TPF-5(179) **QPR #04**

Evaluation of Test Methods for Permeability (Transport) and Development of Performance Guidelines for Durability

Quarterly Progress Report

To the

Pooled-Fund Research Program

(The participating states are: FHWA, Indiana, Michigan, Minnesota, Illinois, Kansas, Montana, Pennsylvania, Iowa, and New York)

For the Period of

April 1st, 2009
to
June 30th, 2009

Limited Use Document

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Prepared by Indiana Department of Transportation, Purdue University, and the National Ready Mixed Concrete Association

Figure 1: Overall Project Schedule

		Project Months																								Estimated
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Completed
Phase I:	**Literature Review of Concrete Permeability (Transport) Test Procedures and Models that Link Tests with Performance**																									
	Task 1: Literature Review	15	30	45	75	80	90	90	90	90	90	90														90
	Task 2: Prepare a Description of Each Procedure		5	15	25	30	90	90	90	90	90	90														90
	Task 3: Develop a Summary Document					10	30	50	70	90	90	90														90
Phase II:	**Evaluate of Promising Concrete Permeability (Transport) Tests and Recommend Procedures For Further Use**																									
	Task 1: Prepare Reference Concretes	15	25	40	60	60																				60
	Task 2: Describe Constituent Materials			10	20	40	40																			40
	Task 3: Develop Reference Material			15	15	20	40	40	40	50	50	50														50
	Task 4: Perform Tests					20		10	20	30	40	40														40
	Task 5: Evaluate Testing Procedures					20						20														20
	Task 6: Recommedations to Existing Procedures																									~
Phase III:	**Develop New or Improve Existing Permeability (Transport) Testing Procedures. Develop Protocols to Use these Tests, Evaluate the Precision and Bias of Tests**																									
	Task 1: Develop Modified Tests					10																				10
	Task 2: Evaluate Modified Tests																									~
	Task 3: Develop a Report of Modified Tests																									~
	Task 4: Develop New Testing Procedures																									~
	Task 5: Perform New Testing Procedures																									~
	Task 6: Evaluate New Testing Procedures																									~
	Task 7: Develop a Summary Document with Recommendations																									~
Phase IV:	**Correlate Permeability (Transport) Tests with Laboratory Tests that Evaluate Durability**																									
	Task 1: Prepare Specimens	5	15	25	45	65	65	70	75	80	85	90														90
	Task 2: Condition Specimens			10	25	30	30	35	40	45	50	50														50
	Task 3: Expose Specimens																									~
	Task 4: Evaluate Specimens																									~
	Task 5; Perform ASTM Tests								20	20	20	40														40
	Task 5: Evaluate Field Structures																									~
	Task 6: Develop Recommendations																									~
	Task 7: Develop a Summary Document																									~
Phase V:	**Develop Performance Criteria Guidelines that Link Permeability (Transport) Tests with Exposure Conditions and Anticipated Performance**																									
	Task 1: Prepare Draft of Criteria																									~
	Task 2: Address SAC Comments																									~
	Task 3: Prepare Revised Draft of Criteria																									~
Phase VI:	**Preparation of Techonology Transfer and Educational Materials**																									
	Task 1: Prepare Materials																									~
Deliverables								1																		~
Study Advisory Committee Meetings							1																			~

Continued

		Project Months																								Estimated
		25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	Completed
Phase III:	**Develop New or Improve Existing Permeability (Transport) Testing Procedures. Develop Protocols to Use these Tests, Evaluate the Precision and Bias of Tests**																									
	Task 1: Develop Modified Tests																									~
	Task 2: Evaluate Modified Tests																									~
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	Task 4: Develop New Testing Procedures																									~
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	Task 1: Prepare Materials																									~
Deliverables											2						3				4			5		~
Study Advisory Committee Meetings																										~

1 - Phase I draft report
2 - Phase III draft report
3 - Phase IV draft report
4 - Phase V draft report
5 - Phase VI draft report

Figure 2: Estimated Project Expenses

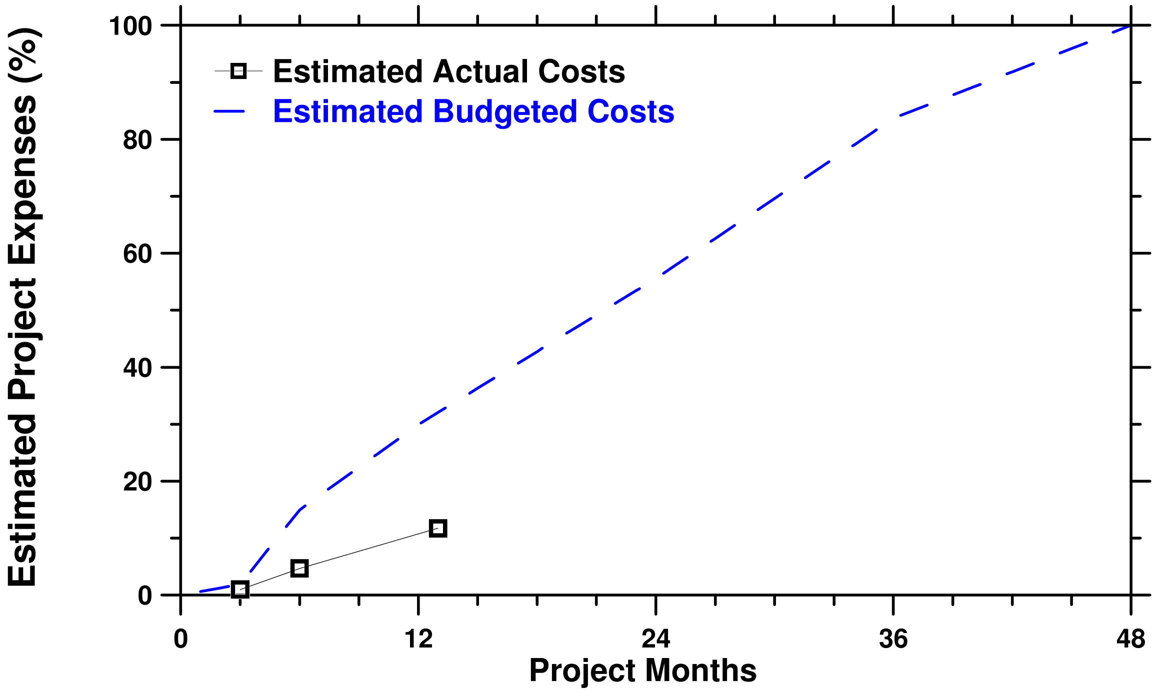

Figure 3: Project Budget and Expenses

Category	Detailed Description	Budgeted Cost	Billed Expense Through 6/30/09
Personnel			
	INDOT Staff (Tommy Nantung*)	~	~
	Purdue Faculty (Jason Weiss and Jan Olek)	$ 121,230	$ 60,880
	Post-Doctoral Research Assistant/Visiting Faculty	$ 168,240	
	Graduate Students	$ 177,848	
	Undergraduate Students	$ 8,679	
	Laboratory Technician	$ 29,343	
Laboratory Expenses			
	Scientific Equipment	$ 62,000	$ -
	Laboratory Supplies/Expendables	$ 13,000	$ 2,884
Travel			
	Domestic Travel	$ 8,400	$ -
Office Expenses			
	Communications	$ 3,000	$ -
	Supplies and Expenses	$ 4,760	$ -
	Printing and Duplication	$ 6,500	$ -
Study Advisory Expenses			
	Participant Travel to SAC	$ 54,000	$ 2,478
	Meeting Expenses	$ 6,000	$ -
Subcontracts			
	NRMCA Consultants	$ 220,000	$ 34,877
Total			
		$ 883,000	$ 101,118

* Costs are estimated on an In-Kind Basis from INDOT

** Note: Subcontractor expensed bills have not all posted to the accounting system

1.0 Summary of Progress

This report provides an update from the first quarter of the project. It covers the three month period ending June 30th 2009

During the reporting period work was performed primarily on Phases I and II. Additional preliminary work was preformed on Phase IV.

1.1 Phase I – Literature Review

The research on Phase I is focused on performing an extensive review of literature pertaining to the measurement of permeability (transport) in concrete. To date the research has focused on collecting a complete listing of papers and test methods currently in existence nationally and internationally for determining permeability. To manage the data obtained from this literature review the research team will focus on developing a summary of each existing permeability (or transport) test that includes:

- a description of the scientific principle behind a particular test,
- the application of the test,
- the size and conditioning of the specimens used in the test,
- the testing procedure,
- the methods used to evaluate the test,
- the advantages and disadvantages of a particular test,
- the length of time that a test takes to perform,
- the commercial availability of the test procedure/equipment, and
- an approximate cost and availability of the testing equipment.

The test methods will then be separated according to like scientific principles of operation and the most promising methods will be recommended for further study in phase II.

This data is being gathered from a conventional literature review that will make use of indexes such as the web of science, TRIS, COMPENDEX, NTIS, SHRP concrete and structures program, PCI, ACI, and AASHTO. In addition, surveys are being developed to be distributed to each state or agency to determine which permeability (transport) test procedures they are currently using. Additional surveys will be sent to International countries and test equipment manufactures

At the completion of Phase I, a report will be prepared that provides a review of the literature on permeability (transport) test methods. This will include the summaries as well as a thorough comparison of the methods and recommendations for Phase II. A draft of this report will be sent to the SAC Members prior to the first Study Advisory Committee meeting.

1.2 Phase II – Evaluate Promising Concrete Permeability (Transport) Tests

The research on Phase II is focused on evaluating several reference concrete mixtures. To fully evaluate the most promising tests, specimen curing, specimen conditioning (duration and relative humidity), sample size, air content, specimen maturity, and variations in mixture proportions that may be anticipated during construction will also be evaluated. This will enable the most promising test methods to be assessed and will indicate the resolution, repeatability, and robustness of these test procedures. Aspects associated with determining the influence of curing procedures, conditioning and curing duration will also be evaluated.

Purdue has begun to assemble materials and prepare samples for conditioning so that the samples can be adequately conditioned. A series of samples have been prepared and are currently conditioning. This includes several of the reference water to cement ratio mixtures. In addition samples have been collected from the field. Testing has begun however additional test methods are still being identified and some samples are still being conditioned.

Specific focus has been placed on electrical resistance methods and sorption measures to provide good baseline measurements. The research team also visited European laboratories (during a separately funded source) and performed a review of techniques that have been used there.

The NRMCA Research Laboratory (NRMCA-RL) is currently working on Phase II and IV with initial focus on the chloride penetration testing part as planned in the PFS. 6 out of 13 concrete mixtures were cast at the NRMCA Research Laboratory. The 6 mixtures covered 4 permeability levels (1 high, 2 moderate, 2 very low, 1 negligible).

Test Methods, Curing Conditions and Test Ages

- Normal Curing – Standard moist room curing starts immediately after making the specimens
- Accelerated Curing – 7 days of normal curing followed by 21 days of curing in 100F water

The following tests will be conducted for all the mixtures

- **Rapid Chloride Permeability test – RCPT (ASTM C1202)**

i) 28 day accelerated – 2 cyl
ii) 56 day normal curing – 2 cyl
iii) 26 week (182 d) normal curing – 2 cyl
iv) 78 week (546 d) normal curing – 1 cyl

- **1 minute Conductivity test (ASTM Draft)**

v) 28 day accelerated – 2 cyl
vi) 56 day normal curing – 2 cyl
vii) 26 week (182 d) normal curing – 2 cyl
viii) 78 week (546 d) normal curing – 1 cyl

- **Rapid Migration Test - RMT (AASHTO TP 64)**

i) 28 day accelerated – 2 cyl
ii) 56 day normal curing – 2 cyl
iii) 26 week (182 d) normal curing – 2 cyl
iv) 78 week (546 d) normal curing – 1 cyl

- **Chloride Diffusion Test (ASTM C1556)**

i) 56d (8 week) normal curing + 126d (18 week) in solution till 26 weeks – 2 cyl
ii) 56 d (8 week) normal curing + 490d (70 week) in solution till 78 weeks – 1 cyl
iii) 59d (8 week) normal curing + cyclic exposure (18 week using 4d in solution/3d at 100F-20%rh cycle) in solution till 26 weeks – 1 cyl
iv) 59d (8 week) normal curing + 49d (7 week) in solution till 15 weeks – 1 cyl to get standard Da value as per Life365 (although 365 uses a 28day Da as baseline).
v) 26 weeks normal cure +35 days in solution – 1 cyl (to get later age Da as per Life365. m-calcs)

- **Sorptivity Test (ASTM C1585)**

i) 28 day accelerated + 18 d specimen conditioning (C1585) – 2 cyls
ii) 56 day normal curing + 18 d specimen conditioning (C1585) – 2 cyls
iii) 26 week (182 d) normal curing + 18 d specimen conditioning (C1585) – 2 cyls

- **Absorption test BS 1881:122**

i) 10 day normal curing + 3 d in oven – 2 cyls
ii) 28 day accelerated + 3 d in oven – 2 cyls
iii) 26 week (182 d) normal curing + 3 d in oven – 2 cyls

The yield adjusted mixtures proportions and 28 day test results are provided in the Table below

Table 1. Yield Adjusted Mixture Proportions and Preliminary Test Results

Calculated Batch Quantities						
	0.49Ctrl	**0.49SL25**	**0.39SL50**	**0.49FA15**	**0.39FA30**	**0.34SL40SF5**
Type I/II cement, lb/yd^3	554	416	306	472	431	382
Slag, lb/yd^3		139	306			277
Fly ash, lb/yd^3				83	185	
Silica Fume, lb/yd^3						35
SCM, %	0	25	50	15	30	45
Coarse Agg. (No.57), lb/yd^3	2075	2074	2070	2081	2081	2086
Fine Aggregate, lb/yd^3	1303	1293	1314	1273	1267	1264
Mixing Water, lb/yd^3	272	272	239	273	240	236
w/cm	0.49	0.49	0.39	0.49	0.39	0.34
ASTM C494 Type A, oz/cwt	4.0	4.0	4.0	4.0	4.0	4.0
ASTM C494 Type F, oz/cwt	2.5	2.9	4.3	2.4	5.0	7.8
Fresh Concrete Properties						
ASTM C143, Slump, in.	7 1/2	4 1/2	8	7	6 3/4	9
ASTM C231, Air, %	1.4	1.7	1.3	1.5	1.6	1
ASTM C138, Density, lb/ft^3	156.5	156.1	157.7	155.7	156.5	159.3
ASTM C1064, Temperature, °F	76	76	75	76	75	75
Hardened Concrete Properties						
ASTM C39, Compressive Strength, psi						
28 days	6,830	7,550	10,520	6,640	7,970	12,440
Draft ASTM Standard, Water Absorption Test at 105 °C, %						
10d normal cure	2.89	2.24	1.69	3.25	2.33	1.43
28d accelerated cure	2.52	1.77	1.34	2.44	1.63	1.26

196d normal cure	2.30	1.80	1.29	2.29	1.44	1.49
ASTM C1202, Rapid Chloride Permeability, Coulombs						
28d accelerated cure	4657	1992	561	2414	723	166
56d normal cure	4674	1912	581	3013	1417	270
196d normal cure	3356	1581	496	1551	340	147
Draft ASTM Standard, 1 minute Conductivity, Sm^{-1}						
28d accelerated cure	0.019	0.009	0.003	0.009	0.003	0.001
56 normal cure	0.015	0.007	0.003	0.013	0.006	0.001
196d normal cure	0.010	0.005	0.002	0.006	0.002	0.001
AASHTO TP64, Rate of Penetration (RMT), mm/(V-hr)						
28d accelerated cure	0.065	0.030	0.004	0.046	0.015	0.003
56d normal cure	0.044	0.025	0.006	0.043	0.024	0.002
196d normal cure	0.047	0.016	0.006	0.025	0.006	0.002
ASTM C157, Length Change (Drying Shrinkage), %						
28 days^{+}	0.035	0.039	0.031	0.029	0.028	0.028
56 days^{+}	0.046	0.048	0.037	0.039	0.036	0.032
90 days^{+}	0.055	0.054	0.044	0.048	0.043	0.039
180 days^{+}	0.062	0.060	0.049	0.054	0.049	0.044
ASTM C 1585, Rate of Water Absorption (Sorptivity), x10^{-4} mm/s$^{1/2}$						
28d accelerated cure (Initial/Secondary)	10.0 / 7.5	3.1* / 2.8	1.8* / 1.7	7.5 / 4.6	4.8* / 2.1	2.6* / 0.86
56d normal cure (Initial/Secondary)	9.9 / 6.9	6.8 / 2.4*	2.6* / 1.4	20.0 / 13.0	7.1* / 3.3	4.1* / 1.9*
196d normal cure (Initial/Secondary)	6.8* / 6.8	4.1* / 1.3	4.9* / 1.3	4.1 / 2.4	3.6* / 1.8	1.2* / 0.82*
28d accel. cure (Initial/Secondary), g	1.77 / 6.85	0.82 / 2.59	0.66 / 1.75	1.48 / 4.93	1.20 / 2.71	0.51 / 1.13
56d normal cure (Initial/Secondary), g	1.78 / 6.74	1.06 / 2.94	0.67 / 1.62	2.62 / 12.2	1.4 / 3.76	0.87 / 2.17
196d normal cure (Initial/Secondary), g	1.34 / 5.74	0.96 / 1.81	1.13 / 1.94	1.09 / 2.73	0.95 / 2.12	0.64 / 1.14
ASTM C 1556, Chloride Diffusion, x 10^{-12} m^2/s						
Case 4 ^{A}	4.817	2.238	0.618^{-}	8.635	4.814	0.617^{-}
Case 3 ^{B}	10.521	3.200	1.244^{-}	6.454	3.119	0.812^{-}
Case 1 ^{C}	On-going	On-going	On-going	On-going	On-going	On-going
Case 5 ^{C}	On-going	On-going	On-going	On-going	On-going	On-going
ASTM C 1556, Surface Chloride, % by weight of concrete						
Case 4 ^{A}	1.160	1.766	1.304^{-}	0.963	0.751	1.349^{-}
Case 3 ^{B}	1.044	1.368	1.634^{-}	1.225	1.490	2.174^{-}
Case 1 ^{C}	On-going	On-going	On-going	On-going	On-going	On-going
Case 5 ^{C}	On-going	On-going	On-going	On-going	On-going	On-going

$^{+}$ Curing period in 70℉, 50% RH environment NOT included 7 days initial wet curing period in water bath
* a correlation coefficient less than 0.98 indicating that the rate can not be determined according to ASTM C1585
$^{-}$ 1st point at 1mm depth was included in the analysis

Developments in this Quarter

Chloride diffusion testing of Case 1 and Case 5 was completed in addition to Case 3, and Case 4 which had been done earlier and reported in the above Table.

Time was spent on data analysis. Rapid index tests results were compared with chloride diffusion test data. Preliminary observations show promising correlations between the early age RCPT results and chloride diffusion coefficients for scenarios Case 1, and Case 3. It was clearly that more mixes need to be tested and rapid index tests need to correlate with chloride penetration levels for two real life situations:

a. when the structures are in a complete or near complete saturation state such as in a submerged marine exposure or possibly bridge decks in high humidity regions where chloride ingress is primarily diffusion controlled
b. when the structures are not completely saturated such as bridge decks in low humidity regions where the chloride ingress could be due to sorption and diffusion.

Data analysis conducted between NRMCA and University of Toronto showed that the interpretation of surface chloride levels and diffusion coefficients from measured chloride profiles was consistent between NRMCA and University of Toronto procedures.

A conference call and multiple discussions were held between NRMCA and University of Toronto to ensure grinding of concrete layers and measurement of chlorides through the potentiometric titration was consistent. 15 concrete powder samples were tested for chlorides by NRMCA and University of Toronto to ensure that the NRMCA techniques are consistent with that of University of Toronto which has more than a decade of experience in conducting this test.

A detailed experimental plan was drawn up as given below.

Experimental Plan

w/cm	PC	15%FA	30%FA	25%SL	50%SL	7%SF	40%SL+5%SF
0.29	Yes - l						
0.34							~~**Yes - n**~~
0.39	Yes - m	Yes – l	~~**Yes - vl**~~	Yes - l	~~**Yes - vl**~~	Yes - vl	
0.49	~~**Yes - h**~~	~~**Yes – m**~~		~~**Yes - m**~~			
0.62			Yes - h		Yes - h		

The mixtures crossed out have already been tested. The remaining 7 mixtures will be cast in the NRMCA laboratory in July-August 2009. Curing conditions and most of the other test conditions are the same as that provided earlier with the only change being in the 5 cases for the chloride diffusion testing.

- **Chloride Diffusion Test (ASTM C1556)**

i) 56d (8 week) normal curing + 35d (5 week) in solution
ii) 6 months normal curing + 35d (5 week) in solution

iii) 18 months normal curing + 35d (5 week) in solution
iv) 56d (8 week) normal curing + cyclic exposure (18 week using 3d in solution/4d at 73F-50%rh cycle) in solution
v) 56d (8 week) normal curing + cyclic exposure (70 week using 3d in solution/4d at 73F-50%rh cycle) in solution

The objectives are as follows:
Cases i, ii, iii can be used to estimate the long term chloride ingress in that concrete in a submerged scenario where the ingress is mainly due to chloride diffusion. The aim would be to observe which of the rapid index tests correlates well with Da (at oldest age – Case iii). Cases iv, v are wet/dry chloride exposure and chloride ingress in that concrete is expected to be due to a combination of diffusion and absorption mechanisms. The aim would be to observe which of the rapid index tests correlates well with Da (at oldest age – Case v).

2.0 Proposed Activities for the Next Period

The research team had a SAC meeting during Quarter 3.

2.1 Phase I - Literature Review

The research team is completing the literature review and providing a draft to the stakeholders for review and discussion. This is near completion and is being completed by Amir Pourasee who is a post-doctoral associate that has been added to this project. This is the main task that he is currently working on so that this can be brought to completion.

2.2 Phase I - Survey of Permeability Test Methods

A survey of permeability test methods was prepared and sent to DOT, material suppliers and testing labs that evaluates the current state of the practice as it relates to permeability (transport tests). The survey outlined the most common tests used in the US. Data from the survey has been used in guiding the research program. Javier Castro a graduate research assistant is currently completing this phase of the research. Purdue ended up performing this task.

2.3 Phase II - Sample Preparation and Conditioning

Work will continue to prepare the reference concrete for Phase II and IV. The constituent materials will be fully characterized and the samples will be conditioned using both accelerated and natural curing conditions.

Progress on this phase has been slightly delayed as a renovation of the laboratory is currently underway that will be used to condition the samples. This renovation is scheduled to be completed in the August and a large number of samples can be exposed to conditioning at that time.

In addition the Purdue research team is currently designing and building two devices for measuring permeability based on the Swiss experience. They have also offered to test a small number of samples in a variety of equipment to provide additional data for comparison.

A new graduate research assistant will be added to this phase of the project in August.

2.4 Field Core Testing Program (PROPOSED NO COST ADDITIONAL WORK BY NRMCA)

In addition to that lab experimental program it would be useful to get concrete cores from structures between 10-30 years old from structures in marine - submerged, tidal zone, spray zones, deck (low relative humidity), deck (high relative humidity). These samples would be used by NRMCA to measure sorptivity, chloride profile on top 2 in., discard the next 1 inch and conduct ASTM C1556 chloride diffusion test on next 2 inches. Do 2 rapid index test results (RCPT, gas permeability) from sample just below that. So a 7 to 10 in. core thickness of 4 in. diameter may be required for this program. The aim would be to see if there is a unique relation between measured rapid index test result and calculated chloride diffusion coefficient from chloride profile. Also it would be worthwhile to compare those diffusion coefficients with mixture proportions and the 56 day rapid index results attained during quality assurance or mix qualification stage (if such is available).