Asphalt Research Consortium

Quarterly Technical Progress Report
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INTRODUCTION

This document is the Quarterly Report for the period of January 1 to March 31, 2014, for the Federal Highway Administration (FHWA) Contract DTFH61-07-H-00009, the Asphalt Research Consortium (ARC). The Consortium is coordinated by Western Research Institute with partners Texas A&M University, the University of Wisconsin-Madison, the University of Nevada Reno, Advanced Asphalt Technologies, and the National Center for Asphalt Technology.

The report is presented as a progress report on the 82 anticipated project deliverables. The project deliverables are grouped into three areas, Reports, Test Methods/Practices, and Models and/or Software. The deliverables consist of 33 Reports, 42 Test Methods/Practices, and 7 Models and/or software. Of the 82 deliverables, 18 draft reports and 33 test methods/practices have been submitted for review. Most of the planned work is completed or nearing completion, therefore, many of the original Work Elements and Subtasks have coalesced into a larger product(s), as planned. The Table of Deliverables is presented following this introduction and identifies the title of the deliverable, expected draft delivery date, and expected final delivery date. The table is updated each quarter. In addition, this Quarterly Report reports on Other Research Activities which may develop deliverables as the work progresses. The project deliverables result from research that was grouped into seven areas, Moisture Damage, Fatigue, Engineered Paving Materials, Vehicle-Pavement Interaction, Validation, Technology Development, and Technology Transfer.

The Quarter of January 1 to March 31, 2014, is the fourth quarter of the Year 7 contract year. Reviewers may want to reference the previous Annual Work Plans and many other documents that are posted on the ARC website, www.ARC.unr.edu. The more detailed information about the research such as approaches to test method development, data collection, and analyses have been and will continue to be reported in research publications as part of the deliverables.

SUPPORT OF FHWA AND DOT STRATEGIC GOALS

The Asphalt Research Consortium research is responsive to the needs of asphalt engineers and technologists, state DOT's, and supports the FHWA Strategic Goals and the Asphalt Pavement Road Map. More specifically, the research reported here supports the Strategic Goals of safety, mobility, and environmental stewardship. By addressing the causes of pavement failure and thus determining methods to improve asphalt pavement durability and longevity, this research will provide the motoring public with increased safety and mobility. The research directed at improved use of recycled asphalt pavement (RAP), warm mix asphalt, and cold mix asphalt supports the Strategic Goal of environmental stewardship.

TABLE OF ASPHALT RESEARCH CONSORTIUM DELIVERABLES

Deliverable	Title	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Description/Note
Report AD	Executive Summary Report: ARC History, Participants and Accomplishments	5/15/2014	5/31/2014	All	All	Report outline has been prepared
Report A0	Summary Report of Asphalt Research Consortium Research at Texas A&M University	2/28/2014	5/31/2014	TAMU	All	Reference level 2 and 3 deliverables for details, 508
Report A	Moisture Damage of Asphalt Pavements: Mechanisms, Characterization, Prediction and Numerical Modeling	Completed 3/21/2013	9/30/2013	TAMU	Masad	Sent to FHWA for review, Reference level 3 deliverables for details, NTIS
Report B	Characterization of Fatigue Damage and Relevant Properties in Asphalt Binders and Composites	Completed 8/22/2013	10/31/2013	TAMU	Bhasin	NTIS
Report C	PANDA: Pavement Analysis Using Nonlinear Damage Approach	Completed 9/26/2013	11/30/2013	TAMU	Darabi	Summary of PANDA methodology including descriptions of methods for indentifying model parameters, 508
Report D	Microstructural Characterization of the Chemo-Mechanical Behavior of Asphalt in Terms of Aging and Fatigue Performance Properties	Completed 7/26/2013	10/31/2013	TAMU	Little	Summary report on methodology for characterizing the phases of asphalt binder with description of composite implications NTIS

Deliverable	Title	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Description/Note
Report E	A Multiscale Virtual Fabrication and Lattice Modeling Approach for the Fatigue Performance Prediction of Asphalt Concrete	Completed 9/30/2013	9/30/2013	NCSU	R. Kim	Submitted to FHWA for review, Comprehensive report on lattice model.
Report F	Microstructure Cohesive Zone Modeling for Moisture Damage and Fatigue Cracking	Completed 3/21/2013	8/31/2013	UNL	Y.R. Kim	Sent to FHWA for review, Comprehensive report on cohesive zone model
Report G	Design System for HMA Containing a High Percentage of RAP Material	4/30/2014	6/30/2014	UNR	Sebaaly Hajj	
Report H	Critically Designed HMA Mixtures	12/31/2013	3/31/2014	UNR	Hajj Sebaaly	Comprehensive report describing the developed mechanistic-based approach for critically designed mixtures
Report I	Thermal Cracking Resistant Mixes	2/15/2014	5/31/2014	UNR	Hajj Sebaaly	
Report I-A	Study of Pavement Temperature Rates in HMA Layers	9/26/2013		UNR	Hajj Sebaaly	Received MS Word and Hardcopy
Report I-B	Low Temperature Cracking Characterization of Asphalt Binders	2/15/2014		UNR	Hajj Sebaaly	Recently separately from report I on 1/5/2014

Deliverable	Title	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Description/Note
Report J	Pavement Response Model to Dynamic Loads 3D Move	2/28/2014	5/31/2014	UNR	Hajj Sebaaly	Delayed. Research team focused on addressing and solving the various bugs reported by the users for newly released Ver. 2 of the software
Report K	Development of Materials Database	2/28/2014	5/31/2014	UNR	Hajj Ekedahl	Outline only
Report L	Development and Validation of the Bitumen Bond Strength Test (BBS)	Completed 10/31/11	Completed 10/31/13	UWM	Hanz	Extended to incorporate new information from NCHRP 9-50
Report M	Development of Test Procedures for Characterization of Asphalt Binder Fatigue and Healing	Completed	Completed 3/31/2014	UWM	Tabatabaee	Received MS Word version and tech brief. Section 508 and image descriptions needed.
Report N	Guideline for Selection of Modification Techniques	Completed 3/31/2014	6/30/2014 Pending Review	UWM	Tabatabaee	3 month extension of draft report deadline approved by FHWA
Report O	Characterization of Binder Damage Resistance to Rutting	Completed 9/30/2013	Completed 3/31/2014	UWM	Tabatabaee	Complete 508 formatting, Tech Brief, etc.
Report P	Quantifying the Impacts of Warm Mix Asphalt on Constructability and Performance	4/30/2014 (from 9/30/2013, 12/31/2013)	6/30/2014 from (12/31/2013, 3/31/2014)	UWM	Hanz	3 month extension of draft report deadline requested

Deliverable	Title	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Description/Note
Report Q	Improvement of Emulsion Characterization and Mixture Design for Cold Bitumen Applications	5/30/2014, from 9/30/2013, 12/31/2013	6/30/2014 (from 3/31/2014)	UWM	Hanz	3 month extension of draft report deadline requested
Report R	Studies on Tire-Pavement Noise and Skid Response	Completed 12/31/11	Completed 7/30/2013	UWM	Roohi	Received MS Word version and tech brief
Report S	Molecular dynamics results for multiple asphalt chemistries	5/15/2014	5/31/2014	URI	Greenfield	3 month extension of draft report deadline requested.
Report T	Progress Toward a Multi-scale Model of Asphalt Pavement- Including Test Methods for Model Input Parameters	5/15/2014	5/31/2014	WRI/VT/ URI/TUD	Pauli	3 month extension of draft report deadline requested.
Report U	Design Guidance for Fatigue and Rut Resistance Mixtures	3/15/2014	6/30/2014	AAT	Bonaquist Christensen	3 month extension of draft report deadline requested. NTIS format report with Technical Brief
Report V	Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures (Level 2)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Draft submitted to FHWA Reference appropriate level 3 deliverables NTIS
Report W	Characterization of Fatigue and Healing Properties of Asphalt Mixtures (Level 2)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Draft submitted to FHWA Reference appropriate level 3 deliverables NTIS
Report X	Characterization of Field Cores of Asphalt Pavements (Level 2)	Completed 07/26/2013	10/30/2013	TAMU	Lytton/Luo	Draft submitted to FHWA Reference appropriate level 3 deliverables NTIS

Deliverable	Title	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Description/Note
Report Y	Water Vapor Diffusion in Pavement and Its Effects on the Performance of Asphalt Mixtures (Level 2)	Completed 07/26/2013	10/30/2013	TAMU	Lytton/Luo	A revised version of this report is submitted to FHWA for review
Report Z	Effect of Extraction Methods on the Properties of Aggregates in Reclaimed Asphalt Pavement (NTIS format)	Completed 3/1/2013	10/30/2013	UNR	Hajj Sebaaly	Draft submitted to FHWA Final pending receipt of peer review comments
Report AA	Laboratory Assessment of Asphalt Mixture Long Term Aging	3/31/2014	6/30/2014	UWM	Tabatabaee	3 month extension of draft submittal requested
Report AB	Summary Report on ARC Comparative Pavement Test Sections	5/15/2014		WRI	Farrar	Report summarizing progress of establishing and maintaining the WRI-ARC and FPIII comparative pavement test sections.
Report AC	Summary Report on NCAT Warm-Mix Pavement Test Sections	5/15/2014		NCAT	Nam	Report summarizing progress of establishing and maintaining the NCAT test sections.

TABLE OF ASPHALT RESEARCH CONSORTIUM PRODUCT DELIVERABLES

Deliverable/ Product	Description/Title	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
AASHTO Method	Simplified Continuum Damage Fatigue Analysis for the Asphalt Mixture Performance Tester	5/15/2014	6/30/2014	AAT	Bonaquist Christensen	Development documented in Report U
AASHTO Method	Using a Wilhelmy Plate Device to Determine Surface Energy Components of Asphalt Binders (Level 3)	Completed 03/07/2013	6/30/2013	TAMU	Bhasin	Draft submitted to FHWA Referenced in Reports A & B
AASHTO Method	Using a Sorption Device to Determine Surface Energy Components of Aggregates (Level 3)	Completed 03/07/2013	6/30/2013	TAMU	Bhasin	Draft submitted to FHWA Referenced in Reports A & B
AASHTO Method	Conducting Dynamic Mechanical Analyzer (DMA) Tests (Level 3)	Completed 03/07/2013	6/30/2013	TAMU	Kassem	Draft submitted to FHWA Referenced in Reports A & B
ASTM Method	Automated Flocculation Titrimetric Analysis	Completed		WRI	Pauli	ASTM D-6703
AASHTO Method	Determination of Polymer in Asphalt	Completed		WRI	Harnsberger	
AASHTO Method	Preparing Dynamic Mechanical Analyzer (DMA) Specimens (Level 3)	Completed 03/07/2013	6/30/2013	TAMU	Kassem	Draft submitted to FHWA Referenced in Reports A & B
AASHTO Method	Quantifying Intrinsic Healing of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)	Completed 03/07/2013	9/30/2012	TAMU/ UT	Bhasin	Draft submitted to FHWA Referenced in Report B
AASHTO Method	Calibration of the Pavement Analysis using Nonlinear Damage Approach (PANDA) Constitutive Relationships (Level 3)	Completed 09/26/2013	2/28/2014	TAMU	Kassem Darabi	Referenced in Report C
Test Method & Model	Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures (Level 3)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Appendix in Report V

Deliverable/ Product	Description/Title	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Test Method & Model	Characterization of Fatigue and Healing Properties of Asphalt Mixtures (Level 3)	Completed 07/26/2013	9/30/2013	TAMU	Lytton/Luo	Appendix in Report W
Test Method Analysis Program	Nondestructive Characterization of Tensile Viscoelastic Properties of Undamaged Asphalt Mixtures (Level 3)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Appendix in Report W
Test Method & Model	Characterization of Field Cores of Asphalt Pavements (Level 3)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Appendix in Report X
Test Method Analysis Program	Nondestructive Characterization of Anisotropic Viscoelastic Properties of Undamaged Asphalt Mixtures under Compressive Loading (Level 3)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Appendix in Report V
AASHTO Practice	Mix Design for Cold-In-Place Recycling (CIR)	4/30/2014		UNR	Sebaaly Hajj	Detailed in Report Q
AASHTO Practice	Mix Design for Cold Mix Asphalt	3/31/2014 from 9/30/2013	6/30/2014 from 3/31/2014	UWM	Hanz	Extension requested to coincide with submittal of draft for Report Q
AASHTO Practice	Evaluation of RAP Aggregates	12/31/2012		UNR	Sebaaly	Detailed in Report G
AASHTO Practice	Determining Asphalt Mixture Critical Conditions for Rutting Evaluation by Means of Dynamic Repeated Load Triaxial (RLT) Test	Completed 5/31/2013		UNR	Hajj Sebaaly	Detailed in Report H
AASHTO Method	Determining Thermal Crack Properties of Asphalt Mixtures Through Measurement of Thermally Induced Stress and Strain	Completed 5/31/2012		UNR	Hajj Tabatabaee	Detailed in Report I
AASHTO Method	Determining Asphalt Binder Bond Strength by Means of the Bitumen Bond Strength Test (BBS)	Completed	Completed 6/30/13	UWM	Hanz	Complete, no additional work planned.
AASHTO Method	Measurement of Asphalt Binder Elastic Recovery in the Dynamic Shear Rheometer (DSR)	Completed 1/31/2013	Complete 6/30/2013	UWM	Tabatabaee	Complete, no additional work planned.
AASHTO Method	Estimating Fatigue Resistance of Asphalt Binders Using the Linear Amplitude Sweep (LAS)	Completed	Completed 9/30/2013	UWM	Tabatabaee	Complete, no additional work planned.
AASHTO Method	Binder Yield Energy Test (BYET)	Completed 1/31/2013	Complete 6/30/2013	UWM	Tabatabaee	Complete, no additional work planned.

Deliverable/ Product	Description/Title	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
AASHTO Method	Measurement of Rigden Voids for fillers	Completed 1/31/2013	Completed 6/30/2013	UWM	Hanz	Complete, no additional work planned.
AASHTO Method	Measurement of Asphalt Binder Lubricity Using the Dynamic Shear Rheometer (DSR)	12/31/2013 from 9/30/2013	3/31/2014 from 12/31/2013	UWM	Hanz	3 month extension requested to coincide with submittal of draft final Report P
AASHTO Method	Procedure for Evaluation of Coating for Cold Mix Asphalt	Completed 4/30/2013	Completed 9/30/2013	UWM	Hanz	Complete, no additional work planned
AASHTO Method	Cold Mix Laboratory Specimen Preparation Using Modified SGC Molds	Completed 8/30/2013	Completed 12/31/2013	UWM	Hanz	Pending comments from FHWA/ETG
AASHTO Method Software	RAP Binder PG True Grade Determination	Completed 9/30/2012	Completed 6/30/2013	UWM	Hanz	Complete, no additional work planned
AASHTO Method	Measurement of Asphalt Binder Fracture Properties Using the Single Edge Notch Bending Test	Completed 9/30/2012	Completed 9/30/2013	UWM	Tabatabaee	Complete, no additional work planned
AASHTO Method	Test Method for Measurement of the Glass Transition Temperature of Asphalt Binders	Completed 1/31/2013	Completed 6/30/2013	UWM	Tabatabaee	Action pending FHWA/ETG comments
AASHTO Method	Test Method for Measurement of the Glass Transition Temperature of Asphalt Mixtures	Completed 4/30/2013	Completed 6/30/2013	UWM	Tabatabaee	Refer to UNR TSRST procedure for additional information
AASHTO Method Software	Analysis of Asphalt Mixture Aggregate Structure through Use of Planar Imaging and Image Processing & Analysis System (IPAS)	Completed 4/30/2013	Completed 9/30/2013	UWM	Roohi	Action pending ETG comments
AASHTO Method	Determining the Resistive Effort of Asphalt Mixtures during Compaction in a Gyrator Compactor using an Internal Device	Completed ASTM	12/31/2013 from 9/30/2013	UWM	Hanz	Extended to address comments from ASTM
AASHTO Method	Micromechanical Properties of Various Structural Components in Asphalt using Atomic Force Microscopy (AFM) (Level 3)	Completed 03/07/2013	8/31/2013	TAMU	Little	Draft submitted to FHWA, Referenced in Report D

Deliverable/ Product	Description/Title	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
AASHTO Method	Test Method for Fatigue of Binder and Mastics: A cyclic direct tension test that can provide direct evaluation of fatigue for binder and mastic. It can also provide model validation and model parameter inputs.	12/30/2013	3/30/2014	VT	Wang	Draft data extension requested
AASHTO Method	AASHTO Method: Method to Quantify (Self) Healing in Asphalt Composites Based on Viscoelastic Continuum Damage Theory (Level 3)	Completed 08/22/2013	8/31/2013	TAMU/ UT	Bhasin	Appendix in Report B
Test Method & Analysis Program	Self-Consistent Micromechanics Models of Asphalt Mixtures	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Appendix in Report W
AASHTO Method & Analysis Program	AASHTO Method: Prediction of Apparent Viscosity of Asphalt Binders Using a Generalized Oldroyd-B Model	Completed 10/16/2013	9/30/2013	TAMU	Little	Draft submitted to FHWA for review
AASHTO Method	Test method to determine surface roughness of aggregate and fines based on AFM	9/30/2013	5/30/2014	WRI	Grimes	Will be subject of Tech. Pub., Discussed in Report T
AASHTO Method	Test method to determine ductile-brittle properties via AFM measurements	10/30/2013	5/30/2014	WRI	Grimes	Will be subject of Tech. Pub., Discussed in Report T
AASHTO Method	AFM-based micro/nano-scale cyclic direct tension test	Completed 3/31/2013	10/31/2013	WRI	Grimes	Draft submitted to FHWA Will be subject of Tech. Pub., Discussed in Report T
AASHTO Method	Measurement and Texture Spectral Analysis of Pavement Surface Profiles Using a Linear Stationary Laser Profiler (SLP)	Completed 9/30/2012	Completed 6/30/2013	UWM	Roohi	Complete, FHWA decided not to pursue draft standard.
Model	HMA Thermal Stresses in Pavement	3/31/2014		UNR	Hajj	Detailed in Report I
Software	Dynamic Model for Flexible Pavements 3D-Move	3/31/2014		UNR	Hajj Siddharthan	Detailed in Report J

Deliverable/ Product	Description/Title	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Model & Test Method	Improved Oxygen and Thermal Transport Model of Binder Oxidation in Pavements (Level 3)	5/31/2013	10/31/2013	TAMU	Glover	Part of Report B & Summary Report References to Dissertations and Journal Papers
Model & Test Method	Pavement Air Voids Size Distribution Model for use in an Oxygen and Thermal Transport Model of Binder Oxidation in Pavements (Level 3)	5/31/2013	10/31/2013	TAMU	Glover	Part of Report B & Summary Report References to Dissertations and Journal Papers
Model	Approaches to interpret MD simulation results and experimental data to quantify the composition and temperature dependence of free energy.	8/15/2013		URI	Greenfield	Detailed in Report S
Model and Software	Phase-Field Model of Asphalt Binder Fracture and COMSOL Code for Model	5/15/2014	5/31/2014	VT	Wang	Extension Requested Detailed in Report T
Software	PANDA Software (Pavement Analysis using a Nonlinear Damage Approach)	5/31/2014	6/20/2014	TAMU	Sun-Myung Kim	This software supports the PANDA constitutive models(UMAT) used in conjunction with Abaqus FE software. This includes the PUI and PPI software

REPORTS

REPORT A0: ARC TAMU COMPREHENSIVE SUMMARY REPORT

Status: The report is completed and submitted to FHWA for review.

REPORT A: SUMMARY REPORT ON MOISTURE DAMAGE

Status: The report is completed and submitted to FHWA for review.

REPORT B: CHARACTERIZATION OF FATIGUE DAMAGE AND RELEVANT PROPERTIES

Status: The report is completed and submitted to FHWA for review.

REPORT C: PAVEMENT ANALYSIS USING A NONLINEAR DAMAGE APPROACH (PANDA)

Status: The report is completed and submitted to FHWA for review.

The main progress of this quarter can be outlined as follows:

- **PANDA chapter**

The PANDA chapter in the comprehensive summary report was completed during this quarter. The focus of the current and next quarter will be on addressing the FHWA comments on PANDA report and chapter.

- **Panda Parameter Identifier package (PPI)**

During this quarter, the ARC team continued to finalize the PANDA Parameter Identifier (PPI) package by implementing the procedure for identification of parameters associated with the hardening-relaxation constitutive relationship. The focus of this quarter will be on finalizing PPI to be delivered to the FHWA.

- **Further validation of PANDA**

During this quarter, PANDA was further validated against cyclic stress-controlled, and cyclic strain-controlled, and repeated creep-recovery laboratory tests on aged and unaged specimens. These test results were used to further validate the aging and fatigue damage constitutive relationships.

The focus of the next quarter will be on further calibration and validation of PANDA against ARC test results as well as the other available and on-going experimental data (Waterways Experiment Station data, ARC lab experiments on selected asphalt mixtures, and Ohio test sections) and previously collected data from the Accelerated Loading Facility at Turner-Fairbanks, the Nottingham facility at Nottingham University.

The effect of realistic tire contact stresses will also be incorporated in PANDA for more accurate analysis of pavement structures. Dr. Imad Al-Qadi and his team from University of Illinois-Urban, Champaign is assisting in this task by predicting the contact pressures from different types of tires at different temperatures. Those predictions will be used as inputs into the realistic rutting and fatigue damage simulations using PANDA. This work is still undergoing and will be the focus of the current and next quarter.

- **Effect of layer properties on performance of pavements**

During this quarter, PANDA was used to conduct a comprehensive analysis on the effect of geometry, material properties, and applied load on rutting performance of pavements. Several simulations were conducted to investigate the effects of layer thickness, wheel load, and properties of asphalt layer on the rutting performance. Finalizing these sensitivity analyses will be the focus of the current and next quarters.

- **Auditing constitutive relationships of PANDA and development of extrapolation techniques**

The ARC researchers have been collaborating closely with Dr. David Allen, Adjunct Professor at TAMU and former dean of engineering at the University of Nebraska at Lincoln. Dr. Allen is well-known in the fields of constitutive modeling and mechanics and will audit the constitutive relations implemented in PANDA. Because of his extensive experiences with Schapery's non-linear viscoelastic and viscoplastic models and computational modeling of asphalt and composites, we have asked Dr. Allen to critically examine the constitutive relations implemented in PANDA and provide us with the areas that may need more refinements and enhancements. Dr. Allen is also evaluating the efficacy of simplification of the computational framework of PANDA into a standalone package that is no longer dependent upon use of the Abaqus FE framework. Development of the standalone package will not be done within ARC, but the final PANDA report will include a plan to move forward in that direction.

The focus of this quarter was to carefully evaluate the different techniques to extrapolate the PANDA simulation results to large number of loading cycles. These extrapolation techniques are necessary to predict the performance of pavements subjected to millions of traffic loading cycles. The final PANDA report will include a plan to move forward in development of a robust extrapolation technique.

We will focus our future efforts on the following subjects:

- Finalize PUI and PPI packages to be delivered to FHWA.
- Further validate PANDA against ARC data, Waterways Experiment Station data, and Ohio test sections.
- Incorporate realistic tire contact stresses in PANDA.
- Investigate the effect of layer properties on performance of pavements.
- Investigate the efficacy of incorporating PANDA into a standalone package.
- Investigate the efficacy of enhancing PANAD by implementing a robust extrapolation technique in order to predict the performance under large number of loading cycles.

REPORT D: CHARACTERIZATION OF ASPHALT BINDERS USING ATOMIC FORCE MICROSCOPY

Status: The report is completed and submitted to FHWA for review. The work described below is beyond the original scope of our proposed AFM work, but successes with the AFM have prompted our continued effort in this area as described below.

Main progress achieved during this quarter and focus of future work

Finite element modeling of asphalt binder AAD and BI0002 under unaged conditions has been completed. The geometries for both models were based on actual AFM images obtained during the tensile testing using the micro-loading frame previously designed. The material properties were obtained through AFM creep indentation experiments. These material properties were then used to fit three separate phases within the asphalt binder that were referred to the bee" phase, "bee casing" phase, and the "interstitial" phase. Bonding among the separate phases was defined as perfect bonding and only the composite response of the three micro-constituents were of primary focus.

A stress relaxation virtual experiment was performed and the results showed that highest stresses occurred within the interstitial regions and the lowest stresses were experienced by the "bee" phases. These results were found to be consistent with the experimental tensile testing results. The high stress regions in the finite element model coincided with regions where cracks or phase separation zones occurred in the asphalt samples. A journal publication draft regarding this work has been completed and the final draft will be submitted by the end of April.

Numerical analysis regarding the formation of the "bee" structures is also under progress. There are two mechanisms that may be responsible for the formation of these phases. The first being the variance in material model parameters such as the stiffness of the different phases, and the second factor is the difference in the coefficient of thermal expansion between the different phases. Preliminary results indicate that during the cooling process the asphalt binder undergoes differential shrinkage in different locations leading to the formation of the buckled sinusoidal shape referred to as the bee structures.

The application of this work will be presented in a separate publication and will demonstrate its ability to analyze damage/micro-cracking in asphalt binder with respect to both unaged and aged binders. A discussion regarding the formation of the bee structures and the numerical investigations regarding these formations will also be part of a separate publication.

Experimental testing involving tensile testing is still under progress. Tensile testing using the micro-loading frame is being performed on both AAD, and BI0002 samples under RTFOT, and RTFOT+PAV aged conditions. The intent of these tests is to see how the experimental observations vary between different aging conditions for the same binder.

REPORT E: MULTISCALE VIRTUAL FABRICATION AND LATTICE MODELING.

Status: The report is completed and submitted to FHWA for review.

REPORT F: MICROSTRUCTURE COHESIVE ZONE MODELING FOR MOISTURE DAMAGE AND FATIGUE CRACKING

Status: The report is completed and submitted to FHWA for review.

REPORT G: DESIGN SYSTEM FOR HMA CONTAINING A HIGH PERCENTAGE OF RAP MATERIAL

Included Work Elements/Subtasks
Work Element E2b:Design System for HMA Containing a High Percentage of RAP Materials

Status and Work Planned
Behind Schedule.

The following list describes the work items completed this quarter:

- Completed five out of eight chapters of the final report.
- A new aggregate source was recently selected to restart the dust to binder ratio (DP) study. The previously selected aggregates did not achieve the target VMA requirements for higher dust proportions. Two mix designs were completed with corresponding dust proportions of 1.35 and 1.6. Minimum VMA requirement was 12%. Mixture one with DP of 1.35 had 13.4% while mixture two with DP of 1.6 had barley met VMA requirements of 12%. Several trials were attempted to establish a third mixture with higher DP (> 1.9). However, VMA requirement was not met (VMA for the third mix design ranged from 8.8% to 10.6%). Furthermore, low flow number values were observed with the first two mixtures indicating a potential instability of the mixture.
- This delay was accompanied with a delay in conducting a parallel experiment on the impact of dust proportion on the filler portion of RAP mixtures conducted by University of Wisconsin, Madison.
- Initial mix designs based on the new aggregate source are in progress.

The following list the work planned for next quarter:

- Finalize the mix design of three dust proportions.
- Complete phase I of the DP work plan including testing 18 specimens using RLT.
- Start Phase II of the study including testing beam fatigue specimens at several factors against the DP levels.
- Complete writing the final report.

REPORT H: CRITICALLY DESIGNED HMA MIXTURES

<u>Included Work Elements/Subtasks</u>
Work Element E2c: Critically Designed HMA Mixtures

<u>Status and Work Planned</u>
The report has been completed and reviewed internally at UNR and will be submitted to FHWA for technical review and editing.

REPORT I: THERMAL CRACKING RESISTANT MIXTURES

<u>Included Work Elements/Subtasks</u>
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States

<u>Status and Work Planned</u>
Behind Schedule. The following list describes the work items completed this quarter:

- The evaluation of the laboratory-produced mixtures has been completed and the analysis of the results for the field validation samples is currently undergoing.
- Effect of oxidative aging on thermo-volumetric, viscoelastic, and fracture properties of asphalt mixtures has been quantified using the test results of asphalt mixtures at various laboratory aging levels.
- The effect of cooling rate on the thermo-volumetric, thermo-viscoelastic, and fracture properties of asphalt mixtures has been evaluated. A paper was accepted and will be presented at the upcoming ISAP2014 meeting in Raleigh, North Carolina.
- Writing of the E2d report on thermal cracking resistant mixtures is underway by both UNR and UWM.
- Development of the thermal cracking analysis package (TCAP) software is underway.

The following list the work planned for next quarter:

- Completion of Report I.
- Releasing the alpha-version of the thermal cracking analysis package (TCAP) software.

REPORT J: PAVEMENT RESPONSE MODEL TO DYNAMIC LOADS 3D-MOVE

Included Work Elements/Subtasks
Work Element VP3a: Pavement Response Model to Dynamic Loads

Status and Work Planned
Behind Schedule.

The work on the report continued this quarter and it is 65% complete.

The following is a list work elements planned for next quarter:

- Continue work on Final Report and the 3D-Move documentation;
- Work on the new platform for next version of 3D-Move (Ver. 3).

REPORT K: DEVELOPMENT OF MATERIALS DATABASE

Included Work Elements/Subtasks
Work Element TT1d: Development of Materials Database

Status and Work Planned
The following list summarizes the work items completed or in progress this quarter.

- Missing measurement data feature
- Modify pavement site subsystem to include geographic coordinates
- Status of batch upload of data from Texas A&M group
- Acquisition of additional data storage
- Status of announcement system
- Status of the role system
- Status of the database initialization feature
- Summary reports for measures and reports
- DQA report completed
- Report K completed
- General code enhancements and code cleanup
- General user interface improvements
- Work planned for next quarter
- Revisit the FileLinker form and subsystem, as necessary (no activity reported this quarter)

1. Significant Results (Missing Measurement Data Feature)
The missing measurement data feature for single-factor and multi-factor measures completed last quarter was deployed as planned. The code has been tested and is working correctly. No bugs or errors have been reported at this time. The technical details of these changes were discussed in the last quarterly report and are not repeated here.

2. Significant Results (Modify Pavement Site Subsystem to Include Geographical Components)
Note that this was an unplanned activity for the quarter. The pavement site subsystem was enhanced this quarter to include geographical coordinates, where appropriate. These changes are discussed in this section. In addition, to improve consistency of the ARC application user interface, DetailsView controls were replaced with FormView controls. The table named tblValidationSite was modified to add the following fields:

- fldLongitude (float) (nullable)
- fldLatitude (float) (nullable)
- fldElevation (float) (nullable)

The table named tblValidationSection was originally designed to store the starting and ending point of the pavement section using a defined unit of measure. The table was modified to add the following fields that describe the geographical coordinates of the pavement section's starting and ending points:

- fldLongitudeStart (float) (nullable)

- fldLatitudeStart (float) (nullable)
- fldElevationStart (float) (nullable)
- fldLongitudeEnd (float) (nullable)
- fldLatitudeEnd (float) (nullable)
- fldElevationEnd (float) (nullable)

The table named tblValidationLayer was not modified. The following stored procedures were modified to account for the above location fields. These stored procedures perform inserts, updates, deletes, and record selection for the above tables:

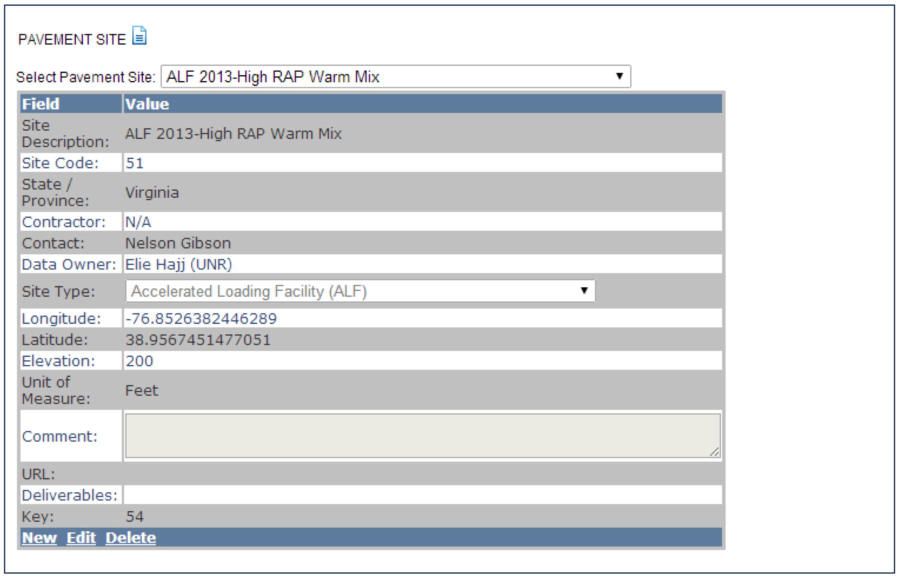
- spDELETEValidationSite
- spINSERTValidationSite
- spUPDATEValidationSite
- spValidationSite
- spDELETEValidationSection
- spINSERTValidationSection
- spUpdateValidation
- spValidationSection

The following forms, user controls, and other items were also modified:

- The control named ucValidation.ascx was replaced by the control named ucValidationFV.ascx. This control contains the fields for the new data items and corresponding validation code. In all cases, the validation code checks that the longitude, latitude, and elevation values are numeric and within valid data point ranges.
- The form ValidationManager was updated to use these new controls.
- The procedures in the class DBUtility that call the preceding stored procedures were updated, as necessary, to add the additional arguments for the geographical coordinates.
- This form was also updated use FormView controls to improve the user interface consistency with other forms.
- The help files were modified accordingly.

Figure TT1D.1 shows the new form segment for pavement sites having the FormView interface and the added geographical fields. As shown in the figure, the new fields include Longitude, Latitude, and Elevation. The Unit of measure shown in the figure is feet. Figure TT1D.2 shows the new form segment for pavement sections having the FormView interface and the added geographical features.

In addition to the above enhancements, a request has been made to develop an additional subsystem that would track pavement distress characteristics for pavement sites based on distress characteristics described in the following FHWA report: https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/reports/03031/.The development team is evaluating the feasibility of enhancing the existing system of properties, measures, and validation sites, to record these distress characteristics over time.

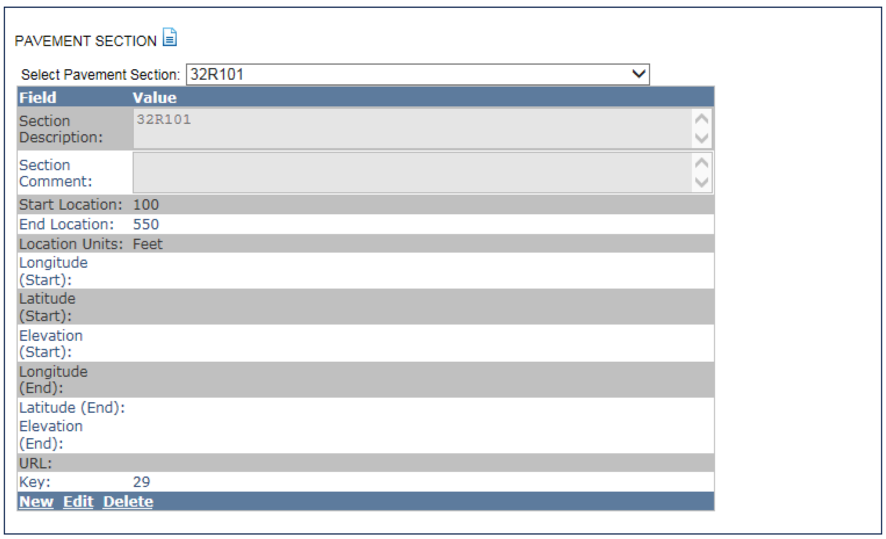


PAVEMENT SITE

Select Pavement Site: ALF 2013-High RAP Warm Mix

Field	Value
Site Description:	ALF 2013-High RAP Warm Mix
Site Code:	51
State / Province:	Virginia
Contractor:	N/A
Contact:	Nelson Gibson
Data Owner:	Elie Hajj (UNR)
Site Type:	Accelerated Loading Facility (ALF)
Longitude:	-76.8526382446289
Latitude:	38.9567451477051
Elevation:	200
Unit of Measure:	Feet
Comment:	
URL:	
Deliverables:	
Key:	54
New Edit Delete	

Figure TT1D.1: Pavement site form improvements



PAVEMENT SECTION

Select Pavement Section: 32R101

Field	Value
Section Description:	32R101
Section Comment:	
Start Location:	100
End Location:	550
Location Units:	Feet
Longitude (Start):	
Latitude (Start):	
Elevation (Start):	
Longitude (End):	
Latitude (End):	
Elevation (End):	
URL:	
Key:	29
New Edit Delete	

Figure TT1D.2: Validation section improvements

3. Significant Results (Status of Batch Upload – Texas A&M)

As discussed in previous reports, Texas A&M University has a significant volume of data to be uploaded to the ARC database and ARC file system resulting from PANDA tests. Last quarter, the system to upload the PANDA data was completed and the first prototype batch of data was tested. A few small inconsistencies were discovered during these final tests. The following list describes the process that was performed to upload the data and the changes that were made to achieve a successful upload:

- The input template file (Excel file) was enhanced to include an optional material. For the current input template, the same material was used for all uploaded reports. However, the system will allow different materials to be associated with each file.

- The input template content was modified so that work tasks applicable to the same file were separated by a semi-colon instead of a comma. The upload software assumes that a comma is a field delimiter within the current record.
- The ARC consortium has implemented a hierarchical work task system categorized into program area, category, work element, and subtask. The template file provided by Texas A&M associated tasks at the work element level. However, report associations must be made at the subtask level. The template file was modified accordingly. For example, the work element V3c: Validation of PANDA, was modified to V3c-1: Validation of PANDA.
- The ARC database requires that all reports be associated with a batch. When the import subsystem was created, the development team expected that the batches would have been previously created and the corresponding batch IDs would appear in the template file. Final testing revealed that this was not the case. Texas A&M requested that batches be dynamically created, and metadata assigned, based on the following file structure:
    - Multiple files appear within a folder.
    - One batch was created for each unique folder containing files.
    - The batch description was set to the path name of the file.
    - Emad Kassem from Texas A&M was assigned as the owner of the uploaded files.
    - The batch status of the uploaded files was set to “Entered not Checked”.
- A new metadata type with the file extension of .txt was created with a description of PANDA. All reports were associated with this metadata type.
- When the validation part of the import program was run, there were a few errors caused by template file names not matching actual file names. These errors were reconciled manually until the input file could be validated and processed correctly.
- The input data were processed and added to the ARC file system and added to the production database.
- Note that the import subsystem produces a complete log and description of the upload and reports any inconsistencies.

The following figure shows the final user interface form used to import the data from Texas A&M University:

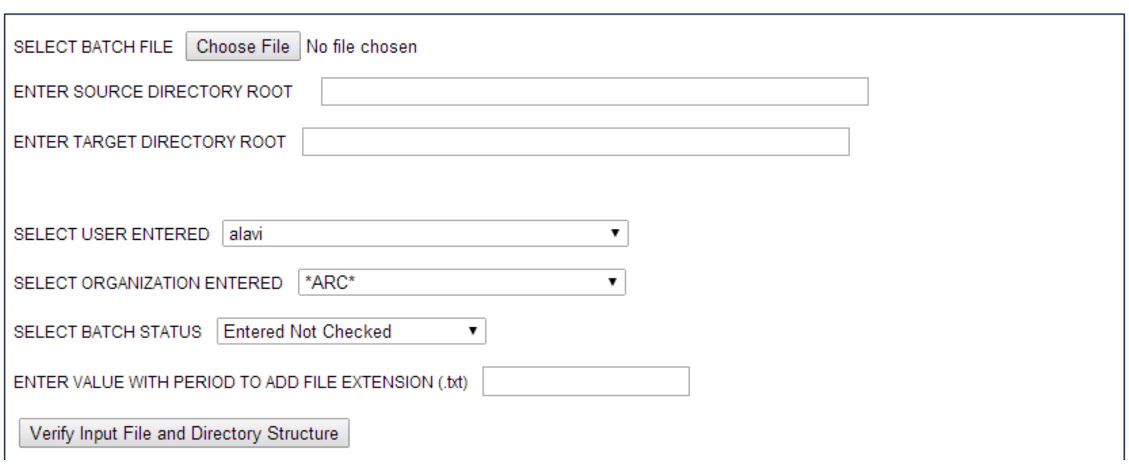


Figure TT1D.3: Batch file import utility form

As shown in the above figure, the template file must first be selected. The source and target directories must contain the physical file system where the data will be uploaded. The drop-down boxes are used to populate the user and batch status fields for the uploaded records. If files did not have an extension, the user input is used to define the file extension.

At the time of this writing, the first batch of three batches has been imported into the production system. The first batch of data was roughly 32 GB and took about 30 minutes to copy the files and record them to the database. Since the error checking and bugs have been worked out, the import of the remaining two batches will require no testing or development time. Limited time might be required to correct small errors and inconsistencies between the ARC file system and the template file.

Note that care must be exercised when using this subsystem. While significant error checking is performed on the input template, the system does not check for all possible inconsistencies.

4. Significant results (Acquisition of Additional Data Storage)

The College of Business at the University of Nevada, Reno has been hosting the ARC application and ARC database since development began. In 2013, data inventory estimates were calculated and it was determined that the existing College of Business hardware was not sufficient to store the complete ARC data inventory. This quarter, network storage was purchased that would allow the ARC consortium to upload all report files through the completion of the project.

5. Significant Results (Status of the Announcement System)

The announcement system, discussed in last quarter's report, was proposed, allowing relevant information to be communicated between ARC users and from ARC administrative users and general users. This informational system supports the application's adherence to the Data Quality Act (DQA). This system is made up of the following parts:

- The form named AnnouncementMaintenace.aspx allows users with the proper role to create, edit, and delete announcements. At the time of this writing, announcement forms and announcement topics have been hardcoded into the form. Consideration is being given to make these categories dynamic, as time permits.
- The form named Announcements.aspx contains the user interface to display announcements based on the announcement date, applicable form, and topic.
- The user control named ucAnnouncements.aspx contains the user control used to display current announcements on other forms.

Figure TT1D.4 shows the main form to create and edit announcements. As shown in the figure, the form operates in three modes (Add, Modify, and Delete). The figure shows the Announcement form in Add mode. The form and topic are selected from the drop-down boxes. The message is entered in a text box. The general announcements form allows users to select announcements based on topic, form, and date range. At the time of this writing, the user interface and code has been completed. However, the formatting has not been completed. Figure TT1D.5 shows the general announcements form. At the time of this writing, the implementation of the announcement system is nearing completion and will be finished next quarter.

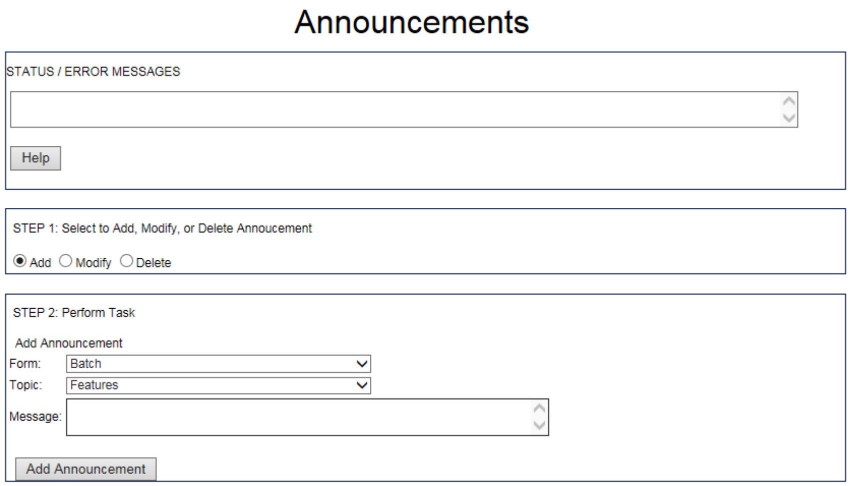


Figure TT1D.4: Announcement Maintenance form

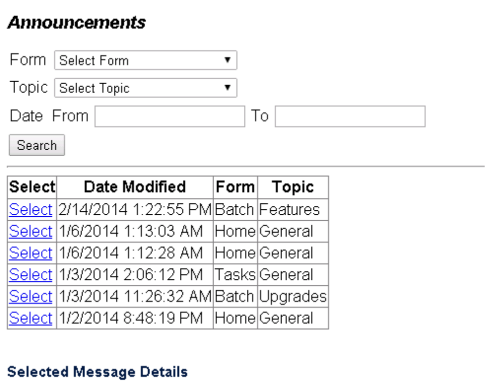


Figure TT1D.5: Announcement form

6. Significant Results (Status of the Role System)

Conversion continues from the old status role system to the new dynamic role system. The following forms were converted this quarter:

- Contacts,aspx.
- ValidationManger.aspx (note that the checks are actually performed in the user control named ucValidationFV.ascx)
- FileDownloadR2.aspx (note that all users can use this form).

At the time of this writing, all forms, with the exception of the following, have been converted: BatchApproval.aspx, BatchViewer.aspx, FieldSamples.aspx, FileApplyDefaultMetaData.aspx, FileLinker.aspx, FileMove.aspx, FileUpload.aspx, ListReports.aspx, Materials.aspx, MeasureApproveTestRun.aspx, MeasurEditTestRun.aspx, Measures.aspx, MeasureCreateTestRun.aspx, VerifyReports.aspx.

7. Significant Results (Status of the Database Initialization Feature)

The database initialization feature was not completed last quarter although progress was made. These scripts will be completed this quarter in preparation for the final software distribution.

8. Significant Results (Summary Lists for Measures and Reports)
Summary lists for reports have existed for some time now that display report counts based on organization, date range, and by user. These lists were created to track the population rate of the ARC database. Eric Weaver requested that similar reports be developed to tally the number of measurement records that have been entered to the database. During this quarter, the prototype queries were developed to extract record totals. These queries will be embedded into the database application and forms next quarter so that they can be run by any user with appropriate privileges. They will also be extended to add selection filters added similar to the selection criteria for the reporting subsystem.

The following query counts the multi-factor quantitative measures by organization:

```
select fldOrgDesc,COUNT(tbltestrun.fldMembershipid)as measurecount from tblTestrun
leftjoin tblQnMeasure qn on qn.fldTestRunID = tbltestrun.fldTestRunID
leftjoin tblMeasureDim qnmd on qnmd.fldQNMeasureID = qn.fldqnmeasureid
INNERJOIN tblMembership on tbltestrun.fldMembershipID = tblMembership.fldID
INNERJOIN tblOrganization ON tblMembership.fldOrgID = tblOrganization.fldOrgID
where qnmd.fldQNMeasureID ISnotNULL
groupby tblOrganization.fldOrgdesc
```

The following query counts the single factor quantitative measure by organization:

```
select fldOrgDesc,COUNT(tbltestrun.fldMembershipid)as measurecount from tblTestrun
leftjoin tblQnMeasure qn on qn.fldTestRunID = tbltestrun.fldTestRunID
leftjoin tblMeasureDim qnmd on qnmd.fldQNMeasureID = qn.fldqnmeasureid
INNERJOIN tblMembership on tbltestrun.fldMembershipID = tblMembership.fldID
INNERJOIN tblOrganization ON tblMembership.fldOrgID = tblOrganization.fldOrgID
where qnmd.fldQNMeasureID ISNULL
groupby tblOrganization.fldOrgdesc
```

The following query counts the single factor qualitative measure by organization:

```
select fldOrgDesc,COUNT(tbltestrun.fldMembershipid)as measurecount from tblTestrun
leftjoin tblQLMeasure ql on ql.fldTestRunID = tbltestrun.fldTestRunID
INNERJOIN tblMembership on tbltestrun.fldMembershipID = tblMembership.fldID
INNERJOIN tblOrganization ON tblMembership.fldOrgID = tblOrganization.fldOrgID
groupby tblOrganization.fldOrgdesc
```

Table TT1D.1 shows the results of these queries. Table TT1D.2 shows the progress of the uploaded files. These results were obtained by running the form named ListReportCounts. The following list describes the selection criteria for the report:

- All reports were selected, regardless of approval status. At the time of this writing, only two reports have been approved.
- All reports were selected, regardless of the metadata assigned.

Table TT1D.1: Summary of qualitative and quantitative measures contained in the ARC database.

Organization	Single Factor (Quantitative)	Single Factor (Qualitative)	Multi-factor (Quantitative)	Total
Texas A&M University	34	27	218	279
University of Nevada, Reno	256	48	2219	2523
University of Wisconsin-Madison	42	25	101	168

Table TT1D.2: Summary of report counts

Organization	Q1 2014	Q4 2013	Q3 2013	Q2 2013	Total Yr. 1-7
Ohio University					508
Texas A&M University	640	503			1853
University of Illinois					419
University of Nevada, Reno	5	1	2	148	1750
University of Wisconsin Madison	83	750		514	1682
Western Research Institute			579	221	1522

Notes to the table.

- Michael Harnsberger was an organizational super user for WRI and had uploaded several files. His status was changed to a public user. This change caused the organization assignment to be incorrect. Changed his affiliation back to WRI, but removed all roles except public access, which given the changes to the role system have the same effect.
- There are a small number of test files owned by UNR that have been used to test the file system. The number of test files is less than 10.
- The size of the ARC file system is presently 46.3 GB excluding the size of the ARC database.

9. Significant Results (Report K Completed)

The first draft of the Final Report (Report K) was completed this quarter. The report is divided into the following three chapters:

- Chapter 1 contains a functional overview of the ARC database for internal users and master data administrators.
- Chapter 2 describes the master data and transactional data elements that make up the ARC database and ARC application. The content of this chapter would likely be relevant to those responsible for maintaining and enhancing the ARC application or database.
- Chapter 3 describes the implementation details of the ARC database and application along with how various technologies are employed. This chapter would be relevant to

those responsible for installing, configuring, and tuning the ARC application and database.

- Appendix A contains a list and descriptions of the .aspx forms that comprise the ARC application. Custom HTTP handlers are also listed in this appendix.
- Appendix B contains a list and descriptions of the user controls that comprise the ARC application.
- Appendix C contains a list of other relevant files.

In addition to the report itself, the Section 508 captions were completed for the document and forwarded with the draft copy.

10. Significant Results (General Code Enhancements and Code Cleanup)

As preparation continues toward the final software distribution, the following general code cleanup enhancements have continued.

- The obsolete multi-dimensional editor was removed (ucMultiDimMeasure.ascx, usMultiDimMeasure.ascx.cs.)
- Several unused styles were removed from the style sheet named changes.css. All style sheets were localized to the folder css. References to this css file were updated, as necessary.
- Fixed a bug in the revised property selector. It is possible for a qualitative and quantitative property to belong to the same property group and have the same primary key. This caused a duplicate key value in an internal list. The necessary code was added to check for and remove the duplicate, as needed.

11. Significant Results (General User Interface Enhancements)

The following general user interface enhancements were made during the quarter:

- As final edits are made to the application pages, required fields are being marked as such by adding a field name suffix (*) to depict a required file. This change is being made to GridView and FormView controls.
- Additional validation code was added to check for required data.

12. Work planned for Next Quarter

The following work items are planned for next quarter:

- In some cases, the request was made to make record descriptions searchable. The development team will add a description search on a table by table basis, based on the number of table records.
- Complete the announcement system and deploy.
- Complete the role conversion for the remaining forms.
- Finish the SQL scripts to clean master and transactional data for the ARC database distribution backup.
- Integrate measure queries into the user interface for the ARC application.
- Import final batches of Texas A&M data.

REPORT L: DEVELOPMENT AND VALIDATION OF THE BITUMEN BOND STRENGTH TEST (BBS)

Included Work Elements/Subtasks
Work Element M1a: Affinity of Asphalt to Aggregate

Status and Work Planned
Complete

Work Completed: None. All work was completed in 2013Q3.

Work Planned: None.

Revised Delivery Dates
Draft Report: 10/30/11 (Submitted)
Final Report: 10/30/2013(Completed) (Revised – Extended from 6/30/2012, 9/30/2012, 3/30/2013, 6/30/2013, 9/30/2013)

REPORT M: DEVELOPMENT OF TEST PROCEDURES FOR CHARACTERIZATION OF ASPHALT BINDER FATIGUE AND HEALING

Included Work Elements/Subtasks
Work Element F1d: Healing
Subtask F1d-6: Evaluate Relationship Between Healing and Endurance Limit of Asphalt Binders
Work Element F2a: Binder Tests and Effect of Composition
Work Element F2e: Verification of the Relationship Between DSR Binder Fatigue Tests and Mixture Fatigue Performance

Status and Work Planned
Completed.

Work Completed: Addressed technical review comments and submitted final report. Section 508 document, Image Descriptions, and Tech Brief are also submitted.

Work Planned: None.

Revised Delivery Dates
Draft Report: 10/31/11 (Submitted)
Final Report: 3/31/2014 (Completed), (Revised from 10/31/13).

REPORT N: GUIDELINES FOR SELECTION OF MODIFICATION TECHNIQUES

Included Work Elements/Subtasks
Work Element E2a: Comparison of Modification Techniques
Work Element E3a: Effect of Extenders (such as Sulfur) and Alternative Binders (such as Bio-Binders) on Mixture Performance

Status and Work Planned
On Schedule

Work Completed: Submitted draft final report and Tech Brief. This is intended to be an NTIS report.

Work Planned: Address FHWA technical comments as needed.

Delivery Dates
Draft Report: 3/31/2014 (Complete), (revised from 9/30/2013, 12/31/2013)
Final Report: 6/30/2014, (revised from 3/31/2013), date pending receipt of technical review on draft report.

REPORT O: CHARACTERIZATION OF BINDER DAMAGE RESISTANCE TO RUTTING

Included Work Elements/Subtasks
Work Element E1b: Binder Damage Resistance Characterization (DRC)
Subtask E1b-1: Rutting of Asphalt Binders
Subtask E1b-2: Feasibility of Determining Rheological and Fracture Properties of Asphalt Binders and Mastics Using Simple Indentation Tests
Work Element V3f: Validation of the AASHTO MP-19 Specifications and Improvements of the TP-70 Procedure

Status and Work Planned
Completed.

Work Completed: Addressed technical review comments and completed Tech Brief.

Work Planned: Submit Section 508 document and Image Descriptions to FHWA.

Delivery Dates
Draft Report: 9/30/2013 (Completed), extended from 6/30/2013
Final Report: 4/30/2014, (Revised from, 3/31/2014, 12/31/2013)

REPORT P: QUANTIFYING THE IMPACTS OF WARM MIX ASPHALT ON CONSTRUCTABILITY AND PERFORMANCE

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
Subtask E1c-1: Warm Mixes

Status and Work Planned
Behind Schedule

Work Completed: 80% of draft final report was completed.

Work Planned: Incorporate comments related to ETG discussion regarding optimum binder content selection for WMA. Complete internal review and submit draft final report.

Reason for Delay
Additional time is requested to complete the draft report and conduct internal review.

Delivery Dates
Draft Report: 4/30/2014 – extended from 9/30/2013, 3/31/2013, 12/31/2014
Final Report: 6/30/2014 – extended from 10/31/2013, 12/31/2013

REPORT Q: IMPROVEMENT OF EMULSION CHARACTERIZATION AND MIXTURE DESIGN FOR COLD BITUMEN APPLICATIONS

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
Subtask E1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications
Work Element E3b: Development of PG Specification for Emulsions used in Surface Treatments, Cold Mixes, and Cold-In-Place Recycled Mixes

Status and Work Planned
On Revised Schedule

Work Completed: Completed testing of emulsion residues samples from NCAT test track and continued working on final report sections including emulsion characterization, performance of chip seals, and mix design methods for micro-surfacing and cold mix asphalt.

Work Planned: Complete internal review of final report and submit.

Delivery Dates
Draft Report: 5/30/2014, from 9/30/2013, 12/31/2013
Final Report: 6/30/2014, from 3/31/2014

REPORT R: STUDIES ON TIRE-PAVEMENT NOISE AND SKID RESPONSE

Included Work Elements/Subtasks
Work Element VP2a: Mixture Design to Enhance Safety and Reduce Noise of HMA

Status and Work Planned
Complete.

Work Completed: Reviewer comments were addressed and final report was submitted to FHWA.

Work Planned: None, report considered complete.

Delivery Dates
Draft Report: 12/31/2011 (Submitted)
Final Report: 7/30/2013 (Submitted)

REPORT S: MOLECULAR DYNAMICS RESULTS FOR MULTIPLE ASPHALT CHEMISTRIES

This report will be delivered in non-508 format. A technical brief will be provided in section 508 format. Completing the report and uploading data into the ARC database has been delayed due to extreme teaching pressures on Prof. Greenfield during the semester.

<u>Included Work Elements/Subtasks</u>

Subtask F3a-1: *ab initio* Theories, Molecular Mechanics/Dynamics and Density Functional Theory Simulations of Asphalt Molecular Structure Interactions
- Sub-subtask F3a-1.1. Specify desired asphalt compositions and chemistries for testing multiscale asphalt modeling effort (large cluster simulations) (URI, WRI)
- Sub-subtask F3a-1.2. Develop algorithms and methods for directly linking molecular simulation outputs and phase field inputs (URI, NIST)
- Sub-subtask F3a-1.3. Obtain temperature-dependent dynamics results for model asphalts that represent asphalts of different crude oil sources (URI)
- Sub-subtask F3a-1.4. Simulate changes in asphalt dynamics after inducing representations of chemical and/or physical changes to a model asphalt (URI)

Subtask F3a-4. Overall integration for multiscale modeling (VT, URI, and WRI)
Subtask F3a-5. Experimental verification and validation (VT, URI, and WRI)

<u>Status and Work Planned</u>

Sub-subtask F3a-1.1. Specify desired asphalt compositions and chemistries for testing multiscale asphalt modeling effort (large cluster simulations) (URI, WRI)

On Schedule.

Compositions were identified in previous quarters. A peer-reviewed publication that disseminates new proposed compositions for AAA-1, AAK-1, and AAM-1 appeared on-line in the journal *Fuel* during 2013 and appeared in print in January 2014.

Sub-subtask F3a-1.3. Obtain temperature-dependent dynamics results for model asphalts that represent asphalts of different crude oil sources (URI)

Continued delay during the past quarter with analyzing results.

Results from molecular simulations of model asphalts continued to be analyzed to obtain physical insights. A manuscript appeared in print (in January 2014) in the *Journal of Chemical Physics* that quantified the raw dynamics results. Revisions were made to a manuscript that described complex modulus results obtained from molecular dynamics simulation results. It was not yet resubmitted to the *Journal of Chemical Physics* as a consequence of the busy teaching load of Prof. Greenfield. Both of these papers have focused on the new AAA-1 model system, with results for other model asphalts set aside as the methods and understanding are refined.

Sub-subtask F3a-1.4. Simulate changes in asphalt dynamics after inducing representations of chemical and/or physical changes to a model asphalt (URI)

Continued delay during the past quarter.

Work to simulate additional asphalt systems continues to proceed more slowly than expected. The main ongoing cause of the delay is the teaching load assigned to the PI (capstone design), which has slowed research progress significantly. Getting existing computer hardware operational and new computer hardware in place has also been impacted by the very large teaching load.

Sub-subtask F3a-1.2. Develop algorithms and methods for directly linking molecular simulation outputs and phase field inputs (URI)
Subtask F3a-4. Overall integration for multiscale modeling (VT, URI, and WRI)
Subtask F3a-5. Experimental verification and validation (VT, URI, and WRI)

Technical work – Progressing during past quarter.

These Subtasks and Sub-subtasks constitute the ARC Model Deliverable for obtaining free energy from a molecular perspective. Developing models to interpret molecular simulations to parameterize free energy models is proceeding. The calculation inputs are the simulation outputs, i.e. molecule positions, velocities, and stress fluctuations that are obtained during the atomistically detailed molecular simulations.

Work has continued on formulating an equation-of-state approach that incorporates the chemistry of the model asphalt system into composition-dependent computations of the free energy. Inputs will include direct molecular simulation outputs and some group contribution correlations.

The Model Deliverable itself will be a detailed description of the steps that can be taken to set up a model asphalt system, to run a molecular simulation, and to interpret the quantitative results. Report S will focus especially on interpreting the peer-reviewed publications in the chemistry literature into language and concepts that are most familiar to the asphalt pavement research community. The report will include detailed descriptions of the simulation data that will be included within the ARC database.

Results from the sequence of molecular simulations, interpretations, correlations, interpolations, and extrapolations will be incorporated into Report S. This includes relationships between the simulation conditions and the energy. Report T, entitled “Progress Toward a Multi-scale Model of Asphalt Pavement- Including Test Methods for Model Input Parameters”, will be written primarily by Troy Pauli of WRI.

REPORT T: PROGRESS TOWARD A MULTI-SCALE MODEL OF ASPHALT PAVEMENT

Included work elements/subtasks

Sub-subtask F3a-1.5. Molecular mechanics simulations of asphalt-aggregate interfaces (VT)
Sub-subtask F3a-1.6. Modeling of fatigue behavior at atomic scale (VT)
Sub-subtask F3a-1.7. Modeling of moisture damage (VT)
Sub-subtask F3a-1.8. *ab initio* Calculations of Asphalt Molecular Structures and Correlation to Experimental Physico-Chemical Properties of SHRP Asphalts (WRI-TUDelft)
Subtask F3a-2. Multiscale modeling based on phase field method and MD simulation (VT)
Sub-subtask F3a-2.1. Multiscale modeling of single mode cracking (VT)
Sub-subtask F3a-2.2. The generalized *J* – integral in multiscale modeling (VT)
Sub-subtask F3a-2.3. Multiscale modeling of Phase separation (VT)
Sub-subtask F3a-2.4. Potential multiscale applications (VT)
Subtask F3a-3. Phase-Field and Continuum Mechanical (Finite Element) Modeling of Asphalt Binder, the Unified Chemo-Mechanical Model of Asphalt Binder
Subtask F3a-4. Overall integration for multiscale modeling (VT, URI, TUDelft and WRI)
Subtask F3a-5. Experimental verification and validation (VT, URI, TUDelft and WRI)

Status and Work Planned for Work Element F3a:

The writing of Report T is in progress with an anticipated draft completion date of Dec. 30, 2013. Elements of Report S will be reflected in the present report regarding Subtask F3a-1. Both reports S and T are delayed and require an extension to the end of the next quarter.

Status and Work Planned for Sub-subtasks F3a-1.5, 6 and 7:

On Schedule

Status and Work Planned for Sub-subtasks F3a-1.8:

Complete

Status and Work Planned for Subtask F3a-2:

On Schedule

Sub-subtask F3a-2.4 Potential multiscale applications (VT)
Sub-Sub-subtask F3a-2.4-1: Visco-elastic cracking in cohesive zone
Sub-Sub-subtask F3a-2.4-2: Determination of cohesive zone
Sub-Sub-subtask F3a-2.4-3: Cohesive zone work
Sub-Sub-subtask F3a-2.4-4: Viscous energy dissipation
Sub-Sub-subtask F3a-2.4-5: Comprehensive view of cohesive zone mechanical behavior

Status and Work Planned

On Schedule

At this moment, this research progress is on time according to the plan.

Note that surface energy dominates cracking process in our multi-scale model. It should also be mentioned that the surface energy in viscoelastic cracking consists of two parts: energy in the cohesive-zone of crack tip and energy dissipation to the existence of viscous stress, which is loading rate dependent, and energy direct contributing to fracture due to elastic stress. The cohesive zone work is given by [1]

$$T_{max} = T_{max}^{ref}\{1 + \beta_T \ln(\frac{\dot{\delta}_e}{\dot{\delta}_e^{ref}})\} \quad \text{(F3a-2.4.1)}$$

$$G_{cohesive} = G_{cohesive}^{ref}\{1 + \beta_G \ln(\frac{\dot{\delta}_e}{\dot{\delta}_e^{ref}})\} \quad \text{(F3a-2.4.2)}$$

where $\dot{\delta}_e^{ref}$ is the reference displacement jump rate, T_{max}^{ref} is cohesive strength at $\dot{\delta}_e^{ref}$, $G_{cohesive}^{ref}$ is the cohesive fracture energy at $\dot{\delta}_e^{ref}$, β_T and β_G are model parameters and δ_e represents the evolving effective displacement jump in cohesive zone.

Note our model is different from Aragao's. Aragao (2011) considers the total energy consists of elastic energy, energy dissipation and cohesive zone work while in our phase-field model, the latter two energy consumptions are considered as to be the viscous energy dissipation that is not relevant to cracking, which means

$$W_{all} = J + W_{viscous} \quad \text{(F3a-2.4.3)}$$

where W_{all} is the total work on the viscoelastic material, J is the elastic J-integral and $W_{viscous}$ is the viscous energy dissipation. Note that surface energy γ as a cracking material parameter in phase-field is calculated excluding the viscous energy dissipation and cohesive zone work from the total work.

Figure 1 shows the flowchart of viscoelastic fracture calculation by Phase-field method. Note that Allen-Cahn Dynamics controls the fracture process and dominates the stress field.

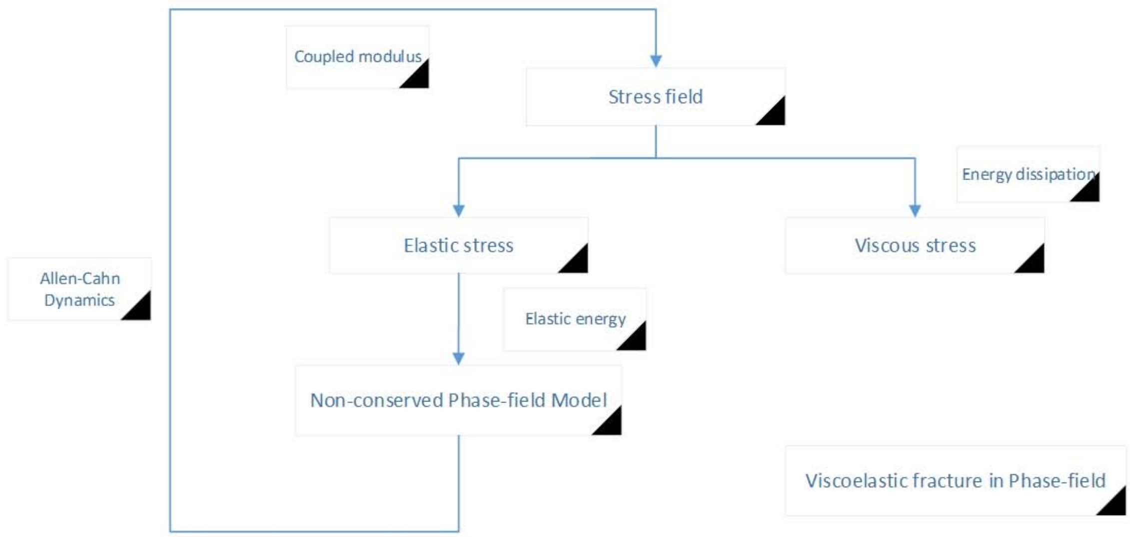


Figure F3a-2.4.1 Phase-field Model of viscoelastic fracture calculation flowchart.

Status and Work Planned for Subtask F3a-3:
Complete

Status and Work Planned for Subtask F3a-4 and F3a-5:
On Schedule

References

Aragao, F. 2011. Computational Microstructure Modeling of Asphalt Mixtures Subjected to Rate-Dependent Fracture. Thesis (PhD). University of Nebraska-Lincoln.

REPORT U: DESIGN GUIDANCE FOR FATIGUE AND RUT RESISTANCE MIXTURES

Included Work Elements/Subtasks
Work Element E2e: Design Guidance for Fatigue and Rut Resistance Mixtures

Status and Work Planned
Behind Schedule

Work on the NTIS report continued this quarter. The report is approximately 95 percent complete.

The report will be submitted next quarter.

REPORT V: CONTINUUM DAMAGE PERMANENT DEFORMATION ANALYSIS FOR ASPHALT MIXTURES

Status: The report is completed and submitted to FHWA for review.

REPORT W: CHARACTERIZATION OF FATIGUE AND HEALING PROPERTIES OF ASPHALT MIXTURES

Status: The report is completed and submitted to FHWA for review.

REPORT X: CHARACTERIZATION OF FIELD CORES OF ASPHALT PAVEMENTS

Status: The report is completed and submitted to FHWA for review.

REPORT Y: MODEL WATER VAPOR DIFFUSION IN PAVEMENT AND ITS EFFECTS ON THE PERFORMANCE OF ASPHALT MIXTURES

Status: A revised version of this report is submitted to FHWA for review after the authors addressed the comments provided earlier by FHWA.

REPORT Z: EFFECT OF EXTRACTION METHODS ON THE PROPERTIES OF AGGREGATES IN RECLAIMED ASPHALT PAVEMENT

Included Work Elements/Subtasks
Work Element TT1d: Development of Materials Database

Status and Work Planned
Completed.

In this quarter, no additional technical or editorial comments were requested from FHWA on Report Z.

REPORT AA: LABORATORY ASSESSMENT OF ASPHALT MIXTURE LONG-TERM AGING

Included Work Elements/Subtasks
Work Element E3c: Laboratory Assessment of Asphalt Mixture Long-term Aging

Status and Work Planned
Completed.

Work Completed: Submitted draft final report and Tech Brief to FHWA.

Work Planned: Address comments as needed.

Delivery Dates
Draft Report: 3/31/2014 (Completed), revised from 9/30/2013, 12/31/2013
Final Report: 6/30/2104

REPORT AB: SUMMARY REPORT ON ARC COMPARATIVE PAVEMENT TEST SECTIONS

Included Work Elements/Subtasks
Work element V1b, Construction and Monitoring of Additional Comparative Pavement Validation Sites

Status and Work Planned
On Schedule, The preparation of this report is in progress.
Draft delivery date for this report is scheduled for May 15, 2014.

REPORT AC: SUMMARY REPORT ON NCAT WARM-MIX PAVEMENT TEST SECTIONS

Included Work Elements/Subtasks
Work element V1a, Use and Monitoring of Warm Mix Asphalt Sections

Status and Work Planned
On Schedule, The preparation of this report is in progress.
Draft delivery date for this report has not been set.

REPORT AD: EXECUTIVE SUMMARY REPORT: ARC HISTORY, PARTICIPANTS AND ACCOMPLISHMENTS

Included Work Elements/Subtasks
ALL

Status and Work Planned
On Schedule. The preparation of this report is in progress.
Draft delivery date for this report is scheduled for May 15, 2014.

Report AB: Summary Report On ARC Comparative Pavement Test Sections
Report AC: Summary Report on NCAT Warm-Mix Pavement Test Sections
Report AD: Executive Summary Report: ARC History, Participants and Accomplishments

TEST METHODS

DRAFT AASHTO METHOD/PRACTICE: SIMPLIFIED CONTINUUM DAMAGE FATIGUE ANALYSIS FOR THE ASPHALT MIXTURE PERFORMANCE TESTER

Included Work Elements/Subtasks
Work Element E2e: Design Guidance for Fatigue and Rut Resistance Mixtures

Status and Work Planned
Behind schedule

The majority of the draft practice has been completed.

The draft practice will be submitted next quarter with the Task U Report.

TEST METHOD AND MODEL: CONTINUUM DAMAGE PERMANENT DEFORMATION ANALYSIS FOR ASPHALT MIXTURES

Included Work Elements/Subtasks
Work Element F2c: Mixture Testing Protocol (TAMU)
Work Element E1a: Analytical and Micro-mechanics Models for Mechanical Behavior of Mixtures (TAMU)

Status and Work Planned
Status: Competed.

The Test Method and Model “Continuum Damage Permanent Deformation Analysis of Asphalt Mixtures” has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Model has been attached to and referenced in the Level 2 Report V “Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures” as an appendix.

TEST METHOD AND MODEL: CHARACTERIZATION OF FATIGUE AND HEALING PROPERTIES OF ASPHALT MIXTURES

Included Work Elements/Subtasks
Work Element E1a: Analytical and Micro-mechanics Models for Mechanical Behavior of Mixtures (TAMU)

Status and Work Planned
Status: Completed.

The Test Method and Model "Characterization of Fatigue and Healing Properties of Asphalt Mixtures" has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Model has been attached to and referenced in the Level 2 Report W "Characterization of Fatigue and Healing Properties of Asphalt Mixtures" as an appendix.

TEST METHOD AND ANALYSIS PROGRAM: NONDESTRUCTIVE CHARACTERIZATION OF TENSILE VISCOELASTIC PROPERTIES OF UNDAMAGED ASPHALT MIXTURES

Included Work Elements/Subtasks
Work Element E1a: Analytical and Micro-Mechanics Models for Mechanical Behavior of Mixtures (TAMU)

Status and Work Planned
Status: Completed.

The Test Method and Model "Nondestructive Characterization of Tensile Viscoelastic Properties of Undamaged Asphalt Mixtures" has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Model has been attached to and referenced in the Level 2 Report W "Characterization of Fatigue and Healing Properties of Asphalt Mixtures" as an appendix.

TEST METHOD AND MODEL: CHARACTERIZATION OF FIELD CORES OF ASPHALT PAVEMENTS

<u>Included Work Elements/Subtasks</u>
Work Element E1a: Analytical and Micro-mechanics Models for Mechanical Behavior of Mixtures (TAMU)

<u>Status and Work Planned</u>
Status: Completed.

The Test Method and Model "Characterization of Field Cores of Asphalt Pavements" has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Model has been attached to and referenced in the Level 2 Report X "Characterization of Field Cores of Asphalt Pavements" as an appendix.

TEST METHOD AND ANALYSIS PROGRAM: NONDESTRUCTIVE CHARACTERIZATION OF ANISOTROPIC VISCOELASTIC PROPERTIES OF UNDAMAGED ASPHALT MIXTURES UNDER COMPRESSIVE LOADING

<u>Included Work Elements/Subtasks</u>
Work Element F2c: Mixture Testing Protocol (TAMU)
Work Element E1a: Analytical and Micro-mechanics Models for Mechanical Behavior of Mixtures (TAMU)

<u>Status and Work Planned</u>
Status: Completed.

The Test Method and Analysis Program "Nondestructive Characterization of Anisotropic Viscoelastic Properties of Undamaged Asphalt Mixtures under Compressive Loading" has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Model has been attached to and referenced in the Level 2 Report V "Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures" as an appendix.

DRAFT AASHTO PRACTICE: MIX DESIGN FOR COLD-IN-PLACE RECYCLING (CIR)

Included Work Elements/Subtasks

Work Element E1c-2: Improvement of Emulsion Characterization and Mixture Design for Cold Bitumen Applications

Status and Work Planned

The following list describes the work items completed this quarter:

- Completed the material evaluation for the RAP from Matterhorn (third source for the validation).
  - Analyzed the RAP particles and selected the medium gradation that meets PCCAS specification.
  - Determined the asphalt binder content of the RAP material.
- Completed the Mix design for all four CIR mixes from three different sources.
- Moisture susceptibility test (AASHTO T283) was conducted on all selected combinations of emulsion and water content. The test results will be discussed in the next quarterly report.
- Started the sample preparation for the performance related tests such as raveling, cohesion test, dynamic modulus test and flow number test for all CIR mixes.

The following list describes the work planned for next quarter:

- Continue the performance related tests
- Start writing the draft AASHTO Practice and supporting document.

DRAFT AASHTO METHOD/PRACTICE: MIX DESIGN FOR COLD MIX ASPHALT

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
SubtaskE1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications
Subtask E1c2-Yr6-I: Protocol for Selecting Aggregates and Emulsions for CMA
Subtask E1c2-Yr6-II: Evaluation of CMA Laboratory Compaction Methods and Curing Conditions

Status and Work Planned
Behind Schedule

Work Completed: All experimental work related to development of standard is completed.

Work Planned: Prepare standard in AASHTO format similar to AASHTO R 35.

Reasons for Delay: Submission of standard was extended to coincide with revised delivery date of draft final report.

Delivery Dates
Draft AASHTO Practice: 5/30/2014, from 9/30/2013
Final AASHTO Practice: 6/30/2014, from 3/31/2014

DRAFT AASHTO PRACTICE: EVALUATION OF RAP AGGREGATES

Included Work Elements/Subtasks
Work Element E2b: Design System for HMA Containing a High Percentage of RAP Materials
Subtask E2b-1: Develop a System to Evaluate the Properties of RAP Materials

Status and Work Planned
On Schedule.

The findings from the report entitled: "Effect of Extraction Methods on the Properties of Aggregates in Reclaimed Asphalt Pavement," were considered in the final recommendations of NCHRP 09-46 study completed by NCAT.

DRAFT AASHTO PRACTICE: DETERMINING ASPHALT MIXTURE CRITICAL CONDITIONS FOR RUTTING EVALUATION BY MEANS OF DYNAMIC REPEATED LOAD TRIAXIAL (RLT) TEST

Included Work Elements/Subtasks
Work Element E2c: Critically Designed HMA Mixtures

Status and Work Planned
On schedule. No work completed this quarter.

DRAFT AASHTO METHOD: DETERMINING THERMAL CRACK PROPERTIES OF ASPHALT MIXTURES THROUGH MEASUREMENT OF THERMALLY INDUCED STRESS AND STRAIN

Included Work Elements/Subtasks
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States
Subtask E2d-3: Identify an Evaluation and Testing System

Status and Work Planned
On Schedule

The following list describes the on-going and completed work items:

- Continue working with a manufacturer/supplier company to modify its TSRST setup to meet the UTSST requirements.
- Revise and refine the UTSST AASHTO draft as needed.
- The damage characteristic curves (C vs. S curve) for the Laboratory-produced asphalt mixtures has been determined at different aging levels based on the results from the dynamic modulus and the UTSST tests. Work will continue on refining the calculation of the damage characteristic curves from the UTSST.

DRAFT AASHTO METHOD/PRACTICE: DETERMINING ASPHALT BINDER BOND STRENGTH BY MEANS OF THE BINDER BOND STRENGTH TEST

Included Work Elements/Subtasks
Work Element M1a: Affinity of Asphalt to Aggregate

Status and Work Planned
Completed

Work Completed: None, product was completed last quarter.

Work Planned: None planned, product considered complete.

Delivery Dates
Revised Standard: 6/30/2013 (Complete)

DRAFT AASHTO TEST METHOD: MEASUREMENT OF ASPHALT BINDER ELASTIC RECOVERY IN THE DYNAMIC SHEAR RHEOMETER (DSR)

Included Work Elements/Subtasks
Work Element F2a: Binder Tests and Effect of Composition

Status and Work Planned
Completed

Work Completed: Product combined with BYET procedure. Please see BYET report for details.

Work Scheduled: Please see BYET report for details

Delivery Dates
Completed, see BYET report for delivery dates.

AASHTO TEST METHOD: ESTIMATING FATIGUE RESISTANCE OF ASPHALT BINDERS USING THE LINEAR AMPLITUDE SWEEP

Included Work Elements/Subtasks
Work Element F2e: Verification of the Relationship between DSR Binder Fatigue Tests and Mixture Performance

Status and Work Planned
Complete

Work Completed: Presented update to Asphalt Binder ETG regarding new failure criteria and updated ruggedness testing results.

Work Planned: Work item is considered complete. Any comments by AASHTO or ETG for implementation will be addressed.

Delivery Dates
Submit Revised Draft AASHTO Method to ETG: Completed.
Presentation at FHWA Binder ETG Meeting: 5/02/2013 (Complete)
Presentation at FHWA Binder ETG Meeting: 9/17/2013 (Complete)
Final AASHTO Method: 9/30/2013 (Complete), based on new findings and ETG comments (Extended from 6/30/2013)

AASHTO TEST METHOD: BINDER YIELD ENERGY TEST (BYET)

Included Work Elements/Subtasks
Work Element F2e: Verification of the Relationship between DSR Binder Fatigue Tests and Mixture Performance

Status and Work Planned

Completed.

Work Completed: Draft of combined ER-DSR and BYET procedures were submitted to the AASHTO SOM by FHWA for consideration in the August 2013 meeting.

Work Scheduled: Product is considered complete. Comments from AASHTO will be addressed as necessary.

Delivery Dates
Draft AASHTO Method: 1/31/2013 (extended from 12/31/2012) (Complete)
Presentation at FHWA Binder ETG Meeting: 5/02/2013 (Complete)
Final AASHTO Method: 6/30/2013 (Complete)

DRAFT AASHTO TEST METHOD: MEASUREMENT OF RIGDEN VOIDS FOR MINERAL FILLERS

Included Work Elements/Subtasks
Work Element F2e: Verification of the Relationship between DSR Binder Fatigue Tests and Mixture Performance

Status and Work Planned

Completed

Work Completed: Response to comments received from AASHTO SOM was completed and sent to FHWA.

Work Planned: None. Product is considered complete.

Revised Delivery Dates

Draft AASHTO Method: Complete (1/31/2013).
Final AASHTO Method: Complete (9/30/2013).

DRAFT AASHTO TEST METHOD: MEASUREMENT OF ASPHALT BINDER LUBRICITY USING THE DYNAMIC SHEAR RHEOMETER (DSR)

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
Subtask E1c-1: Warm Mixes
Subtask E1c-1-Y6-I: Guideline for Determination of Mixing and Compaction Temperatures for Conventional HMA Mixes
Subtask E1c-1-Y6-II: Guideline for Determination of Acceptable WMA Production Temperatures

Status and Work Planned
Behind Schedule

Work Completed: Work on draft AASHTO standard continued.

Work Planned: Complete draft of AASHTO standard, complete internal review, and submit to FHWA.

Reasons for Delay: Deadline extended to coincide with submittal of draft final report.

Delivery Dates
Draft AASHTO Method: 4/30/2014, from 6/30/2013, 3/31/2013, 9/30/2013, 12/31/2014
Final AASHTO Method: 6/30/2014 - from 9/30/2013, 12/31/2013

DRAFT AASHTO METHOD/PRACTICE: PROCEDURE FOR EVALUATION OF COATING FOR COLD MIX ASPHALT

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
SubtaskE1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications
Subtask E1c2-Yr6-I: Protocol for Selecting Aggregates and Emulsions for CMA

Status and Work Planned
Completed.

Work Completed: None. Product is considered complete.

Work Planned: None, product is considered complete. Address comments from FHWA/ETG as necessary.

Delivery Dates
Draft AASHTO Method: Completed 4/30/2013 – extended from 3/31/2013 and 12/31/2012
Presentation at FHWA Mixtures ETG Meeting (if necessary): N/A
Final AASHTO Standard: 9/30/2013 (Complete)

DRAFT AASHTO METHOD/PRACTICE: COLD MIX LABORATORY SPECIMEN PREPARATION USING MODIFIED SGC MOLDS

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
Subtask E1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications
Subtask E1c2-Yr6-II: Evaluation of CMA Laboratory Compaction Methods and Curing Conditions

Status and Work Planned

Completed.

Work Completed: None, product is considered complete.

Work Planned: None, product is considered complete.

Delivery Dates
Draft AASHTO Method: 8/30/2013 (Complete) – extended from 6/30/2012, 12/31/2012
Final AASHTO Standard: 12/31/2013 (Complete)

DRAFT AASHTO TEST METHOD: RAP BINDER PG TRUE GRADE DETERMINATION

<u>Included Work Elements/Subtasks</u>
Work Element E2b: Design System for HMA Containing a High Percentage of RAP Materials

<u>Status and Work Planned</u>
Completed.

Work Completed: Response to comments received from AASHTO SOM was completed and sent to FHWA.

Work Planned: None. Product is considered complete.

<u>Delivery Dates</u>
Draft AASHTO Test Method: Completed (9/30/2012)
Presentation at Mix ETG Meeting: Completed (4/30/2013).
Presentation at Binder ETG Meeting: Completed (9/20/2013)
Final AASHTO Test Method: Completed (6/30/2013)

AASHTO TEST METHOD: MEASUREMENT OF ASPHALT BINDER FRACTURE PROPERTIES USING THE SINGLE EDGED NOTCHED BENDING TEST

<u>Included Work Elements/Subtasks</u>
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States

<u>Status and Work Planned</u>
Completed.

Work Completed: None, this product is considered completed.

Work Planned: No additional work is planned this task is considered complete. Will address additional comments from ETG/FHWA as needed.

<u>Delivery Dates</u>
Draft AASHTO Method: Completed (9/30/2012)
Presentation at Binder ETG Meeting: 5/2/2013 (Completed)
Presentation at Binder ETG Meeting (if necessary): 9/20/2013
Final AASHTO Test Method: Completed (9/30/2013) (Extended from 6/30/2013)

DRAFT AASHTO TEST METHOD: TEST METHOD FOR MEASUREMENT OF THE GLASS TRANSITION TEMPERATURE OF ASPHALT BINDERS

Included Work Elements/Subtasks
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States

Status and Work Planned
Completed

Work Completed: None, no request for presentation was made by FHWA Binder ETG. Draft standard and context document were completed last quarter.

Work Planned: None, product is considered complete.

Delivery Dates
Draft AASHTO Test Method: Complete (1/31/2013)– extended from 12/31/2012
Presentation to Binder ETG (if necessary): 9/20/2013.
Final AASHTO Test Method: 6/30/2013, revisions pending ETG review and comment.

DRAFT AASHTO TEST METHOD: TEST METHOD FOR MEASUREMENT OF THE GLASS TRANSITION TEMPERATURE OF ASPHALT MIXTURES

Included Work Elements/Subtasks
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States

Status and Work Planned
Completed.

Work Completed: Combined ATCA/UTSST test method was completed and submitted to Mix ETG by UNR.

Work Planned: None planned under this product. UNR team has taken the lead in obtaining approval of combined test procedure from Mixture ETG.

Revised Delivery Dates
Draft AASHTO Test Method: 4/30/2013 (Completed)
Presentation to Mix ETG: 5/2/2013. (Completed)
Final AASHTO Test Method: 6/30/2013 (Completed)

DRAFT AASHTO TEST METHOD/PRACTICE: ANALYSIS OF ASPHALT MIXTURE AGGREGATE STRUCTURE THROUGH USE OF PLANAR IMAGING.
ARC MODELS AND/OR SOFTWARE: IMAGE PROCESSING AND ANALYSIS SYSTEM (IPAS^2)

Included Work Elements/Subtasks
Work Element E1b: Binder Damage Resistance Characterization (DRC)
SubtaskE1b-1: Rutting of Asphalt Binders

Status and Work Planned
Completed.

Work Completed: Comments submitted by AASHTO SOM were addressed and sent to FHWA.

Work Planned: None. This item is considered complete.

Delivery Dates
Draft AASHTO Method: 3/31/2013
Presentation to Mix ETG (if necessary): 9/20/2013
Final AASHTO Standard: 9/30/2013 (Complete)

DRAFT AASHTO METHOD/PRACTICE: DETERMINING THE RESISTIVE EFFORT OF ASPHALT MIXTURES DURING COMPACTION IN A GYRATORY COMPACTOR USING AN INTERNAL DEVICE

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
SubtaskE1c-1: Warm Mix Asphalt
Subtask E1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications

Status and Work Planned

Completed.

Work Completed: Redline version of ASTM standard, analysis of precision and bias based on maximum eccentricity, and recommendations for advancing the test procedure were submitted to manufacturer.

Work Planned: None planned at this time.

Delivery Dates
Draft ASTM Standard: Complete
Finalize ASTM Standard: Complete 12/31/2013
Complete Precision and Bias StatementP&B Statement: 3/31/2014 (Completed) (extended from 6/30/2013, 9/30/2013, 12/31/2014).

TEST METHOD AND ANALYSIS PROGRAM: SELF-CONSISTENT MICROMECHANICS MODELS OF ASPHALT MIXTURES

Included Work Elements/Subtasks
Work Element E1a: Analytical and Micro-mechanics Models for Mechanical Behavior of Mixtures (TAMU)

Status and Work Planned
Status: Completed.

The Test Method and Analysis Program "Self-Consistent Micromechanics Models of Asphalt Mixtures" has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Analysis Program has been attached to and referenced in the Level 2 Report W "Characterization of Fatigue and Healing Properties of Asphalt Mixtures" as an appendix.

DRAFT AASHTO METHOD: A METHOD TO DETERMINE SURFACE ROUGHNESS OF AGGREGATE AND FINES BASED ON AFM

Included Work Elements/Subtasks
M1b-2: Work of Adhesion at Nano-Scale using AFM

Status and Work Planned
Progress on this work element involves the development of a method to analyze AFM surface contour data to remove low-frequency (saw-cut) roughness so that the micro-scale (higher-frequency) roughness can be separated out. The method uses a Fourier transform to separate the frequency domains associated with the saw cut from the higher frequency associated with the micro-scale surface roughness. This technique should provide a simple method for the measurement of micro-scale roughness for an unpolished surface as typically left by a diamond saw.

Archival data (surface scans of selected aggregate types) that will be used for this subtask was retrieved and assembled in the previous quarter. Due to conflicting demands for personnel, no work was conducted on this project during this quarter. This work is currently scheduled to be completed by 5/31/14.

DRAFT AASHTO METHOD: A METHOD TO DETERMINE DUCTILE-BRITTLE PROPERTIES VIA AFM

Included Work Elements/Subtasks
M1b-2: Work of Adhesion at Nano-Scale using AFM
M2a-2: Work of Cohesion at Nano-Scale using AFM

Status and Work Planned
Force displacement curves have been collected and analyzed as a function of temperature and stress rate for two SHRP core asphalts. Both asphalts exhibit a clear step in an otherwise smooth change in fracture energy as the test temperature is increased. Work to date suggests that the dissipative component of the fracture energy drops significantly at temperatures well above those typically associated with the 'glass-transition', i.e. the dissipative function becomes negligible at the onset of the glass-transition.

This draft method is nearly completed. The method involves measuring the dissipative component of the adhesive energy at three temperatures somewhat above the DBTT establishing a function that relates the dissipative energy to temperature and solving for the temperature at which this energy becomes zero. We are currently reanalyzing existing data using the appropriate integration limits to verify the validity of this new method for determining DBTT. This work is on track to be completed by 5/31/14.

DRAFT AASHTO METHOD: AFM-BASED MICRO/NANO-SCALE CYCLIC DIRECT TENSION TEST

Included Work Elements/Subtasks
M1b-2: Work of Adhesion at Nano-Scale using AFM
M2a-2: Work of Cohesion at Nano-Scale using AFM

Status and Work Planned
Draft AASHTO Method has been completed

CHIP ADHERENCE STABILITY TEST APPARATUS

This new work element will generate a scaled-up adhesion test based upon the micro/nano-scale work described in previous reports. The new test method measures the adhesion of an aggregate chip as a function of both rate and temperature. The test provides a measure of fracture toughness as well as ultimate adhesive strength. The fracture toughness term incorporates the effects of embrittlement and should, therefore, provide a much better performance predictor than simple measures of ultimate adhesive strength. The new test is designed specifically to help assess and predict the performance, both short and long term, of various surface applied pavement preservation materials. Other possible applications are also being considered.

Status and Work Planned
A prototype chip adherence stability (CAS) test apparatus has been assembled at the time of this writing. Major elements of the test apparatus includes an environmental chamber capable of maintaining sample temperatures ranging from -40 to +60 C, a pneumatically actuated force element, two LVDT distance transducers, and a dedicated data acquisition system. The system is ready for calibration and shakedown testing.

DRAFT AASHTO METHOD/PRACTICE: MEASUREMENT AND TEXTURE SPECTRAL ANALYSIS OF PAVEMENT SURFACE PROFILES USING A LINEAR STATIONARY LASER PROFILER (SLP)

Included Work Elements/Subtasks
Work Element VP-2a: Mixture Design to Enhance Safety and Reduce Noise in HMA

Status and Work Planned
Completed

Work Completed: Standard was not pursued by FHWA. Test procedure has been used for other research projects.

Work Planned: None planned; AASHTO Standard was included in an Appendix in Report R.

Delivery Dates
Draft AASHTO Method: Complete (9/30/2012)
Final AASHTO Standard: Complete (6/30/2013), extended from 3/31/2013

MODELS AND SOFTWARE

MODEL: HMA THERMAL STRESSES IN PAVEMENT

Included Work Elements/Subtasks
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States

Status and Work Planned
On Schedule.

The following list describes the work items completed or in progress this quarter:

- Preliminary studies were carried out to determine the difference and the probable cause of the difference in oxidative aging kinetics of asphalt binder as determined from binder aging versus mixture aging.
- The effect of oxidative aging on thermal coefficient of contraction, viscoelastic, and fracture properties of asphalt mixtures has been evaluated and quantified.
- The development of the thermal cracking analysis package (TCAP) is in progress. The research version of the software is scheduled to be released by next quarter.
- The development of a stand-alone software for predicting pavement temperature profile and history.

The prediction of pavement temperature as a function of time and depth is needed for the estimation of carbonyl change in asphalt pavement as a function of time. A software was developed at UNR in the MATLAB® environment to predict pavement temperature using the Finite Control Volume Method (FCVM). The results of the software were verified using the LTTP database and the comparison demonstrated a high correlation between the measured and predicted values.

Based on the extremely positive inputs from the FHWA ETG members, a stand-alone software for pavement temperature profile and history prediction was deemed necessary. As a result, UNR decided to migrate the code from MATLAB to C#.NET. Since C#.NET, unlike MATLAB, is an object oriented programming language, the whole program code had to be rewritten. Furthermore, there were some restrictions with the MATLAB program which are now modified in the C# version. The main aspects that have been enhanced are as follows:

- The new software is project based.
- Unlike the previous version, the new version is capable of handling user-defined materials, climatic data and surface characteristics. Pavement structure is then defined based on the user inputs and meshing is applied on the structure afterwards.
- Data can be imported or saved in a CSV file extension.

In addition, a high quality Graphical User Interface (GUI) is employed to make the software even look better and more user-friendly. This feature includes different tables and toolbars with graphical icons. The output is shown in an interactive manner and the progress can be monitored throughout the analysis period. A snapshot of the software is shown in Figure E2d.1.

The current focus is to increase the performance of the software. Currently, a mass amount of matrix calculation is conducted during analysis. The approximate runtime for one year temperature analysis is about 8 hours. Developers are looking at different scenarios to decrease the analysis period.

The following list the work planned for next quarter:

- Releasing the alfa-version of the temperature profile prediction stand-alone software.
- Releasing the alfa-version of the Thermal Cracking Analysis Package (TCAP).

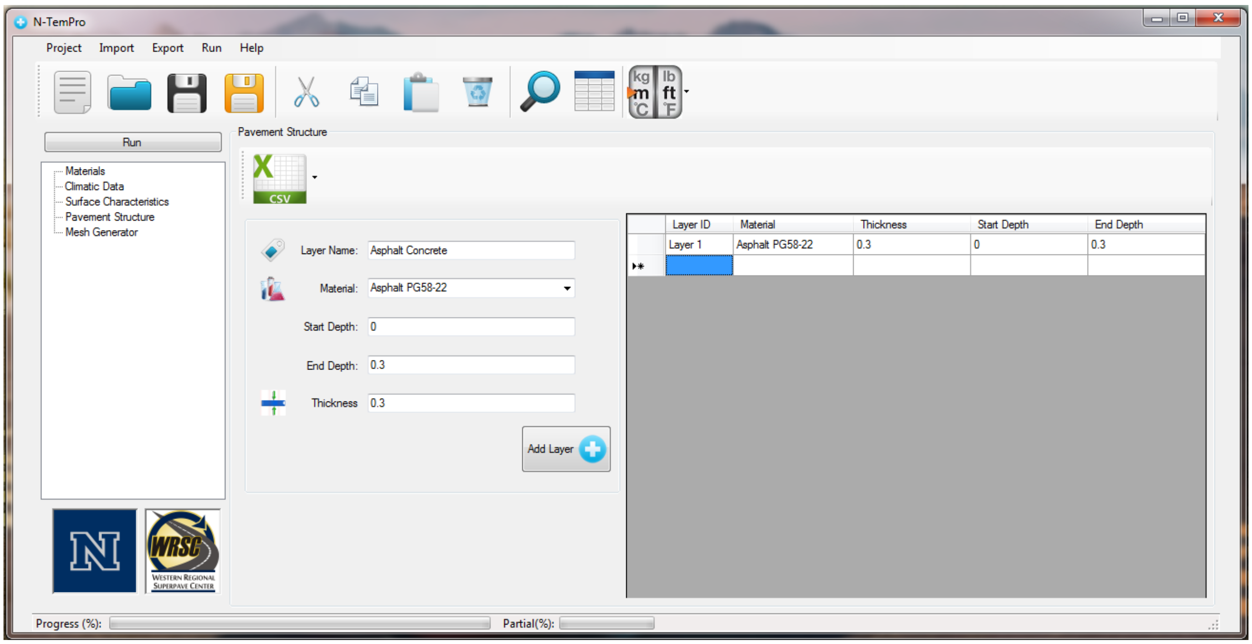


Figure E2d.1: Snapshot of the main program

SOFTWARE: DYNAMIC MODEL FOR FLEXIBLE PAVEMENTS 3D-MOVE

Included Work Elements/Subtasks
Work Element VP3a: Pavement Response Model to Dynamic Loads

Status and Work Planned
The work done on 3D-Move Analysis Software during this period can be divided on two parts. The first part (Part A) consists of modifications and corrections made to the current version of the software (Version 2.1). The second part(Part B) includes many additional work done for the newer version (Version 3) of the software.

PART A: List of modifications done to current version of 3D-Move Analysis (Version 2.1)

- Corrections to Principal Stress and Strain computations and graphical display;
- Corrections to definition of array response points in dynamic analysis;
- Correction to response points graphical display in dynamic analysis; and
- Correction to vertical static deflection calculations in DOS file.

Some of the above modifications were needed because of minor coding errors.

PART B: List of work completed on the next version of 3D-Move Analysis (Ver. 3)

- Establishment of new framework to handle multi-projects (Figure VP3a.1);
- Site/Project Identification;
- Static/Dynamic Analysis (Figure VP3a.2); and
- Axle Configuration/Contact Pressure Distribution. The following are the loading cases:
  - Uniform Contact Pressure Distribution (Figure VP3a.3);
  - Non-Uniform Contact Pressure Distribution from Database (Figure VP3a.4);
  - Semi-Trailer Truck Including Vehicle Dynamics;
  - Special Non-Highway Vehicle Loading;
  - Braking/Non-Braking Condition; and
  - Dynamic Variation of Tire Load.

The following is a list work elements planned for next quarter:

- Completed the Final Report and the 3D-Move documentation;
- Assist users with issues ranging from usage questions, concepts clarifications, and bugs;
- Continue working the new platform for next version of 3D-Move (Ver. 3);
- Keep maintaining the 3D-move forum.

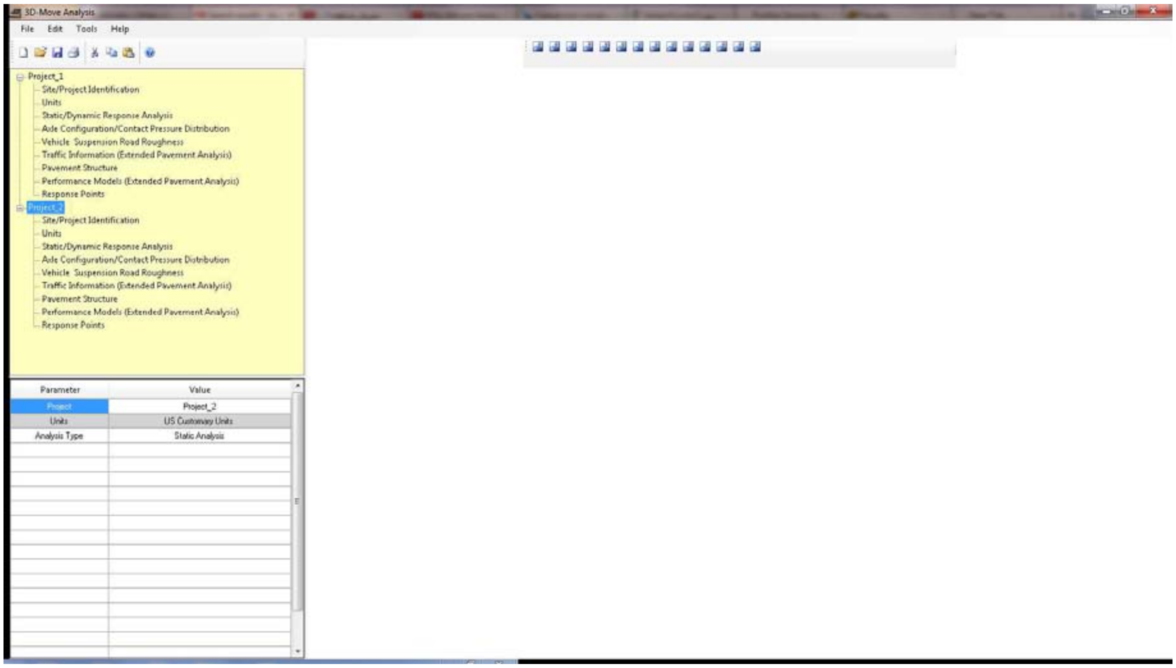


Figure VP3a.1: Multi-projects feature (ver. 3)

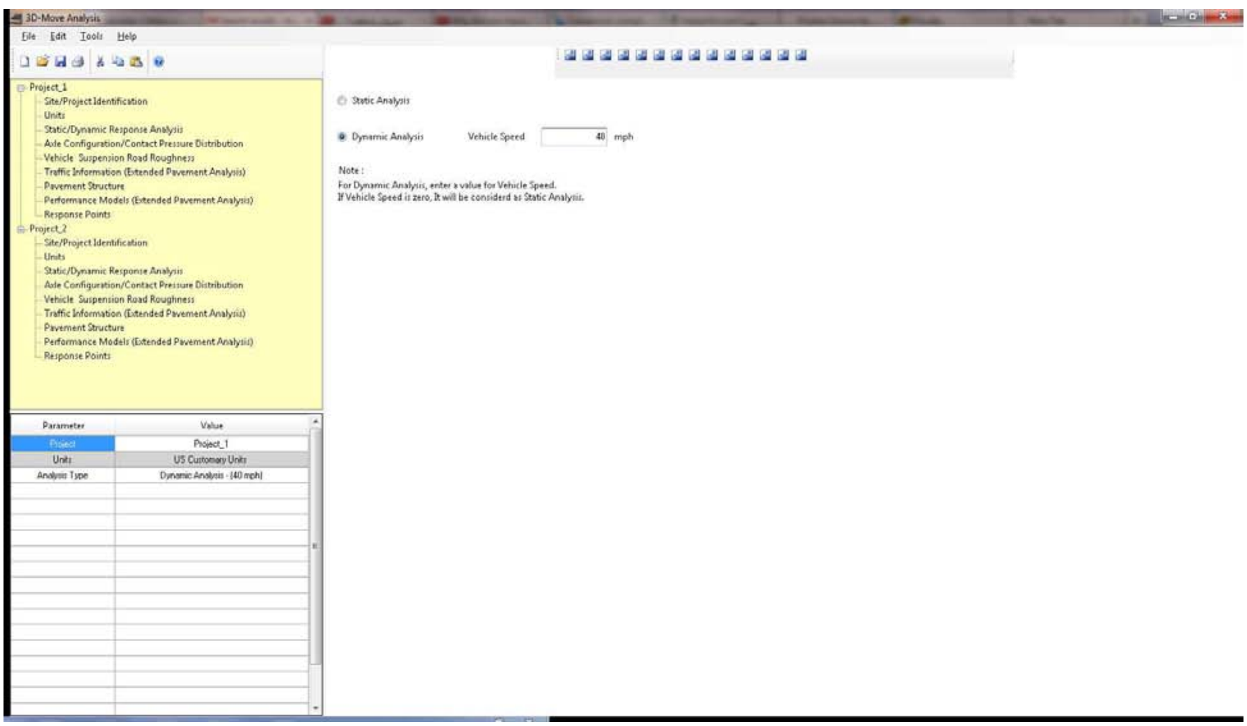


Figure VP3a.2: Analysis type section(ver. 3)

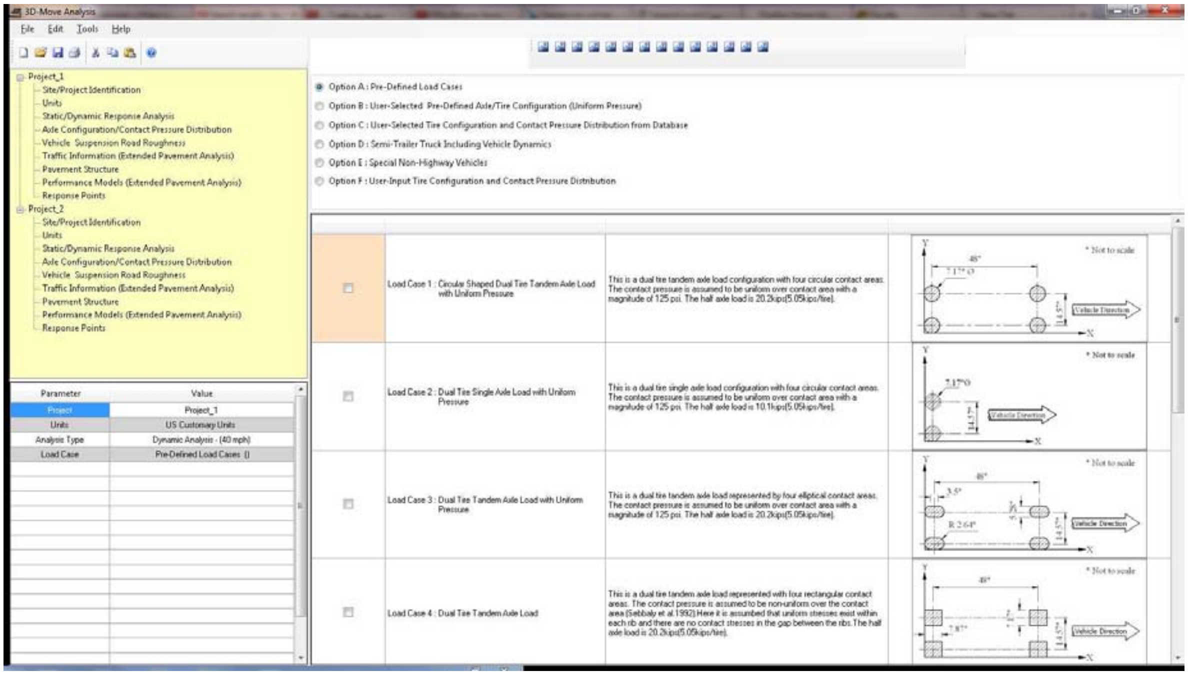


Figure VP3a.3: Axle configuration/contact pressure distribution, Option A(ver. 3)

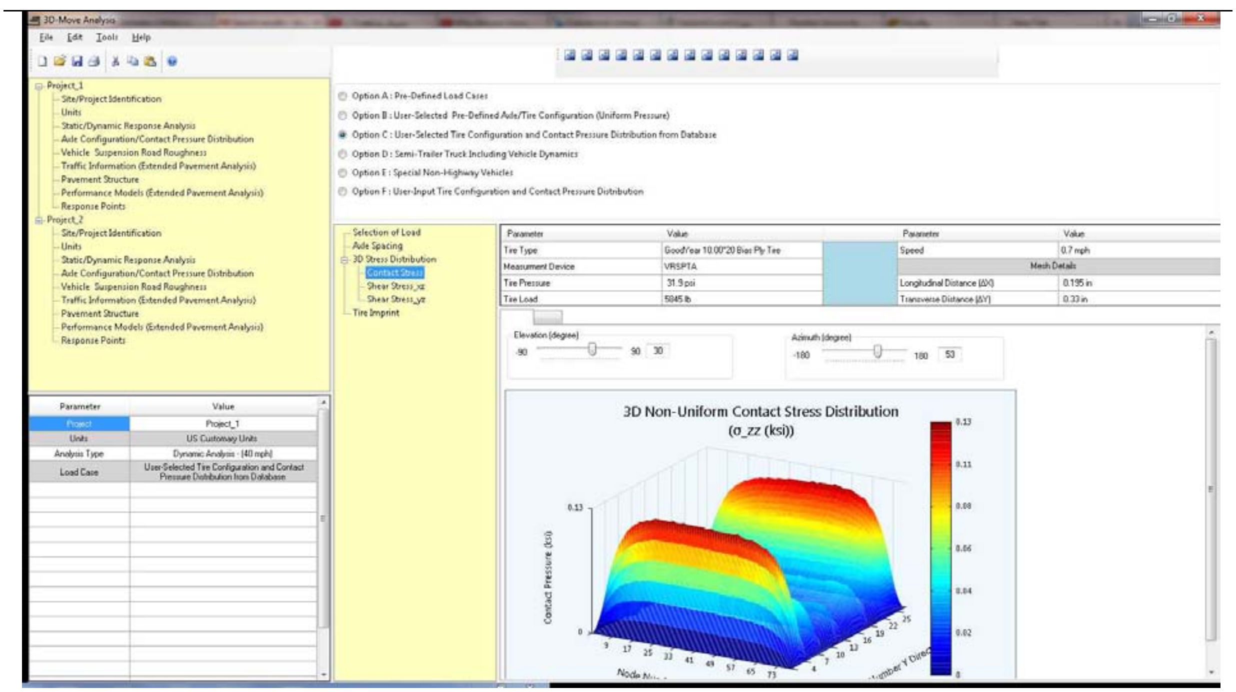


Figure VP3a.4: Axle configuration/contact pressure distribution, Option C (Tire Database)(ver. 3)

OTHER RESEARCH ACTIVITIES

Subtask E2b-2: Compatibility of RAP and Virgin Binders

<u>Work Planned Next Quarter</u>

The viscosities of crossblends will be used to verify if the Pal-Rhodes model, that was developed from Einstein's colloid theory in terms of accommodating for more concentrated suspensions to account for asphalt flow property, can be employed to characterize the flow properties of recycled asphalt pavement (RAP) binder blends.

<u>Status and Work Done This Quarter</u>

The Pal-Rhodes model which describes asphalt viscosity based on asphalt chemical compositions has been shown to be suitable for characterizing the flow properties of RAP binder blends. This modeling approach also presents terms for mixing of virgin and RAP maltenes and a resultant solvation factor after mixing. The detail information on how the Pal-Rhodes model employed into virgin binder/RAP binder blending issue was presented at the annual AAPT conference that was held in Atlanta, Georgia, March, 2014. The manuscript will be published in the journal of the association of asphalt paving technologists (AAPT).

<u>Work Planned Next Quarter</u>

A mixing rule, based on Pal-Rhodes model, for blending high RAP contents and virgin binder will be continued and reported in the next quarter.

Work Element E3a: Effects of Extenders and Alternative Binders on Performance

Work Done This Quarter
Chapter related to extenders was included in Report N, which was submitted to FHWA in draft form this quarter.

Work Planned Next Quarter
Address comments as needed.

Proposed Research Product and Timeline
Results were added as a number of chapters to Report N: Guidelines for Selection of Modification Techniques.

Due Date for Draft Report Submittal: See Report N.
Due Date for Final Report Submittal: See Report N.

Significant Problems, Issues and Potential Impact on Progress
None.

Work Element E3b: Development of a PG Specification for Emulsions used in Surface Treatments, Cold Mixes, and Cold-In-Place Recycled Mixes

Work Done This Quarter
Proposed changes to the mix design procedure for slurry seals and micro-surfacing were completed and are being integrated into the draft final report. NCAT emulsion residue testing was completed, result will be compared to early performance of the Lee County Rd. sections. Work to incorporate results of residue performance testing, surface treatments, and cold mix continued.

Work Planned Next Quarter
Revisit WI Chip Seal sites in spring to collect final data point for field performance comparison. Deliver draft final report.

Proposed Research Product and Timeline
Results will be summarized as part of Report Q: Improvement of Emulsion Characterization and Mixture Design for Cold Bitumen Applications

Due Date for Draft Report Submittal: 5/31/2014, extended from 9/30/2013, 12/31/2103, 3/31/201
Due Date for Final Report Submittal: 6/30/2014

Significant Problems, Issues and Potential Impact on Progress
None, on revised schedule.

Work Element E3c: Laboratory Assessment of Mixture Long Term Aging

Work Done This Quarter
Completed draft final report.

Work Planned Next Quarter
See report AA.

Proposed Research Product and Timeline

Results will be summarized in a final report titled: "Laboratory Assessment of Long Term Aging of Asphalt Mixtures" it is proposed this deliverable be labeled as "Report AA."

Due Date for Draft Report Submittal: See Report AA.
Due Date for Final Report Submittal: See Report AA.

Significant Problems, Issues and Potential Impact on Progress

Work element V1a: Use and Monitoring of Warm Mix Asphalt Sections

Work Done This Quarter

Laboratory testing at NCAT has been completed for the following field projects:

- 2 test sections on I-84 in CT
- 2 test sections on US 287 in TX
- 2 test sections on US 69 in MS
- 3 test section on CR 159 in AL

Work was performed at WRI on preparing a compilation of the pavement distress data and material properties on all the test sites, which includes a number of WMA sites, for upload to the ARC database and for inclusion in an ARC final report summarizing the validation site study.

Work Planned Next Quarter

NCAT will finish all laboratory testing for 4 test sections on I-70 in CO and will work on a final report for this work element.

WRI is currently discussing with FHWA the possibility of having FHWA continue the pavement distress surveys on the ARC/WRI sites under LTPP.

WRI will present a paper on the Universal Simple Aging Test (USAT) at the June 2014 ISAP conference. The paper reports a new method for simulating the short term aging of WMA binder in the laboratory. Part of the USAT study was performed with ARC validation site materials.

[Farrar, M. J., Jean-Pascal Planche, R. William Grimes, Qian Qin, The Universal Simple Aging Test (USAT): Simulating Short- and Long Term Hot and Warm Mix Oxidative Aging in the Laboratory, accepted for presentation to the June 2014 ISAP conference at NCSU.]

Work element V1b: Construction and Monitoring of Additional Comparative Pavement Validation Sites

<u>Work Done This Quarter</u>

NCAT conducted laboratory testing for 3 test sections on Route 7 in MO.

WRI completed binder mechanical testing on several of the more recently completed test sites.

<u>Work Planned</u>

The NCAT team will finish laboratory testing for the MO field project. Data from this testing will be analyzed and added to the report that NCAT will prepare for Work Element V1a.

A compilation of the pavement distress data and material properties on all the ARC sites for upload to the ARC database and for inclusion, in part, to an ARC final report summarizing the validation site study will be completed.