State of Wisconsin/Department of Transportation

RESEARCH PROGRESS REPORT FOR THE QUARTER ENDING: September 30, 2006

Program: SPR-0010(36) FFY99	**Part: II Research and Development**
Project Title: Investigation of Concrete Properties to Support Implementation of the New AASHTO Pavement Design Guide	**Project ID: 0092-06-03**
Administrative Contact: James McDonnell	**Sponsor: WHRP**
WisDOT Technical Contact: Jim Parry	**Approved Starting Date: 10/01/05**
Approved by COR/Steering Committee: $60,000	**Approved Ending Date: 12/01/06**
Project Investigator (agency & contact): Tarun R. Naik, UWM Center for By-Products Utilization	

Percent Complete: 90%

Project Description:

The overall objective of this project is to provide material properties to be used for input into a mechanistic-empirical design procedure for concrete pavements. The use of the mechanistic-empirical design basis for design of concrete pavements is expected to provide increased reliability of pavement structures and to provide a basis for the prediction of service life, and how the pavement design parameters will affect various pavement failure modes including cracking, faulting, and IRI (International Roughness Index). In order to provide the input required for the new mechanistic-empirical design, this project has the following minimum objectives.

(1) Collect existing literature.
(2) Develop a work plan for testing splitting tensile strength and coefficient of thermal expansion (CTE) of concrete.
(3) Evaluate the effect of portland cement, slag, and fly ash sources on splitting tensile strength and CTE of concrete.
(4) Evaluate the effect of source change of glacial gravel on splitting tensile strength and CTE of concrete.
(5) Evaluate the effect of source change of crushed stone on splitting tensile strength and CTE of concrete.
(6) Generate test results for compressive strength in addition to the splitting tensile strength and CTE of concrete.
(7) Submit a final report to WHRP that contains all test results regarding splitting tensile strength, compressive strength, and CTE of concrete and recommendations for future work.

Progress This Quarter:
(Includes project committee mtgs, work plan status, contract status, significant progress, etc.)

The following work was completed during this quarter:

- Testing of compressive strength, splitting tensile strength, and CTE of all concrete mixtures required for the project were completed. A summary of the aggregate sources, mixture proportions, and test results for the project are given in the Appendix.
- Literature review was finalized.
- Test results were compiled and analyzed.
- A draft of the final report was submitted to WHRP on August 31, 2006.
- A summary of the project results was presented to the Rigid Pavement Technical Oversight Committee (TOC) in Madison, Wis., on September 19, 2006. Initial comments and questions from the TOC on the presentation and final report were addressed.

Work Next Quarter:

The following work is planned during the next quarter of the project:

- Although the literature review on CTE of concrete has been completed, we will continue to monitor new information related to the new AASHTO mechanistic-empirical design procedure.
- Obtain reviewers comments on the final report and incorporate and/or address comments.
- Obtain input from TOC Chair to complete the Implementation Plan Page of the final report and the Research Closure Form.
- Finalize report.
- Copy and bind final report.
- Submit electronic copy and hard copies to WHRP and WisDOT.

Circumstances Affecting Progress/Budget:

None – A no-cost extension was requested and approved for two additional months. This extension was not due to the progress of the project. As required, a draft of the final report was issued on August 31 to WHRP; however, the extension was requested to allow time for the review by the Rigid Pavement TOC, to incorporate/address TOC comments, and to copy and bind the copies of the final report.

Gantt Chart:

PROJECT SCHEDULE

Tasks	2005			2006										
	Q2			Q3			Q4			Q1			Q2	
	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Task 1: Literature Review														
Task 2: Selection of Materials and Concrete Mixtures														
Task 3: Production of Concrete Mixtures														
Task 4: Laboratory Testing of Splitting Tensile and Compressive Strengths														
Task 5: Laboratory Testing of Coefficient of Thermal Expansion														
Task 6: Evaluation of Results														
Task 7: Reports														

Planned activity start/stop and duration
Actual project progress

Note: Gantt chart shown in State Fiscal Year Quarters

APPENDIX

Table 1. Sources of WisDOT No. 1 and No. 2* Coarse Aggregates Used

Aggregate designation	Lab No.	Aggregate type**	Source name	County
Gvl1	5	Glacial Gravel – Lake Michigan Lobe	J. W. Peters	Racine
Gvl2	8	Glacial Gravel – Lake Michigan / Green Bay Transition	Evanson Quarry	Manitowoc
Gvl3	4	Glacial Gravel – South End of Green Bay Lobe	Janesville Sand & Gravel	Rock
Gvl4	12	Glacial Gravel – Central Green Bay Lobe	Wimme Pit	Portage
Gvl5	13	Glacial Gravel – Wisconsin Valley Lobe	Crass Road Pit	Lincoln
Gvl6	14	Glacial Gravel – Chippewa River Gravel	Todds Ready-Mix	Barron
Qtz	1	Baraboo Quartzite	Williams Quarry	Columbia
Gnt	10	Granite	Haske Quarry	Wood
Dbs	11	Diabase	RME - Athens	Marathon
Bst	15	Basalt Traprock	Dresser Quarry	Polk
Dlm1	6	Niagara Dolomite	Franklin Quarry - Vulcan	Milwaukee
Dlm2	3	Galena Dolomite	Haverland Quarry	Grant
Dlm3	7	Galena-Platteville Dolomite	Carew Concrete	Outagami
Dlm4	2	Prairie Du Chien Dolomite – SW Wisconsin	Slama Quarry	Crawford
Dlm5	9	Prairie Du Chien Dolomite – NE Wisconsin	Faulk Bros. Quarry	Waupaca

* Same as AASHTO No. 67 (19.0 to 4.75 mm [0.75 to 0.1875 in.]) and No. 4 (37.5 to 19.0 mm [1.5 to 0.75 in.]), respectively.

** Aggregate types are from WisDOT description of the sources.

Table 2. Mixture Proportions and Fresh Properties of Concrete (SI [Metric] Units)

Mixture Designation	Gvl1-c1-f1	Gvl2-c1-f1	Gvl3-c1-f1	Gvl4-c1-f1	Gvl5-c1-f1	Gvl6-c1-f1	Qtz-c1-f1	Gnt-c1-f1	Dbs-c1-f1	Bst-c1-f1
Laboratory mixture designation	5	8	4	12	13	14	1	10	11	15
Cement, Lafarge I (kg/m^3)	236	241	232	241	239	238	233	229	248	244
Class C fly ash, Pleasant Prairie (kg/m^3)	102	104	100	104	103	103	101	99	107	105
Grade 120 GGBFS, Lafarge (kg/m^3)	0	0	0	0	0	0	0	0	0	0
Water (kg/m^3)	135	138	133	138	137	136	130	134	143	140
Fine aggregate, SSD (kg/m^3)	652	664	641	664	661	657	644	633	685	673
No. 1 coarse aggregate, 19 to 5 mm, SSD (kg/m^3)	729	737	719	738	735	732	712	701	756	743
No. 2 coarse aggregate, 38 to 19 mm, SSD (kg/m^3)	486	491	477	491	489	487	475	465	504	494
Water-reducing admixture (L/m^3)	0.18	0.17	0.05	0.05	0.08	0.07	0.32	0.77	0.15	0.05
Air-entraining admixture (L/m^3)	0.93	1.41	0.96	1.49	1.07	0.98	1.93	1.66	1.14	2.35
Water-cementitious ratio, W/Cm	0.40	0.40	0.40	0.40	0.40	0.40	0.39	0.41	0.40	0.40
Slump (mm)	80	80	70	75	75	105	50	75	30	55
Air content (%)	5.9	6.4	6.1	5.4	5.8	5.2	6.1	7.9	4.8	6.4
Air temperature (°C)	22	22	23	22	22	22	22	22	21	21
Concrete temperature (°C)	21	20	21	22	22	22	21	21	21	21
Density (kg/m^3)	2340	2370	2300	2380	2360	2350	2300	2260	2440	2400

Mixture Designation	Dlm1-c1-f1	Dlm2-c1-f1	Dlm2-c2-f1	Dlm3-c1-f1	Dlm3-c1-s	Dlm4-c1-f1	Dlm4-c1	Dlm5-c1-f1	Dlm5-c1-f2
Laboratory mixture designation	6	3	3-c2	7	7-s	2	2-c1	9	9-f2
Cement, Lafarge I (kg/m^3)	232	226	231*	241	238	229	323	239	234
Class C fly ash, Pleasant Prairie (kg/m^3)	100	97	99	104	0	99	0	103	101†
Grade 120 GGBFS, Lafarge (kg/m^3)	0	0	0	0	102	0	0	0	0
Water (kg/m^3)	133	123	124	138	137	132	127	138	135
Fine aggregate, SSD (kg/m^3)	641	624	636	664	661	635	634	661	647
No. 1 coarse aggregate, 19 to 5 mm, SSD (kg/m^3)	719	707	721	736	731	711	711	740	724
No. 2 coarse aggregate, 38 to 19 mm, SSD (kg/m^3)	478	470	479	490	486	475	478	491	480
Water-reducing admixture (L/m^3)	1.31	0.73	0.16	0.17	0.67	0.32	0.94	0.16	0.16
Air-entraining admixture (L/m^3)	0.58	0.89	0.87	1.49	1.56	0.80	1.17	2.14	1.64
Water-cementitious ratio, W/Cm	0.40	0.38	0.38	0.40	0.40	0.40	0.39	0.40	0.40
Slump (mm)	65	75	65	65	30	105	55	25	100
Air content (%)	7.0	7.3	6.0	6.2	5.6	6.0	6.1	5.6	6.8
Air temperature (°C)	21	22	22	22	22	21	22	22	22
Concrete temperature (°C)	21	22	22	19	22	21	22	22	21
Density (kg/m^3)	2300	2250	2290	2370	2360	2280	2270	2370	2320

* St. Marys cement.

† Weston fly ash.

Table 3. Mixture Proportions and Fresh Properties of Concrete (U.S. Customary Units)

Mixture Designation	Gvl1-c1-f1	Gvl2-c1-f1	Gvl3-c1-f1	Gvl4-c1-f1	Gvl5-c1-f1	Gvl6-c1-f1	Qtz-c1-f1	Gnt-c1-f1	Dbs-c1-f1	Bst-c1-f1
Laboratory mixture designation	5	8	4	12	13	14	1	10	11	15
Cement, Lafarge I (lb/yd^3)	398	405	391	405	403	401	393	386	418	410
Class C fly ash, Pleasant Prairie (lb/yd^3)	172	175	169	175	174	173	169	167	180	177
Grade 120 GGBFS, Lafarge (lb/yd^3)	0	0	0	0	0	0	0	0	0	0
Water (lb/yd^3)	227	233	224	232	231	230	219	225	240	236
Fine aggregate, SSD (lb/yd^3)	1100	1120	1080	1120	1110	1110	1090	1070	1150	1130
No. 1 coarse aggregate, 0.75 to 3/16 ", SSD (lb/yd^3)	1230	1240	1210	1240	1240	1230	1200	1180	1270	1250
No. 2 coarse aggregate, 1.5 to 0.75", SSD (lb/yd^3)	818	826	804	828	823	821	799	783	848	832
Water-reducing admixture (fl oz/yd^3)	4.6	4.3	1.2	1.3	2.1	1.7	8.3	19.8	4.0	1.3
Air-entraining admixture (fl oz/yd^3)	23.9	36.4	24.8	38.5	27.7	25.4	49.8	42.9	29.5	60.6
Water-cementitious ratio, W/Cm	0.40	0.40	0.40	0.40	0.40	0.40	0.39	0.41	0.40	0.40
Slump (in.)	3-1/4	3-1/4	2-3/4	3	3	4-1/4	2	3	1-1/4	2-1/4
Air content (%)	5.9	6.4	6.1	5.4	5.8	5.2	6.1	7.9	4.8	6.4
Air temperature (°F)	71	71	73	71	71	71	71	71	70	70
Concrete temperature (°F)	70	68	69	71	71	71	70	70	70	69
Density (lb/ft^3)	146	148	144	148	147	147	143	141	152	150

Mixture Designation	Dlm1-c1-f1	Dlm2-c1-f1	Dlm2-c2-f1	Dlm3-c1-f1	Dlm3-c1-s	Dlm4-c1-f1	Dlm4-c1	Dlm5-c1-f1	Dlm5-c1-f2
Laboratory mixture designation	6	3	3-c2	7	7-s	2	2-c1	9	9-f2
Cement, Lafarge I (lb/yd^3)	391	381	388*	405	400	386	545	403	394
Class C fly ash, Pleasant Prairie (lb/yd3)	168	164	167	175	0	167	0	174	170†
Grade 120 GGBFS, Lafarge (lb/yd^3)	0	0	0	0	173	0	0	0	0
Water (lb/yd^3)	225	207	209	233	231	223	213	232	227
Fine aggregate, SSD (lb/yd^3)	1080	1050	1070	1120	1110	1070	1070	1110	1090
No. 1 coarse aggregate, 0.75 to 3/16 ", SSD (lb/yd^3)	1210	1190	1210	1240	1230	1200	1200	1250	1220
No. 2 coarse aggregate, 1.5 to 0.75", SSD (lb/yd^3)	805	791	807	825	819	800	804	827	809
Water-reducing admixture (fl oz/yd^3)	33.8	18.9	4.1	4.3	17.2	8.3	24.2	4.3	4.2
Air-entraining admixture (fl oz/yd^3)	14.9	22.9	22.5	38.5	40.4	20.5	30.2	55.3	42.5
Water-cementitious ratio, W/Cm	0.40	0.38	0.38	0.40	0.40	0.40	0.39	0.40	0.40
Slump (in.)	2-3/4	3	2-1/2	2-3/4	1-1/4	4-1/4	2-1/4	1	4
Air content (%)	7.0	7.3	6.0	6.2	5.6	6.0	6.1	5.6	6.8
Air temperature (°F)	70	72	71	71	72	70	71	71	71
Concrete temperature (°F)	70	72	71	66	72	70	71	71	70
Density (lb/ft^3)	144	140	143	148	147	142	142	148	145

* St. Marys cement.

† Weston fly ash.

Table 4. Compressive Strength of Concrete (MPa)

Mixture	7-day	14-day	28-day	90-day
Gvl1-c1-f1	24.5	26.3	33.6	41.2
Gvl2-c1-f1	19.0	20.5	26.1	31.8
Gvl3-c1-f1	20.3	24.0	28.0	34.3
Gvl4-c1-f1	23.3	27.4	30.5	35.0
Gvl5-c1-f1	19.8	22.4	24.5	30.7
Gvl6-c1-f1	19.9	25.0	28.9	37.9
Qtz-c1-f1	22.5	25.2	30.1	34.7
Gnt-c1-f1	23.9	26.4	27.0	34.6
Dbs-c1-f1	26.2	27.5	38.3	40.8
Bst-c1-f1	19.1	20.8	26.9	29.5
Dlm1-c1-f1	28.3	32.9	36.4	41.4
Dlm2-c1-f1	21.7	24.9	29.9	35.0
Dlm2-c2-f1	19.6	34.1	36.4	46.1
Dlm3-c1-f1	25.0	30.1	35.3	40.7
Dlm3-c1-s	27.9	33.8	37.0	40.7
Dlm4-c1-f1	20.0	23.5	27.2	31.9
Dlm4-c1	24.1	29.6	32.8	33.9
Dlm5-c1-f1	25.5	32.4	36.1	40.3
Dlm5-c1-f2	19.0	22.0	24.6	31.2

Table 5. Compressive Strength of Concrete (psi)

Mixture	7-day	14-day	28-day	90-day
Gvl1-c1-f1	3550	3820	4870	5970
Gvl2-c1-f1	2760	2980	3780	4610
Gvl3-c1-f1	2950	3480	4060	4970
Gvl4-c1-f1	3380	3970	4430	5070
Gvl5-c1-f1	2870	3250	3550	4450
Gvl6-c1-f1	2880	3620	4190	5490
Qtz-c1-f1	3270	3660	4370	5040
Gnt-c1-f1	3470	3830	3910	5020
Dbs-c1-f1	3800	3990	5560	5920
Bst-c1-f1	2770	3020	3900	4280
Dlm1-c1-f1	4110	4770	5280	6010
Dlm2-c1-f1	3150	3610	4340	5070
Dlm2-c2-f1	2840	4940	5280	6690
Dlm3-c1-f1	3620	4360	5120	5900
Dlm3-c1-s	4050	4900	5370	5910
Dlm4-c1-f1	2900	3410	3940	4630
Dlm4-c1	3490	4300	4750	4920
Dlm5-c1-f1	3700	4700	5240	5840
Dlm5-c1-f2	2750	3190	3570	4520

Table 6. Splitting Tensile Strength of Concrete (MPa)

Mixture	7-day	14-day	28-day	90-day
Gvl1-c1-f1	2.90	3.31	3.79	4.34
Gvl2-c1-f1	3.03	2.96	3.45	4.62
Gvl3-c1-f1	3.31	3.65	4.00	4.69
Gvl4-c1-f1	2.83	3.45	3.79	4.55
Gvl5-c1-f1	2.76	3.17	3.38	4.14
Gvl6-c1-f1	2.76	3.45	3.72	4.48
Qtz-c1-f1	3.38	3.45	4.07	4.62
Gnt-c1-f1	3.03	3.65	3.72	4.21
Dbs-c1-f1	3.65	3.72	4.48	5.03
Bst-c1-f1	3.24	3.86	4.00	4.76
Dlm1-c1-f1	3.72	4.14	4.62	5.52
Dlm2-c1-f1	2.76	2.83	3.45	4.27
Dlm2-c2-f1	2.83	3.72	3.86	4.21
Dlm3-c1-f1	2.76	3.59	3.59	5.45
Dlm3-c1-s	3.86	4.21	4.21	5.03
Dlm4-c1-f1	3.24	3.45	3.72	4.48
Dlm4-c1	3.45	3.72	4.07	4.34
Dlm5-c1-f1	3.45	3.45	3.86	4.69
Dlm5-c1-f2	2.62	2.90	3.72	3.72

Table 7. Splitting Tensile Strength of Concrete (psi)

Mixture	7-day	14-day	28-day	90-day
Gvl1-c1-f1	420	480	550	630
Gvl2-c1-f1	440	430	500	670
Gvl3-c1-f1	480	530	580	680
Gvl4-c1-f1	410	500	550	660
Gvl5-c1-f1	400	460	490	600
Gvl6-c1-f1	400	500	540	650
Qtz-c1-f1	490	500	590	670
Gnt-c1-f1	440	530	540	610
Dbs-c1-f1	530	540	650	730
Bst-c1-f1	470	560	580	690
Dlm1-c1-f1	540	600	670	800
Dlm2-c1-f1	400	410	500	620
Dlm2-c2-f1	410	540	560	610
Dlm3-c1-f1	400	520	520	790
Dlm3-c1-s	560	610	610	730
Dlm4-c1-f1	470	500	540	650
Dlm4-c1	500	540	590	630
Dlm5-c1-f1	500	500	560	680
Dlm5-c1-f2	380	420	540	540

Table 8. Coefficient of Thermal Expansion (CTE) of Concrete

Mixture	28-day CTE (microstrain/°C)	28-day CTE (microstrain/°F)
Gvl1-c1-f1	10.4	5.8
Gvl2-c1-f1	10.5	5.9
Gvl3-c1-f1	10.7	5.9
Gvl4-c1-f1	9.9	5.5
Gvl5-c1-f1	9.7	5.4
Gvl6-c1-f1	10.1	5.6
Qtz-c1-f1	12.2	6.8
Gnt-c1-f1	9.5	5.3
Dbs-c1-f1	9.3	5.2
Bst-c1-f1	9.3	5.2
Dlm1-c1-f1	10.6	5.9
Dlm2-c1-f1	10.5	5.8
Dlm2-c2-f1	10.5	5.8
Dlm3-c1-f1	10.4	5.8
Dlm3-c1-s	10.5	5.8
Dlm4-c1-f1	10.6	5.9
Dlm4-c1	10.7	6.0
Dlm5-c1-f1	10.8	6.0
Dlm5-c1-f2	10.6	5.9