Partnered Pavement Research Center

Annual Report

Fiscal Year 2021-2022

California Department of Transportation/
University of California Pavement Research Center

Caltrans

UCPRC
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Davis • Berkeley
PAVEMENT RESEARCH CENTER


ELITE

About the Partnered Pavement Research Center

The Partnered Pavement Research Center (PPRC) is operated by the California Department of Transportation (Caltrans) and the University of California Pavement Research Center (UCPRC).

Caltrans Mission

Provide a safe and reliable transportation network that serves all people and respects the environment.

UCPRC Mission

Provide the timely, high-quality data, analysis, and technology needed to support decision-making by the California Department of Transportation (Caltrans) and other partners.

Caltrans Vision

A brighter future for all through a world-class transportation network.

UCPRC Vision

Caltrans and other partners will have continuously improving state-of-the-art pavement technology to maximize the level of service to all users of California's pavements, while optimizing the results from expenditures on pavement infrastructure and minimizing the environmental impacts. These goals will be accomplished by strategic planning for current and future challenges and opportunities, and execution of projects from idea to implementation through conceptual studies, research, development, implementation support, and operational support.

Welcome to the FY 2021-2022 Annual Report for the Partnered Pavement Research Center!

The following are highlights of work that the Caltrans/UCPRC Partnered Pavement Research Center (PPRC) started, completed, or implemented during the last fiscal year:

Updates to CalME mechanistic-empirical design method for asphalt surfaced pavements based on outside critical review and continued feedback from Caltrans.

In this fiscal year, outside critical review of the *CalME* software and its results was solicited anonymously from experts in all pavement industries and through a task order to NCE, in addition to continued feedback from Caltrans technical experts and users. Updates and improvements to *CalME* were begun based on the comments and will be completed in the next fiscal year, leading to publication of an updated production version of *CalME*. A new model was added to *CalME* for consideration of strains from changes in temperature in the asphalt contributing to fatigue and reflective cracking.

Use of performance-related specifications (PRS) and new testing methods for asphalt materials for the reconstruction of Interstate 5 through Sacramento.

The UCPRC continued support during the second year of the Interstate 5 Sacramento AC Long Life project, including the second-year job mix formula approval and continued quality control/quality assurance testing. This year the construction quality performance-related test was changed from I-FIT to IDEAL-CT.

Comparison of rubberized hot mix asphalt-gap graded (RHMA-G) gradations, and use of recycled asphalt pavement (RAP) in RHMA-G and RHMA-G thickness.

Heavy vehicle simulator (HVS) testing and analysis were completed on five of seven HVS test sections before supply chain difficulties with replacement HVS parts stopped the testing. Laboratory testing and analysis and *CalME* simulations were also completed to make preliminary recommendations regarding the use of RAP in RHMA-G, the use of increased RHMA-G surface thicknesses, and the use of different aggregate gradations in RHMA-G.

New RHMA materials with recycled asphalt pavement (RAP)/recycled asphalt shingles (RAS) for interlayers and base for rigid pavements.

A full-scale test track was built at the Davis site of the UCPRC in May and June 2022. The instrumented test track includes full-scale concrete slabs on either RHMA-G or lean concrete base

(LCB), including different slab-LCB interlayers (curing compound, microsurfacing, and geotexile) intended to reduce tensile stresses in the concrete.

Updated Caltrans rigid pavement design catalog using Pavement ME.

Design tables for thin concrete overlays on asphalt (COA), jointed plain concrete pavement (JPCP), and continuously reinforced concrete pavement (CRCP) were completed using *Pavement ME* (version 2.5.5) and summary reports were produced for each design option. Potential problems with *Pavement ME* CRCP design calculations were identified. A database of the results was used to prepare a beta version web catalog for COA and JPCP.

Concrete coefficient of thermal expansion moisture-dependency and tensile creep.

Work started on a new project that will produce a framework for modeling the structural response of concrete pavements under thermal and drying shrinkage actions, including experiment design and equipment setup. Concrete mixtures being tested include typical concrete mixtures used by Caltrans and several alternative mixtures.

Alternative supplementary cementitious materials (SCM) sources.

Work began on this new research project to identify and provide an initial assessment of performance, environmental impact, cost, technology readiness, and availability in California of potential alternative SCM sources. A total of 14 sources were identified and are currently being assessed.

Updated guidance and specifications for in-place recycling (IPR).

HVS testing was completed on two sections (one with asphaltic emulsion and one with foamed asphalt). Satisfactory performance was observed on both sections. The addition of supplemental fines to partial-depth recycling (PDR) and cold central plant recycing (CCPR) projects to improve strength and raveling resistance was tested on a pilot project in Glenn County. Two other completed pilot studies compared emulsified and foamed asphalt recycling agents and compared procedures to reduce maximum size of the recycled aggregates. A new, comprehensive IPR guideline was published, and the UCPRC participated in statewide IPR training.

Guidance, tests, and specifications for high RAP/RAS contents in hot mix asphalt (HMA) and RHMA mixes.

The testing of mixes with high RAP content that had been subjected to different amounts of time aging in the silo was completed. Materials from the first high RAP/RAS pilot project were sampled and tested this fiscal year on State Route 49 in El Dorado County, and a report was delivered to Caltrans. The mixes included 0% RAP, 15% RAP, 25% RAP, 35% RAP, 45% RAP, and 3% RAS with 10% RAP. The properties of the mixes with high recycled contents were generally similar to those of the control mix with no RAP.

Environmental life cycle analysis (LCA) updates and applications.

The updated life cycle models and data for the material and construction stages and transportation from 2019 and 2020 were implemented in the Caltrans pavement LCA tool, *eLCAP* (*environmental Life Cycle Assessment for Pavements*), this fiscal year. Reports and technical memoranda were updated based on critical review and published on the UCPRC life cycle inventories (LCIs) used in *eLCAP*, pavement structural response and vehicle fuel use empirical modeling, modeling of the effects of construction work zones on vehicle fuel use, and lessons learned from the Caltrans environmental product declaration pilot project. In addition, a draft report was prepared on the effect of pavements on electric vehicles and their batteries.

Implementation of environmental LCA data and models for project-level use in the eLCAP software.

The *eLCAP* software was updated with models; data for materials, construction, use stage, and end-of-life stage were added; and a case study was completed. An outside expert critical review panel of three international experts reviewed the LCI data and models report and the *eLCAP* user manual and technical report, and the reports were updated and submitted to Caltrans. *eLCAP* training material was developed.

Updates and improvements to RealCost-CA.

The maintenance and rehabilitation (M&R) schedules for both asphalt and concrete pavements were updated using the current Caltrans mechanistic-empirical approaches (*CalME* and *Pavement ME*) for cracking and the pavement management system (*PaveM*) models for roughness. The M&R schedules had previously been based on judgment. Maintenance costs were updated, historical discount rate trends were investigated, and a method to update the discount rate for LCCA was proposed. Traffic delay models in *RealCost* were updated. *RealCost 2.5CA* was updated to be compatible with Microsoft Office 64-bit. *RealCost 3.0CA* was completely debugged and prepared for launch in summer 2022.

Continued support to Caltrans operations of the pavement management system (PMS), mechanistic-empirical (ME) design, life cycle assessment (LCA), and life cycle cost analysis (LCCA) software and guidance.

This support task provides real-time help for questions from software users, updating of software in response to user comments, and development and periodic updating of guidance documents and training. The UCPRC provided extensive support for rewriting of the Caltrans *Highway Design Manual* to reflect updated practice using ME design and performance-related specifications. The *Site Investigation Guide for Mechanistic-Empirical Design of California Pavements* was completed and delivered to Caltrans. The guide provides details for desk and field studies, sampling, and testing needed to help finalize project plans and provide inputs for ME design of both asphalt and concrete pavements.

Continued operation of the calibration and certification centers for Caltrans and industry smoothness and falling weight deflectometer (FWD) testing personnel and equipment.

The UCPRC provided staff for testing, calibration data analysis, and certifications of profilers at the profiler certification test section in Sacramento and the FWD certification center at the UCPRC research site in Davis. Three FWDs were calibrated. Profiler testing and certification this fiscal year included 37 Caltrans, 67 industry, and 4 UCPRC operators; 15 Caltrans and 27 industry vehicles; and a UCPRC vehicle.

The following sections of this annual report includes updates on current projects and summaries of reports published during FY 2021-2022.

The UCPRC staff, students, and faculty and Caltrans staff will continue to work together to improve pavements, enhance their contributions to the quality of life across California, and reduce their environmental impacts.

John Harvey, Director and Principal Investigator, UCPRC
David J. Jones, Associate Director and Co-Principal Investigator, UCPRC
Jeremy D. Lea, Co-Principal Investigator, UCPRC
Somayeh Nassiri, Co-Principal Investigator, UCPRC
Angel Mateos, UC Berkeley Director and Co-Principal Investigator, UCPRC
UCPRC staff and students

SON 116 STA 132
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Introduction: Pavement Research Processes and Status

This annual report provides an overview of the strategic plan, research roadmaps, current research areas, and projects for the Caltrans/UCPRC Partnered Pavement Research Center (PPRC) and progress over FY 2021-2022.

Strategic Planning and Contract Development Process and Documents

Caltrans and the UCPRC have a robust process for working with industry and other partners to strategically identify, prioritize, plan, and communicate how to solve current and future challenges and take advantage of opportunities. The main strategic planning process is conducted as part of the preparation of each PPRC contract, typically every three years. The strategic planning documents are reviewed and updated as needed on an interim basis during the three-year contracts.

Strategic Planning Elements

The **Strategic Planning Process** is managed by the Caltrans Division of Research, Innovation and System Information (DRISI); the Caltrans Division of Maintenance/Pavement Program; and the UCPRC. The outcomes of this process include updated and new Pavement Research Roadmaps and a prioritized list of projects for inclusion in the three-year contract.

The **Pavement Research Roadmaps** include one roadmap for each Caltrans strategic goal. Each roadmap identifies the scope and vision of the strategic goal; projects needed for conceptual studies, research, development, and implementation support to achieve the vision; and progress toward the vision in terms of completed, current, and next projects.

The **Partnered Pavement Research Center Contract** shows all research, development and implementation projects, support tasks for Caltrans operations, and project support tasks.

Current Pavement Research Roadmaps[1]

- Mechanistic-Empirical Design of Asphalt Pavement
- Mechanistic-Empirical Design of Concrete Pavement
- In-Place and Cold Central Plant Recycling
- Performance-Related Specifications for Concrete Including Construction Quality Assurance/ Quality Control (QA/QC)

[1] The complete Pavement Research Roadmaps are included in Appendix B.

- Performance-Related Specifications for Asphalt Superpave and Quality Assurance/ Quality Control (QA/QC)
- Surface Treatments and Noise, Grind and Groove (GnG), and Open Grade Friction Course (OGFC)
- Multi-Functional Pavements for Climate Resilience, Urban Environments, and Active Transportation
- Life Cycle Cost Analysis (LCCA)
- Roadway Life Cycle Assessment (LCA)
- Rubberized Asphalt
- Recycled Asphalt Pavement (RAP) and Recycled Asphalt Shingles (RAS)
- Smoothness
- Pavement Management Systems (PMS)
- New Concepts for Materials and Structures
- New Technologies and Integrated Frameworks

Strategic Planning and Contract Development

The strategic planning and contract development processes involve the following steps:

Caltrans and the UCPRC continually scan for current and future challenges to the department and for potential opportunities—from ongoing communication with all stakeholders; review of work and ideas from outside California; and work the UCPRC does with other federal, state, and local agencies, industry, and other universities.

DRISI and the UCPRC meet with Caltrans domain area stakeholders in the Pavement Program (Concrete Pavement, Asphalt Pavement, Pavement Management System); Materials Engineering and Testing Services (METS); Construction; Planning; Sustainability; areas such as Asset Management, Traffic Operations, Environmental Analysis, and Aeronautics; and other offices depending on current strategic issues and opportunities. In coordination with the Pavement Program, DRISI and the UCPRC also visit with district staff working on pavement to discuss the research program, review research results, and listen to needs.

DRISI and the UCPRC meet with industry groups to discuss challenges and needs and brief the Pavement Program on the discussions.

The UCPRC prepares new Pavement Research Roadmaps as needed and retires and archives research roadmaps whose visions have been completed.

The UCPRC prepares conceptual project ideas for next projects based on the discussions, the updated Pavement Research Roadmaps, and any new Pavement Research Roadmaps.

The UCPRC holds briefings on the updated set of roadmaps and conceptual project ideas with the Pavement Program in consultation with METS, Construction, and any other interested stakeholders and gets initial feedback. Also discussed are needs for Pavement Program operations support tasks.

The UCPRC updates the conceptual project ideas and roadmaps and submits them to the Pavement Program.

The Pavement Program—with input from other divisions—reviews, comments on, and prioritizes project ideas.

The UCPRC submits updated roadmaps and a prioritized project list to the State Pavement Engineer for approval.

Based on the prioritization and feedback, DRISI and the UCPRC prepare contract documents, including budgets for each project and support task.

If a new challenge or opportunity is identified during the course of the contract by the Pavement Program or other Caltrans stakeholders and funding is available, DRISI and the UCPRC prepare a new project work plan (and new roadmap, if needed) and submit it to State Pavement Engineer for inclusion in the roadmaps and approval for funding in the contract.

All projects must have a Caltrans "champion" assigned by Caltrans as the technical reviewer for the project or support task. The Caltrans champion is responsible for working with other Caltrans stakeholders, industry, and the UCPRC on preparing for and supporting implementation, in addition to technical review. If a project or support task does not have a champion, it is not funded by DRISI. If circumstances or priorities change and the purpose of the project or support task no longer exists or if the project or support task is no longer of sufficient priority to continue, the project or task is immediately halted by DRISI.

Work Plan Development Process and Documents

Once the contract is in place, the UCPRC prepares a detailed work plan for each project and submits the plan to that project's Caltrans technical reviewer. The technical reviewer solicits comments within Caltrans, which are incorporated into the final detailed work plan. The detailed work plan[2] includes:

- Background
- Problem statement
- Objectives and tasks
- Scope
- Schedule

The work plan is updated as needed during execution of the project, including review by the Caltrans technical manager. The budget is managed by DRISI and the UCPRC in consultation with the State Pavement Engineer or, for some projects, another Caltrans official who acts as the sponsor for the project or task.

Reporting Processes and Documents

The reporting process includes quarterly reports and project deliverables.

Quarterly Reporting

In addition to periodic technical meetings organized with the technical reviewer and others, the overall progress is reported quarterly in the form of a detailed quarterly report showing progress on scope and spending. The UCPRC submits the quarterly report to DRISI, and DRISI reviews and shares it with the Pavement Program. Delivery of the quarterly report is followed by quarterly update meetings on all projects with the domain offices in the Pavement Program and METS, and biannually with the task groups and sub-task groups of the Pavement Materials Partnering Committee, comprising Caltrans and industry.

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[2] Available from the UCPRC (contact Camille Fink at cnyfink@ucdavis.edu) and Caltrans DRISI (contact Joe Holland at t.joseph.holland@dot.ca.gov).

Project Deliverables

Periodic meetings are held during projects to present and get feedback and direction regarding interim results. Project reports and technical memoranda move through a formal five-step technical review process led by the Caltrans technical reviewer and the UCPRC project manager and managed by the UCPRC publications manager with DRISI. The technical reviewer solicits additional technical input from within Caltrans and industry as part of the initial steps. The UCPRC then responds to all comments and submits a revised version to Caltrans for final approval before publication. All reports can be accessed through the **UCPRC publications page**, the **DRISI research publications page**, or the **University of California eScholarship website**.

In addition to written documentation of research results, most reports, technical memoranda, and software results are presented at meetings with Caltrans, which sometimes include industry and other stakeholders.

Current Status of Contract

The current PPRC contract began in September 2020 and finishes in September 2023. Strategic planning and preparation of the next contract were begun in April 2022.

Implementation and Research Projects in the PPRC 2020-2023 contract, organized by research area with their Caltrans project IDs (4-digit number) and UCPRC project numbers, are shown in the following section. The following chapter provides details of each project and progress this fiscal year. Summaries of FY 2021-2022 publications are presented in Appendix A.

Mechanistic-Empirical Design

Caltrans committed to replacing historical empirical pavement design methods with mechanistic-empirical (ME) methods in 2005. ME methods and design tools are periodically updated to reflect new materials, changes in specifications, new structure types, updates in reliability calculation approaches, policy changes, and changes in climate. They are also periodically recalibrated using improved performance databases from the pavement management system and new statistical techniques. ME simulation is the primary method of evaluating new materials and structures.

CalME Materials Library for Flexible Pavements (3809 | 3.51)

Further Improvement of CalME and Integration with Performance-Related Specifications (PRS) Into Routine Practice (3810 | 3.52)

Updated Caltrans Rigid Pavement Design Catalog Using Pavement ME (3811 | 3.53)

Monitoring Performance of Concrete Overlay Projects (3812 | 3.54)

Rubberized Hot Mix Asphalt-Gap Graded (RHMA-G) Layer Thickness Limits (3760 | 4.75)

New Rubberized Hot Mix Asphalt (RHMA) Materials with Recycled Asphalt Pavement (RAP)/Recycled Asphalt Shingles (RAS) Part A: for Structural Layers in Flexible Pavements (3761 | 4.76A)

New Rubberized Hot Mix Asphalt (RHMA) Materials with Recycled Asphalt Pavement (RAP)/Recycled Asphalt Shingles (RAS) Part B: for Interlayers and Base for Rigid Pavements (3977 | 4.76B)

Concrete Coefficient of Thermal Expansion Moisture-Dependency and Tensile Creep (3768 | 4.83)

Performance-Related Specifications

Performance-related specifications use performance-related tests to tie the assumptions regarding materials used in ME design to the properties that the materials must have when placed in the pavement by the contractor during construction. This requires performance-related tests, specification approaches and limits, and quality control/quality assurance processes.

Asphalt Rubber Binder Specifications (3816 | 4.77)

Alternative Supplementary Cementitious Materials (SCMs) Sources (3775 | 4.84)

Recycling

Recycling of existing pavement into new pavement materials and recycling of waste products and co-products from other supply chains can have economic and environmental benefits—but not always and only if tests, specifications, quality assurance, structural design, and materials design methods are available. To be beneficial, recycling must be safe, produce the same or better life cycle costs, produce the same or better life cycle environmental impacts, be practically feasible at desired scale, and not break the chain of repeated recycling of pavement materials.

Updated Guidance and Specifications for In-Place Recycling (3817 | 4.78)

Guidance, Tests, and Specifications for High Recycled Asphalt Pavement/Recycled Asphalt Shingle Contents in Hot Mix Asphalt (HMA) and Rubberized Hot Mix Asphalt (RHMA) Mixes (3819 | 4.79)

Sustainability

Sustainability considers economic, social, and environmental impacts and ways to reduce or eliminate those impacts. Research includes development of data, methods, and tools for quantifying impacts and use of the information in decision support.

Implementation of Environmental Life Cycle Assessment (LCA) Data and Models for Project-Level Use in the eLCAP Software (3821 | 3.55)

Multi-Criteria Decision Support for Prioritization of Strategies to Reduce Environmental Impacts (3822 | 3.56)

Environmental Life Cycle Analysis (LCA) Updates and Applications (3820 | 4.80)

Pavement Management System

The pavement management system is used for decision support in asset management of the Caltrans pavement network. Work in this area includes improvement of data, models, use of results in decision support, and use of the information in life cycle cost analysis.

Tri-Annual Performance Model Update (3814 | 3.57)

Continued Calibration of Mechanistic-Empirical Design Models with Pavement Management System Data (3764 | 3.58)

Updates and Improvements to RealCost-CA (3815 | 3.59)

Improved Traffic Models for PaveM and Mechanistic-Empirical Design (3765 | 4.81)

Potential for Advanced Image Evaluation in Automated Pavement Condition Surveys (APCS) (3766 | 4.82)

Support Tasks

Support tasks include tasks that support Caltrans operations (the follow-on to successful implementation for tasks where Caltrans has found it cost efficient to have the UCPRC provide the support) and tasks that support research, development, and implementation projects.

Develop and Manage Partnered Pavement Research Program (3823 | 2.01)

Provide Advice to State Government on Pavement Technology (3829 | 2.02)

Provide Support for Pavement Management System (PaveM) Operations (3832 | 2.03)

Provide Support for CalME, Pavement ME, and CalBack (3831 | 2.04)

Provide Support for eLCAP and RealCost-CA (3779 | 2.05)

Maintain Laboratory Testing AASHTO Re:source Certification (3828 | 2.06)

Maintain Laboratory and Field-Testing Equipment Capability (3826 | 2.07)

Maintain Heavy Vehicle Simulator Equipment (3827 | 2.08)

Operate Falling Weight Deflectometer and Profiler Calibration Centers (3825 | 2.09)

Update/Maintain Research Support Space (3824 | 2.10)

Provide Support to Division of Aeronautics (3780 | 2.11)

Conduct Advanced Pavement Research for Long-Term Future Needs (3830 | 2.12)

Mechanistic-Empirical Design

CalME Materials Library for Flexible Pavements

DRISI Project ID: 3809 | **UCPRC Project Number:** 3.51
Caltrans Technical Lead: Cathrina Barros and Raghubar Shrestha, Office of Asphalt Pavement
UCPRC Project Manager: Rongzong Wu

Research Needs

The current *CalME* Standard Materials Library has limited regional materials and does not adequately cover certain material types listed in *CalME*, including but not limited to the following:

- Partial-depth recycled materials
- Full-depth recycled materials
- Asphalt mixes with higher recycled asphalt pavement contents
- Dense-graded asphalt materials with small amounts of recycled tire rubber (referred to as PG+X mixes)

The asphalt concrete specimen production procedures for performance-related testing need to be more standardized, and the fatigue life determination of asphalt concrete mixes with polymer- or rubber-modified binders is not well defined following current ASTM or AASHTO test methods. Performance-related test methods require further refinement to be more practical and implementable.

Objective/Goals

This study is a continuation of PPRC Project 3.38 (CalME Materials Library for Flexible Pavements). The objective of this project is to update the Standard Materials Library for *CalME*.

Deliverables

Task 1: Updated strategy for collecting and testing regional materials

- PowerPoint presentation on the development of a strategy for collecting and testing regional materials

Task 2: Material sampling and testing

- Updated *CalME* Standard Materials Library
- Technical memorandum summarizing the materials tested

Task 3: Development of an asphalt concrete specimen production procedure

- Technical memorandum describing the standard test procedure for producing asphalt concrete specimens for performance testing for use in performance-related specifications

Task 4: Development of fatigue testing procedures for polymer- and rubber-modified mixes

- Technical memorandum describing the procedure for evaluating fatigue performance of asphalt concrete mixes with polymer- or rubber-modified binders

Task 5: Refinement of new performance testing methods for asphalt binder, fine aggregate matrix mixes, and asphalt concrete mixes

- Technical memorandum summarizing the recommendations for various performance tests
- Draft of new or updated test methods

Task 6: Preparation of project reports

- Internal laboratory database tracking the production, testing, and analysis
- Quarterly presentation to Caltrans regarding research progress
- Technical memoranda listed in Tasks 2, 3, 4, and 5, and new and updated test methods from Task 5

Summary of Progress FY 2021-2022

To date in the 2020–2023 contract, 11 new asphalt concrete mixes have been sampled, nine of which have been tested and added to the Standard Materials Library. This includes all six of the mixes used in the Interstate 5 Sacramento AC Long Life project mixes, two polymer modified mixes, and three RHMA-G mixes (two with PG 70 base binder). Additional polymer modified mixes and mixes with PG 70 binder are still being sought to fill the identified gaps. Evaluation of a new compaction device as an alternative to the rolling wheel compactor to improve efficiency and practicality in routine laboratory testing is underway. Development of procedures to address the effects of aging from time in the silo at the plant, sample handling, and cooling and reheating is also underway. Aging affects performance test results used in pavement design, job mix formula approval, and quality control/quality assurance specifications. Development of an improved procedure to determine the fatigue life of polymer- and rubber-modified mixes is underway. An initial report on surrogate tests for asphalt mix stiffness and fatigue performance has been completed.

Further Improvement of CalME and Integration with Performance-Related Specifications (PRS) Into Routine Practice

DRISI Project ID: 3810 | **UCPRC Project Number:** 3.52

Caltrans Technical Lead: Cathrina Barros and Raghubar Shrestha, Office of Asphalt Pavement

UCPRC Project Manager: Rongzong Wu

Research Needs

New features that can significantly improve *CalME* in terms of design workflow and efficiency have been identified and need to be developed and/or implemented. Some models in *CalME*, such as the aging model for asphalt materials, and consideration of the effects of wandering on pavement rutting need to be further improved. Some additional pavement behavior parameters need to be modeled in *CalME*, such as the effects of moisture on the mechanical properties of unbound and partially bound layers. Consideration and use of the significant amount of new accelerated pavement testing data collected in recent years are needed to improve the damage models used in *CalME*. These tests cover topics such as recycled asphalt pavement in rubberized hot mix asphalt-gap graded (RHMA-G) mixes, thicker RHMA-G layers, alternative RHMA-G mixes, full-depth reclamation materials, and cold central plant recycling materials. Performance tests need to be further refined and improved for more practical use in *CalME* designs and construction specifications. Finally, there is no centralized database that integrates both performance test data and mix volumetrics for Caltrans highway construction projects.

Objective/Goals

This study is a continuation of PPRC Project 3.41 (M-E Algorithms and Field Calibrations). The objective of this project is to deliver updated *CalME* software to Caltrans.

Deliverables

Task 1: Development/implementation of new *CalME* features

- Quarterly PowerPoint presentations to update Caltrans on progress of the new features
- Online documentation on how to use these new features

Task 2: Updated and new *CalME* models

- Quarterly PowerPoint presentations to update Caltrans on progress of model updates
- Implementation of the new models in *CalME*
- Online documentation on how to use these updated or new models

Task 3: **Calibration of *CalME* damage models with recently collected data**

- Technical memorandum on data cleaning, model selection, and calibration

Task 4: **Updated performance tests for design and construction**

- Technical memorandum detailing updated specimen preparation performance tests for developing *CalME* design inputs, performance tests for performance-related construction specifications, and a summary of performance test data collected from AC Long Life and performance-related specifications projects

Task 5: **Integration of *CalME* and Caltrans Data Interchange for Materials Engineering (DIME) database**

- Technical memorandum on recommended procedures for incorporating performance test results into Caltrans Materials Engineering and Testing Services (METS) and district materials laboratory operations and loading of results into the DIME database

Task 6: **Preparation of project documentation**

- Quarterly presentation to Caltrans regarding research progress
- Technical memoranda listed in Task 3, 4, and 5

Summary of Progress FY 2021-2022

The UCPRC coordinated with Caltrans to conduct an outside review of *CalME*, with comments received from industry and from a review by NCE through a Caltrans task order. Comments related to pavement designs have been addressed, and comments about the user interface and other aspects of the software have largely been addressed. Work is underway to prepare *CalME* for the next major release, which will include support for in-place recycled materials, improved models for cement or lime stabilized materials, and recalibrated overlay designs accounting for thermal strains. Development of a finite element model for evaluating thermal strains in overlays was completed. Support of the second year of the Interstate 5 Sacramento AC Long Life project included job mix formula approval and quality control/quality assurance testing. Review of correlations between volumetrics and performance test results from the Sac 5 project is underway.

The *Site Investigation Guide for Mechanistic-Empirical Design of California Pavements* was completed and delivered to Caltrans. The site investigation guide provides details for desk and field studies, sampling, and testing needed to help finalize project plans and provide inputs for mechanistic empirical design of both asphalt and concrete pavements. Implementation of the guide will require additional resources to perform the site investigations, which was a need identified during review of the guide by district engineers. Use of the guide should provide better design inputs, resulting in more cost-efficient designs, and help avoid additional costs during construction because of previously unknown site conditions. Initial planning is underway for communication with DIME, the METS laboratory testing database, about potential integration of data used by *CalME* and *PaveM*.

Updated Caltrans Rigid Pavement Design Catalog Using Pavement ME

DRISI Project ID: 3811 | **UCPRC Project Number:** 3.53

Caltrans Technical Lead: Kuo-Wei Lee and Dulce Rufino Feldman, Office of Concrete Pavement

UCPRC Project Manager: Angel Mateos

Research Needs

The concrete pavement design catalog in the current *Highway Design Manual* was implemented in 2007. The jointed plain concrete pavement (JPCP) catalog tables are based on calculations conducted with the *Mechanistic-Empirical Pavement Design Guide* (version 0.8) in 2005 and 2006 and later adjustments based on design catalogs from other states. The tables do not acknowledge the changes that the AASHTO mechanistic-empirical design method (*MEPDG* in the past, *Pavement ME* now) has undergone over the past 15 years or the validation, calibration, and catalog development efforts conducted as part of PPRC Project 3.49. In addition, the current *Highway Design Manual* concrete pavement design catalog does not include concrete overlay on asphalt (COA), and the continuously reinforced concrete pavement (CRCP) thickness values have not been updated since the 2007 implementation.

Objective/Goals

The primary goal of Project 3.53 is to develop and implement a new *Highway Design Manual* concrete pavement design catalog using *Pavement ME* (version 2.5.5). This research will consider climate, traffic, materials, design, and construction practices and standards applicable to the Caltrans road network.

Deliverables

Task 1: Finalized JPCP design catalog tables
- JPCP design catalog tables

Task 2: Finalized COA design catalog tables
- COA design catalog tables

Task 3: Development of CRCP design catalog tables
- CRCP design catalog tables

Task 4: Implementation of design catalog tables in a web-based tool
- Online catalog and documentation

Summary of Progress FY 2021-2022

The design tables of thin COA, JPCP, and CRCP have been prepared using *Pavement ME* (version 2.5.5) with the nationally calibrated cracking and punchouts models. The JPCP sections were also verified in terms of faulting and the International Roughness Index. The tables consider the different thin COA, JPCP, and CRCP structures that are expected to perform properly on the Caltrans road network. Summary reports have been produced for each of the three design options, and each report outlines the hypothesis and design values adopted in *Pavement ME* to develop the design tables. The thickness obtained for CRCP was not realistic. In many scenarios, the CRCP thickness was much greater (up to 4 in.) than the JPCP thickness for the same design conditions. A database was created with the *Pavement ME* outputs required to run a web version of the design catalog. The beta version of the web catalog has been developed, but it does not yet include the CRCP design.

Monitoring Performance of Concrete Overlay Projects

DRISI Project ID: 3812 | **UCPRC Project Number:** 3.54

Caltrans Technical Lead: Kuo-Wei Lee and Dulce Rufino Feldman, Office of Concrete Pavement

UCPRC Project Manager: Angel Mateos

Research Needs

While concrete overlay on asphalt (COA) and concrete overlay on concrete (COC) can be regarded as mature technologies, their increasing use results in the need to evaluate their performance, optimize their design, and potentially improve their construction. The relevance of concrete overlays is emphasized by the Targeted Overlay Pavement Solutions (TOPS) initiative launched by the Federal Highway Administration's Every Day Counts program (EDC-6) for the 2021-2022 cycle.

Although the performance of most concrete overlay alternatives is not very different from the performance of standard jointed plain concrete pavement (JPCP) or continuously reinforced concrete pavement (CRCP), a number of factors and phenomena deserve special study, including the reduced slab thickness of some concrete overlay alternatives, the interaction between the concrete overlay and the existing pavement, and the risk of distresses that result from the bottom-up propagation of the distresses in the existing pavement. From the construction point of view, one of the main differences between concrete overlay and regular JPCP and CRCP is the preparation of the existing asphalt or concrete surface prior to placing the concrete overlay and the possible use of an interlayer between the concrete overlay and the existing surface. The study of COA with short transverse joint spacing deserves special attention since this rehabilitation alternative is relatively new to the Caltrans road network, and it has mostly been used in colder, wetter climates than California that experience much less drying shrinkage.

Objective/Goals

The primary goal of Project 3.54 is to develop guidance for COA design and construction in California. This goal will be achieved through the evaluation of concrete overlay projects to determine performance under different climate, traffic, and existing site conditions and identification of current best and improved practices and standards applicable to California's climate, materials, and construction work zone practices.

Deliverables

Task 1: **Continued monitoring of the State Route 113 COA pilot project**

- Summary of updated observations on the early performance of the State Route 113 COA pilot project to be included in the final project report

Task 2: **Evaluation of the condition of concrete overlay projects in California**

- Summary of observations that will be included in the final project report

Task 3: **Monitoring of the construction and initial performance of new concrete overlay projects**

- Construction report for each project

Task 4: **Preparation of research report**

- Final research report

Summary of Progress FY 2022-2022

Monitoring of the Caltrans thin COA pilot on State Route 113 in Woodland has continued. The monitoring began during the construction of the pilot in October 2018 and includes continuous measurement of concrete temperature and strain with embedded sensors, periodic evaluation of the smoothness and surface texture, and occasional evaluation of the structural response under falling weight deflectometer loading and traffic loading using embedded sensors. Support to Caltrans for the Federal Highway Administration's EDC-6 TOPS initiative is included in this research project. As part of this support, the performance of a number of COA and COC projects identified by Caltrans is being analyzed. The analysis is based on pavement management system data and limited testing conducted by the UCPRC. Among the COA and COC projects being evaluated are several JPCP-COC projects on the Interstate 80 corridor between Sacramento and Lake Tahoe, a thin COA project on State Route 247 in San Bernardino County, and two CRCP-COC projects on the Interstate 8 corridor in Imperial County.

Rubberized Hot Mix Asphalt-Gap Graded (RHMA-G) Layer Thickness Limits

DRISI Project ID: 3809 | **UCPRC Project Number:** 4.75

Caltrans Technical Lead: Cathrina Barros and Raghubar Shrestha, Office of Asphalt Pavement

UCPRC Project Manager: David Jones

Research Needs

The decision criteria for thickness limits of gap-graded rubberized hot mix asphalt (RHMA-G) layers—whether 3/4 in. nominal maximum aggregate size (NMAS) mixes can be used in 0.2 ft. thick layers, whether surface mix thicknesses can be increased to 0.25 ft. where appropriate, and whether RHMA-G layers can be used in layers other than surface layers—are dated. These criteria need to be updated based on life cycle cost analysis, environmental life cycle assessment, and expected performance according to mechanistic-empirical design simulations using *CalME*.

Objective/Goals

This study is a continuation of PPRC Project 4.63. The objective of this project is to develop updated criteria for determining thickness limits of RHMA-G layers and whether RHMA-G layers can be used in layers other than surface layers.

Deliverables

Task 1: **Heavy Vehicle Simulator (HVS) and associated laboratory testing of RHMA-G mixes**

- Research report covering first-level analysis of HVS and associated laboratory testing

Task 2: ***CalME* simulations using data collected during Task 1**

- PowerPoint presentation of Task 2 results

Task 3: **Revision of life cycle cost analysis and life cycle assessment information for RHMA-G applications and case study evaluations of the effects of implementing preliminary recommendations**

- PowerPoint presentation of Task 3 results

Task 4: **Research report and recommendations for updated *Highway Design Manual* language for RHMA-G design and use criteria**

- Research report documenting work done in Task 2 and Task 3 with recommendations for updated *Highway Design Manual* language for RHMA-G design and use criteria, if justified

Summary of Progress FY 2021-2021

This project is behind schedule due to delays caused by breakdowns of the two HVS machines and problems with obtaining spare parts that originate in Europe, where manufacturers and suppliers have had extended shutdowns due to COVID-19. HVS testing on five of the seven sections (Task 1) was completed and updates made to the preliminary first-level analysis report of the results. The report is under review. Laboratory characterization testing on plant-mixed, laboratory-compacted specimens for each of the four mixes was completed. Periodic dynamic modulus testing on cores removed from the track is in progress to track aging of the mixes.

Preliminary findings from the HVS and laboratory testing have shown that performance of the three RHMA-G mixes (two different aggregate maximum sizes, both with inclusion of a small amount of recycled asphalt pavement [RAP], and one mix with no RAP) was satisfactory in terms of the level of trafficking required to reach a terminal average maximum rut of 0.5 in., no significant damage was caused by the loading, and blending of the recycled asphalt pavement binder may have stiffened the mix. Comparison of the rutting performance of the mixes with RAP and the mix without RAP were inconsistent with expectations that the mix with RAP would have less rutting because of the stiffening effect of the RAP. An investigation revealed that the mix without RAP had been stored in a silo for considerably longer period than the other mixes, leading to additional aging/stiffening, which exceeded that caused by the RAP binder in the mixes with RAP. Task 2 was completed using the data collected to date, and preliminary recommendations were made to Caltrans regarding the use of RAP in RHMA-G and use of thicker layers of RHMA-G. Work on Task 3 has not started.

New Rubberized Hot Mix Asphalt (RHMA) with Recycled Asphalt Pavement (RAP)/ Recycled Asphalt Shingles (RAS) Part A: For Structural Layers in Flexible Pavements

DRISI Project ID: 3761 | **UCPRC Project Number:** 4.76 A

Caltrans Technical Lead: Cathrina Barros and Raghubar Shresthra, Office of Asphalt Pavement

UCPRC Project Manager: Angel Mateos and John Harvey

Research Needs

Previous research has shown that rubberized binders age at a slower rate than conventional binders. The effects of aging on rubberized binders and rubberized hot mix asphalt-gap graded (RHMA-G) and other RHMA mixes containing both fine- and coarse-graded recycled asphalt pavement (RAP) are not fully understood and need to be investigated. The performance of RHMA-G and other RHMA mixes produced with fine RAP (binder replacement is likely), coarse RAP (binder replacement is unlikely), recycled asphalt shingles (RAS), or RAP with RAS in different structural layers within different types of flexible pavement structures needs to be assessed in the laboratory and with mechanistic-empirical analysis. Whether rich bottom layers age deep in the pavement is of particular interest.

If RHMA-G layers and potentially RHMA layers with other gradations—with RAP, RAS, or RAP with RAS—used within pavement structures appear to result in a notable improvement in performance and pavement life, validation and calibration of results using accelerated pavement testing should be considered. For those applications that appear promising, guidance needs to be developed regarding how and where to use RHMA with and without RAP and/or RAS beyond current applications and an initial framework of properties and tests for use in performance-related specifications.

Objective/Goals

This research is a continuation of two previous CalRecycle-funded studies to investigate the use of RAP in RHMA. The objective of this phase of the study is to develop guidance on the use of RHMA (gap and other gradation) mixes containing RAP, RAS, or RAP with RAS in pavement structures, with special focus on use in structural layers, including rich bottom layers, in flexible pavements.

Deliverables

Task A.1: Updated literature review to include recently completed research

- PowerPoint presentation on the literature review results
- Summary of the literature review to be included in the research report prepared after completion of Task A.4

Task A.2: Initial *CalME* simulations in various structural layer applications in flexible pavements

- PowerPoint presentation on the results of the initial simulations and how they will be used to refine the Task A.3 laboratory testing plan

Task A.3: Laboratory testing of RHMA mixes with fine and coarse RAP, RAS, or RAP with RAS

- PowerPoint presentation on Task A.3 results
- Laboratory test results and analysis to be included in the research report prepared after completion of Task A.4

Task A.4: Refined *CalME* simulations using RHMA with RAP, RAS, or RAP with RAS in various structural layer applications in flexible pavements

- Research report documenting the findings from Tasks A.1 through A.4 with recommendations for further validation and calibration of results from the study if warranted, including pilot studies and/or Heavy Vehicle Simulator (HVS) testing to calibrate and verify the mechanistic simulations conducted in this task
- If justified, interim recommended language for the *Highway Design Manual* and for non-standard specifications covering the use of RHMA layers containing RAP, RAS, or RAP with RAS in structural layers
- Interim framework for the development of performance-related specifications for RHMA mixes containing RAP, RAS, or RAP with RAS for each application

Task A.5: If results from the first four tasks warrant, pilot studies and/or HVS testing to verify simulations

- Research report documenting pilot study and/or test track design and construction and pilot study and/or HVS test results and first-level analysis
- Updated *CalME* models
- Updated recommended language for the *Highway Design Manual* and for non-standard specifications covering the use of RHMA layers containing RAP, RAS, or RAP with RAS in structural layers in flexible pavements
- Updated framework for the development of performance-related specifications for RHMA layers containing RAP, RAS, or RAP with RAS

Summary of Progress FY 2021-2022

Significant progress has been made this year on the laboratory testing of RHMA mixes with fine and coarse RAP and RAS. The addition of relatively small amounts of rubber to dense-graded mixes is being considered as well. A detailed laboratory testing plan was prepared and sampling of raw materials was started. *CalME* simulations have been made using materials with different amounts of RAP and rubber versus conventional dense-graded mixes and RHMA-G mixes. Additional simulations will be done once laboratory testing is completed. As part of this project, sampling from pilot projects of RHMA-G mixes with 10% RAP used as a surface layer was planned to begin the process of long-term performance evaluation. Construction of the pilots is expected to begin early in FY 2022-2023.

New Rubberized Hot Mix Asphalt (RHMA) with Recycled Asphalt Pavement (RAP)/ Recycled Asphalt Shingles (RAS) Part B: For Interlayers and Base for Rigid Pavements

DRISI Project ID: 3977 | **UCPRC Project Number:** 4.76 B

Caltrans Technical Lead: Deepak Maskey, Office of Concrete Pavement

UCPRC Project Manager: Angel Mateos

Research Needs

Asphalt bases currently being used under concrete are optimized for use as asphalt pavement surface layers, not as a base for concrete. Also, while the use of lean concrete base (LCB) presents some economic and ambient advantages compared to hot mix asphalt (HMA) bases, jointed plain concrete pavement (JPCP) performs worse with LCB than with HMA bases in terms of cracking. There is little knowledge about the mechanical properties that an asphalt mix should have to constitute a good base for a concrete pavement. In particular, no validated tests exist to evaluate the performance of an asphaltic material as a base for concrete pavement. There is also little knowledge about the interaction between the JPCP slab and its base. The simplistic conception of this problem in current mechanistic-empirical design methods fails to reproduce observed performance. While the use of rubberized hot mix asphalt-gap graded (RHMA-G) mixes—with or without recycled asphalt pavement (RAP), recycled asphalt shingles (RAS), or RAP with RAS—as a base for concrete pavements may provide technical, economic, and ambient benefits compared to currently used HMA, further research is required to determine these potential benefits.

Objective/Goals

The objective of Part B of PPRC Project 4.76 is to develop guidance on the use of RHMA mixes—with or without RAP, RAS, or RAP with RAS—as a base for rigid pavements and as a very thin interlayer between LCB and JPCP.

Deliverables

Task B.1: Completion of literature review

- PowerPoint presentation on the literature review results
- Summary of the literature review to be included in the research report prepared after completion of Task B.4

Task B.2: Laboratory testing of RHMA-G as JPCP base or JPCP slab-LCB interlayer

- PowerPoint presentation about Task B.2 results
- Laboratory test results and analysis to be included in the research report prepared after completion of Task B.4

Task B.3: Field evaluation of JPCP slab-base interaction

- PowerPoint presentation about Task B.3 results
- Field evaluation results and analysis to be included in the research report prepared after completion of Task B.4

Task B.4: Preparation of research report

- Research report detailing the study and including a set of performance-related tests and their corresponding performance limits to evaluate asphalt materials as a base or slab-base interlayer for JPCP
- Updated recommended language for the *Highway Design Manual* and for non-standard specifications covering the use of RHMA—with and without RAP, RAS, or RAP with RAS—as a base for rigid pavements and the use of engineered interlayers between LCB and JPCP

Summary of Progress FY 2021-2022

A full scale test track was built at the Davis site of the UCPRC from May to June 2022. The test track includes 12×12 ft. wide and 7 in. thick slabs on either RHMA-G or LCB, including different slab-LCB interlayers (curing compound, microsurfacing, and geotextile). Data provided by instrumentation embedded in the concrete and deflections measured with the falling weight deflectometer are being used to study base support and slab-base interaction. A laboratory testing procedure is being developed to evaluate the suitability of a material as an asphaltic base of a concrete pavement or as an interlayer between the concrete pavement and LCB. The laboratory procedure is being used to test the asphalt base and the slab-LCB interlayers in the test sections. This research also includes the development of a slab curling/warping prediction model and a finite-element structural response model.

Concrete Coefficient of Thermal Expansion Moisture-Dependency and Tensile Creep

DRISI Project ID: 3768 | **UCPRC Project Number:** 4.83

Caltrans Technical Lead: Kuo-Wei Lee and David Lim, Office of Concrete Pavement

UCPRC Project Manager: Angel Mateos

Research Needs

The coefficient of thermal expansion (CTE) is one of the material properties of concrete that has the largest impact on rigid pavement performance. Concrete CTE is typically measured in the laboratory under saturated conditions, as specified in AASHTO T 336-15, and the value from this test is typically assumed in the mechanistic-empirical (ME) design of concrete pavements. However, previous UCPRC research has shown that the moisture conditions significantly impact the CTE of concrete. As a result, the way CTE is measured in the laboratory leads to systematic underestimation of the thermal deformations and resulting stresses in concrete pavements.

The prediction of the structural response of the concrete pavements under the hydrothermal actions is systematically oversimplified by current ME design procedures by neglecting the creep capacity of the concrete. The standard practice of concrete pavement design assumes that the concrete is a linear elastic material whose elastic modulus represents the stiffness under the relatively rapid loading of truck traffic. This practice results in systematic overestimation of the concrete stiffness under the hydrothermal actions and, consequently, systematic overestimation of the hydrothermal stresses.

While the creep capacity of the concrete in compression has been the focus of a number of studies in the past, the creep capacity of plain concrete in tension, which is the most relevant to concrete pavements, has received little attention.

Objective/Goals

The objective of Project 4.83 is to develop tests to measure concrete CTE-moisture dependency and tensile creep and to develop a framework for modeling CTE evolution in the field. The evolution of CTE is then used to model the structural response of concrete pavements under thermal and drying shrinkage actions, including concrete tensile creep/relaxation capacity.

Deliverables

Task 1: **Literature review**

- Literature review summary that will be included in the final report

Task 2: **Study of moisture dependency of concrete CTE**

- Laboratory test results and analysis that will be included in the final report

Task 3: **Study of concrete tensile creep**

- Laboratory test results and analysis that will be included in the final report

Task 4: **Development of testing and modeling framework**

- Final research report, including framework for modeling the structural response of concrete pavements under thermal and drying shrinkage actions

Summary of Progress FY 2021-2022

The experimental design and the setup of laboratory testing equipment to measure concrete tensile creep and CTE-moisture dependency were completed during this year. A set of concrete mixtures was selected for each of the tests, including typical concrete mixtures used in the Caltrans road network and several alternative mixtures with fibers, large amounts of fly ash, calcium sulfoaluminate cement, or limestone aggregates. Laboratory testing specimens were collected, and testing of the specimens started. Tensile creep testing under several conditions (73°F and 50% and 100% relative humidity [RH]), was accomplished during FY 2021-2022. Testing at 104°F and 50% RH will be conducted during the second half of 2022. The CTE-moisture dependency testing began in early 2022 and is expected to conclude in the second half of 2022. The development of the framework for modeling the structural response of concrete pavements under thermal and drying shrinkage actions, including CTE-moisture dependency and tensile creep, will begin in early 2023.

Performance-Related Specifications

Asphalt Rubber Binder Specifications

DRISI Project ID: 3816 | **UCPRC Project Number:** 4.77

Caltrans Technical Lead: Tom Pyle and Kee Foo, Office of Asphalt Pavement

UCPRC Project Manager: David Jones

Research Needs

Precision and bias statements need to be developed for the recommended performance grading (PG) testing procedures to make the PG binder specification applicable to asphalt rubber. Base binder selection criteria for asphalt rubber binders need to be reviewed, especially for inland valley and desert applications. New developments in fine rubber preparation and pelletizing of rubber particles to improve digestion need to be reviewed and recommendations made for their use in California, if applicable. Binders made with these products will typically meet Caltrans performance grading-modified (PG-M) specifications (except for solubility) and can be considered for wider use in dense-graded mixes where *CalME* evaluations indicate potential benefits.

Objective/Goals

This study is a continuation of PPRC Projects 4.45, 4.50, and 4.63. The objective of this project is to finalize PG testing procedures for asphalt rubber binders.

Deliverables

Task 1: Completion of outstanding testing on field-produced binders, delayed because of COVID-19 restrictions, and finalized draft of PG testing method

- Research report detailing Phase 3 PG testing of asphalt rubber binders
- Updated proposed draft of PG testing procedure for asphalt rubber binders
- Provisional PG map for asphalt rubber binders

Task 2: Preparation and implementation of statewide round robin study to develop precision and bias statements for the proposed PG testing procedure

- Technical memorandum documenting the design, analysis, and results of the round robin study
- Provisional precision and bias statements for PG testing of asphalt rubber binders

Task 3: Review and, if appropriate, updating of base binder selection criteria for asphalt rubber binders

- Technical memorandum documenting the findings of the review
- If laboratory testing is justified, research report documenting laboratory testing with recommendations for revising base binder selection procedures

Task 4: **Investigation of use of fine dry rubber and polymerized/pelletized, soluble rubber for use in asphalt mixes, primarily dense graded**

- Technical memorandum documenting results of the literature review and *CalME* simulations
- If further laboratory testing is justified, research report documenting laboratory testing with recommendations for implementation in pilot studies

Summary of Progress FY 2021-2022

Task 1 of this project is near completion, and the report will be submitted in FY 2022-2023. Research focused on the testing of binders after larger, incompletely digested rubber particles had been removed—first by sieving, then by using a simple centrifuging process. Earlier phases of the study had determined that these incompletely digested particles were influencing the test results and leading to unrealistically high PGs. Results for the binders with larger particles removed appear to be consistent with expected performance. Work on Task 2, if required by Caltrans, cannot be started until Task 1 has been completed and the testing approach is provisionally adopted by Caltrans. As results become available, they are being analyzed in terms of preparing recommended base binder and asphalt rubber binder PG maps for the different climatic regions of California (Task 3). The literature on and testing of fine, dry rubber and polymerized/pelletized, soluble rubber in asphalt rubber binder applications continues, but no testing of these binders will be undertaken unless directed by Caltrans.

Alternative Supplementary Cementitious Materials (SCMs) Sources

DRISI Project ID: 3775 | **UCPRC Project Number:** 4.84
Caltrans Technical Lead: Kuo-Wei Lee and David Lim, Office of Concrete Pavement
UCPRC Project Managers: Angel Mateos and Somayeh Nassiri

Research Needs

A supplementary cementitious material (SCM), when used in conjunction with portland cement, contributes to the properties of hardened portland cement concrete (PCC) through hydraulic activity, pozzolanic activity, or both. In addition to the benefits to PCC performance, the use of SCMs contributes to a reduction in the environmental impacts of PCC by replacing part of the portland cement.

While cement demand is expected to increase by 65% by the year 2050 (compared to 2015 levels) and the demand for SCMs is expected to similarly increase, the amount of fly ash (the traditional source of SCM) produced in the United States is expected to decline as coal-fired power plants are decommissioned or converted to natural gas. As production from traditional SCM sources decreases, the increased demand for SCM represents a major challenge for the cement and concrete industries.

One option to address this challenge is alternative sources of SCMs. There are several alternative materials that are rich in reactive silica or in silica and alumina and that may perform adequately as SCMs. Among these alternative materials that deserve particular attention in California are ash from the combustion of biomass for electricity production and the natural pozzolans abundant in the state.

Objective/Goals

The objective of Project 4.84 is to perform a first-order assessment of the feasibility of alternative SCMs to improve concrete properties, reduce environmental impacts and costs, and reduce waste biomass stockpiles. The research will provide recommendations for further development of the most promising alternative SCMs produced using California rocks and minerals, biomass-based materials, waste, and co-products of industrial and agricultural processes.

Deliverables

Task 1: Literature review

- Literature review summary that will be included in the final report

Task 2: Identification of alternative SCM sources

- SCMs selected for initial screening

Task 3: Initial screening of alternative SCM sources

- Laboratory test results and analysis that will be included in the final report
- SCMs that show promise for additional laboratory evaluation

Task 4: Laboratory and thermodynamic evaluation of alternative SCM sources

- Laboratory test results and analysis that will be included in the final report

Task 5: Environmental and economic assessments of alternative SCM sources and initial ranking based on supply curve

- Environmental impact and economic and supply-chain assessment of SCMs that will be included in the final report

Task 6: Final report

- Final report detailing the results of the project

Summary of Progress FY 2021-2022

The first year of this research project has focused on identification of potential alternative SCM sources and an initial assessment based on a literature review and consultation with industries. A total of 14 sources were identified, and they are currently being assessed. The assessment of the different sources includes the potential pozzolanic reactivity and the expected impact on PCC properties based on previous studies. In addition, the assessment considers a number of environmental, logistical, and economic factors required to assess the viability of the source to contribute to the shortage of traditional SCMs. The factors considered in the initial assessment include the amount of the material produced in California, the environmental and economic cost required to transform the material into an SCM, and the geographic and seasonal distributions and current use of the material.

Some of the 14 sources have been identified for further examination and selected for initial screening in Task 3. The sampling and laboratory conditioning (drying and milling) of these sources has started, and they will be tested for pozzolanic reactivity and other properties during the second half of 2022. Several laboratory trials were also conducted using cellulose and chitin nanomaterials.

Recycling

Updated Guidance and Specifications for In-Place Recycling

DRISI Project ID: 3817 | **UCPRC Project Number:** 4.78

Caltrans Technical Lead: Allen King and Cathrina Barros, Office of Asphalt Pavement

UCPRC Project Manager: David Jones

Research Needs

The following problem statements are still outstanding or require refinement/calibration for California conditions:

- Mechanistic-empirical parameters for cold recycling (CR) projects need to be finalized.
- Consistent mix design procedures for all CR strategies need to be developed and laboratory performance testing needs to be done to refine mechanistic-empirical design and performance modeling parameters. Mix design procedures should include raveling tests, given that recycled layers are exposed to traffic for up to 15 days before the asphalt surfacing is placed.
- Partial-depth recycling (PDR) and cold central plant recycling (CCPR) materials produced with only recycled asphalt pavement typically have coarse gradations, which leads to compacted layers having relatively high air-void contents. The use of supplemental fines to improve gradations needs to be investigated. Use of fines derived from forest waste biomass materials should also be considered.
- Time limits for stockpiling of CCPR materials need to be established.
- The effects on construction and performance of rubberized hot mix asphalt and fabrics in the recycled layer are not fully understood and need to be further evaluated.
- Current PDR construction techniques are not conducive to the application of tack coats between the recycled and underlying layers. Consequently, debonding of these two layers is often observed in cores removed from the pavement. Recent developments in spray pavers need to be assessed to see if this equipment can be effectively used in PDR applications to improve long-term performance.
- The long-term performance of deep-lift full-depth recycling (FDR-C) projects has not been quantified. Although this strategy is being used on city and county roads with reported success, to date there are no published studies documenting longer-term performance on roads carrying traffic volumes typical of those on Caltrans roads where FDR-C may be considered. Concerns regarding the compaction of thicker layers on weak/moist subgrades, the potential for cracking resulting from drying shrinkage and/or differential compaction over the thickness of the layer, and the applicability of shrinkage crack mitigation of these thicker layers need to be investigated.

- The use of rejuvenating agents and other stabilizers (e.g., synthetic polymer emulsions) has not been investigated in CR projects to date.
- Preliminary international research on the use of nano-stabilizers to improve emulsified asphalt performance in recycled layers has shown promising early results and warrants further investigation.
- Preliminary national research on the use of geosynthetics between subgrades and recycled layers and between recycled layers and asphalt concrete surfacings has also shown positive results, especially in the former application where the recycled layer material is processed through a cold central plant. The use of geosynthetics provides a potential alternative to subgrade stabilization and/or can provide a barrier to prevent fines contaminating the recycled layer. Geosynthetics between an FDR-C layer and the asphalt concrete surface may limit shrinkage cracks in the FDR-C layer from reflecting through the asphalt.
- Guidance has not been developed to identify when in-place recycling (IPR) of material that is primarily subgrade soils, as opposed to primarily recycled asphalt concrete and aggregate base, should be modeled and designed as FDR and when it should be modeled and designed as stabilized subgrade or subbase.

Objective/Goals

This study is a continuation of PPRC Projects 4.65 (FDR Microcracking), 4.69 (FDR Emulsion and Field), and 4.70 (PDR Guidance). The objective of this project is to update guidance and mechanistic-empirical design procedures for cold recycling.

Deliverables

Task 1: Continued long-term monitoring of existing and new field IPR pilot projects to assess stiffness, cracking, rutting/densification, freeze-thaw, moisture sensitivity, and other observed distresses

- Updated list of IPR projects evaluated/suitable for future evaluations
- Database of observations and measurements for *CalME* modeling
- Summary of observations and measurements from field monitoring, with recommendations for updating IPR guidance and *CalME* models and for adopting NCHRP 9-62 quality control/quality assurance procedures

Task 2: Completion of Heavy Vehicle Simulator (HVS) and associated laboratory testing to assess mechanistic behavior and performance properties of CCPR materials

- Research report documenting HVS testing, with recommendations for updating IPR guidance and *CalME* models

Task 3: Literature reviews and laboratory testing to refine mix design procedures

- Research report documenting laboratory testing, with recommendations for updating IPR guidance and *CalME* models

Task 4: **Field monitoring and associated laboratory testing of deep-lift FDR-C projects**

- Research report documenting task findings, with recommendations for updating IPR guidance, relevant *Highway Design Manual* chapters, and *CalME* models

Task 5: **Updated guidance, CalME models, and CalME materials library**

- Updated IPR guidance
- Updated *CalME* models and materials library
- Revised *Highway Design Manual* and specification language, if applicable
- High level summary report documenting IPR research undertaken by the UCPRC since 2008

Summary of Progress FY 2021-2022

Progress on tasks 1, 3, 4, and 5 is on schedule. Field projects (Task 1, construction and long-term performance) continue to be monitored, with specific focus on projects where procedures are being adapted for specific circumstances. HVS testing of CCPR materials (Task 2) was delayed. However, testing on two sections (one with asphaltic emulsion and one with foamed asphalt) was completed in the review period. Satisfactory performance was observed on both sections. Laboratory testing (Task 3) continued according to the work plan, with primary focus during this review period on identifying appropriate laboratory compaction procedures and adding supplemental fines to PDR and CCPR projects to improve gradation/reduce air-void content to improve strength and raveling resistance. Concepts were tested on a pilot project in Glenn County. Two other pilot studies comparing emulsified and foamed asphalt recycling agents and comparing procedures to reduce maximum size of the recycled aggregates were also completed. Specimens cored from the test track at periodic intervals have also been tested for dynamic modulus to track aging of recycled layers. The expected behavior of deep-lift FDR pavements stabilized with cement (Task 4) was modeled, with initial findings indicating that shrinkage cracking is likely if full compaction and pre-cracking (i.e., microcracking) to the bottom of the layer are not achieved. Field projects are being sought to assess these findings. A new, comprehensive guideline on IPR was published, and the UCPRC participated in statewide training on IPR.

Guidance, Tests, and Specifications for High Recycled Asphalt Pavement/ Recycled Asphalt Shingle Contents in Hot Mix Asphalt (HMA) and Rubberized Hot Mix Asphalt (RHMA) Mixes

DRISI Project ID: 3819 | **UCPRC Project Number:** 4.79

Caltrans Technical Lead: Allen King, Office of Asphalt Pavement

UCPRC Project Manager: John Harvey (Mohamad Elkashef to August 15, 2021)

Research Needs

The degree of blending between recycled asphalt pavement (RAP), RAP/recycled asphalt shingles (RAS), and virgin binders could be significant, particularly for mixes using highly aged RAP and RAS, typical of inland valley scenarios. Incomplete blending could alter the properties of the mix because of less available binder and partial activation of the stiff RAP and/or RAS binder. Plant-produced mixes subjected to silo storage undergo additional blending and aging leading to increased stiffness, improved rutting, and reduced cracking and fatigue resistance. This incomplete and additional blending need to be better understood for consideration in mix design procedures and performance-related testing. The impact of long-term aging on the performance of high RAP and RAP/RAS mixes with different rejuvenators needs to be fully investigated using various aging protocols.

Objective/Goals

This study is a continuation of PPRC Project 4.64 (Continued Development of Guidelines for Determining Binder Replacement in High RAP/RAS Content Mixes). The objective of this project is to develop guidelines for determining binder replacement rates in high RAP/RAS content mixes without the need for binder extraction and performance-related tests for use in routine mix design and construction quality control/quality assurance.

Deliverables

Task 1: **Updated literature review to include recently completed research**

- PowerPoint presentation on updated literature review

Task 2: **Testing of high RAP and RAP/RAS mixes to determine their performance properties**

- PowerPoint presentation on high RAP and RAP/RAS testing findings

Task 3: **Testing of extracted and recovered RAP, RAP/RAS, and RAP/RAS/virgin binder blends to assess the effectiveness of different rejuvenators**

- PowerPoint presentation on RAP, RAP/RAS, and RAP/RAS/virgin binder blend testing findings

Task 4: **Complete investigation into the use of fine aggregate matrix (FAM) mix testing to assess the fatigue performance of mixes and to predict binder properties**

- PowerPoint presentation on FAM mix testing findings

Task 5: **Investigation of long-term aging effects of high RAP and RAP/RAS mixes using different laboratory-aging protocols**

- PowerPoint presentation on high RAP and RAP/RAS mix test findings

Task 6: **Monitoring of field performance of high RAP and RAP/RAS mixes and use results to evaluate laboratory-aging protocols**

- PowerPoint presentation on monitoring of field performance of RAP and RAP/RAS mixes

Task 7: **Preparation of research report with recommendations for use of RAP and RAP/RAS as binder replacement, and, if applicable, recommendations for accelerated wheel load testing**

- Report documenting research findings
- Recommendations for accelerated pavement testing of select RAP and RAP/RAS mixes, if justified

Summary of Progress FY 2021-2022

The large laboratory testing factorial experiment was completed during FY 2021-2022 and looked at binder sources, binder grades, RAP, RAS, and rejuvenator types as well as aging of all these sources. The factorial includes testing of the extracted binders and testing of mixes for fatigue, stiffness, and rutting as well as surrogate tests for stiffness and cracking. Analysis of the results and preparation of the report are currently underway. A report was completed on the results of testing of mixes with high RAP content that had been subjected to different amounts of time aging in the silo. The results showed the importance of aging before road placement for initial rutting and fatigue properties. Plans were developed for sampling, testing of materials, and monitoring of high RAP and RAS pilot sections that have been added to overlay construction projects. During FY 2021-2022, materials on El Dorado State Route 49 were sampled and tested, and a draft report was delivered summarizing the properties of the mixes with no RAP, 15% RAP, 25% RAP, 35% RAP, 45% RAP, and 3% RAS with 10% RAP. The properties of the mixes with high recycled contents were generally similar to the control mix with no RAP.

Sustainability

Implementation of Environmental Life Cycle Assessment (LCA) Data and Models for Project-Level Use in the eLCAP Software

DRISI Project ID: 3821 | **UCPRC Project Number:** 3.55

Caltrans Technical Lead: Deepak Maskey, Office of Concrete Pavement

UCPRC Project Manager: Ali Azhar Butt and Jon Lea (to June 29, 2021)

Research Needs

Caltrans personnel—working on project delivery from conceptual design through complete design; evaluation and improvement of specifications, guidance, and policy development; and reporting of emissions—do not currently have a comprehensive project-level tool for full-system life cycle assessment. There are existing spreadsheets and consultant reports for elements of the design stage, such as particular materials and construction. These tools have been intermittently updated, and some do not have documentation that permits the analyst to understand important assumptions, calculations, and data sources. Furthermore, in many cases the data used in these tools have not been reviewed and adjusted where necessary to match local conditions.

Objective/Goals

This study is a continuation of PPRC Project 3.46 (Environmental Life Cycle Assessment Pavement: Tool for Project-Level Use). The objective of this project is to continue the development of a web-based online life cycle assessment (LCA) pavement tool that uses energy and material datasets specific to California and follows the construction practices of Caltrans. It will use other updates developed by the UCPRC for Caltrans in the previous contract projects (Project 4.66: Environmental Life Cycle Assessment Updates and Applications; Project 4.73: Fast Model Energy Consumption Structural Response) and the companion project in the current contract (Project 4.80: Environmental LCA Updates and Applications). The tool will be consistent with the Federal Highway Administration (FHWA) Pavement Life Cycle Assessment Framework and the work of federal agencies (including FHWA) in the Federal Commons initiative.

The data and procedures in *eLCAP* will be updated for use at the conceptual-level design and project-level design stages. User interfaces based on user feedback will also be updated along with documentation for the tool. The compatibility of greenhouse gas emissions and other calculations in *PaveM* will be updated in *eLCAP*. The work will include an outside critical review of the tool itself (the inventories and models will be subject to a formal outside critical review as part of Project 4.80).

Deliverables

Task 1: Updating of *eLCAP* with updated and new models at every pavement life cycle stage

- Implementation of updates
- Updated inventory libraries
- Documentation of all the updates in *eLCAP*

Task 2: Implementation of conceptual design-level module for roadway analysis

- Incorporation of roadway elements and ability to use them at early stages of design in *eLCAP*
- Documentation with capability for analysis of policy, conceptual designs, and final designs

Task 3: Updated user interface and system requirements

- User and system requirement document
- Set of use cases
- User interface, report, and graph mockup documents

Task 4: Implementation, including UCPRC and Caltrans unit testing and review

- Online help system
- Results of UCPRC testing
- Results of Caltrans testing
- Results of regression testing

Task 5: Critical review

- Identification of willing outside reviewers
- Documentation of the critical review comments and responses
- Updated *eLCAP* project documentation
- Final online web help system
- Review of *eLCAP* (version 2.0)

Task 6: Updated software, software documentation, and help system

- Updated software
- Software documentation
- Online help system embedded in the software

Summary of Progress FY 2021-2022

The *eLCAP* software was updated with models and data for materials, construction, and the use stage developed in 2019 and 2020. Updates were also made to the user interface. The end-of-life stage was added to *eLCAP*, and it can now quantify the environmental impacts for all the life cycle stages of a pavement. Extensive testing was done by the UCPRC with Caltrans through a case study. The critical review panel of three international experts reviewed two reports: (1) the life cycle inventory data and models report that was developed to reflect California conditions and Caltrans construction practices and (2) the *eLCAP* user manual and technical report. Based on the reviewer comments, the reports were updated and submitted to Caltrans for review. Both reports were published in 2022. The *eLCAP* training material was developed and a dry run was completed with the Caltrans Pavement Program. *eLCAP* training for other Caltrans offices and districts is planned to continue in FY 2022-2023.

Multi-Criteria Decision Support for Prioritization of Strategies to Reduce Environmental Impacts

DRISI Project ID: 3822 | **UCPRC Project Number:** 3.56

Caltrans Technical Lead: Kuo-Wei Lee, Office of Concrete Pavement, and Cathrina Barros, Office of Asphalt Pavement

UCPRC Project Managers: Ali Azhar Butt and John Harvey

Research Needs

Caltrans roadway decision makers need to quantify changes they are making to reduce greenhouse gas (GHG) emissions. They also need to prioritize proposed changes in practices and policies to reduce GHG emissions and other environmental impacts, considering both cost and reduction in environmental impact, to arrive at the most cost-effective use of limited resources. In the prioritization framework, consideration can also be given to social indicators and the equity of impacts. The multi-criteria decision analysis framework developed in the previous project for Caltrans that considers reduction in life cycle GHG emissions and life cycle cost needs to be updated and improved by considering other existing and current work. The system boundaries for the updated framework need to be updated to consider additional environmental impacts and the possible inclusion of social indicators and the equity of environmental impacts from implementation of GHG mitigation strategies. The analysis will be applied to approaches for reducing GHG emissions and other environmental impacts identified by Caltrans.

Objective/Goals

This study is a continuation of PPRC Project 4.72 (Life Cycle Assessment of Alternate Strategies for GHG Reduction). The objective of this project is to include other environmental impacts in the supply curve method, identify potential social indicators and equity considerations, and investigate other multi-criteria decision analysis frameworks—life cycle assessment and life cycle cost analysis—that can be used by Caltrans in its decision-making process.

Deliverables

Task 1: Literature review of existing multi-criteria decision analysis (MCDA) frameworks

- Summary literature survey of MCDA, including a critique of the previously developed supply curve framework, additional strategies and more details for those identified in the Caltrans study, and inclusion of social indicators and equity in LCA at the state, regional, and neighborhood levels

Task 2: **Expansion of the system boundaries of the supply curve method to include other impacts**

- Technical memorandum including literature survey and updated supply curve framework

Task 3: **Case studies to demonstrate the enhanced framework and other MCDA methods**

- Technical memorandum on evaluation of several strategies as case studies using the updated supply curve and relevant MCDA methods

Task 4: **Preparation of white paper and policy brief**

- White paper
- Policy brief

Summary of Progress FY 2021-2022

A literature review was performed to identify the multi-criteria decision support methods that are currently being used by Caltrans. A work plan for this project was developed mainly focusing on the needs of the Caltrans Office of Planning. However, the Office of Planning subsequently decided to not continue participation, resulting in a pause in work. Since then, the Caltrans Pavement Program has become interested in this project. Work will begin in FY 2022-2023 applying the supply curve approach to evaluate and prioritize recommendations for district designers for approaches to reduce the environmental impacts of pavement projects.

Environmental Life Cycle Analysis (LCA) Updates and Applications

DRISI Project ID: 3820 | **UCPRC Project Number:** 4.80
Caltrans Technical Lead: Deepak Maskey, Office of Concrete Pavement
UCPRC Project Manager: Ali Azhar Butt

Research Needs

This project expands, improves, and updates the capabilities of Caltrans to address current and future issues required to meet the California Global Warming Solutions Act of 2006 (AB 32) greenhouse gas emissions targets and category pollutant regulations and to conduct more informed decision-making with respect to environmental, energy, and resource use impacts using life cycle analysis (LCA). A triennial update of existing life cycle inventory (LCI) databases using updated data from the government and other sources is needed. Industry-submitted environmental product declarations (EPDs) need further study for their potential use in LCA tools and for procurement as Caltrans receives them in its EPD implementation pilot project. Additional and improved data and algorithms for LCA for the range of design, construction, maintenance, and rehabilitation strategies used in California—including technology changes such as new materials production, construction equipment, and pavement structures—need to be developed. The ability to perform LCA at the conceptual design stage of project development and to consider roadway structures such as culverts, drainage, and standard highway bridge materials, construction, maintenance, and end-of-life, in addition to pavement, is needed. Updated and new LCIs need to be sent for external critical review of assumptions, data, models, and results. LCA procedures for considering uncertainty of data and models for application in California need to be improved.

Objective/Goals

This study is a continuation of PPRC Project 4.66 (Environmental Life Cycle Assessment Updates and Applications). The objective of this project is to continue updating and applying environmental LCA procedures for improving the sustainability of roadway operations in California.

Deliverables

Task 1: Updating of LCA with new material inventories

- Improved LCA capabilities in terms of data, models, and procedures
- Technical memorandum on LCI of newly inventoried materials
- Technical memorandum on evaluation of data from Caltrans EPD program

Task 2: **Development and finalizing of models to be implemented in *eLCAP* and in simplified form in *PaveM***

- Technical memorandum on use stage models (roughness, structural response, speed effects, electric vehicles)
- Technical memorandum on other life cycle stage models (construction work zone, materials and construction, end-of-life)

Task 3: **Critical review of inventories and models**

- Completed critical review
- Updated technical memoranda from Task 2

Task 4: **Information and data for implementation of models in tools**

- Information and data ready for updates in *eLCAP*
- Information and data ready for updates in *PaveM*

Summary of Progress FY 2021-2022

The updated life cycle models and data for the material and construction stages and transportation from 2019 and 2020 were implemented in the Caltrans pavement LCA tool (*eLCAP*) this fiscal year. The UCPRC LCI report was updated and finalized after being critically reviewed by the contracted critical review panel of three international experts, and it was published in 2022. A technical memorandum including the literature review on the effect of pavements on electric vehicles and their batteries was drafted. The literature review and social LCA framework development for Caltrans were initiated after approval of the project by Caltrans. Progress was also made on preparing the LCA using conceptual design-level information for standard bridges and culverts. Some reports from the 2017-2020 contract (pavement structural response empirical modeling report and the construction work zone [CWZ] modeling report) were updated based on the reviews received from Caltrans. The technical memorandum on lessons learned from the Caltrans EPD pilot project and the vehicle fuel use/pavement structural response report were published, and the CWZ report is nearing publication. The UCPRC continued attending bimonthly meetings and supporting Caltrans with the implementation of EPDs. Updating of the life cycle models and data will continue so that they can be implemented in the next version of *eLCAP*.

Pavement Management System

Tri-Annual Performance Model Update

DRISI Project ID: 3814 | **UCPRC Project Number:** 3.57
Caltrans Technical Lead: Robert Hogan, Office of Pavement Management
UCPRC Project Manager: Jeremy Lea

Research Needs

By 2023 Caltrans will have collected four additional years of automated pavement condition survey (APCS) data, which are not included in the current performance models. Additional possibilities to improve processing of the old data need to be explored. *PaveM* will replace the built-in model framework with a custom script-based implementation to enable the direct use of the statistical models in *PaveM*. New models will be needed for any new treatments and included in the new implementation framework. Currently, continuously reinforced concrete; full-depth recycling; partial-depth recycling; and crack, seat, and overlay treatments have models that need improvements.

Study Objective/Goal

This study is a continuation of PPRC Project 4.68 (Improved Smoothness and Distress Models for *PaveM*). The objective of this project is to develop updated performance models and any improvements in *PaveM* needed to use them.

Deliverables

Task 1: Continued performance model database development
- Updated performance modeling database

Task 2: Continued and enhanced empirical model development
- New empirical performance models

Task 3: Delivery and integration of new performance models into *PaveM*
- Performance models implemented and validated in *PaveM*

Task 4: Development of alternative models as needed
- Implementation of alternative models in *PaveM* as needed

Task 5: Reporting of model results
- A final report detailing the empirical models developed, along with updates to the relevant *PaveM* documentation sections

Summary of Progress FY 2021-2022

Most of the work on this project has continued to focus on Task 1 (updating the performance modeling database). During FY 2021-2022, the 2020 and 2021 APCS data were imported into the database, along with the 2021 transportation system network database and associated linear referencing system. An algorithm to improve the GPS coordinate to post mile conversion in the historical data is also under development. Additionally, minor improvements in data extraction have been implemented, including fixing an issue with transverse cracking. Work continues on documentation of the *PaveM* engineering configuration.

Continued Calibration of Mechanistic-Empirical Design Models with Pavement Management System Data

DRISI Project ID: 3764 | **UCPRC Project Number:** 3.58

Caltrans Technical Lead: Raghubar Shrestha, Office of Asphalt Pavement, and Kuo-Wei Lee, Office of Concrete Pavement

UCPRC Project Managers: Jeremy Lea and Rongzong Wu

Research Needs

Pavement performance data are collected for Caltrans on a yearly basis. An extensive amount of data is generated through various Caltrans activities. These data need to be organized and integrated to provide ever-growing data for periodic mechanistic-empirical (ME) calibration. Detailed field testing and performance data are needed for jointed plain concrete pavement (JPCP) projects with current design features at midlife to supplement pavement management system data. Data are needed to review performance of thin concrete overlay on asphalt (COA) pavements. The calibrations for *CalME* and *Pavement ME* need to be updated using the newly available data.

Objectives/Goals

The objective of this project is to establish an efficient and repeatable procedure for updating field calibration of ME design methods.

Deliverables

Task 1: Updated calibration data

- Technical memorandum with results of field testing and laboratory testing of field-sampled materials, comparisons with *Pavement ME*, and recent calibration assumptions and results
- Updated calibration database

Task 2: Updated *CalME* calibration

- Technical memorandum on updated *CalME* calibration

Task 3: Updated *Pavement ME* calibration

- Technical memorandum on updated *Pavement ME* calibration

Task 4: **Integration of network-level ME data management**

- Technical memorandum on how to integrate various data at the network level for ME calibration

Task 5: **Preparation of project documentation**

- Quarterly presentation to Caltrans regarding research progress
- Technical memoranda listed in Task 2, 3, and 4

Summary of Progress FY 2021-2022

Field testing and condition surveys of four long-life concrete projects built 18 to 20 years ago and one recent thin COA project in District 8 were completed. Scheduling continued for asphalt long-life project follow-up field sampling. Testing of samples from long-life concrete projects, up to 20 years old, continued for comparison with *Pavement ME* simulation predictions. The development of a strategy for updating *CalME* and *Pavement ME* calibration is underway.

Updates and Improvements to RealCost-CA

DRISI Project ID: 3815 | **UCPRC Project Number:** 3.59
Caltrans Technical Lead: Leonardo Mahserelli, Office of Concrete Pavement
UCPRC Project Manager: Changmo Kim

Research Needs

Variability and uncertainty of agency and user cost estimates and treatment lives of pavement materials are the key areas of life cycle cost analysis (LCCA) and decision support. Variability and uncertainty in LCCA need to be investigated, and methods of considering them in decision support need to be developed. Caltrans has implemented new pavement materials and treatments and their LCCA procedures, and maintenance and rehabilitation schedules need to be developed and included in the LCCA procedures manual and *RealCost-CA*.

The LCCA procedures manual needs to be continuously updated as new materials and treatments are developed so that designers can consider them along with current materials and treatments when comparing alternatives. An operation manager's manual needs to be developed with detailed procedures for updating default variables such as material unit prices, construction price indices, and other time-sensitive variables. The manual should also describe use of the software and management of input and output files by users. Traffic congestion in construction work zones (CWZs) during reconstruction and rehabilitation causes additional delay and associated road user costs—particularly on urban highways but also on rural routes. Consideration of construction-related delay is a part of Caltrans and Federal Highway Administration LCCA procedures. Better procedures are needed for estimating project-based road user costs from CWZ congestion on future maintenance and repair treatments.

Objective/Goals

This study is a continuation of PPRC Project 3.44: Update Life-Cycle Cost Analysis Manual and RealCost Version 3.0. The objective of this project is to continue updating the Caltrans *Life-Cycle Cost Analysis Procedures Manual* and *RealCost 3.0CA*.

Deliverables

Task 1: Consideration of variability and uncertainty for cost and treatment lives

- Summary notes and presentation file

Task 2: Procedures for estimating maintenance and repair schedules for new treatments

- Engineering configuration for maintenance and repair schedules for new treatments
- Updated maintenance and repair sequence selection function in *RealCost-CA*

Task 3: Operation manager's manual for *RealCost-CA*

- Online operation manager's manual for *RealCost-CA*
- Summary notes and presentation file

Task 4: Implementation of CWZ studies into *RealCost-CA*

- Engineering configuration for CWZ calculation and an updated *RealCost-CA* version reflecting new CWZ calculation methods

Task 5: Preparation of project documentation

- Technical memorandum

Summary of Progress FY 2021-2022

The maintenance and rehabilitation schedules for both asphalt and concrete pavements were updated using Caltrans current mechanistic-empirical approaches (*CalME* and *Pavement ME*) for cracking and pavement management system (*PaveM*) models for roughness. The maintenance and rehabilitation schedules had previously been based on engineering judgment and typical practice. The maintenance costs—including preventive treatment, capital maintenance, and rehabilitation—were calculated from the latest construction cost data and updated in the *Life-Cycle Cost Analysis Procedures Manual.* Trends for the discount rate in the past decades were investigated and a method to update average discount rate for LCCA was proposed. Literature reviews were done on variability and uncertainty for cost and treatment lives and maintenance and repair schedules for new treatments. The existing traffic delay models in *RealCost* were reviewed and updated to estimate realistic construction work zone traffic delay in this task. A framework for an operations manual was designed, and development continued for an interface for the operation manual. *RealCost 2.5CA* was updated to be compatible with Microsoft Office 64-bit as Caltrans upgraded Microsoft Office from 32-bit to 64-bit. *RealCost 3.0CA* was completely debugged and ready to launch during summer 2022.

Improved Traffic Models for PaveM and Mechanistic-Empirical Design

DRISI Project ID: 3765 | **UCPRC Project Number:** 4.81

Caltrans Technical Lead: Robert Hogan, Office of Pavement Management

UCPRC Project Managers: Jeremy Lea and Changmo Kim

Research Needs

The traffic calculation models in *PaveM* need to be updated based on changes and updates to the road networks made over time in California. The traffic information calculated from the updated process needs validation to ensure its accuracy across the statewide network, especially for the segments where changes in geometry or post mile have occurred and for routes with limited traffic information. The traffic information models in *PaveM* are accessed by pavement design and life cycle cost analysis and life cycle assessment software.

Objective/Goals

The objective of this project is to update the traffic calculation models in *PaveM* to improve the accuracy of traffic information for road segments.

Deliverables

Task 1: Improvement of current traffic models

- Summary notes of literature review
- Summary notes of traffic models
- Updated version of network-level traffic information
- Presentation materials

Task 2: Development of lane-based traffic information for heavy vehicles

- Lane-based traffic information database, including lane distribution factors, truck information, and weigh-in-motion (WIM) spectra per lane
- Summary notes and presentation materials

Task 3: Calculation of the traffic index for *PaveM*

- Traffic index data file
- Summary notes and presentation materials of traffic index estimates

Task 4: Implementation of WIM spectra in *CalME* and *Pavement ME*

- Functional traffic information (monthly and hourly distribution tables) of WIM spectra for *CalME* and *Pavement ME*
- Summary notes and presentation materials of WIM spectra files

Task 5: Collection of traffic data for model verification on roads with no sensors

- Traffic data files and summary notes
- Presentation materials on the verification results

Task 6: Preparation of study report

- Technical memorandum

Summary of Progress FY 2021-2022

The existing traffic models and collected literature have been reviewed, and a framework for updating current traffic models was developed. Caltrans traffic information from different sources were collected and checked for consistency. Annual average daily traffic (AADT) and annual average daily truck traffic (AADTT) data from the Caltrans Performance Measurement System (PeMS), Traffic Census Program, and data WIM systems were collected and compared. The WIM data were separated and analyzed by lane to investigate the lane-based WIM spectra on California highways. A framework was designed to develop traffic models for estimating AADT and AADTT on the highway sections where no traffic information is available. Work will continue to develop lane-based WIM spectra for the California highway system and traffic estimate models.

Potential for Advanced Image Evaluation in Automated Pavement Condition Surveys (APCS)

DRISI Project ID: 3766 | **UCPRC Project Number:** 4.82

Caltrans Technical Lead: Imad Basheer, Office of Pavement Management

UCPRC Project Manager: Jeremy Lea

Research Needs

New technologies are available that use image analysis to discover features of the pavement from automated pavement condition surveys (APCS) images and data that would be useful for performance prediction and treatment selection. These technologies are best evaluated by testing their readiness on problems such as drainage evaluation and flagging of replaced concrete slabs. This investigation will involve the development of extensive "training" datasets where these features have been manually flagged.

Objective/Goals

The objective of this project is to propose improvements to APCS data collection to facilitate advanced image analysis and a possible pilot implementation.

Deliverables

Task 1: Capacity development at the UCPRC, including background and establishment of a knowledge and computing environment suitable for training deep learning neural network models

- A functional machine-learning environment accessible to UCPRC researchers, with training materials about how it can be used

Task 2: Library of tagged images, using various right-of-way and pavement surface images from different vendors

- Database of tagged images tied to the performance modeling database

Task 3: Model for flagging recently replaced slabs on jointed plain concrete pavements and patches on asphalt

- A trained deep learning agent capable of predicting if a slab observed in an image has been recently replaced
- A trained deep learning agent capable of identifying recently patched areas of the pavement surface

Task 4: **Model for categorizing the drainage conditions and other roadside features at various locations**

- A trained deep learning agent capable of predicting, from the right-of-way image, the state of the drainage at a particular location

Task 5: **Georgia Institute of Technology (Georgia Tech) subcontract**

- Advice to the UCPRC on state-of-the-art automated pavement condition survey machine-learning technology advances and planned future developments being funded by the Federal Highway Administration
- Assistance in development of two case studies on finding replaced concrete slabs, identifying drainage features, and classifying their condition

Task 6: **Final report and possible pilot implementation**

- Technical memorandum on and recommendations for future uses of advanced image analysis in automated pavement condition surveys

Summary of Progress FY 2021-2022

In FY 2021-2022, this project mainly involved working with Georgia Tech to develop the required datasets. The slab cracking database developed previously has been imported along with the raw 2018 APCS data used as a basis for this work. Right-of-way images from the 2011 APCS data were extracted based on shoulder type because shoulder type is a fundamental precursor to evaluating drainage. A team of undergraduate students reevaluated the shoulder type, and the resulting database was then shared with Georgia Tech researchers, who are now developing machine learning models for both the replaced slabs and shoulder type.

Support Tasks

Develop and Manage Partnered Pavement Research Program

DRISI Project ID: 3823 | **UCPRC Project Number:** 2.01

Overview

Provide management and administration of the overall PPRC contract, and work to establish partnerships with organizations outside of Caltrans to improve Caltrans pavements.

Summary of Progress FY 2021-2022

The UCPRC provided contract and financial administration for projects and worked with industry and other government agencies to support Caltrans-sponsored research.

Provide Advice to State Government on Pavement Technology

DRISI Project ID: 3829 | **UCPRC Project Number:** 2.02

Overview

Perform conceptual and feasibility studies (small projects at a cost of less than $10,000), answer questions, and provide information, as requested by Caltrans.

Summary of Progress FY 2021-2022

The UCPRC's advice has primarily involved supporting Caltrans with requests for information, background briefings, and input for decision-making not tied to current PPRC projects.

Provide Support for Pavement Management System

DRISI Project ID: 3832 | **UCPRC Project Number: 2.03**

Overview

Provide continued support for implementation of pavement and asset management within Caltrans, including updates and enhancements to *PaveM*, support for the "pavement portal" applications and other tasks as directed by Caltrans. Specific tasks include the restructuring and improvement of project information within *PaveM*; annual updating of the linear referencing system (LRS), traffic data, and other data; application of the segmenting processes; and documentation of existing engineering configuration, software, and processes.

Summary of Progress FY 2021-2022

Work on this task is as needed by Caltrans. In FY 2021-2022, this work has involved assistance to Caltrans with debugging issues in *PaveM*, discussions around the transition to the new LRS and models, meetings and planning for software upgrades to *PaveM*, and various updates to the UCPRC information technology infrastructure that supports the PaveM Portal applications. This support work also included responding to questions from Caltrans about the various *PaveM* support tools (PCR, H-Chart, iGPR, iGPR-Core, PaveM Portal, RP-List) and making changes to them, updating the various files (Highway Log, Project History, APCS, and Previous Year Actuals) that are exported out of *PaveM* for use in the UCPRC *PaveM* tools, and fixing bugs and resolving issues related to the server, as necessary.

The programmer/engineer who developed the PaveM Portal applications retired in June 2021, and a new programmer was hired at the end of FY 2020-2021 to assume this role. This personnel change has involved recruitment efforts and transitioning of the tools, including moving the revision tracking from an internal Subversion server to GitHub, where the code can be shared with Caltrans.

Provide Support for CalME, Pavement ME, and CalBack

DRISI Project ID: 3831 | **UCPRC Project Number:** 2.04

Overview

Provide support and training for use of *CalME*, *Pavement ME*, and *CalBack* to Caltrans users and other users as identified by Caltrans. Update the interface and internal operations of *CalME*, *Pavement ME*, and *CalBack* as requested by Caltrans.

Summary of Progress FY 2021-2022

The UCPRC provided extensive support for rewriting of the *Highway Design Manual* to reflect updated practice using mechanistic-empirical design and performance-related specifications. A site investigation guide for asphalt- and concrete-surfaced pavement was developed along with updates to the CT-357 method for falling weight deflectometer testing and analysis. Updates were made to the *CalME* software based on input from the districts and other users.

Provide Support for eLCAP and RealCost-CA

DRISI Project ID: 3779 | **UCPRC Project Number:** 2.05

Overview

Provide support and training for use of *eLCAP* and *RealCost-CA* to Caltrans users and other users as identified by Caltrans. Update the interface and internal operations of *eLCAP* and *RealCost-CA* as requested by Caltrans.

Summary of Progress FY 2021-2022

The UCPRC provided support to Caltrans to answer questions from the districts and headquarters regarding life cycle cost analysis and to update the current *RealCost-CA* software. Support for *eLCAP* primarily consisted of helping Caltrans perform life cycle assessment case studies with the cement industry and supporting districts with case studies.

Maintain Laboratory Testing AASHTO Re:source Certification

DRISI Project ID: 3828 | **UCPRC Project Number:** 2.06

Overview

Calibrate laboratory equipment as needed for AASHTO and Caltrans quality assurance specifications to complete Caltrans projects, and pay for certification costs.

Summary of Progress FY 2021-2022

Funds for this support task were used for management of the UCPRC laboratories, including annual and biannual equipment calibrations and all aspects of maintaining Caltrans and AASHTO accreditations. Additionally, improvements to laboratory safety, occupational health, ergonomics, material and specimen flows, and general and management procedures continued. Changes to sustain operations during the COVID-19 pandemic were also implemented. Laboratory consumables (e.g., personal protective equipment, small tools, sample storage, cleaning materials) were also covered under this task.

Maintain Laboratory and Field-Testing Equipment Capability

DRISI Project ID: 3826 | **UCPRC Project Number:** 2.07

Overview

Maintain and/or replace laboratory and field equipment to complete Caltrans projects.

Summary of Progress FY 2021-2022

Funds for this support task were used to maintain and/or replace laboratory and field equipment to complete Caltrans projects. Equipment purchases included an asphalt mixer and gyratory compactor for preparing asphalt and recycled material specimens, two auto core driers for asphalt specimens, a jig for running the IDEAL-RT asphalt rutting test, two cutting chambers for conditioning cement treated and concrete specimens, and a planetary ball mill and bench mixer for cement research.

Maintain Heavy Vehicle Simulator Equipment

DRISI Project ID: 3827 | **UCPRC Project Number:** 2.08

Overview

Maintain, replace, and calibrate equipment used for accelerated pavement testing with the Heavy Vehicle Simulators (HVS) to complete Caltrans projects.

Summary of Progress FY 2021-2022

Funds for this task were used to maintain, replace, and calibrate equipment used for accelerated pavement testing with the HVS machines to complete Caltrans projects. Both machines were overdue for comprehensive hydraulic system overhauls, and this work was initiated. Unfortunately, COVID-19 shutdowns significantly delayed delivery of critical parts for the overhaul process. Work on both machines included replacement of all hydraulic hoses, overhaul of the hydraulic pumps, and replacement of drive chains and sprockets. Work on HVS-2 included overhaul of the gearbox and replacement of the carriage control unit. Work on HVS-3 included replacement of the loading ram and side shift rails and installation of a cooling system for the environmental chamber.

Operate Falling Weight Deflectometer and Profiler Calibration Centers

DRISI Project ID: 3825 | **UCPRC Project Number:** 2.09

Overview

Maintain space, equipment, and certifications for calibration of Caltrans and contractor profiler equipment to support Caltrans smoothness specifications. Maintain space, equipment, and certifications for operation as a Federal Highway Administration falling weight deflectometer (FWD) calibration center.

Summary of Progress FY 2021-2022

Three FWDs were calibrated. Profiler calibrations were undertaken on 18 days during the year, during which 37 Caltrans, 67 industry, and 4 UCPRC operators were certified, and 15 Caltrans and 27 industry vehicles and a UCPRC vehicle were certified.

Upgrade/Maintain Research Support Space

DRISI Project ID: 3241 | **UCPRC Project Number:** 2.10

Overview

Update, augment, and rehabilitate research support space in Davis and Richmond as need to perform research for Caltrans.

Summary of Progress FY 2021-2022

Work included construction of two new concrete testing laboratories and repurposing of the old saw room to a third concrete testing laboratory.

Provide Support to Division of Aeronautics

DRISI Project ID: 3780 | **UCPRC Project Number:** 2.11

Overview

Provide research, development, and implementation support for improved technologies and practices for airfields as requested by the Caltrans Division of Aeronautics. Coordinate activities with research sponsored by the Federal Aviation Administration.

Summary of Progress FY 2021-2022

No work was completed on this task due to personnel changes at the division, which have delayed approval of the work plan and the start of work.

Conduct Advanced Pavement Research for Long-Term Future Needs

DRISI Project ID: 3830 | **UCPRC Project Number:** 2.12

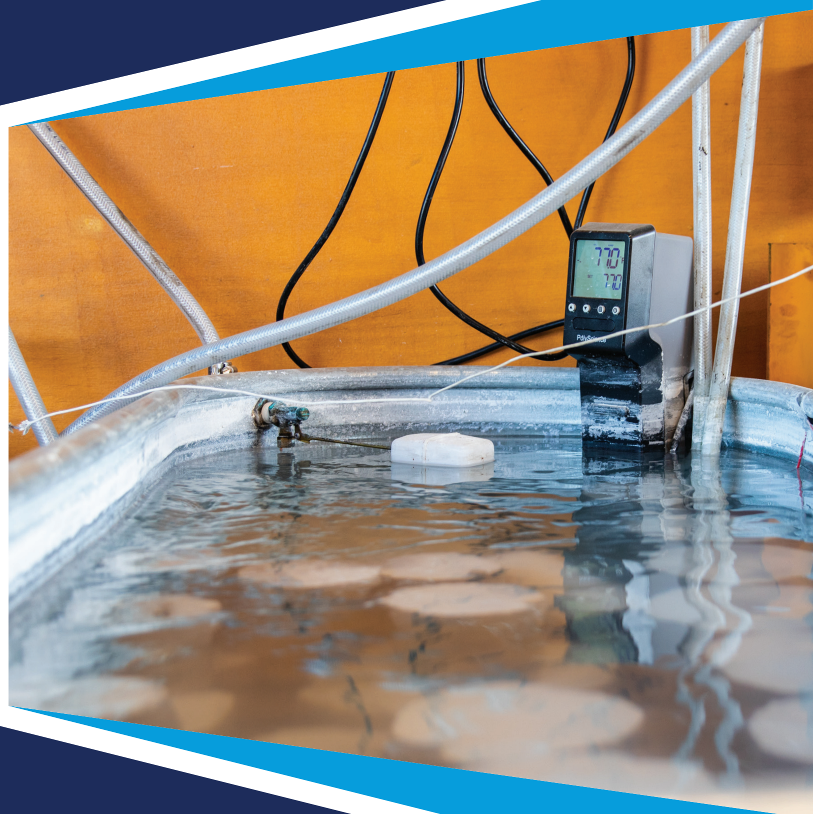
Overview

Perform conceptual, research, and development studies for long-term future Caltrans and California transportation needs not directly tied to Caltrans line functions at the direction of DRISI.

Summary of Progress FY 2021-2022

Work continued on a study of urban metabolism (circular economy) considering materials for hardscape and the water cycle in urban areas.

Appendix A:
UCPRC Publications
FY 2021-2022



Continued Noise and Smoothness Monitoring on Concrete Pilot Projects of Grind and Groove and Continuously Reinforced Concrete Pavements

Technical Memorandum Number: UCPRC-TM-2021-04

Publication Date: March 2022

Authors: Irwin Guada and John Harvey

Principal Investigator: John Harvey

Caltrans Technical Lead: Kuo-Wei Lee

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Element 3.35 (DRISI Task 2710): Quieter Pavement Monitoring

Download: doi.org/10.7922/G22N50K0

Need for Research

Over the past few decades, awareness of the impacts of highway traffic noise has grown with increases in the number of vehicles and the populations either living close to highway corridors or conducting activities near them. In response, many departments of transportation have recognized the need to better understand the surface characteristics of pavements—not only because of the effect of pavement surface friction on safety and ride quality, but also because pavement surface characteristics contribute to noise generation through interaction with the vehicle’s tires.

Research Approach

This project gathered data in 2016 and early 2017 on the performance of three concrete pavement types relatively new to California: (1) continuously reinforced concrete pavement (CRCP) textured primarily with longitudinal tining (LT), (2) joint plain concrete pavement (JPCP) textured with conventional diamond grinding (CDG), and (3) JPCP textured with the grind and groove (GnG) surfacing. The GnG technology on test sections in Caltrans pilot projects was evaluated in terms of measured tire/pavement noise, smoothness, friction, and surface drainability.

Results

The results presented in this technical memorandum show two years of measurements of tire/pavement noise in terms of on-board sound intensity (OBSI) and smoothness in terms of the International Roughness Index (IRI). The following are preliminary conclusions regarding tire-pavement noise, OBSI, and pavement smoothness, IRI, from the two sets of data collected about four years apart:

- OBSI levels on the concrete pavements evaluated in this study originally ranged from 100 dBA to 116 dBA. The data from four years later ranged from 101 dBA to 116 dBA.
- Among the four pavement types and textures, the CRCP with LT sections on average were the loudest, at 106 dBA. The CRCP with CDG sections on average (with two sections) were the next loudest, at 104 dBA. The CRCP sections overall also showed the lowest rate of change, at 0.2 dBA/yr.; excluding the Placer 80 section, which is affected by truck chain wear, the LT sections rate of change is 0.02 dBA/yr.
- The OBSI values for the JPCP sections with CDG ranged from 101 dBA to 105 dBA and averaged 103 dBA. The OBSI change rate for the CDG sections averaged 0.3 dBA/yr.
- The OBSI values for the JPCP sections with GnG ranged from 100 dBA to 106 dBA and averaged 102 dBA. On average, the GnG sections were the quietest pavements in this study; however, GnG sections also had the highest OBSI change rate, at 0.4 dBA/yr.
- The effect of truck traffic versus passenger car traffic on the OBSI change rate is indicated by the JPCP data, excluding the CRCP data. For CDG sections, trucks increased the OBSI change rate from 0.2 dBA/yr. to 0.4 dBA/yr. compared to passenger car lanes, and for the GnG sections, trucks increased the OBSI change rate from 0.3 dBA/yr. to 0.5 dBA/yr.

Recommendations

Regarding development and implementation of quieter concrete pavement strategies in California, the results to date in this study suggest the following preliminary recommendations: (1) continue the use of CDG; (2) continue the study and use of GnG, specifically looking into long-term performance; and (3) consider using the GnG surface texture on CRCP pavement sections.

Concrete Overlay on Asphalt Pilot Project at Woodland SR 113: Construction

Research Report Number: UCPRC-RR-2020-01

Publication Date: July 2021

Authors: Angel Mateos, John Harvey, Miguel Angel Millan, Rongzong Wu, Fabian Paniagua, Jessica Cisneros, and Julio Paniagua

Principal Investigator: John Harvey

Caltrans Technical Lead: Dulce Rufino Feldman

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Element 3.39 (DRISI Task 3201): Implementation and Field Performance Evaluation of Concrete Overlay on Asphalt

Download: doi.org/10.7922/G2PV6HN4

Need for Research

Concrete overlay of asphalt (COA), formerly known as whitetopping, is a pavement rehabilitation technique that consists of placement of a 4 to 7 in. thick concrete overlay on an existing flexible or composite pavement. This technique, an alternative to conventional overlay construction, has been used frequently on highways and conventional roads in several US states as well as in other countries, but its use in California has been very limited. This research focuses on the design and construction of a COA pavement pilot project on State Route 113 in Woodland, California, one of the first projects in the Caltrans road network where this rehabilitation technique has been used.

Research Approach

The project site extended over approximately four miles of a two-lane secondary road. The concrete slabs were a half-lane wide (6×6 ft.) and 6 in. thick. The transverse joints were undoweled, but tie bars were installed at all the longitudinal joints. The outside slabs were 2 ft. wider than the interior slabs to provide a concrete shoulder. The project included a section with newly placed, rubberized, gap-graded asphalt mix base. A rapid-strength concrete mixture with Type II/V portland cement designed to be opened to traffic in 24 hours was used for construction of the overlay. The northern part of the project was built in October and November 2018, while the southern part was built in April and May 2019. The concrete mixture was produced in a fixed plant and transported in ready-mix trucks 25 miles to the construction site. A slipform paver was used to consolidate and finish the concrete.

Results

A number of the quality control/quality assurance (QC/QA) tests and evaluations summarized in this report were conducted before, during, and after the construction of the concrete overlay. These tests and evaluations revealed no major design or construction issues with the concrete overlay, but they did show that the condition of the asphalt base was very poor, particularly in the northern part of the project.

Recommendations

The main recommendations from the construction QC/QA tests and evaluations are the following:

- Before a decision is made about whether to use the COA rehabilitation technique and to proceed with developing a design, it is recommended that a detailed field investigation of the existing pavement that includes a comprehensive coring plan be conducted. The field investigation should focus on both the pavement's lanes and its shoulders, particularly if the use of widened slabs is going to be considered in the design.
- Milling of asphalt that is still in good condition reduces the structural capacity needed to reduce the overlay thickness. The COA technique is more efficient when sound asphalt remains in place, which usually requires no restriction against elevation of the road surface.
- It is recommended that future COA projects specifically address the necessary repairs to the asphalt base after the milling operation.
- It is recommended that future COA projects continue the practice of cleaning the asphalt surface thoroughly before the concrete overlay is placed, as indicated in the Woodland SR 113 rehabilitation special provisions. Additional measures should be implemented to ensure that the contractor fulfills this requirement.
- It is recommended that the special provisions of COA on asphalt projects specifically prohibit the manual insertion of tie bars.
- It is recommended that future COA projects specifically address the need to install dowels in the construction transverse joints.
- The large postconstruction mean roughness index (MRI) values measured in this project emphasize the need to explore modern techniques like stringless (3D) paving and real-time smoothness evaluation, which may help to achieve smoother concrete surfaces. It is recommended that these techniques be combined with vibrating wire strain gauge measurements to estimate the hygrothermal component of MRI.
- For circumstances where the structural contribution of the asphalt base is expected to be minimal (as was the case with the Woodland SR 113 overlay), it is recommended that consideration be given to expanding the current range of concrete pavement design procedures.

Site Investigation Guide for Mechanistic-Empirical Design of California Pavements

Guideline Number: UCPRC-GL-2020-02

Publication Date: March 2021

Authors: David Jones, John Harvey, and Rongzong Wu

Principal Investigator: John Harvey

Caltrans Technical Leads: Raghubar Shrestha and Deepak Maskey

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Element 3.41 (DRISI Task 3200): ME Algorithms and Field Characterization

Download: doi.org/10.7922/G21R6NT3

Need for Research

The purpose of a site investigation is to allow pavement engineers to collect sufficient data to make informed and appropriate decisions throughout the project development and pavement design processes and to provide inputs for a chosen structural design method. This document provides guidance to project engineers and material engineers for performing site investigations as a first critical step in confirming the recommended approach for capital maintenance projects and in developing structural designs for projects that involve rehabilitation, widening, reconstruction, or new pavement.

Research Approach

The guide's primary focus is on collecting the data required for mechanistic-empirical pavement design using the *CalME* software for flexible-surfaced pavement and on using the *Pavement ME* software and the Caltrans rigid pavement design catalog for rigid-surfaced pavement. The guide also includes information specific to California conditions, providing details about site investigation procedures that can be used to supplement the current *Highway Design Manual* and other available design guides.

Results

A project site investigation includes the following four steps, which form the basis of the structure of this guide: (1) preliminary investigation, which includes initial desktop study data collection and a preliminary site investigation; (2) detailed site investigation; (3) data analysis; and (4) project investigation report.

Recommendations

This study provides guidance on site investigations for new highway construction, reconstruction, rehabilitation, and widening projects. This site investigation guide is an integral part of the *CalME* mechanistic-empirical design procedures for flexible-surfaced alternatives, and *Pavement ME* procedures or use of the Caltrans catalog for rigid-surfaced pavement design.

eLCAP: A Web Application for Environmental Life Cycle Assessment for Pavements

Technical Memorandum Number: UCPRC-TM-2018-04

Publication Date: January 2022

Authors: Jon Lea, John Harvey, Arash Saboori, and Ali Azhar Butt

Principal Investigator: John Harvey

Caltrans Technical Lead: Deepak Maskey

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Elements 3.46 (DRISI Task 3207): Environmental Life Cycle Analysis Tool for Project Level Use; 4.54 (DRISI Task 2718): Environmental Life Cycle Assessment Updates and Applications, and 4.66 (DRISI Task 3191): Environmental Life Cycle Assessment Updates and Applications

Download: doi.org/10.7922/G2ST7N5G

Need for Research

Caltrans has a growing need to be able to quantify its greenhouse gas (GHG) emissions and the other environmental impacts of pavement operations, and to consider GHG and those other impacts in pavement management, conceptual design, design, materials selection, and construction project delivery decisions. Caltrans also needs to be able to evaluate the life cycle environmental impacts as part of policy and standards development. All these tasks can be performed using life cycle assessment (LCA), although there are different constraints and requirements with respect to the scope of the LCA and the data available for each of these different applications.

Research Approach

The web-based software *eLCAP* (*environmental Life Cycle Assessment for Pavements*) is a project-level LCA tool that uses California- and Caltrans-specific life cycle inventories (LCIs) and processes. The LCI database has been critically reviewed by outside experts following International Organization for Standardization (ISO) standards.

Results

eLCAP models the life cycle history of a pavement project by allowing a user to specify any number of construction-type events, occurring on a user-specified date, followed by an automatically generated Use Stage event that begins immediately afterward and lasts until the next construction-type event or the end-of-life date. The Use Stage models currently consider the effects of roughness in terms of the International Roughness Index (IRI) and use the same performance models that are used in the Caltrans pavement asset management system software, *PaveM*. *eLCAP* performs a formal mass-balancing procedure on a pavement LCA project model and then computes 18 different impact category values—including Global Warming Potential, Human Health Particulate Air, Acidification, and different forms of Primary Energy—and generates a detailed *Excel* report file to display graphs and tables of results. The results can be presented in terms of life cycle stage, material types, and other details.

Recommendations

Currently, *eLCAP* has 58 specific LCIs (exported from *GaBi* [*Ganzheitliche Bilanz*, or *GaBi*, is the LCA software from thinkstep AG which is now owned by Sphera]) and 43 user-addressable processes grouped into 21 types of models, such as Hot Mix Asphalt, Portland Cement Concrete, Electricity, Paver, and Grinder for construction-type events (Materials and Equipment) and a Use Stage that computes GHG as a function of the IRI and traffic. The following are potential enhancements being considered for future versions of *eLCAP*:

- Additional materials
- Additional transports
- Additional pieces of equipment
- Use Stage to include mean profile depth and pavement deflection
- Additional impact categories for the Use Stage
- Comparisons by users of one Project Trial to another Project Trial
- *eLCAP* functioning at the conceptual project-level evaluation stage, similar to the Federal Highway Administration's Intersection Control Evaluation (ICE) tool
- Updating of *eLCAP* database libraries with publicly available data

Lessons Learned from Caltrans Pilot Program for Implementation of EPDs

Technical Memorandum Number: UCPRC-TM-2021-01

Publication Date: September 2021

Authors: Ali Azhar Butt and John Harvey

Principal Investigator: John Harvey

Caltrans Technical Lead: Jacquelyn Wong

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Element 3.47 (DRISI Task 3211): Support Caltrans with EPDs

Download: doi.org/10.7922/G2GB22CM

Need for Research

An environmental product declaration (EPD) is a transparent, verified report used to communicate the environmental impacts (e.g., resource use, energy, emissions) associated with the manufacture or production of construction materials such as asphalt, cement, asphalt mixtures, concrete mixtures, or steel reinforcement. EPDs, which are also called Type III environmental declarations, are product labels developed by industry in accordance with International Organization for Standardization (ISO) standards. The scoping document for an EPD, which is also referred to as a product category rule (PCR), defines the requirements for EPDs for a certain product category. Beginning in 2019, Caltrans initiated a pilot study requiring EPDs for hot mix asphalt, aggregates, and concrete in addition to the materials specified by the Buy Clean California Act (BCCA) (Assembly Bill 262). The requirement to submit EPDs for these materials is how plans made several years prior to passage of the BCCA, for use of EPDs to help achieve environmental goals, are being implemented. While the BCCA considers only the greenhouse gas emissions contributing to global warming, the Caltrans pilot program for pavement and bridge materials also looks for other emissions in the EPDs, primarily emissions that cause air pollution.

Research Approach

This project consisted of the UCPRC reviewing and helping develop the Caltrans plans for collecting EPDs, reviewing PCRs and EPDs for consistency and inconsistencies, helping to communicate strategy with industries and the Federal Highway Administration, supporting Caltrans's development of a web-based portal for entry of EPD data and the underlying database, and writing of a summary report.

Results

This technical memorandum is the summary report. This report documents the roadmaps developed for collecting and using EPDs, other support activities for the Caltrans EPD program, and a review of the EPDs supplied to Caltrans as of the summer of 2020 and their underlying PCRs.

Recommendations

The PCRs for the materials in the Caltrans EPD program have inconsistencies that should be relatively simple to resolve with direction from Caltrans. Currently, consistent data entry is difficult in the Caltrans EPD portal. To improve the consistency and quality of EPDs, Caltrans staff must receive guidance on how to review EPDs and staff at materials producers require training about how to interpret PCRs to produce EPDs. Systems for inputting data from EPDs into department of transportation (DOT) reporting systems that include data quality checks, system consistency, and certification are also needed. Similarly, a nationally accepted and adopted data quality assessment standard is needed for EPDs as DOTs move toward their use in procurement. A single data quality matrix should also be included in a harmonized PCR.

Pavement ME JPCP Transverse Cracking Model Calibration and Design Catalog Framework (Version 2.5.5)

Research Report Number: UCPRC-RR-2020-02

Publication Date: September 2021

Authors: Ashkan Saboori, Jeremy Lea, John Harvey, Jon Lea, Angel Mateos, and Rongzong Wu

Principal Investigator: John Harvey

Caltrans Technical Lead: Dulce Rufino Feldman

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Element 3.49 (DRISI Task 3199): Implement Concrete ME Design Tools

Download: doi.org/10.7922/G26D5R8W

Need for Research

The *Mechanistic-Empirical Pavement Design Guide* (*MEPDG*) is a comprehensive method, including models and guidance, developed in 2002 by the American Association of State Highway and Transportation Officials (AASHTO) to analyze and design both flexible and rigid pavements. The *MEPDG* is implemented in a software called *Pavement ME*. The MEPDG models were calibrated using data from the Long-Term Pavement Performance (LTPP) sections throughout the United States, including some from California. The *MEPDG* recommends that nationally calibrated models be validated using local data and, if necessary, recalibrated. This recommendation is particularly applicable to the Caltrans road network, considering the climate and materials differences between California and the rest of the nation.

Research Approach

The first step in recalibrating *Pavement ME* is to perform a sensitivity analysis to identify which variables are most important and to look for results that do not match expected performance. This was the subject of a previous report titled *Pavement ME Sensitivity Analysis*. Based on the sensitivity analysis, the decision was made to perform a new calibration of the MEPDG models as implemented in the *Pavement ME* software. A new approach was developed for the calibration using network-level performance data from the pavement management system (PMS) with orders of magnitude more observations and length of pavement than are used in the traditional approach and in the national calibration of the MEPDG models. The framework does not require sampling of materials from specific sections in the network. Rather, it uses the statewide median values from mechanistic testing from a representative sample of materials across the network. Variability of performance and reliability of design (probability that the design will meet or exceed the design life) is accounted for through separate consideration of within-project and between-project variability. The calibration reduced significant bias in the application of the nationally calibrated models to California.

Results

This report presents the results of the application of the new procedure to calibrate the *Pavement ME* transverse cracking model for jointed plain concrete pavements (JPCP). The California pavement management system (PaveM) database—with about 4,600 lane-miles of JPCP built on 446 lane replacement projects completed between 1947 and 2017—was used to calibrate the transverse cracking model in *Pavement ME*. The nationally calibrated *Pavement ME* transverse cracking model prediction on the PaveM performance database has bias and standard error of 13.3% and 23.03%, respectively. After calibration, the bias and standard error of the locally calibrated model decreased to 0.039% and 5.69%, respectively.

Recommendations

Two important variables—portland cement concrete (PCC) coefficient of thermal expansion and PCC compressive strength—were not available for calibration and had a significant impact on the *Pavement ME* transverse cracking model prediction. The designer of a JPCP project does not know these variables prior to construction; the designer only knows the minimum specified values. Use of the minimum specified values will tend to impart additional unquantifiable conservatism into the designs. The distribution of measured strengths, translated to flexural strengths, was considered in the calibration and will be considered in the updated Caltrans JPCP design catalog. The new approach presented in this study accounts for the uncertainties produced by these unknown factors by incorporating different types of variabilities in the calibration process and hence different levels of reliabilities in the model predictions. However, having better data for these variables from projects in California in the future will definitely reduce the calibrated model errors for future calibrations.

The weigh-in-motion (WIM) spectra that were believed to have a significant impact on JPCP performance (i.e., higher level WIM Spectra 4 and 5 cause less cracking) were found to have an opposite effect in first- and third-stage cracking performance model development. These data should be fixed in the PaveM database for better future performance model development and *Pavement ME* calibrations.

Pavement Recycling: Shrinkage Crack Mitigation in Cement-Treated Pavement Layers—Phase 2a Literature Review and FDR-C Test Road Construction and Monitoring

Research Report Number: UCPRC-RR-2019-05

Publication Date: December 2020

Authors: Stephanus Louw, David Jones, Joseph Hammack, and John Harvey

Principal Investigator: John Harvey

Caltrans Technical Lead: Allen King

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Elements 4.52B and 4.65 (DRISI Tasks 2709 and 3194): Microcracking of Cement-Treated Pavement Layers

Download: doi.org/10.7922/G2Q81BC1

Need for Research

Caltrans has been using full-depth recycling (FDR) as a rehabilitation strategy since 2001. Early projects were recycled with foamed asphalt and cement, but cement-only treatments were permitted from 2015 to improve the properties of more marginal materials. However, shrinkage cracking associated with the hydration and curing of the cement-treated layers remains a concern, especially with regard to crack reflection through asphalt concrete surfacings and the related problems caused by water ingress.

Research Approach

The research discussed in this report builds on earlier work with a focus on better understanding microcracking mechanisms and identifying key factors influencing performance—including but not limited to aggregate properties, cement content, the time period before microcracking starts, layer moisture contents, roller weights and vibration settings, the number of roller passes, the field test methods and criteria used to assess the degree of microcracking, and the effects of early opening to traffic. In this phase of the study, a 36-cell test road was designed, constructed, and monitored to evaluate shrinkage crack mitigation procedures.

Results

The main findings from the study included revised mix design procedures based on the initial consumption of stabilizer and target unconfined compressive strengths of 450 psi (3.1 MPa) with a maximum permissible limit of 600 psi (4.1 MPa), the importance of appropriate curing, and a revised microcracking window of between 48 and 56 hours after compacting the layer.

Recommendations

In addition to the revised mix design procedures, it is recommended that a stiffness reduction target of 40% of the stiffness prior to microcracking, measured with the soil stiffness gauge, be considered instead of the current method specification.

Investigation of the Effect of Pavement Deflection on Vehicle Fuel Consumption: Field Testing and Empirical Analysis

Research Report Number: UCPRC-RR-2021-03

Publication Date: January 2022

Authors: Ali Azhar Butt, John Harvey, Dillon Fitch, Sampat Kedarisetty, Jeremy D. Lea, Jon Lea, and Darren Reger

Principal Investigator: John Harvey

Caltrans Technical Lead: Deepak Maskey

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Element 4.53 (DRISI Task 2691): Validation of Greenhouse Gas Emissions from Pavement Deflection

Download: doi.org/10.7922/G2X34VRF

Need for Research

The 2015 Federal Highway Administration (FHWA) report *Towards Sustainable Pavement Systems* summarized the state of field experimental measurement and model validation for the effects of pavement structural response on vehicle fuel use. A summary from the FHWA report shows that several field experiments have been conducted. However, none of these experiments were comprehensive with respect to pavement and vehicle types, and they did not characterize the pavement structural responses under different temperature conditions and loading durations that control the viscoelastic response. The purpose of this project is to develop, calibrate, and validate models for vehicle energy consumption due to pavement structural response for use in network-level pavement management systems and project-level design.

Research Approach

The field investigation presented in this report included 21 California pavement sections with different pavement types: flexible, semi-rigid, jointed plain concrete, continuously reinforced concrete, and composite structures. The vehicles selected and instrumented for the fuel economy measurements included a five-axle semi-trailer tractor, a diesel truck, a sports utility vehicle, a gasoline-fueled car, and a diesel-fueled car. Vehicles were run on cruise control and data were recorded at 45 and 55 mph on state roads and at 35 and 45 mph on local roads. The data from the field investigation were analyzed and used to develop an empirical modeling framework considering road geometry, wind, temperature, and pavement structural and surface (roughness and texture) effects on vehicle fuel consumption. Based on the final framework, a final empirical model was developed for each section.

Results

The report presents results of a factorial analysis of the effects of each variable using the final model for each vehicle type on each pavement type and in different California climate regions. The within-section variability was almost always greater than the variability between sections for a given pavement type and efficiency condition (tailwind, speed, and climate region) and the within-section variability was also usually larger than the variability between pavement types. Only the data for the heavy heavy-duty truck (HHDT) showed any meaningful difference in results between sections, but that variability is not tied to pavement type and is only present under certain conditions of speed, tailwind, and air temperature (tied to climate region). These results indicate that missing variables (or errors in the existing variables) need to be reduced in further experiments to observe measurable effects of pavements on fuel consumption in real-world driving. While air temperature interacted with cruise control speed for the HHDT, there was a lack of clear evidence that asphalt roads cause more fuel consumption for the HHDT even under the conditions where the most possible effect of pavement type was found. This suggests that pavement type is not the correct explanation for that variation. Instead, the variation in the effect of air temperature by cruise control speed for the HHDT likely has to do with differences in engine efficiency under different conditions.

Recommendations

The results of the study show that the magnitude of a pavement structure type's influence on fuel consumption from the measurement campaign of this study is too small for meaningful conclusions about the effect of pavement type for broad classes of pavements (e.g., concrete and asphalt) to be drawn, based on the size of the dataset used in this project and the effort required to control the variables in the experimental design. These results indicate that missing variables (or errors in this study's existing variables) need to be reduced in any future experiments to observe the measurable effects of pavements on fuel consumption in real-world driving. It is also recommended that the inability of this study to find a consistent measurable effect of structural response on fuel use not be used as a reason to exclude structural response from consideration in life cycle assessment.

Increasing Crumb Rubber Usage by Adding Small Amounts of Crumb Rubber Modifier in Hot-Mix Asphalt. Phase 1: Laboratory Tests and CalME Simulations

Research Report Number: UCPRC-RR-2020-06

Publication Date: October 2021

Authors: Yanlong Liang, David Jones, Jeffrey Buscheck, John Harvey, Rongzong Wu, and Liya Jiao

Principal Investigator: John Harvey

Caltrans Technical Lead: Cathrina Barros

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Elements 4.61 and 4.62 (DRISI Tasks 3024 and 3190): CRM Asphalt Binder in DGAC Mixes

Download: doi.org/10.7922/G2MG7MTK

Need for Research

In 2015, Caltrans expressed interest in studying the addition of small amounts of crumb rubber (CRM) in dense-graded asphalt mixes to increase the total amount of recycled tire rubber used. Small amounts were defined as 5% to 10% CRM by weight of the binder or approximately 0.25% to 0.5% CRM by weight of the aggregate.

Research Approach

Four approaches for adding the rubber were proposed: (1) addition of 5% to 10% CRM particles smaller than 250 µm to the asphalt binder, not resulting in a change to the performance grade (PG) of the base binder, achieved by blending softer base binders and/or polymers with the rubber at the refinery/terminal; (2) addition of 5% to 10% CRM particles smaller than 2.36 mm to the asphalt binder, with allowable changes to the PG of the base binder, and produced using a field-blending process similar to that used for producing asphalt rubber binders with between 18% and 22% CRM; (3) adding 0.25% to 0.5% CRM by weight of the aggregate directly into the mix using a dry process; and (4) addition of 5% to 10% CRM with particles smaller than 250 µm to the asphalt binder, with allowable changes to the PG of the base binder, and produced using a field-blending process.

Results

Laboratory test results and mechanistic-empirical performance simulations both indicate that dense-graded mixes produced with binders containing between 5% and 10% CRM by weight of the binder will generally have equal or better performance compared to dense-graded mixes produced with unmodified binders. Finer CRM gradations (i.e., smaller than 250 μm) in wet process approaches allow binder testing with standard Superpave performance grading tests and appear to provide more consistent results. Based on literature reviews, adding between 0.25% and 0.5% CRM with particles sizes smaller than 500 μm in dry process mixes will also provide equal or better performance compared to mixes that contain no CRM. If any of the approaches are adopted, more scrap tires would be recycled into pavement applications.

Recommendations

The following recommendations are proposed based on the findings from this study:

- Additional mechanistic-empirical performance simulations followed by pilot studies should be carried out to confirm the findings discussed in this report, to better quantify the benefits, to expand the *CalME* materials library, and to identify the most appropriate applications in pavement structures in the different California climate zones.
- Some relaxation of the solubility requirements in the PG-M specification should be considered to allow more use of Approach-4 binders. Laboratory test results and performance simulations did not indicate that a relaxation in solubility requirements would have a detrimental effect on performance.
- Given that dry process approaches are the simplest and cheapest method of incorporating CRM into mixes, limited additional testing with finer CRM particles, along with performance simulations, should be conducted to confirm that findings from research conducted in other states and countries are applicable to California applications.

Pavement ME Evaluation of the NCHRP 1-61 Thin Concrete Overlay on Asphalt Sections

Research Report Number: UCPRC-RR-2022-01

Publication Date: February 2022

Authors: Angel Mateos and John Harvey

Principal Investigator: John Harvey

Caltrans Technical Lead: Deepak Maskey

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Element 4.67 (DRISI Task 3198): Development of Thin Concrete Overlay on Asphalt Design Method

Download: doi.org/10.7922/G2R78CJ9

Need for Research

The goal of this project is to determine if the experimental data collected in NCHRP 1-61 for concrete overlay on asphalt (COA) sections with half-lane width slabs validate *Pavement ME* COA cracking predictions or suggest the need to recalibrate this AASHTO design tool.

Research Approach

The thin COA longitudinal cracking model of *Pavement ME* was calibrated with empirical data from COA sections with half-lane width slabs in Minnesota, Illinois, and Colorado. The NCHRP Project 1-61 has considerably expanded the range of climatic conditions for which reliable performance data are available by adding projects from Iowa, Kansas, and Philadelphia (in addition to Minnesota, Illinois, and Colorado).

Results

This research assesses *Pavement ME* predictions based on the longitudinal cracking measured on 13 COA sections with half-lane width slabs evaluated as part of NCHRP Project 1-61. None of the 13 sections had more than 3% of slabs with longitudinal cracking, despite four of them being subjected to relatively high traffic volumes (annual average daily truck traffic over 500 vehicles on the design lane) and having been in service between 9 and 19 years. When design values were adopted for the different input variables, *Pavement ME* predicted less than 5% longitudinal cracking in 12 of the 13 sections, which agrees with measured cracking. The root mean square error (RMSE) of *Pavement ME* predictions was 2.4% for the set of 13 sections. The RMSE of the *Pavement ME* predictions improved to 1.2% when constructed slab thickness measured with ground penetration radar was used instead of the design thickness. However, *Pavement ME* predictions did not improve when measured values for concrete strength or load transfer efficiency were used rather than design values.

Recommendations

The recommendation is that the nationally calibrated COA cracking model, implemented in *Pavement ME* version 2.5.5, be used for developing the California COA design catalog.

Early-Age and Premature Cracking in Jointed Plain Concrete Pavements: Literature Review

Technical Memorandum Number: UCPRC-TM-2020-03

Publication Date: July 2021

Authors: Angel Mateos and John Harvey

Principal Investigator: John Harvey

Caltrans Technical Lead: David Lim

Project: Partnered Pavement Research Center (PPRC) Strategic Plan Element 4.74 (DRISI Task 3206): Early-Age and Premature Cracking Evaluation

Download: doi.org/10.7922/G2ZC815G

Need for Research

The primary goal of PPRC Strategic Plan Element 4.74 is to develop a set of recommendations for reducing the risks of early-age and premature cracking in jointed plain concrete pavement (JPCP) projects on the Caltrans road network with a focus on new JPCP, lane replacement, and slab replacement projects. The first step is to identify what factors may lead to early-age and premature cracking on California roadways.

Research Approach

These cracking types are a common problem for all highway agencies, and a literature review was conducted to identify the factors that may result in early-age and premature cracking of JPCPs in California, in other US states, and in other countries.

Results

The review shows that many factors are involved and that many different circumstances can result in these types of cracking. In most of the cases reported in the literature, the early-age and premature cracking were related to poor construction practices. The early-age cracking of JPCP has already received considerable attention, and there is agreement regarding the mechanisms that result in this type of cracking and about the practices recommended to reduce it. The current version of the Caltrans Standard Specifications addresses most of these practices, but Caltrans specifications for paving in adverse weather conditions are not completely clear.

Recommendations

Unlike the causes of early-age cracking on JPCP, premature cracking of JPCP has not been studied extensively. Further, even though it is widely recognized that the early-age condition of concrete has an impact on mid- and long-term JPCP performance, very few studies have focused on determining what that impact is.

First-Level Analysis of Heavy Vehicle Simulator Testing on Three RHMA-G Mixes to Investigate Performance with Reclaimed Asphalt Pavement Aggregate Replacement

Technical Memorandum Number: UCPRC-TM-2020-04

Publication Date: December 2020

Authors: David Jones and Stephanus Louw

Principal Investigator: John Harvey

Caltrans Technical Lead: Nate Gauff

Project: California Department of Resources, Recycling and Recovery: Reclaimed Asphalt Pavement in Rubberized Asphalt Studies

Download: doi.org/10.7922/G2NV9GJ6

Need for Research

This technical memorandum summarizes a literature review update, elements of the construction of a test track to assess various aspects of gap-graded rubberized asphalt concrete (RHMA-G) mixes with and without the addition of reclaimed asphalt pavement (RAP) as aggregate replacement, and a first-level analysis of the results from the first three Heavy Vehicle Simulator (HVS) tests.

Research Approach

Four different RHMA-G mixes were placed on seven sections on the test track at the UCPRC. Mixes differed by nominal maximum aggregate size (NMAS, 1/2 and 3/4 in.) and the addition of 10% RAP by weight of the aggregate as an aggregate replacement. Single and double lifts of each mix were placed. Apart from the addition of RAP, the mix designs all met current Caltrans specifications. Although Caltrans currently does not permit more than one lift of RHMA-G on projects, the placement of each lift of each mix on the test track met current Caltrans specifications for RHMA-G layers.

Results

The first three HVS tests discussed in this technical memorandum covered the control section (0.2 ft. [60 mm], 1/2 in. NMAS with no RAP), a section with a single lift of 1/2 in. mix with RAP, and a section with two lifts of a 3/4 in. mix with RAP. Results from these first three HVS tests, which focused on rutting performance, indicated the following:

- Performance of all three mixes was satisfactory in terms of the level of trafficking required to reach a terminal average maximum rut of 0.5 in. (12.5 mm).
- The addition of RAP as a coarse aggregate replacement did not appear to have a significant influence on the test results.
- The backcalculated stiffnesses of the RHMA-G layer(s) on each section before and after HVS testing indicate that the trafficking did not cause any significant damage (i.e., loss in stiffness) in any of the three test sections. Stiffnesses increased after trafficking on two of the three sections, which was attributed to a combination of aging and densification of the layers under traffic. Some blending of reclaimed asphalt binder with the asphalt rubber binder over time on these two sections, both containing RAP, may have contributed to this stiffness increase.
- No cracks were observed on any of the sections after trafficking.

Recommendations

Given that only three sections have been tested to date, no recommendations on RHMA-G layer thicknesses or permitting the use of coarse RAP in RHMA-G mixes can be made at this time. These recommendations will be made after all the sections have been tested and the forensic investigations and associated laboratory testing have been completed.

Appendix B: Pavement Research Roadmaps and Funding Plan

Caltrans | UCPRC University of California Pavement Research Center, Davis • Berkeley | Pavement Research Roadmap

ME Design of Asphalt

VISION: Develop and use a design procedure that provides the most accurate prediction of asphalt pavement performance possible within a reasonable time and cost

CONCEPT

SCOPE: Mechanistic-empirical approaches and tools for asphalt surfaced pavement evaluation, design and analysis

- **CAL/APT (1999) Fatigue cracking and rutting in classical ME framework; used on LA-710 long Life**
- **3.1/4.1 Framework for *CalME***
  - Incremental-recursive design
  - Calibration framework with laboratory, APT, test track, field and PMS data
  - Spatial variability
  - 2011-2017
- **Integration framework for databases between CalME, PaveM, LCCA, LCA**
- **Mechanistic surface characteristics prediction**
- **Interaction between distresses**
- **New approach for models for climate effects on pavement response**
- **Improved response models**
- **Project level TSD for site investigation for use on big rehab projects**
- **Alternatives to TSD: Find moisture issues, delamination, anomolies tied to GPR**

RESEARCH

- **Initial *CalME* development v1.0** 2003
- **Goal 6 Initial *CalME* reflective cracking approach** 2005
- **R21 Rutting mechanism validation** 2008-2011
- **4.1 Framework for *CalME***
  - Develop climate databases, traffic/WIM databases
  - Initial set of models: rutting, fatigue, crushing, aging, IRI., reflective cracking, etc.
  - 2011-2014
- **3.31 Models**
  - Initial thixotrophy evaluation (rest periods), simplified temperature model, aging model, block cracking, improved reflective cracking model
  - 2014-2017
- **3.32 Comparison of lab & field produced mix properties** 2014-2017
- **3.36 Initial in-place recycling models** 2014-2017
- **3.38/3.41 Improve ME Models**
  - Rest period determination
  - Aging model (3.38 as well)
  - Models for FDR-C and FDR-FA
  - Improved PDR models
  - Characterization of constructed pavements
  - Traffic reflective cracking model, updated strain calculation
  - 2017-2020
- **4.51: tBeam: structural energy model** 2017-2020
- **2.9 Within-project and between-project variability concept** 2017-2020
- **Improved material models**
  - RAP/RAS (4.76, 4.79)
  - IPR (4.78, 3.52)
  - RHMA-G (4.75)
  - 2020-2023
- **3.52 Update ME models**
  - Effects of wander on rutting
  - Effects of moisture on unbound layers
  - New WIM categories
  - 2020-2023
- **Modeling, testing, and validation of interlayer base and overlay reflective cracking performance** MED-D 2020-2023
- **Improved fatigue and top-down cracking models**
- **Integration of empirical-mechanistic surface degradation models in *CalME* for complete analysis for LCA, LCCA**
  - IRI, noise, skid resistance, permeability, age-related cracking, fuel consumption
- **Continued improvement on between- and within-project variability considerations**
  - RAP, material (construction, mix design, binder, rubber)
- **Bonding and delamination model or consideration**

DEVELOPMENT

- **4.1 *LEAP* response model** 2011-2014
- ***CalME* v2.0** 2011
- ***CalBack* backcalculation tool v1.0** 2011
- **Initial HVS alibration** 2005-2011
  - Goal 1: Asphalt-Treated Permeable Base
  - Goal 3: Asphalt rubber and tire types
  - Goal 5: Wet condition ATPB
  - Goal 6: Reflective cracking
  - Goal 9: New rubberized overlays
  - Field data: US-101, StanTec
  - External data: WesTrack, CEDEX, NCAT Florida sections, MnRoad
- **3.18/3.30/3.38 Standard material testing**
  - Building Standard Materials Library
  - 2011-2020
- **3.31/3.32/3.37 Test methods**
  - Sine vs Haversine for fatigue testing
  - RSST to RLT conversion
  - 2014-2020
- **2.9/3.36 *CalME* v3.0 web-based**
  - Software
  - Training
  - Site inv. Guide, HDM, CT 357
  - 2017-2020
- **3.41/3.49 Integrate asphalt & PCC pavement design methods & tools** 2017-2020
- **3.41 Field calibration with Caltrans APCS data** 2017-2020
- **3.51/4.78 Standard material testing**
  - Inverted pavements with CCPR and CSS/LSS
  - CTB, LCB, PG+X, COA
  - 2020-2023
- **3.52 Integration between *CalME* & other operations (Design, *DiME*, *PaveM*)** 2020-2023
- **3.52 Update *CalBack* and make it web-based** 2020-2023
- **2.04 Operations support for *CalME* & *CalBack*** 2020-2023
- **3.51/4.79 Improved asphalt aging calibration** 2020-2023
- **Additional APT calibration**
  - R21 composite pavement
  - FDR (4.36), wet FDR (4.59)
  - WMA, RWMA (4.18)
  - OGFC (3.21)
  - Any new HVS test data
  - FAA NAPTF
- **Top-down cracking model**
- **Integrate improvements in PRS for asphalt & concrete into *CalME***
- **tBeam: calibration of structural energy model against 3-D models**
- **Soils characterization for recycled pavement design: durability, stiffness and shear strength**
- **AB specification for recycled material**

IMPLEMENTATION

- **Pilot and AC long life projects**
  - I-710 AC long life (1999)
  - Pilot use of *CalME* for design (3.15, 2011-14)
  - TEH-5, SIS-5, SOL-80 AC Long Life (2011-14)
- **3.33/3.37 *CalME* for SAC-5 long life** 2014-2021
- **3.52 New models as completed** 2020-2023
- **3.41/2.04 *CalME* v3.0 continued roll out & training** 2020-2023
- **Integrated databases & definitions**
  - *PavementME*, design methods, LCCA, & LCA
- **Integrate LCA and LCCA calculations into pavement design tools**
- **Implement tBeam: structural energy model in *CalME***
- **Implement improved asphalt aging model**
- **CCPIC *CalME* for non-Caltrans users**

FOR MORE INFORMATION
For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu
For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: Past / Current / Proposed / Future

This road map has interactions with the Asphalt PRS, LCA, LCCA, RAS/RAP, Rubberized Asphalt, In-Place Recycling, ME Concrete and PMS road maps

Pavement Research Roadmap
ME Design of Asphalt
version date December 9, 2020

ME Design Concrete

Pavement Research Roadmap

VISION: To develop and use a design procedure that provides the most accurate prediction of concrete pavement performance possible within a reasonable time & cost

CONCEPT

SCOPE: Mechanistic-empirical approaches and tools for concrete surfaced pavement evaluation, design and analysis

Concepts developed by others, including design thickness *PavementME*, *BCOA-ME* (Univ. Pitt.), *MinnPave*, ACPA *StreetPave*, *OptiPave* (Chile), and *HiperPav*

RESEARCH

4.1 Support for development of *EverFE* 2.24 by University of Maine
1998-2005

4.2 Concrete Pavement Study
- Evaluate existing design methods prior to MEPDG and comparison with California performance
- LLPRS Rigid & HiperPav v1 & v2
- Review strengths & other properties of California-specific high early strength mixes for use in ME design

1998-2005

4.8 Evaluate dowel bars and DBR, including alternative dowels
1998-2005

ME Design Concrete, Asphalt, Paver Permeable Pavement (CT DEA)
2010 [3,4]

3.41 Concrete Studies
- Develop understanding of concrete-asphalt and other base types bonding
- Hygrothermal response of concrete slabs, incl. impact of dry weather

2017-2020

3.49/4.74 Evaluate California design and construction effects on JPCP performance
2017-2020

4.58b New models for COA faulting and cracking
2014-2017

3.53 Concrete stress-release mechanisms (creep/relaxation, microcracking, and others)
2020-2023

MED-O 2020-2023 proposal Base design and base-slab interface systems for concrete pavements

Advanced instrumentation techniques for concrete pavements

New methods of calculating fast, accurate concrete responses

Implement new materials in existing ME design procedures (fiber-reinforced concrete, LWA, geo-polymers, etc.)

Develop new pavement designs for low-volume traffic using thinner concrete slabs (based on shorter joint spacing, CCPR, plate dowels, etc.)

DEVELOPMENT

4.1 Concrete Studies
- Evaluate & calibrate MEPDG V0.8
- Collect construction CTE data
- Initial ME Caltrans JPCP designs

1998-2005

ME permeable paver pavement design and HVS validation (ICPI)
2014 [4]

4.17 HVS evaluation of precast concrete pavements
2011-2017

4.67 Develop thin BCOA catalog
2017-2020

2.7 Integrated databases for ME design, PMS, LCA, LCCA[1,2,3]
Pavement ME traffic spectra tool
2017-2020

3.53 Evaluate past long life concrete pavements and support for implementation of new ones
2020-2023

4.81 Improved traffic models for *PaveM* and ME design[1,2,3,6]
2020-2023

Evaluate field performance of precast concrete pavements

Incorporate new PRS tests into ME design

Library of concrete properties for use in Pavement ME, tied to DIME

Web-based version of FE model for concrete pavement structural response

4.2 Evaluated JPCP designs with APT at Palmdale
1998-2005

4.58B Evaluated thin COA designs & identified gaps in knowledge
2014-2017

3.39 Monitor YOL- 113 COA pilot
2017-2020

3.49 Implement ME design tools
- Calibrate *PavementME*, Improve reliability approach, develop catalogue for JPCP, longitudinal cracking model

2017-2020

4.68 Feedback to ME design from *PaveM*
2017-2020

3.54 Develop concrete-asphalt bonding ME model and test
2020-2023

3.53 Develop CRCP catalog with *Pavement ME*
2020-2023

3.54 Monitor thin COA pilots
2020-2023

3.58 Continued calibration of ME design models with PMS data
2020-2023

Integrate improvements in PRS into ME dsign

Updated designs for unbonded concrete overlays of concrete pavements

IMPLEMENTATION

Train Caltrans on ME Design

Training on ME design for local government for more than concrete

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FOR MORE INFORMATION
For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu
For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: Past (solid) / Current (solid) / Proposed (dashed) / Future (dashed)

Linked Roadmaps:
1-Pavement Management System
2-Life Cycle Assessment
3-Life Cycle Cost Analysis
4-New Concepts For Materials & Structures
5-Concrete PRS 6-ME Asphalt

Pavement Research Roadmap
ME Design Concrete
version date December 3, 2020

In Place and Cold Central Plant Recycling

Pavement Research Roadmap

VISION Reduce life cycle cost, environmental impacts, road user impacts, conserve resources through appropriate use of in-place and cold central plant recycling

SCOPE All strategies for in-place and cold central plant recycling of asphalt pavements

CONCEPT

UCPRC/South Africa workshop on FDR-FA
2000

COL-20, SIE-89, SLO/VEN-33 pilot projects
2001-2005

Initial work by Caltrans on CIR, HIR
2008 onwards

RESEARCH

4.12 Ph 1: FDR-FA
- Pilot study monitoring
- Lab mix design testing
- Lab performance testing
- APT SIE-89
- Construction monitoring
- Preliminary gravel factor

2005-2008

FHWA/Illinois LCA Software for FDR and CIR
2014-2017

4.36/4.59/4.69 Ph 2: FDR
- Pilot long-term monitoring
- APT with FDR-N, FA, AE & C
- Lab ME performance testing
- ME model development
- Guidance document

2014-2020

4.52/4.65 Ph 2: FDR-C Crack Mitigation
- Pilot study monitoring
- Test road
- Lab testing

2014-2020

4.70/4.78 Ph 3: IPR
- Pilot study monitoring
- APT track with CCPR
- Lab mix design testing
- Lab ME performance testing
- ME model development[1]
- Revised guidance

2017-2023

4.78 Ph 4: IPR
- Adding supplemental fines in PDR and CCPR mixes and use of excess mineral fines from quarries
- Fabrics and RHMA in IPR
- CCPR – Inverted pavement concept for improved structural capacity
- Role of tack coats in FDR (top), CIR (top and bottom), and CCPR (all layers)
- Stockpiling CCPR mixes
- Lab compaction methods and MDD determination
- Deep lift FDR-C
- PRS framework for IPR[2]
- 9-62 QC/QA refinement

2020-2023

CCPR – New materials using reclaimed asphalt, concrete & other materials

Recycling for rapid repair of natural disasters

In-place rubblization and recycling of concrete

Use of micromillings

Fibers (multiple sources) and other cementitious products in FDR-C

DEVELOPMENT

5.1 *PaveM* FDR/CIR performance models
2014-2017

4.37/4.54/4.66 LCA Inventory
2014-2020

3.44 LCCA Timelines
2014-2020

Literature update and LCA/ LCCA for HIR

PRS framework for IPR materials[2]

Collection of field data to support ME implementation

IMPLEMENTATION

4.12 Initial Guidance for FDR-FA + Specification
2008

3.46/4.69 Include LCA for FDR, PDR in *eLCAP*
2015-2020

4.36/4.59/4.69 Guidance for In-Place Recycling + Specifications, Mix Design Procedures, and *CalME* Models
2015-2020

3.44/4.69/4.78 Update *RealCost*[3] and *eLCAP*[4] software for FDR/PDR/CCPR
2017-2023

4.69/4.70/4.78 Training for Caltrans, local government & industry
2017-2023

4.78 9-62 QC/QA implementation
2020-2023

CCPIC In-place recycling guidance for local government

FOR MORE INFORMATION
For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu
For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: —— Past; —— Current; – – – Proposed; – – – Future

Linked Roadmaps:
[1] Asphalt ME design (*CalME*)
[2] Asphalt performance related specifications
[3] LCCA
[4] LCA

Pavement Research Roadmap
In-Place Recycling
version date November 24, 2020

Performance Related Specifications for Concrete Including Construction QA/QC

Caltrans | UCPRC University of California Pavement Research Center, Davis • Berkeley | Pavement Research Roadmap

VISION: Widespread use of appropriate tests and specifications for QC/QA of materials that measure and influence the critical properties affecting pavement performance; integrate with materials and pavement design procedures

CONCEPT

SCOPE: Performance related tests and specifications for use with concrete pavement of all types

- AASHTO PP84 Performance engineered concrete pavement mixtures
- FHWA Turner Fairbanks effort on PRS
- Important concepts: formation factor, hygro-volume change, freeze-thaw durability, and degree of saturation
- FHWA pooled fund study to advance PRS for concrete
- FHWA project on advancing concrete pavement technology solutions 2017-2023
- Rice Research Board SCMs from Hull and Straw 2018-2022

RESEARCH

- 4.2 Concrete Pavement Studies
  - Use of maturity for high-early strength concrete pavement
  - Relationship between different strength test results
  - Interaction between shrinkage, thermal contraction, and stress

  1998-2005
- 4.58B/3.39/3.41 Change of CTE with moisture conditions 2014-2020
- 4.84 Alternative Supplementary Cementitious Materials Identification of functional criteria, look at specs 2021-2023
- MED-O 2020-2023 proposal Base design, including PRS, and base-slab interface systems for concrete pavements
- PRS-L 2020-2023 proposal Durability of fiber reinforced rapid strength concrete with different cement types and light weight aggregates
- Develop PRS tests and specs for fiber-reincorced concrete
- PRS for curing materials and approaches for concrete pavement
- PRS for concrete pavement abrasion under chain and stud wear
- PRS approaches for rapid strength concrete
- Develop non-destructive PRS tests and specs for early opening time projects, including resistivity and embedded sensors

DEVELOPMENT

- 4.74 Recommendations to reduce early age and premature cracking of lane and slab replacements 2017-2020
- 3.53 Test to measure CTE-moisture dependency 2020-2023
- Develop PRS for bases of concrete pavements
- Implement maturity in fast-track paving
- Evaluate PRS for bond breakers and interlayers in concrete pavement
- Evaluate PRS for curing materials and approaches
- Evaluate benefit/costs of tests and specifications and use of AASHTO/ASTM vs CTM
- Optimize PRS in concrete mix design considering cost and time
- Evaluate PRS for joint sealants for concrete pavement
- Check dowel corrosion performance & PRS for dowels & rebars
- Validate future ASR tests and solutions, including consideration of natural pozzolans
- Develop PRS for use by cities and counties
- PRS for alternative supplementary cementitious materials Nano-cellolotics, biomass, other new SCM for concrete pavement
- PRS for routine projects with different levels of reliability of materials, and new simplified tests

IMPLEMENTATION

- Training in PRS in concrete where there are gaps
- Training for local government on PRS
- Continue operation of Caltrans CTE website

FOR MORE INFORMATION
For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu
For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: Past, Current, Proposed, Future

Linked Roadmaps: New Concepts for Materials & Structures; ME Design Concrete

Pavement Research Roadmap
Performance Related Specifications for Concrete Including Construction QA/QC
version date December 04, 2020

Performance Related Specifications for Asphalt Superpave and QC/QA

Caltrans | UNIVERSITY of CALIFORNIA Davis • Berkeley | UCPRC PAVEMENT RESEARCH CENTER | Pavement Research Roadmap

Vision: Widespread use of appropriate tests and specifications for QC/QA of materials that measure and influence the critical properties affecting pavement performance; integrate with materials and pavement design procedures

CONCEPT

Scope: Performance related tests & specifications for use with ashpalt pavement

- Asphalt-Aggregate Mix Analysis System (AAMAS) NCHRP
- SHRP A-003A
- AC Long Life Specifications Caltrans, TRB symposium
- New Construction Quality Database by Caltrans METS

RESEARCH

- 3.28 Effects of smoothness on GHG
- West Track pay factors
- Goal 1 Caltrans pay factor report
- Goal 1 Compaction, PRS tests, pre-*CalME* design method
- Long life asphalt specs for LA-710 mix design, structural design (1999)
- Updates to LLAC PRS specs TEH-5, SIS-5, SOL-80 and design with *CalME* (2014-2016)
- 3.18 Phase 2 review of potential PRS tests for Caltrans SuperPave mix design (2011-14)
- 3.25 PRS for open graded materials, including rubberized (2011-2014)
- 4.42 Evaluation of previous repairs on smoothness (2011-2014)
- 3.40 Review of simple cracking tests and RLT as PRS tests for Caltrans Superpave mix design (2017-2020)
- 3.51 Use of image analysis in cracking tests to look at strain fields (2020-2023)
- 4.77 PRS for asphalt rubber binders (2020-2023)
  - Refine and implement new AR binder specs
  - Alternative rubber types
  - Review of PGM use

DEVELOPMENT

- *CalME* v.1.0, v.2.0, and v.3.0 (2003, 2011, and 2020)
- 3.30 Mix design guidance for contractors to meet PRS specs (2014-2017)
- 3.32 HWTT round robin (2014-2017)
- 3.33 Updates to LLAC approaches and extension to other mixes (2014-2017)
- 4.46/4.51a/NCST Initial use of FAM compared to mix tests (2014-2017)
- 3.18, 4.51, 4.64 Relationship between binder, FAM, mix properties, aging & test methods (2011-2020)
- 3.31 Updated AASHTO & ASTM tests for 4-point beam (2014-2017)
- 3.37 PRS development (2017-2020)
  - Simplified PRS procedures
  - Monitoring of previous LLAC projects
  - Pilot projects for using SCB and RLT (SAC-5)
- 3.37, 3.40, 3.41 Performance related testing in Superpave (2017-2020)
  - Plant & lab aging effects, conditioning, compaction
  - Testing: SCB vs 4PB & RSST vs RLT
- 4.76 RAP/RAS in RHMA for use in interlayers, Rich Bottom layers, and base for PCC (2020-2023)
  - Framework for PRS for these applications
- 4.78/4.79 Performance related specifications for non-HMA Components (2020-2023)
  - Updated IPR, CCPR guidance, specifications
  - Updated RAP/RAS tests, guidance, specifications
- 3.51 Regional and new materials in standard materials library (2020-2023)
  - Continued development of binder, FAM, & mix tests and correlations
  - Caltrans standard addendum for R30
  - Updates to LP3, high RAP procedure
- 3.52 *CalME* and integration of PRS into routine practice (2020-2023)
  - Simplified categorization of HMA for PRS
  - Simplified tests used in PRS for CalME input
- PRS for geogrids, interlayer materials. Lab tests, PRS; APT verification if needed
- Low temperature crack tests for PRS for binder in addition to rheological properties
- PRS for tack coats.

IMPLEMENTATION

- Pilot and AC long life projects
  - I-710 AC Long Life (1999); TEH-5, SIS-5, SOL-80 (2011-14)
  - SAC-5 (2017-2020)
- Cost/benefit analysis, LCA of extension of PRS state-wide: Determination of improvements, identification of project types where PRS does not have high benefit/cost
- *PaveM* follow up on PRS projects
- CCPIC PRS for local government: Where beneficial, adaptation for local government constraints
- 3.52 *CalME* and integration of PRS into routine practice (2020-2023)
  - Roadmap and support for Caltrans, industry to do testing, analysis
  - Training, new tests, integration of new materials, implementation of classification framework

For more information

For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu
For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: Past (thin solid outline) · Current (thick solid outline) · Proposed (dashed outline) · Future (dashed outline)

Most of the projects in this road map also appear in ME Design, Rubberized Asphalt, RAP/RAS, Smoothness and other road maps

Pavement Research Roadmap
Asphalt PRS & QC QA
version date December 07, 2020

Pavement Research Roadmap

Surface Treatments and Noise, GnG and OGFC

VISION: Optimize the use of surface treatments that preserve the structure; provide a safe and quiet surface texture; and minimize impacts to operations, the environment and life cycle costs.

CONCEPT

SCOPE: Treatments and textures that Improve surface performance And prolong structure life

- Surface treatment research and development by others; noise measurement technology developed by Donovan; surface treatment design methodologies by others; rolling resistance research by others
- Evaluate GnG (aka NGCS) surface texture
- **2.7** Open graded mixes and stormwater quality literature review — 2017 - 2020

RESEARCH

- **4.16/4.19/4.27/4.29** Asphalt overlay noise studies, roughness, cracking and skid — 2005-2011
- **4.22/4.29** Existing concrete bridge and pavement surface noise, skid, roughness studies — 2008-2011
- **4.20/4.29** New open-graded small stone mixes/ Lab method to estimate OG Noise — 2008-2011
- **3.21** Measure noise, skid, roughness on new concrete surfaces (GnG, CRC), GnG pilot monitoring — 2011-2014
- **3.21/3.25** APT on OG small stone mixes & improved OG mix design methods — 2011-2014
- **4.48/CARB** Urban heat island LCA — 2017-2020
- **4.62[1]** PG+X rubberized binder specifications for surface treatments — 2017-2020
- **4.66** Texture and rolling resistance
  - New models for surface texture on fuel economy
  - 2017-2020
- **3.52[2]** Integration of empirical-mechanistic surface degradation models in CalME for LCA, LCCA
  - IRI and Surface Non-Load Related Cracking Model
  - 2020-2023
- **Project 4.80[3]** Electric vehicle & rolling resistance
  - Better models for effects of surface texture on fuel economy
  - 2020-2023
- Autonomous vehicles implications for maintenance treatments
- Recyclable surface treatments for asphalt pavement that can be rolled on like carpet fast construction and quality control
- Thin bonded pavers on asphalt for intersections
- Use of excess quarry fines in thin cemented surface treatments (pavers, slurries)
- Alternative binders in surface treatments
- Reclaimed asphalt/micro-millings use in chip and slurry seals, and microsurfacings.
- Improve chain resistance under trucks of concrete and asphalt surfaces

DEVELOPMENT

- **3.35/3.42** Continued monitoring for noise and roughness of new concrete surfaces (GnG and CRC) — 2014-2020
- Guidance of surface treatments versus rehab selection for local government using LCCA (CCPIC) — 2019
- Chip seal noise (mainline)
  - Selection and design of chip seals to decrease or increase (shoulders) noise or increase skid resistance
- Bicycle ride quality[4]
  - Follow up on implementation of bicycle ride quality research
- Implement improved open graded mix design including stormwater quality

IMPLEMENTATION

- **3.57[1,3]** Implement updated LCA, LCCA results for surface treatments in *PaveM* performance models update — 2020-2023
- Guide for chip seal design, construction, timing and functionality (noise, bicycle and skid)
- Develop specification, pilot studies of small-stone RHMA-O, LCA
- Final monitoring and IRI models for GnG and CRC surfaces
- Evaluate specification, pilot and cost studies of grind and groove surfaces

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FOR MORE INFORMATION
For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu
For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: Past (solid) / Current (solid shaded) / Proposed (dashed shaded) / Future (dashed)

Linked Roadmaps:
[1] Asphalt rubber
[2] Asphalt ME design (*CalME*)
[3] LCA
[4] Smoothness

Pavement Research Roadmap Surface Treatments and Noise, GnG and OGFC version date December 4, 2020

Multi-Functional Pavements for Climate Resilience, Urban Environments, and Active Transportation

Caltrans | UCPRC University of California Pavement Research Center, Davis • Berkeley | Pavement Research Roadmap

VISION: Use best available climate change information in tactical and strategic transportation infrastructure decision-making. Use pavement and street systems to help reduce environmental impacts and create economically and socially vibrant public places that promote personal mobility, healthy choices and safe communities.

CONCEPT

SCOPE: Climate resilience for transportation infrastructure, strategy, development, communication and implementation in California and interaction of pavement design and street design on active transportation (non-motorized).

- Intergovernmental Panel on Climate Change updates
- US Global Climate Change Research Program
- Climate adaptation strategy (Nat Res Agency) 2009
- California climate scoping plan (CARB) 2013
- Nat Res Agency: Safeguarding California Reducing Climate Risk 2014, 2017
- IC Net northeastern US climate modeler and infrastructure managers network (NSF) 2012
- CalAdapt climate change research, UC Berkeley, California Energy Commission
- Literature and concepts developed by others using the Complete Streets (CS) study and other literature that are not covered in CS[1] 2018
- California legislation and policy directives regarding climate resilience
- Nat Assoc of City Trans Officials activities
- Complete Streets America activities
- NCST Urban Metabolism (UM) LCA framework considering permeability and water cycle[1] 2018
- NCST Road Map for Permeable Pavement Research 2017
- Coastal and ocean climate action team (COCAT) impacts on coastal resources (Caltrans)
- ICNet northeastern US climatologist/ infrastructure managers network (NSF) 2012-2017
- Climate change incidents affecting freight
- West Coast ICNet building on other groups in California (through CCPIC)

RESEARCH

- 4.47/4.57 Surface treatments for bicycle ride quality[5] 2014-2020
- NCST LCA framework for CS incl social perf indicators, equity[1] 2018
- UM-LCA Case studies[1] (BlueSkies)
- NCST Case studies: LCA of Complete Streets[1] 2020-2021
- NCST APCS of Complete Streets[1] 2020-2021
- ICNet Gobal climate/infrastructure education/practice/research (NSF) 2019-2022
- Identify scope of potential climate change impacts on transportation infrastructure
- NCST Expand LCA framework for Complete Streets to non-motorized oriented street design
- Identify stakeholders roles and responsibilities
- Improve design & selection of surfaces for Active Transportation
- NCST Guidance and tools for CS LCA[1]
- Inventory best available data and tools for climate change
- LCC approach for CS[2]
- Pavement performance models for Active Transportation
- NCST Models for quantifying consequences of changes in street design on miles traveled, congestion, and motorized-vehicle emissions
- NCST Further improvements of indicators (social, environmental, health, safety, economic, equity)
- New pavement types with reduced environmental impact, faster construction, improved performance, and lower LCC[2]
- Incorporate improved models for CS & related street design strategies
- Identify existing levels of climate change information quality and usefulness, and levels of use in decision making

DEVELOPMENT

- ME design of concrete, asphalt & paver permeable pavement for CT DEA 2010 [3,4]
- ME permeable paver pavement design and HVS validation (ICPI) 2014
- Design and maintenance guidance to reduce costs, improve performance and reduce environmental impacts of active transportation routes
- Optimization of complete streets based on LCA and LCCA[2]
- Simplified on-line CS LCCA tool for local government[2]
- Support for State and Local Scoping for Plans: Climate change and location mapping Infrastructure
- NCST Guidance and tools for CS LCA[2]
- NCST Selection & design guidance & tools for CS for rural & urban functions & contexts
- LCCA of cool pavement[2]
- Simple tests for lab & field for texture, albedo (thermal comfort), durability, friction.

IMPLEMENTATION

- Support and facilitate state & local government implementation & communication with climate change modelers
- Training for selection & design of Complete Streets & nonvehicle oriented streets
- Guidance on assessing vulnerability & asset criticality & cost
- Guidance on incorporating climate change & cost data into design & asset management operation[2]

FOR MORE INFORMATION
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For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: Past / Current / Proposed / Future

Linked Roadmaps: 1 Roadway LCA; 2 LCCA; 3 ME Design Concrete; 4 ME Design Asphalt; 5 Smoothness

Pavement Research Roadmap
Multi-Functional Pavements for Climate Resilience, Urban Environments, and Active Transportation
version date December 09, 2020

Pavement Research Roadmap

Life Cycle Cost Analysis (LCCA)

VISION: Develop and use a comprehensive, web-based, LCCA system that considers variability and maintains competency across all users

CONCEPT

SCOPE: Life cycle cost analysis data, procedure, and software for state and local governments

- FHWA LCCA guidelines, Walls & Smith
  1998
- Caltrans LCCA procedure manual (version 1.0)
  2003
- Caltrans LCCA procedure manual (version 2.5)
  2013
- Caltrans Transportation Asset Management Plan (TAMP)
  2017

RESEARCH

- DEA 2.4.9
  Extension of LCCA frameworks to permeable pavement
  2011-2014
- 5.15
  Analysis of pavement portion cost of long life rehab projects
  2005-2008
- 3.25
  Evaluation of LCC of preservation vs rehabilitation only
  2014-2017
- 3.26/4.37
  Development of framework for optimizing IRI and benefit cost for greenhouse gas reduction and implement in PMS
  2014-2020
- 3.20
  LCCA for composite pavement
  2014-2017
- 2.8
  Network-level road user cost models for life cycle planning
  2017-2020
- Consideration of variability and uncertainty for cost and treatment lives
- Network-level LCCA approach and simulation based on future budget constraints for long-term planning
- LCC approach for CS[2]
- New pavement types with reduced environmental impact, faster construction, improved performance, & lower LCC[2]

DEVELOPMENT

- Development of Caltrans specific software, *RealCost* ver. 2.0
  2005-2008
- Development of traffic delay calculator, ver. 2.0 (also used in *CA4PRS*)
  2014-2017
- 5.10/3.44
  M&R sequence updates from performance models and decision trees
  2017-2020
- 2.8
  Network-level road user cost models for life cycle planning
  2017-202
- 3.44
  Improvement of unit cost updating procedures
  2017-2020
- 3.56[1]
  Multi-criteria decision support for prioritization of strategies to reduce environmental impacts
  2020-2023
- CCPIC 2020 Simplified spreadsheet local government LCCA tool
- Development of procedure for estimating M&R schedule for new treatments
- Integration of common traffic and cost data with *CalME*, *Pavement ME*, *PaveM*, *eLCAP*, and *RealCost*
- Optimization of complete streets based on LCA and LCCA[2]
- LCCA of cool pavement[2]

IMPLEMENTATION

- 3.44
  Web-based *RealCost* ver. 3.0
  2017-2020
- 4.72
  LCA & LCCA decision support (Supply Curve)[3]
  2017-2020
- 3.48
  Life-cycle cost optimized decision trees for *PaveM*[1]
  2017-2020
- 4.82
  Updates and Improvements to *RealCost-CA*
  - Develop an on-line LCCA report tool
  - Create operation manager's manual for LCCA
  2020-2023
- 3.56
  Integration of LCCA results into simpler sustainability evaluation[3]
  2020-2023
- Ongoing updates of new materials LCCA to *RealCost*
- Update CWZ & RUC studies into *RealCost*
- Continue integration of pavement planning, design & construction in LCCA & LCA databases & models[3]
- Convert CCPIC LCCA tool to online
- Guidance on incorporating climate change & cost data into design & asset management operations[2]

FOR MORE INFORMATION
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Project Key: Current / Proposed / Future / Past

Linked Roadmaps:
1 Pavement Management Systems (PMS)
2 Multi-Functional Pavements for Climate Resilience
3 Roadway LCA

Pavement Research Roadmap
Life Cycle Cost Analysis
version date December 04, 2020

Pavement Research Roadmap

Roadway Life Cycle Assessment

VISION: To be able to quantitatively assess the social, economic and environmental impacts of transportation infrastructure

CONCEPT

SCOPE: Systems for quantifying social, economic and environmental impacts for the project identification and delivery process including asset management, conceptual design, design, and construction

- **ISO and other standards:** ISO 14000 series, ISO 21930, EN15804
- **Other related documents:** PAS2050, FHWA Ped and bike perf measures guidebook, impact analysis methods (Traci, Impact+, CML, etc.), ILCD documents, UN env. program docs, UN/SETAC initiative docs, corporate sustainability reporting docs
- **4.28 UCPRC LCA guidelines** 2010
- **FHWA LCA guidelines** 2016
- **FAA airfield LCA guidelines** 2016-2018
- **FHWA reference sustainability docs.** 2015
- **Pavement LCA symposia:** 2010 Davis, 2012 Nantes, 2014 Davis, 2017 Illinois, 2020 Davis
- **NCST complete streets LCA and initial equitable social indicators**[1] 2018
- **NCST urban metabolism LCA framework**[1] 2018

RESEARCH

- **4.28/4.66 Life cycle inventories** 2014-2020
- **Traffic smoothness study and cool pavement LCA** 2014-2017
- **4.37 Smoothness and optimization approach** 2017-2020
- **4.49/4.53 Vehicle pavement structural response** 2014-2020
- **4.54 Expansion and critical review of LCIs** 2014-2017
- **4.54/4.66 Construction work zone (CWZ) analysis** 2014-2020
- **4.48/4.54 Cool pavement framework development, data collection and case studies using cool pavement LCA software** 2014-2020
- **4.72 LCA alternative strategies to reduce GHGs** 2017-2020
- **3.55 LCA at the planning stages** 2020-2023
- **4.54/4.66/4.55 Framework for truck lane selection, recycling and design life** 2014-2023
- **4.80 LCA updates and applications**
  - LCA of capital equipment
  - LCA of roadway structures
  - Improve & expand ability to consider uncertainty & sensitivity
  - Expansion and critical review of updated LCIs
  - LCIs for new materials (biomass, plastic, additives[3,11]

  2020-2023
- **UM-LCA case studies**[1] **(Blueskies)**
- **Develop new social and equity indicators**
- **Spatially explicit impact calculation and relevant indicators**
- **Integration of approaches and methods for consequential LCA:**
  - Improved mode choice models, economic models, behavior models.
- **Impacts of roughness on vehicle life, maintenance of vehicles, freight damage**[2,3]
- **Allocation and open-loop recycling approaches**

DEVELOPMENT

- **FHWA *LCA Pave* tool development** 2016-2020
- **FHWA-University of Illinois LCA software for in-place recycling**[9,11] 2017-2020
- **FAA Airfield LCA Case studies** 2018
- **4.54/3.46 *eLCAP* software conceptual and project levels (v1.0)** 2014-2020
- **4.61/4.66 PG+X rubber asphalt LCA**[4] 2017-2020
- **4.58b/4.66 BCOA LCA**[5] 2017-2020
- **3.47 Policy recommendations and support Caltrans for use of EPDs**[6] 2017-2020
- **4.73 Fast model for Pavement Vehicle Interaction (PVI)** 2017-2020
- **4.69/4.70/4.66 LCA of in-place recycling (FDR, PDR, CCPR)**[9,11] 2017-2020
- **LCA software for heat island LBNL/CARB**
- **3.56 Multi-Criteria Decision Support for Prioritization of Strategies to Reduce Environmental Impacts** 2020-2023[8]
- **NCST Complete streets LCA framework, tool and analysis**[1] 2017-2021
- **3.47/4.80 Support Caltrans with EPDs**[6] 2017-2023
- **3.46/3.55 Update *eLCAP (v2.0)* to allow development of data, inventories, indicators, other models inside tool** 2017-2023
- ***eLCAP* software for local govt.** (UC-ITS-SB1) 2020-2023
- **4.80 Updated regional inventories**[3]
  - North America LCI data center, EPDs and other data, UCB green concrete LCI, UCPRC street features LCI.

  Completed: up to 2017; 2020-2023
- **3.55/4.80 New use stage models:**
  - Traffic congestion, pavement alterations for new technology, structure response (tBeam), CWZ

  2020-2023
- **Policy recommendation on green procurement** (UCPRC funding) 2020-2023
- **Active transportation LCA integration in planning**[2]
- **Evaluation of construction quality impacts**
- **Evaluation of policies on recycling**[9]
- **FAA Airfield LCA software**

IMPLEMENTATION

- **3.47 Caltrans EPD implementation pilot program and AB269 and advice to pavement industries about PCRs and EPDs**[6] 2017-2020
- **4.55 PMS implementation**[7] (initial & updates) 2014
- **4.72 High level B/C across all transportation strategy alternatives**[2,3,8] 2017-2020
- **Continue integration of pavement planning, design & construction in LCCA & LCA databases & models**[8,10]
- ***eLCAP* case studies and training material updates**
- **3.56 Integration of LCA results into simpler sustainability evaluation** 2020-2023
- **Continue updating *PaveM***[7]
- **Standardization of PCRs (one PRC initiative)**
- **Communication tool for progress toward goals based on LCA**
- **Inclusion of consequential LCA in eLCAP**
- **Potential monetization of impacts**

FOR MORE INFORMATION

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Project Key: —— Past; —— Current (shaded); – – – Proposed (shaded); – – – Future

1 Multi-Functional Pavements for Climate Resilience
2 New Technologies and Integrative Frameworks
3 New Concepts For Materials and Structures
4 Rubberized Asphalt
5 ME Design Concrete
6 EPDs
7 PMS
8 Life Cycle Cost Analysis
9 In Place Recycling
10 Design of Asphalt
11 RAP/RAS

Pavement Research Roadmap
Roadway Life Cycle Assessment
version date December 04, 2020

UNIVERSITY of CALIFORNIA | PAVEMENT RESEARCH CENTER
Davis • Berkeley

Pavement Research Roadmap

Rubberized Asphalt

VISION Maximize use of waste tire rubber in asphalt in all applications where it makes life cycle, engineering, economical and environmental sense

CONCEPT

SCOPE Utilize waste tire rubber in asphalt pavements

ADOT, Industry and Caltrans developments
1980 onwards

Caltrans Ravendale, Firebaugh and other overlay test sections
1990's

Asphalt rubber work by other universities, DOTs and industry. RHMA-O on OAK runway
2000 onwards

RESEARCH

Goal 3
Half thickness RHMA overlay validation
1995-2000

4.9
Moisture study/method spec problems
2005-2008

4.10
MB Road. Half thickness comparison of MB overlays with RHMA and HMA
2000-2008

4.18/CalRecycle
RWMA performance and emissions
2008-2011

4.16/4.19/4.27/4.29
RHMA-G and RHMA-O performance
2008-2011

3.30/3.32
RHMA aging comparison between lab and plant mixes
2008-2011

4.61/4.62
PG+X lab tests and LCCA/LCA
2014-2020

4.45/4.50/4.63 Ph 1-3
PG-AR procedure and specification development
2014-2020

4.77 Ph 4
PG-AR procedure and specification development
- Thickness limits
- Other methods of adding rubber
- Rubber in dense-graded mixes
- Base binder selection of AR

2020-2023

4.75
RHMA-G Layer Thickness Limits
2020-2023

4.63/4.79/CalR[1]
RAP in RHMA and RRAP in HMA (including APT)
2014-2023

4.26/4.37/4.54/4.72/3.56
LCA of RHMA + updated LCIs
2014-2023

4.76[1]
RAP in RHMA for PCC base, interlayer, and rich bottom layer
2020-2023

Use of recycled plastic in conjunction with rubber

Use of RHMA-O in permeable pavements

Use of RHMA-G and RHMA-O for airfields

"Roll-up Road" chip seal for maintenance and preservation

DEVELOPMENT

3.25/4.20
New RHMA-O small stone mixes
2014-2017

3.18/3.32
RHMA Superpave mix design
2014-2017

4.63/4.77/CalR
Test method to determine rubber content in binder & mix
2020-2023

4.77
Ongoing support of PG-AR implementation and validate PG-AR specs in pilot studies
2020-2023

4.76/4.79
Validate RAP in RHMA mixes in pilot studies
2020-2023

4.77/4.78
Validate RHMA-G in other layers, with and without RAP

Validate PG+X mixes in pilot studies

Validate small stone RHMA-O mixes in pilot studies[2]

IMPLEMENTATION

CalME
Inclusion of RHMA in models and data
2008-2020

4.63/4.77
Test methods and specifications for PG-AR
2017-2023

2.11
RHMA guidance for airfields (Caltrans and FAA)
2020-2023

CCPIC
RHMA guidance for local government

FOR MORE INFORMATION
For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu
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Project Key
- Past
- Current
- Proposed
- Future

Linked Roadmaps
1 RAP and RAS
2 New Concepts for Materials

Pavement Research Roadmap
Rubberized Asphalt
version date November 20, 2020

Recycled Asphalt Pavement (RAP) and Recycled Asphalt Shingles (RAS)

Pavement Research Roadmap

VISION Optimize the use of reclaimed asphalt in new asphalt mixes for cost, environmental impacts, and performance over multiple lifecycles

CONCEPT

SCOPE Use of reclaimed asphalt in pavement applications

RAP/RAS research by other universities, DOTs and industry (List main studies on high RAP/RAS)

RESEARCH

4.46
Prelim study on RAP/RAS Properties
- Prelim testing on FAM mixes
- Initial investigation of RAP/RAS binders

2011-2014

NCST
Study of RAP/RAS binder blends with virgin binder
- Develop FAM mix testing procedure
- Explore use of FAM as an alternative to extraction

2011-2014

4.51A/FAA Ph1
- FAM test instead of extraction
- Blending chart validation
- Effect of RAP in PM mixes

2011-2014

CalRecycle
RAP in RHMA and RRAP in HMA

2011-2014

4.72[1]
LCCA/LCA for use of RAP in HMA and RHMA

2017-2020

CalRecycle
RAP in RHMA-G and RHMA-O
- Prelim Investigation on use of coarse-graded RAP

2017-2020

4.64/3.40 Ph2
- Use of FAM testing to predict binder properties
- Initial study of high RAP mixes including effect of silo storage
- QC/QA tests for cracking

2017-2020

4.76[2]
RAP in RHMA for PCC base, interlayer, and rich bottom layer
- Evaluate properties of RAP in RHMA-G
- Conduct ME design

2020-2023

4.79
Guidance, Tests, and Specification of high RAP/RAS
- Effect of rejuvenators
- Long-term lab- and field-aging of RAP mixes
- Simplified tests for QC/QA testing of RAP mixes

2020-2023

Validation of high RAP mixes with APT and field monitoring

Assess multiple RAP-use cycles

Develop new materials with high RAP and rubber

Use of RAP with non-petroleum based binders

Impact of future changes in the oil refining industry on use of RAP

LCA of RAP mixes including updating inventory of rejuvenating additives

DEVELOPMENT

3.18/3.30/4.20
High RAP mixes in long life design

2011-2014

4.54[2]
LCA of optimal transport distance for recycled materials

2014-2017

FAA
Airfield LCA RAP case study

2014-2017

4.79/4.64/3.40
FAM test to evaluate binder + cracking tests for mix design and QC/QA

2017-2023

IMPLEMENTATION

Guidance for effective use of RAP/RAS, including *CalME* models

2020-2023

Suggested specification language updates for RAP/RAS mixes

2020-2023

FOR MORE INFORMATION

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Project Key: —— Past; ══ Current; ‒ ‒ Proposed; - - - Future

Linked Roadmaps: 1 LCA; 2 Rubberized Asphalt

Pavement Research Roadmap
Recycled Asphalt Pavement (RAP) & Recycled Asphalt Shingles (RAS)
version date December 04, 2020

Smoothness

Pavement Research Roadmap

UCPRC — University of California Davis • Berkeley | Pavement Research Center

Caltrans

VISION: Standardize practice of the best methods for cost efficiently providing smooth pavements to maximize fuel economy, user comfort and pavement life, and minimize freight damage

SCOPE: Measurement, analysis and use of information for pavement smoothness

CONCEPT

- Development of IRI by World Bank, AASHTO and ASTM specifications, smoothness programs in other states
- Effect of smoothness on variability of pavement life and interactions with pavement thickness
- Identify needed new profile metrics for uses other than car ride quality bicycle profile metric, megatexture, freight damage related metrics
- Create and complete research, development and implementation program for pavement transitions

RESEARCH

- **3.24** Investigate IRI calibration center and process for Caltrans 2011-2014
- **4.42** Smoothness of asphalt overlays and repairs under old profiler graph specification 2014-2017
- **4.47/4.57** Identify bicycle ride quality parameters
  Chip and slurry seal specifications selection guidance
  2014-2017
- **3.44** Consider influence of smoothness on effective Functional life for LCCA 2017-2020
- **4.66/4.80** Identify and then update optimal smoothness levels for different context and goals for greenhouse gas emissions
  - Extend to all treatments, update optimized IRI tables
  2017-2023
- Develop alternative profile metrics to better explain fuel economy and freight damage
  - Analyze at small subsections using 4.53 data, 7 Replicates
- Calibration of smoothness disincentives based on life cycle cost analysis, for different contexts and goals
- Wander pattern weighted roughness matrices using 3D tomography data
  - Remove wander of operator
  - 3D profile/full wheelpath IRI gives indication of variability of IRI measurement due to vehicle wander
- Bicycle Ride Quality[1]
  - Follow up evaluation on bicycle ride quality research implementation

DEVELOPMENT

- **4.42/2.7** Asphalt overlay smoothness under new IRI spec 2014-2017
- **3.35** Evaluation of new IRI construction specification on concrete surfaces (postponed) 2017-2020
- **4.47/4.57** Recommend maintenance treatments for bicycle ride quality 2014-2017
- **3.24/3.45** Support setup & operation of smoothness certification program 2011-2017
- Personal device applications to allow users to access lane based road smoothness data and determine route based on roughness related costs and comfort
- Low cost bumper mounted response ($1,000) type roughness meters for use by maintenance forces and local governments to estimate IRI, flag maintenance location; establish calibration centers for devices
- Software to analyze and report low cost roughness meter data
- Measure and document effectiveness of various construction practices for concrete and asphalt (asphalt overlays done in 4.42), including concrete slab replacement

IMPLEMENTATION

- **2.3** Ongoing operation of IRI calibration center & process for Caltrans & contractors projects & mix designs
- Support implementation of smoothness specification modifications
- Demonstration of construction technologies to improve smoothness IRI behind pavers larger technology rodeo or pilot project[2]
- Support implementation of low cost bumper mounted response meters for maintenance problem location and local government IRI measurement
- Operate low cost roughness meter calibration center
- Implement optimized smoothness disincentives
- Make available personal device application for smoothness data for road users
- Implement new profile metrics in pavement management

FOR MORE INFORMATION
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Project Key: Past / Current / Proposed / Future

Linked Roadmaps: [1] Multi-functional pavement; [2] New materials and structures

Pavement Research Roadmap
Smoothness
version date December 04, 2020

Pavement Management Systems (PMS)

Caltrans | UCPRC — University of California Pavement Research Center, Davis • Berkeley | Pavement Research Roadmap

VISION: Proactively manage networks to maximize efficiency within budget and policy constraints with regards to performance, cost and environmental impact

CONCEPT

SCOPE: Pavement management systems and practices for Caltrans and local government

- **UCPRC evaluation of existing Caltrans PCS/PMS** — 1999 - 2003
- **PMS and Division of Pavement road map** — 2003-2004
- **3.3 As-built & GPR pilot study** — 2003-2004
- **3.3 Support budget change proposal (BCP)** — 2005-2007
- **3.3 1st APCS manual and vendor rodeo** — 2009-2010
- **3.41[1,2] Framework for PMS data for ME calibration** — 2017-2020
- **NSF study in advanced civil infrastructure management using big data approach** (future)

RESEARCH

- **3.2.5 Initial performance modeling with WS-DOT data** — 2006-2008
- **3.2.5 Preservation efficiency LCCA PCS models survivor** — 2009
- **3.9 As-built database, GPR study and coring state network** — 2010-2012
- **3.9 Initial performance modeling with PCS data** — 2011
- **3.9 Traffic database development and integration** — 2009-2011
- **4.60 Traffic Speed Deflectometer (TSD) initial evaluation for PMS** — 2015-2017
- **3.9/3.28 1st generation engineering configuration** — 2010-13
  - Segmentation
  - Distress definition
  - Data aggregation
  - Performance models
  - Decision trees
  - Benefit equations
- **3.28/5.04 Grouping segment into realistic projects** — 2014-2017
- **3.43 Decision support for inclusion of TSD data in *PaveM*** — 2017-2020
- **3.48 Life-cycle cost optimized decision trees** — 2017-2020
- **4.68[1,2] Develop historical condition database for performance models and ME calibration** — 2017-2020
- **4.81 Verification methods for traffic information** — 2020-2023 (current)
- **4.82 Advanced image evaluation of APCS data** — 2020-2023 (current)
- **Optimized decision trees for local government (using PCI)** (current)
- **Improved data collection and PMS approaches for local government** (future)

DEVELOPMENT

- **3.9 GPR and core visualization tool & core database (*iGPR*)** — 2012-2014
- **3.28 Location reference system quality review and recommendation** — 2012-14
- **5.A "H-bar" pavement treatment history and forward projection visualization tool** — 2015
- **5.A Support as-built updates** — 2014-17
- **5.A Include models and decision for new treatment as developing** — 2014-2017
- **5.01/5.02/5.03 Performance model updates with PCS and APCS data** — 2015-17
- **5.08 Traffic database updates** — 2016-17
- **4.55 GHG calculation update** — 2017
- **4.68 Performance Model Updates** — 2017-2020
- **3.58[1,2] Calibration of ME design methods with statewide PMS data** — 2020-2023 (current)
- **4.81[1,2] Improved traffic models for *PaveM* and ME design** — 2020-2023 (current)
- **2.03 Decision trees and performance models for CRCP** — 2020-2023 (current)

IMPLEMENTATION

- **3.9 APCS contractor selection** — 2010
- **3.9 QA of GPR and first APCS contracts** — 2011-12
- **5.A/5.07 2014 LRS update and integration of MAP21 NHS** — 2015
- **5.A PMS and asset management integration** — 2017
- **2.10 PMS Support** — 2017-2020
  - PMS training and assistance
  - Traffic updating
  - As-Built updating & QA
  - LRS updating & QA
  - PaveM portal, H-Bar, RP-List
  - Other improvements
- **3.57[1,2] Tri-annual update for *PaveM* performance models and GHG equations** — 2020-2023 (current)
- **2.03 Continued *PaveM* support, including integration with DIME; Restructure *PaveM* project information** — 2020-2023 (current)
- **PMS for ramps, connectors, parking lots** (future)
- **Implementation support and training for local government on PMS principles and best practices** (future)

FOR MORE INFORMATION
For information on past research projects, visit Caltrans www.dot.ca.gov/research/researchreports/index.htm and UCPRC www.ucprc.ucdavis.edu
For additional information on Caltrans Pavement Research Program, email Nick Burmas, Office Chief of Materials and Infrastructure, nick.burmas@dot.ca.gov

Project Key: Past (solid border) / Current (shaded) / Proposed (shaded, dashed) / Future (dashed border)

Linked Roadmaps: [1] ME Design of Asphalt; [2] ME Design of Concrete

Pavement Research Roadmap
PMS
version date December 4, 2020

New Concepts for Materials and Structures

Caltrans | UCPRC University of California Pavement Research Center, Davis • Berkeley | Pavement Research Roadmap

VISION To quickly and cost efficiently evaluate new technologies and comprehensively develop those that are promising

CONCEPT

SCOPE All new materials, structures, construction methods, and quality improvement technologies for pavement

Past UCPRC new materials and structures projects:
- RHMA-G overlays
- Asphalt drainable layers
- Rapid strength concrete
- BCOA
- FDR
- Grind and groove
- Widened JPC lanes
- GPR
- Dowel bar retrofit
- WMA
- Permeable pavement
- Small-stone open graded mixes

2.8 Biomass for transportation materials
Forest and ag biomass applications
2017-2020

2.8 Urban metabolism[1]
2017-2020

ITS SB1 2020 Response to AB2061 project
EV, NGV, fuel cell vehicles effects on roadway

New structures for urban pavements
Low impact (cost & environment), ability to repair utilities

REC-G 2020-2023 proposal
Conceptual review of roller compacted concrete applications on State highways

Conceptual review of grinding slurry waste

Conceptual review of deicing pavement

RESEARCH

Rice ash for concrete (Rice Research Board)[1,3]
Materials, LCA, economics, improved materials
2018, 2019, 2020

4.76 RAP/RAS in RHMA for use in interlayers, rich bottom layers, and base for PCC[2]
2020-2023

4.80 Environmental LCA updates and applications[1]
LCI of concrete and asphalt biomass materials, other new additives
2020-2023

SUS-E 2020-2023 proposal
Alternative supplementary cementitious materials
Nano-cellolotics, biomass, other new SCM for concrete pavement

REC-F 2020-2023 proposal
Recycled plastic in asphalt pavements

MED-D 2020-2023 proposal
Modeling, testing, and validation of interlayer base and overlay reflective cracking performance

PRS-K 2020-2023 proposal
Microsphere technology as alternative to conventional air-entraining admixtures

Effects of pavement conditions on battery electric and fuel cell vehicle durability and performance

Review of early CRCP performance, crack spacing, edge deflections and other early predictions of performance

Cool pavement technologies for human thermal comfort in urban areas

Review of bonded wearing course performance

DEVELOPMENT

Recommendation in RHMA literature review for DEA 2020
Pilot UCPRC open-graded mix design procedure

REC-G 2020-2023 proposal
Guidance for the use of recycled materials in new PCC, RCC, LCB, and base/subbase layers.

CCR-A 2020-2023 proposal
Permeable pavement validation

Permeable pavement roadmap from 2017 workshop
10 pathways to fill the gaps for full consideration of permeable pavement for stormwater, flood control, transportation and place making

Proposal with Oregon State University to U.S. Endowment for Forestry and Communities 2020
Pilot projects for nano-cellolotics for concrete pavement

IMPLEMENTATION

3.21/3.35/3.42 Monitoring of grind and groove pilot projects
2011-2020

2.10 Add CRC decision trees to PMS (*PaveM*)
2020-2023

CRC repair guidance

FOR MORE INFORMATION
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Project Key: Past (solid line); Current (solid red); Proposed (dashed red); Future (dashed line)

Linked Roadmaps
[1] LCA
[2] RAP/RAS
[3] ME Design Concrete

Pavement Research Roadmap
New Concepts for Materials and Structures
version date December 04, 2020

New Technologies and Integrated Frameworks

Pavement Research Roadmap

VISION Perform conceptual evaluation and research on new technologies and integrated frameworks and, if feasible, move them to their own new road map

SCOPE Continue to look for new technologies and approaches and assess, integrate, develop, and move them forward

CONCEPT	ASSESMENT		RESEARCH		DEVELOPMENT & IMPLEMENTATION
Advanced integrated infrastructure for autonomous and alternative fuel vehicles ASCE T&DI initiative on civil infrastructure **Pavement sensor work at universities** Wireless, distributed, vehicle-powered	**Placing V2V, V2I, I2I communication items in the pavement** **Piezo resistive materials for powering embedded instrumentation**	**Effects of pavement conditions on battery electric and fuel cell vehicle durability and performance**	**CITRIS/UCPRC 2019** **Fiber optic sensors to locate vehicles and communicate via V2I**	**Damage sensors for asset management**	**Technologies and projects from this road map will be used to create new road maps as and when the technology is sufficiently mature to support development and implementation**
Advanced integrated infrastructure for active transportation **NCST UCPRC/Georgia Tech[1]** **Road map for new technologies for assessing active transportation infrastructure condition** 2020	**Photo-sensitive self-lighting crosswalks**		**2.2/3.41** **Digital image correlation for seeing strain field in cracking tests** 2017-2020	**New technologies for assessing active transportation infrastructure using automated PCS data**	
"Big data" and machine learning approaches for pavements[2]	**3.43 Traffic speed deflectometer assessment** 2017-2020 **4.82** **Potential for advanced image evaluation in APCS** 2020-2023 **PMS-D 2017-2020 proposal** **Develop low-cost IRI measurement and localized roughness identification procedure**	**Predicting materials properties & mix design guidance using all performance related testing & AI** **AI incorporated into ME design**	**2.9/3.49[2,5,6]** **Improved processes for calibrating ME design with large data sets** 2017-2020 **3.57[2,3]** **Tri-annual performance model update** 2020-2023	**Integration of intelligent construction approaches to collect large scale construction QC data in PMS and design** **Approaches to use large scale construction QC data being collected in DIME in PMS and design**	
Integration of ME design, LCCA, LCA, and PMS			**4.81[2,4,5]** **Improved traffic models for *PaveM* and ME Design** 2020-2023	**Integrate data collection, probabilistic analysis & reliability based decision support for ME design, LCA, LCCA, asset management**	
4.72[3,4] **LCA alternative strategies for GHG reduction** 2017-2020	**3.56[3,4]** **Multi-criteria decision support for prioritization of strategies to reduce environmental impacts** 2020-2023		**Impacts of energy harvesting on pavement**		

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Project Key: Past; Current; Proposed; Future

Linked Roadmaps: [1] Active Transportation, [2] PMS, [3] LCA, [4] LCCA, [5] ME Design Asphalt, [6] ME Design Concrete

Pavement Research Roadmap
New Technologies & Integrated Frameworks
version date December 04, 2020

UCPRC Contract #65A0788

Funding Plan 2020-23

DRISI Proj ID	PPRC Contract	DRISI Task ID	UCPRC SPE	PROJECT TITLE	Task Funding Total	FY19/20	FY20/21	FY21/22	FY22/23	FY23/24 Jul - Sep
P1239				**Mechanistic-Empirical Design**						
	MED-A	3809	3.51	CalME materials library for flexible pavement	$ 1,773,541.41	99,700.15	1,646,341.26	27,500.00	-	-
	MED-B	3810	3.52	Further Improvement for CalME and Integration with PRS Into Routine Practice	$ 933,480.11	82,517.50	663,549.41	-	187,413.20	-
	MED-E	3760	4.75	RHMA-G Layer Thickness Limits	$ 1,006,725.98	423,423.73	583,302.25	-	-	-
	MED-F	3761	4.76A	RAP/RAS in RHMA for use in Interlayers, Rich Bottom Layers, and Base for PCC (AC)	$ 892,834.65	163,641.32	670,874.46	-	-	58,318.87
	MED-F	3977	4.76B	RAP/RAS in RHMA for use in Interlayers, Rich Bottom Layers, and Base for PCC (PCC)	$ 446,417.33	23,836.98	246,687.55	-	146,733.37	29,159.43
	MED-K	3811	3.53	Updated Rigid Pavement Design Catalog for JPCP and CRCP Using the Latest Version of AASHTOWare Pavement ME Design Software	$ 291,287.17		291,287.17	-	-	-
	MED-Q	3812	3.54	Monitoring Performance of Thin BCOA projects	$ 352,607.50		89,212.00	90,612.45	128,991.20	43,791.85
				MED	**$ 5,696,894.15**	**$ 793,119.68**	**$ 4,191,254.10**	**$ 118,112.45**	**$ 463,137.77**	**$ 131,270.15**
P1240				**Performance Related Specifications**						
	PRS-A	3816	4.77	AR Binder Specs	$ 797,677.50	100,000.00	504,174.80	-	193,502.70	-
	PRS-J	3768	4.83	Test to Measure CTE-Moisture Dependency	$ 224,884.00			79,647.00	145,237.00	
				PRS	**$ 1,022,561.50**	**$ 100,000.00**	**$ 504,174.80**	**$ 79,647.00**	**$ 338,739.70**	**$ -**
P1241				**Recycling**						
	REC-A	3817	4.78	Updated Guidance and Specifications for In-Place Recycling	$ 1,903,677.41	285,625.10	1,618,052.31	-	-	-
	REC-D	3819	4.79	Guidance, Tests and Specifications for High RAP/RAS in HMA and RHMA Mixes	$ 952,817.60	100,000.00	852,817.60	-	-	-
				REC	**$ 2,856,495.01**	**$ 385,625.10**	**$ 2,470,869.91**	**$ -**	**$ -**	**$ -**
P1242				**Sustainability**						
	SUS-A	3820	4.80	Environmental LCA Updates and Applications	$ 1,183,623.51	87,834.50	880,767.01	97,650.00	117,372.00	-
	SUS-B	3821	3.55	Implementation of Environmental LCA Data and Models for Project-Level Use in eLCAP	$ 655,584.09	122,566.49	284,728.87	-	207,085.23	41,203.50
	SUS-E	3775	4.84	Alternative Supplementary Cementitious Materials	$ 347,515.00			87,695.00	259,820.00	
	SUS-H	3822	3.56	Multi-Criteria Decision Support for Prioritization of Strategies to Reduce Environmental Impacts	$ 618,160.31	125,021.10	468,118.11	-	-	25,021.10
				SUS	**$ 2,804,882.91**	**$ 335,422.09**	**$ 1,633,613.99**	**$ 185,345.00**	**$ 584,277.23**	**$ 66,224.60**
P1245				**Pavement Management System**						
	PMS-B	3814	3.57	Tri-Annual Performance Model Update	$ 122,417.10		11,612.90	25,829.70	63,272.30	21,702.20
	PMS-D	3764	3.58	Continued Calibration of ME design Models with PMS Data	$ 396,075.01		53,145.50	85,969.46	225,869.25	31,090.80
	PMS-E	3765	4.81	Improved Traffic Models for PaveM and ME Design	$ 352,366.30		44,514.69	144,764.10	163,087.51	-
	PMS-G	3766	4.82	Potential for Advanced Image Evaluation in APCS	$ 506,970.14		36,128.89	142,045.94	255,198.41	73,596.90
	PMS-H	3815	3.59	Updates and Improvements to RealCost-CA	$ 224,627.00		61,178.00	71,562.40	74,358.70	17,527.90
				PMS	**$ 1,602,455.55**	**$ -**	**$ 206,579.98**	**$ 470,171.60**	**$ 781,786.17**	**$ 143,917.80**

RESEARCH SUPPORT

DRISI Proj ID	PPRC Contract	DRISI Task ID	UCPRC SPE	PROJECT TITLE	Task Funding Total	FY19/20	FY20/21	FY21/22	FY22/23	FY23/24 Jul - Sep
P1259				**Research Services**						
	2.01	3823	2.01	Manage PPRC	$ 294,413.00	24,413.00	270,000.00	-	-	-
	2.02	3829	2.02	Advice to Caltrans	$ 544,264.50		147,121.72	166,270.00	185,645.78	45,227.00
	2.03	3832	2.03	Support & Training for PaveM Operations	$ 694,012.80		157,732.49	212,165.20	266,890.41	57,224.70
	2.04	3831	2.04	CalME support	$ 628,023.50		144,621.48	191,991.80	239,628.62	51,781.60
	2.05	3779	2.05	eLCAP and RealCost support	$ 547,397.50		57,357.29	167,349.00	277,577.31	45,113.90
	2.06	3828	2.06	Laboratory Management and AMRL Accreditation	$ 384,000.00		384,000.00	-	-	-
	2.07	3826	2.07	Laboratory and Field Testing Equipment	$ 900,000.00	500,000.00		200,000.00	200,000.00	-
	2.08	3827	2.08	HVS Maintenance and Equipment Refurbishment	$ 300,000.00		300,000.00	-	-	-
	2.09	3825	2.09	Calibration Centers	$ 355,777.50		79,564.86	103,902.50	128,377.94	43,932.20
	2.10	3824	2.10	Maintain Laboratory Space	$ 519,174.00	79,174.00	440,000.00	-	-	-
	2.11	3780	2.11	Advice to Div Aeronautics	$ 90,000.00		90,000.00			-
	2.12	3830	2.12	Long term research	$ 336,009.70		98,919.60	52,726.00	156,670.20	27,693.90
				2.xx	**$ 5,593,072.50**	**$ 603,587.00**	**$ 2,169,317.44**	**$ 1,094,404.50**	**$ 1,454,790.26**	**$ 270,973.30**

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