**TPF-5(179)** **QPR #01-2010**

# 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, Wisconsin, and New York)**

## For the Period of

## July 1st, 2009
## to
## September 30th, 2009

**Limited Use Document**

This quarterly progress report is furnished only for review by members of the pooled fund research program and is to be regarded as fully privileged. The Dissemination of information included herein must be approved by the INDOT.

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 | 60 | 60 | 65 | | | | | | | | | | | 65 |
| | Task 4: Perform Tests | | | | | 20 | | 10 | 20 | 30 | 40 | 40 | 50 | 50 | 60 | | | | | | | | | | | 60 |
| | Task 5: Evaluate Testing Procedures | | | | | 20 | | | | | | 20 | 25 | 30 | 35 | | | | | | | | | | | 35 |
| | Task 6: Recommedations to Existing Procedures | | | | | | | | | | | | | 10 | 10 | | | | | | | | | | | 10 |
| **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 | 10 | 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 | 90 | 90 | | | | | | | | | | | 90 |
| | Task 2: Condition Specimens | | | 10 | 25 | 30 | 30 | 35 | 40 | 45 | 50 | 50 | 55 | 60 | 65 | | | | | | | | | | | 65 |
| | Task 3: Expose Specimens | | | | | | | | | | | | | 60 | | | | | | | | | | | | 60 |
| | Task 4: Evaluate Specimens | | | | | | | | | | | | | 60 | | | | | | | | | | | | 60 |
| | Task 5; Perform ASTM Tests | | | | | | | | 20 | 20 | 20 | 40 | 50 | 50 | | | | | | | | | | | | 50 |
| | 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 | | | | | | | | | | | | | | | | | | | | | | | | | ~ |
| | 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 | | | | | | | | | | | | | | | | | | | | | | | | | ~ |
| | Task 2: Condition Specimens | | | | | | | | | | | | | | | | | | | | | | | | | ~ |
| | Task 3: Expose Specimens | | | | | | | | | | | | | | | | | | | | | | | | | ~ |
| | Task 4: Evaluate Specimens | | | | | | | | | | | | | | | | | | | | | | | | | ~ |
| | Task 5; Perform ASTM Tests | | | | | | | | | | | | | | | | | | | | | | | | | ~ |
| | 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 | | | | | | | | | | | 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**

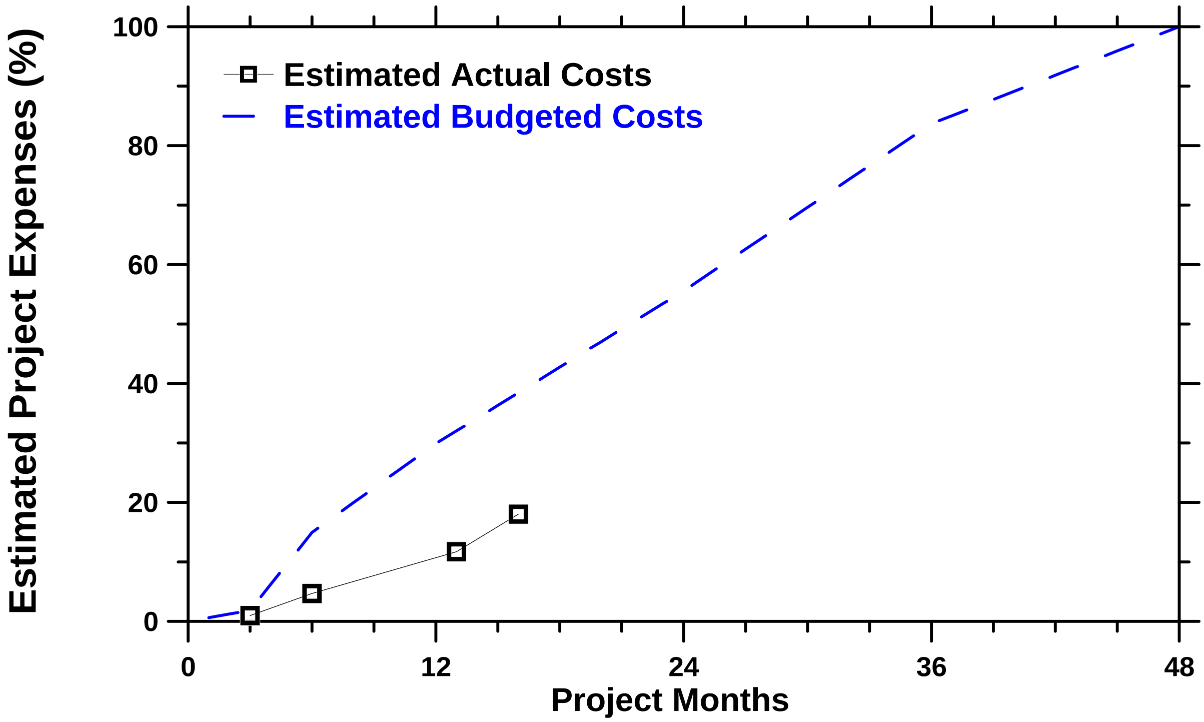


**Figure 3: Project Budget and Expenses**

| Category | Detailed Description | Budgeted Cost | Billed Expense Through 10/30/09 |
|---|---|---|---|
| **Personnel** | | | |
| | INDOT Staff (Tommy Nantung*) | ~ | ~ |
| | Purdue Faculty (Jason Weiss and Jan Olek) | $ 121,230 | |
| | 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 | |
| **Travel** | | | $ 106,507.13 |
| | 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 | |
| | Meeting Expenses | $ 6,000 | |
| **Subcontracts** | | | |
| | NRMCA Consultants | $ 220,000 | $ 52,675.35 |
| **Total** | | | |
| | | $ 883,000 | $ 159,182.48 |

* 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 fifth quarter of the project. It covers the three month period ending September 30th 2009.

During the reporting period work was performed primarily on Phases I and II. Additional preliminary work was preformed on Phases III and 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. The post-doc working on this project, Amir Pourasee, is completing this project as this is the main focus of his current work. 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.

## 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.

In addition, the research team has just completed samples that will be placed in the field at the INDOT test site to evaluate the internal humidity that can be expected in Indiana given five exposures. The exposures will include a 50% environment (indoors), a submerged sample, a vertical surface, a horizontal surface on a drainable base and a horizontal surface on a non drainable base.

The research team also visited European laboratories (during a separately funded source) and performed a review of techniques that have been used there. Based on this review two test methods are currently being developed which will include a method based on the South African oxygen permeability test and a test based on a test that is utilized by the Swiss. In addition, the Swiss have agreed to assist in using several European tests that they have at EMPA.

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

Freeze thaw (F-T) attack is another major concrete deterioration mechanism. Capillary sorption and water vapor diffusion are the two principal transport mechanisms that cause critical saturation of capillary pores which is necessary for freeze thaw damage. An air content of 5% to 7% with an air voids spacing factor less than 0.2 mm is typically necessary to maintain adequate freeze thaw resistance. While the air entrainment requirement is acceptable an attempt will be made to develop test and performance criteria as an alternative to the maximum w/cm requirement. ACI 318 states that for F1, F2, F3 categories max w/cm=0.45, min strength=4500 psi, and air content limits. It is clear that a low w/cm is required to ensure low water penetration and potential for critical saturation. By conducting mixes with different w/cm and various SCM dose and contents we will examine if F-T performance (as measured by no. of cycles for 15% mass loss or relative dynamic modulus of elasticity after 300 cycles) is better correlated with a rapid index test such as sorption or gas permeability criteria than w/cm. If at each w/cm, F-T performance varies widely depending on the test criteria the importance of the test criteria as opposed to w/cm is established. Also it would be determined whether some mixes with low w/cm and higher sorptivity/gas perm can have poorer F-T performance as compared to mixes with higher w/cm and lower sorptivity/gas perm which can again establish the importance of the test criteria as opposed to w/cm.

**ACI 318-08 F classes**

Moderate F1: Concrete exposed to freezing-and thawing cycles and occasional exposure to moisture
Severe F2: Concrete exposed to freezing-and thawing cycles and in continuous contact with moisture
Very severe F3: Concrete exposed to freezing-and thawing and in continuous contact with moisture and exposed to deicing chemicals

From the test results plots Concrete class F2 can be suggested to have RDM of 60-80% while F3 can have RDM>80% after 300 F-T cycles. It is hoped that these RDM and mass loss correlates with rapid index test criteria such as sorptivity and we can use those test criteria rather than RDM.

For C672 Y axis will be mass loss or visual rating

**Mixture Proportions Planned**

| w/cm | PC | 20%FA | 30%SL | 25%SL+5%SF |
|---|---|---|---|---|
| 0.40 | Yes-m | | | Yes-vl |
| 0.45 | Yes-m | Yes-m | Yes-m | Yes-vl |
| 0.50 | Yes-h | Yes-m | Yes-m | Yes-l |
| 0.60 | Yes-h | | | Yes-m |

May add some more mixes with different cement and aggregates

Crushed coarse aggregate (1.0" max) no. 57, natural sand FM=2.88
Adjust water reducer or high range water reducer (if any) for desired slump = 5 to 7 in.
Air entrained concrete mixtures – Target 5 to 6% air. Use AEA from same admix manufacturer

## 2.0 Proposed Activities for the Next Period

The research team had a SAC meeting during Quarter 3. It is anticipate that the next QPR will be held during the spring of 2010.

## 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. Amir Pourasee 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. Javier Castro, a graduate assistant and Phil Kompare a graduate assistant are currently working on this research.

Progress on this phase was slightly delayed as a renovation of the laboratory is currently underway that will be used to condition the samples. This renovation is scheduled was completed at the end of September and a new conditioning room is now available. In addition the laboratory is ready to begin to make samples for use in Phase IV. Pending final validation of the relative humidity and temperature control the 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 and the South African experience. The Swiss have also offered to test a small number of samples in a variety of equipment to provide additional data for comparison. It is currently anticipated that the equipment will be in place for testing at the end of the next quarter. The research team has samples conditioning so the research can

## 2.3 Phase IV NRMCA Test Methods, Curing Conditions and Test Ages (Lab)

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

For all mixtures measure the following: Slump, temperature, air content, density, Strength (28 days of moist curing followed by 28 days of air drying), Shrinkage (7 days moist curing followed by 90 days of air drying). May need to optimize some of this in order to make our usual batches.

**Durability Tests**

For all tests at all ages, make 2 cylinders unless otherwise stated. Make 6 extra cylinders for each mix, moist cure for 28 days and then ship 4 to Purdue/UT for gas permeability testing and keep the other 2.

- Rapid Chloride Permeability test (ASTM C1202)

i) 28 day accelerated
ii) 56 day normal curing
iii) 26 week (182 d) normal curing

- ASTM C666. Test 3 replicate specimens as recommended by C666 standard. 28 day moist curing followed by 28 day air drying in 50% RH and 70F and then start C666. Do dynamic modulus, mass change tests as required by C666. Do test until 1000 cycles or visible differences between mixtures which-ever occurs first. Also mixtures should not be tested for >25% mass reduction or 50% relative dynamic modulus of elasticity.

- ASTM C672. Test no. of specimens (2) recommended by C672 standard. 28 day moist curing followed by 28 day air drying in 50% RH and 70F and then start C672. Do test until 150 cycles or visible differences between mixtures which-ever occurs first. Measure mass loss and visual rating every 5 cycles.

- Sorptivity Test (ASTM C1585) after:

i) 28 day accelerated + 18 d specimen conditioning (C1585)
ii) 38 day normal curing + 18 d specimen conditioning (C1585)
iii) 26 week (182 d) normal curing + 18 d specimen conditioning (C1585)

- Absorption test BS 1881:122 – use latest ASTM draft

i) 28 day accelerated + 3 d in oven
ii) 56 day normal curing + 3 d in oven
iii) 26 week (182 d) normal curing + 3 d in oven

## 2.5 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).