2
Compaction	1	Vibrating hammer
Curing method	1	TG2
Replicates	3	
Tests		
Flexural strength	30	
Unconfined compressive strength	30	
Triaxial stiffness	30	
Monotonic triaxial test (kPa confining stress)	40	50, 100, 150 and 250
No of specimens		
Flexural strength	30	
Unconfined compressive strength	30	
Triaxial	70	
* Mineral fines added to obtain 0.45 power function on <2mm fraction		

The deliverable for this objective will be a technical memorandum detailing the characteristics of the RAP sources investigated and the potential implications of these differences in mix and structural designs. Key tests that need to be undertaken to assess a source will be listed.

4.2.5.4 Compaction Method

A range of laboratory compaction methods will be assessed in order to identify that most representative of field conditions. The preliminary experimental design is shown in Table 15.

Table 15: Experiment design for compaction method

Variable	No of values	Values
Asphalt Content (%)	2	2, 4
Compaction method*	4	Michigan (Hugo), mod Proctor, vibrating*, Gyrotory**
Fixed values		
Specimen size (diameter in mm)	1	150
Relative density (%)	1	100
Active filler	0	No active filler tested
Binder source and type	1	From Exp 4.2.5.2
Rap source and gradation	1	From Exp 4.2.5.3
Curing method	1	TG2
Replicates	3	
Tests		
Unconfined compressive strength	24	
Triaxial stiffness tests (2 replicates)	24	

Variable	No of values	Values
Monotonic triaxial test (kPa confining stress)	32	50, 100, 150 and 250
No of specimens		
Unconfined compressive strength	24	
Triaxial	56	
* Nottingham vibrating hammer procedure		
** The gyratory compactor has been considered in this experiment as this method might be consider for wider use in California in the future. It is also used by many other states in foamed asphalt research		

The deliverable for this objective will be a technical memorandum summarizing the study with recommendations for laboratory compaction procedures.

4.2.5.5 Active Filler Type and Content

A range of active fillers (cement, lime and fly-ash) and filler/binder contents will be assessed in order to obtain a better understanding of how different fillers and filler/binder combinations influence the strength and moisture sensitivity of the RAP material. This study will be carried out in two phases. The first will assess the influence of the various combinations on strength and stiffness. The findings of this phase will be used as a basis for carrying out fatigue tests to assess the influence that the fillers have on this attribute. The preliminary experimental designs are shown in Tables 16a and 16b.

Table 16a: Experiment design for active filler

Variable	No of values	Values
Asphalt content (%)	2	3, 4
Water conditioning	2	With and without
Filler type		
Cement content (%)	2	1, 2
Fly-ash content (%)*	2	3, 4
Lime content (%)**	1	1.5
Fixed values		
Binder source and grade	1	From Exp 4.2.5.2
RAP source and gradation	1	From Exp 4.2.5.3
Compaction	1	From Exp 4.2.5.4
Curing method	1	TG2
Replicates	3	
Tests		
Flexural strength	60	
Unconfined compressive strength	60	
Triaxial stiffness	60	
No of specimens		
Flexural strength	60	
Unconfined compressive strength	60	
Triaxial	60	
* Combinations of fly-ash and cement and fly-ash and lime are not considered as this would significantly increase construction activity and cost		
** Only one lime content is considered as a study on the use of lime in RAP as aggregate base is included in PPRC Strategic Item 2.4.2		

Table 16b: Experiment design for active filler - fatigue testing

Variable	No of values	Values
Water conditioning	2	With and without
Active fillers		
Cement content (%)	1	From Exp in Table 16a
Lime content (%)*	1	1.5
Fly-ash content (%)**	1	From Exp in Table 16a
Fixed values		
Asphalt content (%)	1	2.5
Binder source and grade	1	From Exp 4.2.5.2
RAP source and gradation	1	From Exp 4.2.5.3
Compaction	1	From Exp 4.2.5.4
Curing method	1	TG2
Replicates	3	
Tests		
Fatigue	18	
No of specimens		
Fatigue	18	

The deliverable for this objective will be a technical memorandum summarizing key issues pertaining to the role of active fillers in potential performance, together with preliminary recommendations for their use.

4.2.5.6 Curing Conditions

A range of curing conditions will be assessed in order to obtain a better understanding of critical factors in the early life of a recycled pavement. The preliminary experimental design is shown in Table 17a. An additional testing sequence will be carried out to assess the implications of opening the road to traffic at different times. A permanent deformation test will be used. The experiment design is shown in Table 17b. The experimental design may be altered depending on the findings of field studies conducted to understand this parameter.

Table 17a: Experiment design for curing

Variable	No of values	Values
Time (hours)	2	72, 240
Temperature (°C)	2	25, 40
Containment	2	Sealed and unsealed
Active filler content (%)	2	From Exp 4.2.5.5
Fixed values		
Asphalt content (%)	1	2.5
Binder source and grade	1	From Exp 4.2.5.2
RAP source and gradation	1	From Exp 4.2.5.3
Compaction	1	From Exp 4.2.5.4
Replicates	3	
Tests		
Triaxial stiffness	48	
Free shrinkage	48	
No of specimens		
Triaxial	48	

Table 17b: Experiment design for effect of curing on permanent deformation

Variable	No of values	Values
Time (hours)	4	6, 24, 72, 240
Active filler content (%)	2	From Exp 4.2.5.5
Asphalt content (%)	2	2,3
Fixed values		
Temperature (°C)	1	Determined from 17a results
Containment	1	Determined from 17a results
Binder source and grade	1	From Exp 4.2.5.2
RAP source and gradation	1	From Exp 4.2.5.3
Compaction	1	From Exp 4.2.5.4
Replicates	2	
Tests		
Cyclic triaxial	16	
Free shrinkage	16	
No of specimens		
Triaxial	16	

The deliverable for this objective will be a technical memorandum summarizing key issues influencing curing, together with a preliminary recommendation for a curing procedure. This will be expanded as additional information from field studies is collected and linked to laboratory performance.

4.2.5.7 Aggregate (RAP) Mixing Temperature

In this task, the influence of the aggregate temperature during mixing on performance will be assessed. The experiment design is shown in Table 18.

Table 18: Experiment design for aggregate mixing temperature

Variable	No of values	Values
Aggregate (RAP) temperature (°C)	3	5, 20 and 35
Foaming agents	1	Commercially available foaming agent
Foaming agent application rate (%)	2	0 and supplier recommended
Fixed values		
Asphalt content (%)	1	2.5
Active filler	1	From Exp 4.2.5.5
Binder source and grade	1	From Exp 4.2.5.2
RAP source and gradation	1	From Exp 4.2.5.3
Compaction	1	From Exp 4.2.5.4
Curing	1	From Exp 4.2.5.6
Replicates	3	
Tests		
Flexural strength	18	
Unconfined Compressive Strength	18	
Triaxial stiffness	18	
No of specimens		
Flexural strength	18	
Unconfined Compressive Strength	18	
Triaxial stiffness	18	

The deliverable for this objective will be a technical memorandum detailing the influence of the aggregate temperature of the RAP on laboratory performance. Recommendations on revised testing procedures will be provided if this is found to be a significant factor.

4.2.5.8 Beam Fatigue

Experiments designs for beam fatigue life in terms of controlled strain (small beam) and controlled stress (large beam) are shown in Tables 19 and 20 respectively. The large beam fatigue tests will facilitate a correlation with the smaller beam fatigue tests at different particle size to specimen ratios.

Table 19: Experiment design for beam fatigue life (controlled strain)

Variable	No of values	Values
Active filler content (%)	2	From Exp 4.2.5.5
Asphalt content (%)	2	2, 3
Relative Density (%)	2	97, 102
Strain level	2	To be determined
Fixed values		
Binder source and grade	1	From Exp 4.2.5.2
RAP source and gradation	1	From Exp 4.2.5.3
Compaction	1	From Exp 4.2.5.4
Curing	1	From Exp 4.2.5.6
Replicates	3	
Tests		
Fatigue beam	48	
Frequency sweeps (2 reps at 1 strain level)	16	Range of temperatures and frequencies
No of specimens		
Fatigue beam	64	

Table 20: Experiment design for beam fatigue life (controlled stress)

Variable	No of values	Values
Asphalt content (%)	2	2, 3
Stress level	2	To be determined
Fixed values		
Active filler content	1	From Exp 4.2.5.5
Relative density	1	100
Binder source and grade	1	From Exp 4.2.5.2
RAP source and gradation	1	From Exp 4.2.5.3
Compaction	1	From Exp 4.2.5.4
Curing	1	From Exp 4.2.5.6
Replicates	3	
Tests		
Fatigue beam	12	
No of specimens		
Fatigue beam	12	

The deliverable for this objective will be a technical memorandum detailing the influence of different stress and strain rates on beam fatigue life. Recommendations on testing procedures will be provided.

4.2.5.9 Analysis of results

Results of each of the preceding laboratory objectives will be analyzed to address the following issues:

- Statistical sensitivity of materials properties to variables in the experiment design
- Where possible, development of regression models of the property as a function of the statistically important variables
- Selection of the most appropriate option for the next set of tests for the initial experiments (asphalt foamability, asphalt binder source, RAP source and gradation, compaction method, curing conditions and RAP aggregate temperature).

4.2.5.10 Summary of Materials, Specimens and Tests for Laboratory Study

A summary of the materials, specimens and tests for the laboratory study is provided in Table 21.

Table 21: Experiment summary

Type of test, specimen or material	Total across all experiments	
No. of tests		
Foaming properties	100	
Flexural strength	132	
Unconfined compressive strength	156	
Triaxial stiffness	204	
Monotonic triaxial	72	
Free shrinkage tests on UCS specimens	156	
Cyclic triaxial	16	
Fatigue beam tests (small-strain controlled)	82	
Fatigue beam tests (large-stress controlled)	12	
No. of specimens		
Flexural strength specimens	132	
UCS specimens	156	
Triaxial specimens	268	
Fatigue beam tests (small-strain controlled)	82	
Fatigue beam tests (large-stress controlled)	12	
Materials required*		
	kg	lb
RAP**	11 350	25 050
Asphalt**	500	1101
Cement**	250	550
Lime**	100	220
Fly ash**	100	220
*assumes 50 percent of specimens wasted due to wrong density, wasted material, etc.		
**total quantities across all grades, sources, etc.		

4.2.6 Mix Design Recommendations

A standardized mix design procedure for routine project level design will be presented. First, based on the results of Task 2.5, a viable range of mix design variables will be prescribed to control the risks of premature cracking, crushing, high susceptibility to temperature and moisture. Then standardized simple test procedures and target properties will be suggested to optimize the mix design. For important projects with higher design requirements, more reliable and sophisticated tests will be suggested; while for projects with lower design requirements, an empirical relation between mix design variables and target properties, including variability information will be proposed.

4.2.7 Construction Recommendations

Guidelines for construction of DISR-foamed asphalt will be developed based on the results of Objectives 4.2.1 through 4.2.5. The experience of Caltrans staff involved in projects completed to date will also be documented through interviews, with the intent to capture “lessons learned” and “what to do on the site”. The guideline will include:

- Recommendations for variables that should be tested on the site
- Variables that cannot be tested but that should be monitored
- A summary of checklist items that construction staff must manage
- A spreadsheet for documenting required information from the project.

Guidelines for construction will be suggested based on the analysis of risks identified in the literature survey, laboratory testing, HVS testing, field investigations and especially, prematurely failed case history analysis. This will include both general guidelines to avoid risks of improper construction and suggested in-situ test procedures for quality control and quality analysis.

4.2.8 Structural Design Recommendations

A structural design procedure and guideline will be suggested. First, criteria will be presented to identify suitable projects for deep in-situ recycling with foamed bitumen stabilization. Structural design models will be used to determine the performance, especially the expected life of pavement structures from the properties quantitatively measured in the mix design. For low reliability requirement projects, empirical design equations will be suggested. At the same time, structural design models will also instruct the optimizing procedure in mix design when a certain performance requirement is expected.

Ultimately, structural performance models for mechanistic-empirical (ME) design methods will be developed. In the interim, gravel factors will also be proposed and will be developed based on ME analysis.

Based on the knowledge obtained from the test program, specifically the basic performance models, life cycle cost analysis will be undertaken on the three general categories of treated materials. The optimal stabilization strategy or applicable conditions for each strategy will be determined and subsequent research will mainly be focused on this selected strategy. When laying out the detailed work plan, it is assumed that the highly asphalted material is the optimal strategy; fatigue cracking in the treated base is the major distress mode followed by permanent deformation and AC overlay fatigue.

4.3 Risks for Deliverables

The risk for the deliverables of Objective 4.2.3 is that original mix design, structural design and as-built records are not available. Delays in obtaining those data will delay the data analysis even if the field tests had been successfully performed. The UCPRC will have to rely on Caltrans staffs responsible for those projects to provide all available information.

The risk for Objective 4.2.4 is that Caltrans may not have any new DISR-foamed asphalt projects go to construction in the next construction season. The contingency plan is to work with counties, cities and UC Davis campus that may have DISR-foamed asphalt projects in the next year that

are similar in character to typical Caltrans projects. This contingency will need to be used to obtain a second source of parent RAP material. UCPRC will work with appropriate agencies and contractors to complete this plan for the one (if one Caltrans project is completed) or two projects that may be required.

On the Caltrans or local government projects the UCPRC will need to have the grinding machine move forward without injecting stabilizing agents (foamed asphalt and cement) for a sufficient distance to sample sufficient quantities of RAP material for later laboratory testing. This will require cooperation of the Resident Engineer and the Contractor. UCPRC may need to compensate the Contractor for any additional costs incurred. Two final contingencies in the event that sufficient RAP cannot be obtained from DISR-foamed asphalt projects in the next year are:

- To use grindings from a District 2 pulverization project scheduled for the summer of 2006, which will require Caltrans/Contractor cooperation, or
- Use RAP from millings bought from a contractor and regrade it to match typical DISR-foamed asphalt gradations. The risk in this contingency is that millings have more exposed aggregate faces and sub 0.075 mm sieve particles than RAP from DISR and therefore perform differently in the laboratory testing.

The risk for the deliverable of Objective 4.2.7 is that Caltrans staff from DISR-foamed asphalt projects are unavailable to be interviewed.

5.0 TEST METHODS

The field and laboratory test methods to be used in this research are summarized below. It should be noted that most test procedures were originally developed for other materials such as hot mix asphalt or portland cement concrete. Their applicability and validity for foamed asphalt need further study, which is part of the scope of this work plan. The test procedures will be modified where necessary to better characterize the properties of foamed asphalt mixes. The modified test procedures included in the mix design suggestions will be a deliverable of the proposed research.

- Air and Pavement temperature will be measured during deflection tests and other tests if applicable.
- Climate Data will be collected from local data sources, or National Climate Data Center if available in time
- Dynamic cone penetration, determined with a Dynamic Cone Penetrometer, will be used to measure the penetration rate of the underlying pavement layers. Strength, Young's modulus and density can be correlated to penetration rate for certain materials using ASTM D6951-03.
- Deflection, determined with a Falling Weight Deflectometer (FWD) will be used to assess the integrity of pavement structures before and after recycling. The back-calculation of FWD data is used to estimate the in-situ elastic modulus of each pavement layer from the deflection basin. ASTM D4694-96(2003) will be followed.
- Layer Thickness will be determined from cores.
- Traffic Index or Average Daily Traffic will be obtained from the pavement management systems database.
- RAP Gradation will be determined after an appropriate test has been identified. There is currently no standard test method and conventional sieve analysis (California Test 202)

might be inappropriate. Sieve analyses on aggregates retrieved after determination of binder content by the Ignition Oven Method (California Test 382) is being considered. A simplified method applicable to routine project level mix design is expected to be a deliverable of this proposed research.

- 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.
- Fatigue resistance will be determined by applying repetitive bending loads to a simple beam specimen (380 x 50 x 63 mm). It has been reported in South Africa that this test is not applicable to foamed asphalt mixes as they have virtually no measurable fatigue resistance. However successful testing has been reported in Australia. AASHTO Designation: T 321-03 will be followed.
- Flexibility or strain-at-break determines the flexural strength (stress-at-break) or flexibility (strain-at-break) by loading a simple beam specimen with third-point loading monotonically. AASHTO T97-03 (for PCC) will be followed.
- Indirect tensile strength is an additional strength test determined using indirect loading techniques and is similar to resilient modulus by indirect tension used to measure the strength of bituminous mixes. AASHTO T322-03 will be followed.
- Unconfined compressive strength is the uniaxial compressive strength of a cylinder sample without confining pressure and is typically used for assessing lime and cement treated materials. AASHTO T167-05 or California 373 will be followed. Free shrinkage following ASTM C 157-93 will be determined as part of this test, but keeping in mind that method was originally developed for lime, cement and concrete treatments measures.

- Resilient modulus will be determined by cyclic triaxial and indirect tension tests. In the triaxial tests different confining pressures and deviator stresses will be used. Long-Term Pavement Performance Protocol P46 and ASTM-D4123-82 will be followed for each test respectively.
- Moisture susceptibility will be determined with a number of tests. Measured properties, including fatigue resistance and flexibility and indirect tensile strength, of specimens that have been subjected to water saturation, accelerated water conditioning and freeze-thaw cycles will be compared with measured properties from samples tested in the dry state. Change in the properties is regarded as water-induced damage.

6.0 COSTS

The cost estimate is shown in Figure 1. The risk for cost is the potential need to compensate the contractor for time lost during sampling of RAP. It is doubtful that this will be more than several thousand dollars. There is a risk that the traffic closure will cost more than shown, and that insufficient funds will be available to perform the traffic closures.

Estimated Costs for First Two Years												
all costs are fully loaded w/ bens & overhead			Objective person/month assignments									
Cost Item	unit	\$/unit	Lit survey & tech scan#	Mech Sensitivity Analysis#	Assess Projects Built to Date##	Measure Projects to be Built in the Future	Laboratory Testing	Mix Design Recommend	Construction Recommend	Structural Design Recommend	TOTAL	
PPRC												
Princ Investigator*	mo	\$ 8,580	0.1	0.25	0.5	0.5	1	1	1	1	\$ 45,903	
Project Engineer (Phd)	mo	\$ 9,753			0.5	0.5	1	2	2	2	\$ 78,027	
Phd Grad Student	mo	\$ 2,888	2	3	1	1	15	1.5	1.5	1.5	\$ 76,519	
MS Grad Student	mo	\$ 2,200					4				\$ 8,800	
Staff Engineers	mo	\$ 7,828			1.5	0.5	3	0.15	0.15	0.15	\$ 42,664	
Editor	mo	\$ 7,828	0.1				0.25	0.15	0.15	0.15	\$ 6,263	
Database engineer	mo	\$ 7,828			0.5	0.25	1	0.02	0.02	0.02	\$ 14,169	
Lab tests crew	mo	\$ 8,000					9				\$ 72,000	
Sampling or Deflection Field Crew	mo	\$ 8,000			1	0.5					\$ 12,000	
<u>Staff subtotal</u>											<u>\$ 356,345</u>	
Field Travel & expense	pers-day	\$ 150			\$ 6,000	\$ 2,700					\$ 8,700	
										Total=	\$ 365,045	
*salary portion paid by PPRC												
Equipment (including overhead)				\$ 2,200								\$ 2,200
Equipment details w/o overhead												
compaction molds & other misc				\$ 2,000								
Traffic closures**	day	\$ 3,000				\$ 60,000						\$ 60,000
** 5 sites x 2 years (2 per year)					20							
										TOTAL=	\$ 427,245	
# task nearly complete already												
## task about half completed												

Figure 1. Cost estimate for project

7.0 SCHEDULE

The schedule is summarized in Figure 2. Adherence to the schedule might be influenced by the following:

1. Delays in traffic closures. The cost of traffic closures will need to be covered with an existing expenditure account available to Caltrans Maintenance, or permits will be need to obtained for contract closures.
3. Availability of RAP material. The UCPRC is relying on Caltrans, local government and contractors to cooperate in arranging sampling of sufficient unmixed RAP materials for laboratory experiments.

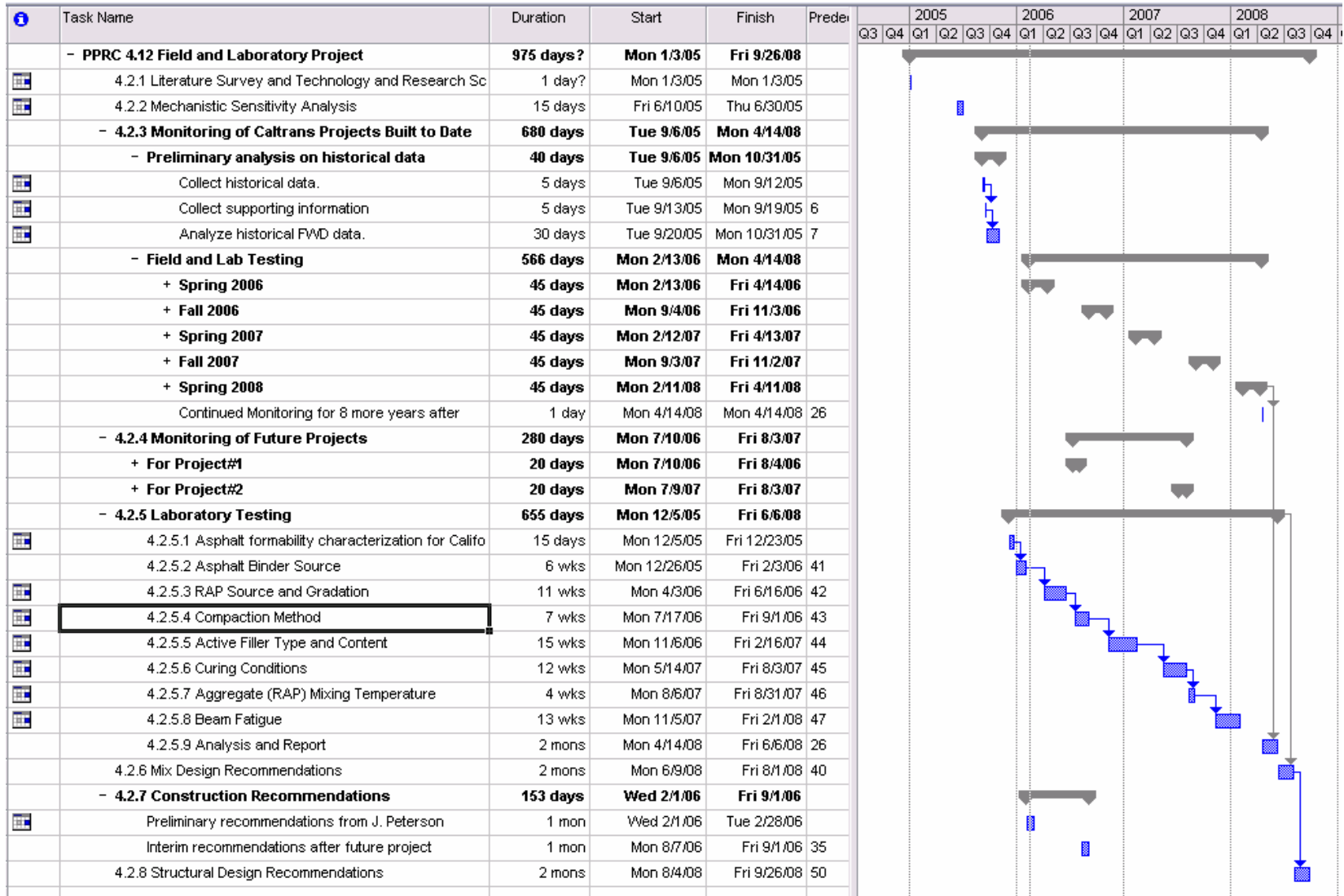


Figure 2. Project schedule.

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