STATE OF MINNESOTA
WORK ORDER CONTRACT

Project Identification: Investigation of Low Temperature Cracking in Asphalt Pavements – Phase II

This Work Order Contract is issued under the authority of State of Minnesota, Department of Transportation (Mn/DOT) Contract No. 89261 between the state of Minnesota acting through its Commissioner of Transportation ("Mn/DOT") and **Regents of the University of Minnesota,** Address: **Office of Sponsored Projects Administration, 450 McNamara Alumni Center, 200 Oak Street Southeast, Minneapolis, Minnesota 55455** ("University) and is subject to all applicable provisions and covenants of that Master Contract, which are incorporated herein by reference.

The University will furnish all products and perform all services defined in the Article 2, Scope of Work and Deliverables.

Work Order Contract

1 Term of Work Order Contract:

1.1 Effective Date: The date that all required signatures are obtained by Mn/DOT, pursuant to Minnesota Statutes Section 16C.05, subdivision 2. **The University must not begin work under this Work Order Contract until all required signatures have been obtained and the University has been notified, in writing, to begin such work by Mn/DOT's Authorized Representative.**

1.2 Final Task Completion Date: **November 30, 2011,** as outlined in Exhibit A, Project Schedule.

1.3 Expiration Date: **January 31, 2012**, or when all obligations have been satisfactorily fulfilled, which ever occurs first.

1.4 Exhibits: Exhibits A through D are attached and incorporated into this Work Order Contract.

2 Scope of Work and Deliverables:

2.1 This scope of work falls under Activity Codes 6251, 6265 and 9025.
2.2 The University, who is not a state employee, will complete the work described in Exhibit A.
2.3 For research Contracts, the University will follow the Technical Advisory Panel (TAP) Guidelines in the completion of this Work Order Contract, which can be found at the following website: http://www.research.dot.state.mn.us/tap/TAPGuidelines.pdf.
2.4 Deliverables are the work products created or supplied by the University pursuant to the terms of this Work Order Contract. Deliverables to be provided for under this Work Order Contract by the University are described in Exhibit A.

3 Items Provided and/or Completed by Mn/DOT:

3.1 After authorizing the University to begin work, Mn/DOT will furnish any data or material in its possession relating to the project that may be of use to the University in performing the work.
3.2 All such data furnished to the University, will remain the property of Mn/DOT and will be promptly returned upon Mn/DOT's request or upon the expiration or termination of this Work Order Contract.
3.3 The University will analyze all such data furnished by Mn/DOT. If the University finds any such data to be incorrect or incomplete, the University will bring the facts to the attention of Mn/DOT before proceeding with the part of the project affected. Mn/DOT will investigate the matter, and if it finds that such data is incorrect or incomplete, it will promptly determine a method for furnishing corrected data. Delay in furnishing data will not be considered justification for an adjustment in compensation.
3.4 See Exhibit A for additional information on Mn/DOT's Assistance.

4 Consideration of Payment:

4.1 Mn/DOT will pay for all services performed by the University on a Lump Sum basis. The University will submit Invoices for tasks completed after receipt of the Deliverable Approval Form from Mn/DOT.

4.2 See Exhibit B for the approved budget for this Work Order Contract.

4.3 The University must use the "Request for Mn/DOT Travel Authorization" form set forth in Exhibit C when requesting to incur travel costs under this Work Order Contract.

4.4 The University will submit invoices for payment in accordance with the following schedule and in the corresponding amounts:

At Completion of Task 1:	$ 16,785.00
At Completion of Task 2:	$ 116,785.00
At Completion of Task 3:	$ 123,286.00
At Completion of Task 4:	$ 81,786.00
At Completion of Task 5:	$ 48,804.00
At Completion of Task 6:	$ 63,804.00
At Completion of Task 7:	$ 23,750.00

4.5 Federal funding applies to this project. See the Master Contract for applicable controls.

4.6 Mn/DOT's total obligation for all compensation and reimbursements to the University will be $475,000.00.

5 Terms of Payment:

5.1 The University will use the format set forth in Exhibit D when submitting Invoices.

5.2 The University will submit an original invoice to Mn/DOT's Authorized Representative listed below and a copy of the invoice to Ann McLellan, Research Services Section, Mail Stop 330, 395 John Ireland Boulevard, St. Paul, Minnesota 55155, or their successors.

6 The University's Designated Personnel:

6.1 The University's Principal Investigator for this Work Order Contract will be:

Name:	Mihai Marasteanu, Assistant Professor
Address:	University of Minnesota Department of Civil Engineering, 122 CivE 500 Pillsbury Drive Southeast, Minneapolis, Minnesota 55455
Phone:	612-625-5558
E-Mail:	maras002@umn.edu

7 Other Designated Personnel:

7.1 Mn/DOT's Technical Liaison for this Work Order Contract will be:

Name:	Ben Worel, Administrative Engineer (or his/her successor)
Address:	Minnesota Department of Transportation Office of Materials, Mail Stop 645 1400 Gervais Avenue, Maplewood, Minnesota 55109
Phone:	651-366-5522
Fax:	651-366-5461
E-Mail:	ben.worel@dot.state.mn.us

7.2 Mn/DOT's Administrative Liaison for this Work Order Contract will be:

Name:	Bruce Holdhusen, Senior Engineer (or his/her successor)
Address:	Minnesota Department of Transportation Research Services Section, Mail Stop 330 395 John Ireland Boulevard, St. Paul, Minnesota 55155-1899
Phone:	651-366-3760
Fax:	651-366-3789
E-Mail:	bruce.holdhusen@dot.state.mn.us

7.3 Mn/DOT's Authorized Representative for this Work Order Contract will be:

Name:	Ashley Duran, Contract Administrator (or his/her successor)
Address:	Minnesota Department of Transportation Consultant Services Section, Mail Stop 680 395 John Ireland Boulevard, St. Paul, Minnesota 55155-1899
Phone:	651-366-4627
Fax:	651-366-4770
E-Mail:	ashley.duran@dot.state.mn.us

8 Additional Provisions

NONE

STATE ENCUMBRANCE VERIFICATION

Individual certifies that funds have been encumbered as required by Minn. Stat. §§16A.15 and 16C.05

By: [signature]

Date: 6-17-2008

CFMS Contract No.: B15674

DEPARTMENT OF TRANSPORTATION

(with delegated authority)

By: ORIGINAL SIGNED BY Richard Arnebeck

Title: Division Director

Date: 6/17/08

UNIVERSITY OF MINNESOTA

By: [signature]

Title: Edward F. Wink, Assoc. V.P. for Research, Sponsored Projects Admin

Date: 6-17-08

COMMISSIONER OF ADMINISTRATION

By: [signature]

Date: 6-17-08

EXHIBIT A
SCOPE OF SERVICES

INVESTIGATION OF LOW TEMPERATURE CRACKING IN ASPHALT PAVEMENTS – PHASE II

BACKGROUND:
Good fracture properties are an essential requirement for asphalt pavements built in the northern part of the United States and in Canada for which the predominant failure mode is cracking due to high thermal stresses that develop at low temperatures. Currently, many agencies are struggling to maintain their pavement networks at acceptable conditions. Minnesota alone spent $355 million dollars on pavement structures last year and nationally the expenditures reached $45 billion. This amount is not enough to satisfactorily maintain the roadways at their current service levels and new methods must be developed to increase pavement service life with the existing resources. Improving the fracture resistance of the asphalt materials used in pavements and understanding the role played by the individual components of the pavement system in the fracture mechanism become a very important priority in the effort to reduce and eventually eliminate the occurrence of thermal cracks in asphalt pavements. This will maximize the service life of both new and rehabilitated pavements and significantly reduce the high costs of repairing low temperature cracks.

CURRENT STATE OF PRACTICE:
In Phase I of this project, a comprehensive research effort in which both traditional and new experimental protocols and analyses were applied to a statistically designed set of laboratory prepared specimens and to field samples from pavements with well documented performance to determine the best combination of experimental work and analyses to improve the low temperature fracture resistance of asphalt pavements.

The two sets of materials were evaluated using current testing protocols, such as creep and strength for asphalt binders and mixtures as well as newly developed testing protocols, such as the disk compact tension test, single edge notched beam test and semi circular bend test. Dilatometric measurements were performed on both asphalt binders and mixtures to determine the coefficient of thermal contraction.

Discrete fracture and damage tools were utilized to model crack initiation and propagation in pavement systems using the finite element method and TCMODEL was used with the experimental data from the field samples to predict performance and compare it to the field performance data.

Phase I has resulted in a number of important findings and recommendations. They can be summarized as follows:
1. Field performance correlates best with fracture parameters for both asphalt mixtures and binders. These results clearly indicated that, while the current properties such as creep and strength are needed for stress calculations and pavement design, the selection of fracture resistant binders and mixtures should be based on simple fracture tests.
2. The PG specification for binders provides a good start; however, other factors such as aggregate type and air voids affect fracture resistance. Therefore, asphalt mixture specification criteria similar to the current PG system for binders need to be developed.
3. At low temperature, asphalt mixtures are complex viscoelastic composite materials that are significantly temperature and loading rate dependent. Any new specification should be based on test results at multiple temperatures and loading rates similar to the rates experienced by real pavements.
4. While the selection of materials with good fracture properties will significantly improve pavement performance, it is critical to understand the role of all components of the pavement system. Therefore, the pavement mechanics models developed in phase I need to be further refined.

PROBLEM STATEMENT:
The current Superpave specifications, based on the linear viscoelastic analysis of creep and strength data at low temperatures on both asphalt binders and mixtures represented a major step forward in the selection of asphalt materials with improved low temperature performance. However, this approach is limited to one single event and cannot provide the tools to predict the evolution of cracks in time and does not allow taking into consideration the effects of traffic loading, of the variable aging through the asphalt layer and of the pavement system on the thermal behavior of the pavement.

This type of analysis can be performed only based on fracture mechanics concepts, which have been successfully used to predict the fracture behavior of metal structures, rocks and concrete. Presently, there is no agreement with respect to what experimental methods and analysis approaches to use to investigate the fracture resistance of asphalt materials and the fracture performance of asphalt pavements.

It becomes therefore a top priority to develop test methods and specifications to select asphalt materials and to realistically consider the entire pavement system to design and construct asphalt pavements resistant to low temperature cracking.

OBJECTIVE:
The objectives for this project include:
- Expanding the work performed in Phase I with additional field samples
- Investigating physical hardening effects for modified asphalt binders
- Developing a specification for low temperature properties of asphalt mixtures
- Developing an improved TC model that uses fracture mechanics properties obtained with the new test methods
- Modeling asphalt mixture behavior during expansion and contraction temperature cycles
- Developing a final report and provide new computer program

SCOPE:
The work proposed for Phase II builds upon the findings and recommendations of Phase I. Each of the four main recommendations will be addressed in this phase; however, the main thrust will be the development of test methods and specification criteria that will allow the selection of fracture resistant asphalt mixtures and binders at low temperatures. In order to accomplish these goals, the following major tasks are proposed for Phase II.

Mn/DOT ASSISTANCE:
Mn/DOT and the participating states will provide assistance with field sites identification and collection of field specimens used in the experimental part.

WORK PLAN

Task 1: Update on Low Temperature Cracking Research
In this task, the research team will perform a brief literature review to document any new research in the area of low temperature cracking, including the work performed by the Asphalt Research Consortium research team. Details of the MnROAD test cells constructed in 2007 and 2008 in relation to low temperature cracking will be provided. In addition, the research team will document test specifications from Canada and Europe that may be similar to the current Semi-Circular Bending (SCB) and Disc-Shaped Compact Tension Test (DCT) tests, as well as any modifications to the SCB and DCT tests that have been done since the end of Phase I.

Deliverable(s): Summary report; Update on Low Temperature Cracking Research

Duration: 6 Months

Estimated Task Completion Date: January 31, 2009

Task 2: Expand Phase I Test Matrix with Additional Field Samples
In this task, the research team will test and analyze nine new asphalt mixtures used in field studies with respect to their low temperature cracking resistance. The research team is proposing the following seven mixtures plus two additional mixtures from Wisconsin and New York. The tests will consists of Indirect Tensile (IDT) creep and strength tests as well as SCB and DCT fracture tests. These include warm mixtures, mixtures with Recycle Asphalt Pavement (RAP) and acid modified and mixtures prepared with similar PG binders but different sources:

Location	Construction Date	Description
MnROAD 33	September 2007	58-34 Acid only no RAP
MnROAD 34		58-34 SBS + Acid no RAP
MnROAD 35		58-34 SBS only no RAP
MnROAD 77		58-34 Elvaloy + Acid no RAP
MnROAD 20	August 2008	58-28, 30% non-fractionated RAP, level 4 SP, wear & non-wear
MnROAD 21		58-28, 30% fractionated RAP, level 4 SP, wear & non-wear
MnROAD 22		58-34, 30% fractionated RAP, level 4 SP, wear & non-wear
Wisconsin 9.5 mm SMA	2008	Wisconsin will provide materials
New York "Typical Mix"	2008	New York with PG 64-22 binder and an aggregate other than limestone and granite.

The experimental variables that are important in differentiating low temperature cracking mix performance are test temperature, long-term aging or mix conditioning, and mix air voids. The proposed experimental plan for establishing the proposed low temperature cracking criteria is shown in the table below.

The initial validation plan detailed in the table above consists of performing 54 tests per mixture for a total of 486 tests. All nine mixtures will be DCT tested at the University of Illinois Urbana Champaign (UIUC) laboratory and SCB and IDT tested at the University's laboratory, respectively. For three of the nine mixtures, DCT tests will be also performed at the University and SCB test will be also performed at UIUC; Iowa State University (ISU) will perform a limited number of tests (SCB and/or DCT), if equipment becomes available. All laboratories will provide a detailed Quality Assurance plan to ensure the accuracy of the test results. The progress of this work will be presented periodically at the Expert Task Group (ETG) meetings and it is expected that at the end of Task 2, or subtask II of Task 3, a round robin will be initiated through ETG mechanisms, at no cost to the current project, to obtain precision and bias information on the test methods.

The laboratory test results will be correlated to the low temperature cracking field performance of the MnROAD mixes. This plan will determine which device is best and the best temperature, mix conditioning and air void level for establishing the low temperature specification criteria. The research team envisions that there will be two levels of specification consisting of simply a mix criteria and a more advanced one using models. The more advanced specification will consist of additional mix testing beyond that of the mix design criteria for use in the developed advanced models.

Test Device	Temp	Mix Conditioning	MN/Road Test Section				SMA WI		Mixture NYS	
			33, 34, 35, 37		20, 21, 22					
			Air Voids, %							
			4	7	4	7	4	7	4	7
SCB	PG	4Hours@135°C	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG+10°C	4Hours@135°C	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG	None	xxx		xxx		xxx		xxx	
	PG+10°C	None	xxx		xxx		xxx		xxx	
DC(T)	PG	4Hours@135°C	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG+10°C	4Hours@135°C	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG	None	xxx		xxx		xxx		xxx	
	PG+10°C	None	xxx		xxx		xxx		xxx	
IDT	PG	4Hours@135°C	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG+10°C	4Hours@135°C	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG	None	xxx		xxx		xxx		xxx	
	PG+10°C	None	xxx		xxx		xxx		xxx	

Subtask on Physical Hardening

This task will also contain a subtask in which the research team will evaluate the effect of PPA, Warm Mix Additives and Polymers on Physical Hardening of Asphalt Binders. In Phase I it was shown that isothermal physical hardening could have serious effects on stiffness and "m" values of binders. It has been indicated in previous studies that modifiers used could change the physical hardening due to effects on morphology of binders. Physical hardening measurements require a long time and could complicate specification testing. However, studies during SHRP program as well as more recent studies have shown that physical hardening trends can be predicted from relatively short time tests. The success of including physical hardening in routine testing depends on simplification of test procedure and understanding effect of various additives used for modification today. The objectives of this subtask are to:

1. Develop a protocol to simplify the measurements of physical hardening and include a numerical approach to adjust S and m values based on such protocol and based on climatic condition.
2. Collect physical hardening for a variety of asphalt binders and verify the model that will be developed in Task 5.
3. Use the glass transition measuring technique to quantify effect of isothermal storage on dimensional stability of asphalt mixtures.

Deliverable(s): Summary Report; Database with Test Date; Expansion of the Phase I Test Matrix, with additional field samples

Duration: 18 Months

Estimated Task Completion Date: April 30, 2010

Task 3: Develop Low Temperature Specification for Asphalt Mixtures

The main objective of this work is the development of low temperature performance specification for asphalt mixtures. Currently, the simple performance test provides the parameters needed to predict the intermediate and high service temperature performance. There is a need for a similar test to fill the gap in the low temperature range. In order to accomplish this goal the following subtasks will be performed:

Subtask 1 – Develop Test Method

The research team will:

1. Refine and possibly simplify the SCB and DCT fracture tests used in Phase I.
2. Propose a standard fracture test method based on SCB configuration for asphalt mixtures (note that the DCT has been already approved as an American Society for Testing and Materials [ASTM] standards).
3. Develop standard fracture method and recommend one fracture test but provide correlations between the results from the two methods.

Subtask 2 – Develop Specification

The research team will:

1. Revisit the supporting field and experimental data that was used to develop the current PG system used to select asphalt binders; a similar approach, based on criteria providing limiting temperature values, will be used for the mixture specification.
2. Develop limiting criteria for selecting asphalt mixtures resistant to low temperature cracking based on the experimental work performed in Phase I, work performed in Task 2 of this project and data available in previous research projects; the criteria will be based on fracture tests performed on specimens prepared from original loose mix.

Subtask 3 – Propose Simplified Method to Obtain Mixture Creep Compliance

The research team will:

1. Revisit the IDT strength and creep test methods and analyses to find out if similar information can be obtained from other simpler tests (since the IDT creep and strength data represent critical inputs in the Mechanistic-Empirical Pavement Design Guide [MEPDG] software this is important).
2. Investigate if creep compliance can be obtained directly from tests performed in the SCB and DCT configuration.

3. Investigate if Bending Beam Rheometer (BBR) testing of thin asphalt mixture beams based on work in progress performed at the University as part of recent National Cooperative Highway Research Program (NCHRP) Idea project.
4. Revisit work performed under previous Mn/DOT project to evaluate the feasibility of using Hirsch model.
5. Investigate if strength can be obtained from BBR testing of thin asphalt mixture beams to failure; this work will be performed in conjunction with Asphalt Research Consortium (ARC) work performed by the University of Wisconsin.

The primary outcome of this task will be the development of a simple mixture design specification, based upon mixture fracture testing and Superpave low-temperature binder test data, to control thermal cracking. It is not anticipated that the specification will involve the use of a computer program as part of routine design. However, the improved TCMODEL program to be developed under Task 4 will be used to choose specification parameters and to set specification thresholds. An optional, more rigorous specification, which will require running the TCMODEL program, will be developed under Task 4.

Deliverable(s): Summary Report; Developed Low Temperature Specification, for asphalt mixtures

Duration: 18 Months

Estimated Task Completion Date: October 31, 2010

Task 4 - Develop Improved TCMODEL

TCMODEL is a computer program developed under SHRP and later revised and adopted for the MEPDG that predicts transverse cracking versus time based upon hourly air temperatures, Hot Mix Asphalt (HMA) creep compliance and tensile strength from the IDT (American Association of State and Highway Transportation Officials [AASHTO] T-332), HMA thermal coefficient, and other pavement layering information. Phase I of the study demonstrated the benefits of the mixture fracture energy measurement as compared to mixture tensile strength, particularly for polymer-modified mixtures.

TCMODEL will be enhanced in Phase II ("NewTCMODEL") to better capture the true fracture properties of hot-mix asphalt. The resulting program will be used to guide the specification design team in the development of a simple specification for the control of thermal cracking based upon a mixture fracture test and standard Superpave binder test results. The program will also be delivered as part of an optional rigorous thermal cracking design specification, where the running of NewTCMODEL is part of the design specification. This system will bear similarity to the MEPDG, although it will use mixture fracture tests instead of tensile strength and will have an improved fracture model (cohesive zone fracture model instead of the Paris law model). Climatic files for participating states (three climatic zones per state) will be developed and included in the software for a range of asphalt layer thicknesses. The TCMODEL program will be made available as a freeware program, to be posted on the University, the Federal Highway Administration (FHWA) and Mn/DOT websites. The program and an accompanying user's manual will be bundled with the final report.

In addition, UIUC researchers will work with other university team members to conduct a preliminary calibration and validation of the new model at the end of the second year of the study. Data from the Phase I project, along with new data generated from the MnROAD project will be used to calibrate and validate the accuracy of the new model. Direct comparisons to the existing TCMODEL code will also be made.

The following subtasks will be performed if additional funding becomes available and an Amendment to this Work Order Contract is developed:

1. Allow multiple (e.g. up to three) HMA layers.
2. Develop interface with environmental integrated climatic model.
3. Development and implementation of a library of cohesive zone models in NewTCMODEL; tailored for pavement fracture behavior.
4. Implementation of temperature-dependent material properties in NewTCMODEL, i.e., consideration of distinct thermal coefficient variation upon heating and cooling. The numerical model will follow a non-linear implementation that accounts properly for the temperature dependency on material properties.
5. Implementation of aging gradients in the viscoelastic bulk material in NewTCMODEL, i.e., the space-time properties of the HMA will be based upon a functionally graded material concept.

6. Development of a professional user interface, online help files, examples, and a troubleshooting guide for the NewTCMODEL program.

Deliverable(s): Summary Report; Developed Improved TCMODEL

Duration: 24 Months

Estimated Task Completion Date: July 31, 2011

Task 5: Modeling of Asphalt Mixtures Contraction and Expansion Due to Thermal Cycling

One of the main findings of Phase I of the project was that asphalt mixture contraction and expansion follows different trends. The existing models for thermal cracking predictions over- simplify thermo-volumetric properties of asphalt mixtures. All published models, including those use in the MEPDG, considers a linear contraction and expansion behavior and a single coefficient value is used. In fact many models use a default value or uses a formula to estimate it form volumetric properties. The formula was introduced in the 1960s and is derived empirically based on testing a relatively small collection of mixtures. The only justification for this over-simplification is the difficulty in measuring the coefficient of contraction and expansion and the lack of sufficient knowledge about effects of various mixture variables on these coefficients. In this phase of the project a model for representing the contraction and expansion will be developed. The data collected in Phase I, as well as new data for mixtures to be tested in Phase II, will be used to simplify model and give average default values that can be used in predicting cracking. The data will first be used to study which material properties are statistically important for contraction and expansion. An estimation procedure for the following parameters will be developed to use materials properties used in mixture design such as binder grade or stiffness, aggregate gradation and angularity and air voids.

1. Coefficients of *contraction* above and below Tg.;
2. Coefficients of *expansion a*bove and below Tg.; and
3. Glass transition temperatures during contraction (TGc) and during expansion (Tge)

It is not clear if all these estimated parameters are needed. The TCMODEL will be used to conduct a sensitivity analysis to determine which are statistically important in terms of effect on cracking of pavements.

The main objectives of this task are to:

1. Expand the data base for thermo-volumetric properties of asphalt binders and mixtures to a wider range of modified asphalts and types of mixtures to fully quantify the effects of binders and aggregates in the asymmetrical thermo-volumetric behavior (glass transitions and coefficients).
2. Develop a micromechanics numerical model that can be used to estimate the glass transition temperatures and coefficients from mixture variables commonly measured for binder grading and for mixture design.
3. Conduct thermal cracking sensitivity analysis to determine which of the glass transition parameters (six parameters) are statistically important for cracking, which ones need to be measured and what is the effect of used estimated values rather than measured values.

This task will be coordinated with the WRI ARC project. The ARC is currently involved in modifying the TG instrument to make it more user friendly. The ARC project is also looking at the effect of aging and effect of cooling rates. Although different mixtures are used, the concepts remain the same and the effect of aging and cooling/heating rates will be used to define what the critical factors for thermal cracking are and which material properties need to be used in modeling and in specification.

Deliverable(s): Summary Report; Modeling of Asphalt Mixtures Contraction and Expansion Due to Thermal Cycling

Duration: 21 Months

Estimated Task Completion Date: July 31, 2011

Task 6: Validation of New Specification
Based upon the outcomes of the testing of the preliminary validation experimental plan, the research team will select the best test device and method of conditioning mixes for long-term aging for final validation. The final validation will be based upon testing of the 11 Olmstead County, Minnesota mixes placed in the 2006 construction season. The testing will be at the low performance grade temperature as well as at 10°C above the low temperature performance grade. The mixes will also be tested in triplicate at both 4 and 7 percent air voids. Based upon the outlined test parameters and the two air void contents for the 11 mixes, a total of 132 samples will be tested in the final validation component of this study.

The other test sections that will be used as part of the validation process in year three of the project are listed below. The IDT will be performed only in this task and IDT creep compliance data will be used to develop and validate new method to predict mixture creep compliance from BBR binder creep compliance, as described in Task 3.

Location	Construction Date	Description
Olmsted Co Rd 104	Jul-07	Reinke's Warm Mix (58-28 w/ RAP & antistrip)
Olmsted Co Rd 112	Aug-06	WRI-Mathy Study (Citgo, 58-28, 12.5 mm)
Olmsted Co Rd 112	Aug-06	WRI-Mathy Study (Citgo, 58-28, 19mm)
Olmsted Co Rd 112	Aug-06	WRI-Mathy Study (Marathon, 58-28, 12.5 mm)
Olmsted Co Rd 112	Aug-06	WRI-Mathy Study (Marathon, 58-28, 19mm)
Olmsted Co Rd 112	Aug-06	WRI-Mathy Study (MIF, 58-34 RAP, 12.5 mm)
Olmsted Co Rd 112	Aug-06	WRI-Mathy Study (MIF, 58-34 Virgin, 12.5 mm)
Olmsted Co Rd 112	Aug-06	WRI-Mathy Study (MIF, 58-34, 19mm RAP)
Olmsted Co Rd 112	Aug-06	WRI-Mathy Study (MIF, 58-34, 19mm virgin)
Olmsted Co Rd 112	Aug-06	WRI-Mathy Study (Valero, 58-28, 12.5 mm)
Olmsted Co Rd 112	Aug-06	WRI-Mathy Study (Valero, 58-28, 19mm)

Deliverable(s): Summary Report; Validation of New Specification

Duration: 12 Months

Estimated Task Completion Date: July 31, 2011

Task 7: Development of Draft AASHTO Standards and Final Report
The research team will deliver a final report containing the updated reports from Tasks 1 to 5 at the end of this task. The report will also contain the following information:

1. An access database containing all the experimental results as well as additional information on the field samples and laboratory prepared specimens.
2. The proposed test protocols (experimental set up and data analysis) for selecting asphalt binders and mixtures with enhanced fracture resistance to low temperature thermal cracking.
3. The software and documentation describing a new fracture mechanics-based thermal cracking program (improved TCMODEL). Stand alone program and user manual will be provided.

Deliverable(s): Final Report; Developed Draft AASHTO Standards

Duration: 6 Months

Estimated Task Completion Date: November 30, 2011

DELIVERABLES:
The research team will deliver quarterly reports documenting the work progress periodically to Mn/DOT. The research team will complete task reports documenting the work performed in each task and deliver them to Mn/DOT at the end of each task. At the end of the 36 months of project time, the research team will deliver a final report to Mn/DOT as indicated under Task 7.

PROJECT SCHEDULE

MONTHS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Task 1	X	X	X	X	X	X														
Task 2				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Task 3										X	X	X	X	X	X	X	X	X	X	X
Task 4													X	X	X	X	X	X	X	X
Task 5																X	X	X	X	X
Task 6																				
Task 7																				

	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Task 1																				
Task 2	X																			
Task 3	X	X	X	X	X	X	X													
Task 4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Task 5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Task 6					X	X	X	X	X	X	X	X	X	X	X	X				
Task 7														X	X	X	X	X	X	X

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EXHIBIT B
ESTIMATED BUDGET

INVESTIGATION OF LOW TEMPERATURE CRACKING IN ASPHALT PAVEMENTS – PHASE II

BUDGET BY LINE ITEM:

Salary Costs:		$179,109.06
Principal Investigator	$ 43,367.97	
Co-Principal Investigator	$ 6,277.53	
Key Personnel 1	$ 4,295.03	
Key Personnel 2	$ 5,340.31	
Scientist	$ 31,296.00	
Graduate Student	$ 52,105.83	
Civil Service	$ 36,426.39	
Fringe Costs:		$72,260.26
Principal Investigator	$ 13,183.86	
Co-Principal Investigator	$ 1,908.37	
Key Personnel 1	$ 1,305.69	
Key Personnel 2	$ 1,623.45	
Scientist	$ 10,233.79	
Graduate Student	$ 32,931.50	
Civil Service	$ 11,073.60	
Subcontractor Costs:		$210,000.00
University of Illinois at Urbana Champaign	$ 85,000.00	
Iowa State University	$ 40,000.00	
University of Wisconsin at Madison	$ 85,000.00	
Equipment Costs:		$4,500.00
Equipment Calibration; Maintenance	$ 4,500.00	
Supply Costs:		$3,000.00
Liquid Nitrogen; Testing & Cleaning Supplies	$ 3,000.00	
Travel Costs:		$5,400.00
National & International Meetings	$ 5,400.00	
Other Expense Costs:		$730.68
Mailing; Printing; Phone	$ 730.68	
WORK ORDER CONTRACT AMOUNT		**$475,000.00**

Budget by Task Breakdown:

Task 1	$ 16,785.00
Task 2	$ 116,785.00
Task 3	$ 123,286.00
Task 4	$ 81,786.00
Task 5	$ 48,804.00
Task 6	$ 63,804.00
Task 7	$ 23,750.00
Work Order Contract Amount	**$ 475,000.00**

EXHIBIT C
REQUEST FOR Mn/DOT's TRAVEL AUTHORIZATION

REQUEST FOR Mn/DOT TRAVEL AUTHORIZATION

NOTE: Submit, in duplicate, to your university sponsored programs administration for approval. Mn/DOT must receive at least 2 weeks prior to travel date.

TO: Research Financial Services Manager
Minnesota Department of Transportation
395 John Ireland Boulevard, Mail Stop 330
St. Paul, Minnesota 55155-1899

Date: ____________________

Mn/DOT Contract Number: ________________ **Work Order Number:** ________________

University Acct. Number: ________________

Project Title:

Principal Investigator(s):

Name(s) of Project Personnel Traveling:

Connection to Project:

Total Estimated Expense: ________________ **Date(s) of Travel:** ________________

Destination:

Purpose of Travel:

Benefit of Travel to Project:

I hereby request approval for travel as described above:

____
Principal Investigator

Approved:

Mn/DOT Authorized Official

____
Research Services Section

Date: __________________________

Authorized University Official

____

Date: __________________________

EXHIBIT D
INVOICE FORM

INVESTIGATION OF LOW TEMPERATURE CRACKING IN ASPHALT PAVEMENTS – PHASE II

INVOICE NO. _______

Mn/DOT Contract No. 89261 Work Order No. 103
Expiration Date: January 31, 2012

Billing Quarter: ____________________
Invoice Date: ____________________

	Total Contract Amount	Total Billing to Date	Amount Previously Billed	Billed This Invoice
Lump Sum Amount: Task 1	$16,785.00			
Lump Sum Amount: Task 2	$116,785.00			
Lump Sum Amount: Task 3	$123,286.00			
Lump Sum Amount: Task 4	$81,786.00			
Lump Sum Amount: Task 5	$48,804.00			
Lump Sum Amount: Task 6	$63,804.00			
Lump Sum Amount: Task 7	$23,750.00			
Net Earnings Totals:	**$475,000.00**			
			Total Amount Due This Invoice:	

Box For Research Services Section Use Only
Payment Breakdown

Activity Code	Line	Fiscal Year	Amount
			$
			$
			$

Box For Consultant Services Section Use Only
Payment Information

I certify that the above statement is correct and payment has not been received.

Signature: ____________________

Print Name: ____________________

Title: ____________________

Billing Address: ____________________
____
____
____

Telephone: ____________________

Mn/DOT's Research Services Section Approval:
Signature Date

____

Mn/DOT's Authorized Representative Approval:
Signature Date

____