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**Final Research Work Plan**

*Date (6/14/2017)*

*NRRA Rigid Team*

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| **Research Title:** | **Reduced Cementitious Material in Optimized Concrete Mixtures** |
| **Research Contact:** | **NRRA Rigid Team - #4 Long Term Research Need**  **Bernard Izevbekhai** |
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**Request Type:** Long Term Research Project using MnROAD test sections

**Contracting Process:** MnDOT Master University Direct Select – Contractor TBD

**Project Overview and Goals:**

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| With increasing environmental regulations, emphasis on lowering carbon footprint, as well as concerns about future availability of supplementary cementitious materials, DOTs are continually seeking ways to lower the use of cementitious materials in concrete pavements.  Through the National Concrete Consortium, several states have shared their efforts in reducing the total amount of cementitious materials in their concrete paving mixes. These efforts are supported by national and state research showing that the total cementitious content in paving mixes can be as low as 470 lb/CY, while still providing adequate strength. Concerns have been expressed however, regarding the durability of the surface with such mixes, especially with exposure to deicing chemicals. Several state DOT specifications currently allow contractors to use a cementitious content as low as 500 lb/CY, but contractors generally supply a minimum of 565lb/CY. Contractors are concerned primarily with early opening strength when using a reduced cementitious content mix. The validation or denial of the concerns described above would be helpful to both contractors and agencies. The MnROAD test sections in this study will be designed to identify the behavior and performance of concrete paving mixes with lower cementitious content.  For this study, two different cementitious content concrete pavement test sections will be constructed on the MnROAD Low Volume Road. Cell 138 will have a cementitious content between 430 to 470 lb/CY, Cell 238 will have a cementitious content between 475 to 500 lb/CY. Placement of these cells on the Low Volume Road will allow custom (i.e. increased) application of deicing chemicals compared to other cells at MnROAD.  The objectives of this study will be:   * + - * Determine the early-age characteristics (i.e. placement issues, slow strength gain) of concrete paving mixes containing lower cementitious contents * Determine causes of, or potential for, durability issues with very low cementitious content * Determine effect of reduced cementitious content on long term serviceability and economics of concrete pavements (i.e. benefits of reduced shrinkage)   + - * Develop recommended specifications, mixing and placement practices for the use of very low cementitious content concrete paving mixes. |

**MnROAD Test Cell Designs:**

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| **Test Cell 138 – Reduced Cementitious Material PCC – Mix A (Ultra-low cementitious content)**   * Rehabilitate existing Cell 38 (west end) - MnROAD Low Volume Road * Length: 258 feet * Construction activities: * Remove 258 feet of existing concrete pavement * Repair existing Class 5 base (if damaged) * Install sensors * Install T2 plates (for thickness verification) * Place new concrete layer * Fabricate research samples (cylinders/beams) * Place new gravel shoulders * Design Details: * Panel thickness = 8 inches * Panel size = Driving lane: 12 ft W x 15 ft L * Concrete Mix Design A = 430 to 470 lb/CY cementitious content * Shoulders = 2 inch thick shoulder gravel * Dowel bars = 1.25 inch diameter epoxy coated steel in standard MnDOT pattern * Joints = Single 0.125 inch width saw cut, depth = T/4, unsealed * Early research activities: * Monitor maturity * Conduct early-age warp and curl tests * Monitor joint deployment * Baseline FWD and truck load tests   **Test Cell 238 – Reduced Cementitious Material PCC – Mix B (Low cementitious content)**   * Rehabilitate existing Cell 38 (east end) - MnROAD Mainline * Length: 260 feet * Construction activities: * Remove 260 feet of existing pervious concrete overlay and underlying concrete pavement * Repair existing Class 5 base (if damaged) * Install sensors * Install T2 plates (for thickness verification) * Place new concrete layer * Fabricate research samples (cylinders/beams) * Place new gravel shoulders * Design Details: * Panel thickness = 8 inches * Panel size = Driving lane: 12 ft W x 15 ft L * Concrete Mix Design B = 475 to 500 lb/CY cementitious content * Shoulders = 2 inch thick shoulder gravel * Dowel bars = 1.25 inch diameter epoxy coated steel in standard MnDOT pattern * Joints = Single 0.125 inch width saw cut, depth = T/4, unsealed * Early research activities: * Monitor maturity * Conduct early-age warp and curl tests * Monitor joint deployment * Baseline FWD and truck load tests |

**Material Samples and Sensors:**

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| **Material Sampling and Testing Plan:**   * Samples to be fabricated or core samples taken and tested for each Cell:   + Compressive and Flexural Strength (1, 3, 7, 14, 28 days, 12, 24, 36 months)   + Modulus of elasticity, Poisson’s ratio   + Coefficient of thermal expansion   + Freeze/thaw durability (including surface scaling)   + Hardened air content and spacing * Testing during paving:   + Slump test   + Box test   + Air content = SAM (Super Air Meter) test   + Workability = VKelly test   + Durability test   + Resistivity Tests   + Calorimetry & Ultrasonic Pulse Velocity   **Sensor Layouts:**  Embedded sensor plans have been created for each cell. Primary sensors include:   * Strain due to environment: Vibrating wire strain gages * Dynamic load response: Quarter-bridge strain gauges * Temperature: Thermocouple trees * Maturity: Maturity loggers   Detailed maps of sensor locations in each cell are available on request. |

**Research Tasks:**

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| **MnDOT Tasks**   * **M1 - Construction Inspection**   + Check for correct cross slope and ensure smooth compacted base prior to concrete placement.   + Monitor concrete production at Ready-Mix plant.   + Record observations of placement or finishing issues.   + Monitor early joint deployment.   + ***Deliverable: Construction inspection report, due 6 months after completion.*** * **M2 – Sampling and testing of materials** **during paving** (Under separate MnDOT contract(s))   + Assist with quality control tests performed before and following the paver, including new performance field tests (i.e. Box test, SAM).   + Create research test samples (cylinders and beams).   + Map unbound layers with IC technology through MnDOT partnerships   + ***Deliverable: Transport research samples to testing lab. IC data and summary.*** * **M3 – Lab Testing and analysis of field samples created during construction** (Under separate MnDOT contract)   + Conduct laboratory tests on research samples collected during construction.     - Tests include: Compressive strength of cylinders, flexural strength of beam samples, modulus of elasticity, Poisson’s ratio and coefficient of thermal expansion tests of cylinder samples.   + Prepare summary report of results from lab tests and testing conducted during paving.   + Estimated task duration: 6 months.   + ***Deliverable: Summary testing report, to be reported at the next scheduled bi-annual NRRA meeting.*** * **M4 – Sensor Installations/Performance Monitoring**   + Assist with installation of conduits and instrumentation with minimal disturbance to grade. Fully document location of embedded sensors.   + Collect, process, and insert performance data into MnROAD database     - Performance data, collected bi-annually, includes: Visual distress, joint faulting, ride quality, friction testing, and joint opening measurements.     - Visual distress surveys and joint faulting measurements will increase in frequency as sections show increasing distress.   + Assist MnROAD staff with collection of seasonal load response data, processing data and inserting into MnROAD database.     - Includes MnROAD truck loading of slabs with embedded sensors in early spring, late spring, summer, and fall of each year while a significant number of sensors function.     - Includes FWD testing of 5 points per test panel, including joints (except summer), corners, mid- panel, and edge in early spring, summer, and late fall.   + Conduct early-age warp and curl testing (ALPS 2, Video Gauge).   + Monitor joint deployment (bi-monthly).   + Manage maturity sensor data (if installed separately from thermocouples).   + Estimated task duration: Seasonally for 4 years, or until sections fail.   + ***Deliverable: Data collection summary report every 6 months, to be delivered to principal investigator.*** * **M5 – Custom Deicing Chemical Application**   + Implement custom deicing application rate plan for Cells 138 and 238.   + Estimated task duration: Dependent on severity and duration of winter seasons. To be performed annually for up to 5 years, or until sections fail.   + ***Deliverable: Annual report of deicing application on Cells 138 and 238, to be delivered to principal investigator.*** * **M6 - Construction Report** (all 2017 efforts into one report)   + Gather as-built construction details and summarize material sample test results available within 6 months of completion of construction.   + Estimated task duration: 1 month (to be completed within one year from completion of construction).   + ***Deliverable: Chapter within overall construction report for 2017 MnROAD Construction.*** * **M7 – Final forensics and Final Report**   + Not in current budget. Will plan and budget for as cells fail and require replacement.   **Contractor Tasks**   * **T1** – **Literature search**    + Conduct literature search to identify similar experiments or documented field performance of concrete pavements containing lower quantities of cementitious materials.   + Collecting data from other agencies   + Estimated time: 2 months   + ***Deliverable: Task report - to be presented at next scheduled bi-annual NRRA meeting.*** * **T2 – Annual cell performance report (At cell ages of 1, 2, and 3)**    + Gather and organize all available data collected during previous year for each test cell.   + Create summary report using simple plots and discussions to highlight cell behavior and trends.   + Estimated time: 1 month per year   + ***Deliverable: Annual summary report of cell behavior and trends - to be presented at next scheduled bi-annual NRRA meeting.*** * **T3 – Analysis to determine the early-age characteristics of concrete paving mixes with lower cementitious content**    + Analyze sample test results, sensor data and field performance data as it relates to early-age characteristics (i.e. placement issues, slow strength gain).   + Identify lower limits on cementitious content that mitigate placement and strength gain issues during construction.   + Estimated time: 12 months. Task to be completed within one year after paving of test cells.   + ***Deliverable: Task report and recommendations to NRRA Rigid Team and Technical Transfer Committee - to be presented at next scheduled bi-annual NRRA meeting.*** * **T4** **– Analysis to determine causes of, or potential for, durability issues with very low cementitious content pavement mixes**   + Analyze sample test results, sensor data and field performance data as it relates to durability issues, particularly those related to the pavement surface.   + If no distress occurs in the test cells after 3 years, identify potential durability issues that may appear in the test cells at later ages. This might be based on the data from core samples extracted at that time.   + Estimated time: 12 months. Task to be completed as sections show significant distress, or after 3 years, whichever occurs first.   + ***Deliverable: Task report and recommendations to NRRA Rigid Team and Technical Transfer Committee - to be presented at next scheduled bi-annual NRRA meeting.*** * **T5** – **Analysis to determine effect of reduced cementitious content on long term serviceability and economics of concrete pavements**    + Analyze sample test results, sensor data and field performance data as it relates to the serviceability of concrete pavements with lower cementitious content mixes.   + Report the effects that lower cementitious mixes might have on reduced shrinkage, potential for reduced surface durability, or other factors that might affect the frequency of maintenance or the long–term ride quality of these type of pavements.   + Perform a life-cycle cost benefit analysis for concrete pavements with lower cementitious contents.   + Estimated time: 12 months. Task to be completed as sections show significant distress, or after 3 years, whichever occurs first.   + ***Deliverable: Task report and recommendations to NRRA Rigid Team and Technical Transfer Committee - to be presented at next scheduled bi-annual NRRA meeting.*** * **T6** – **Develop recommended specifications, mixing and placement practices for the use of very low cementitious content concrete paving mixes.**   + Utilize findings from cells to create implementable draft construction specifications and guidelines for low cementitious content concrete paving mixes.   + Estimated time: 6 months. Task to be completed as sections show significant distress, or after 3 years, whichever occurs first.   + ***Deliverable: Task report containing draft construction specifications and guidelines, to be delivered to NRRA Rigid Team and Technical Transfer Committee. Also to be presented at next scheduled bi-annual NRRA meeting.*** * **T7** **– Draft final report**   + Summarize analysis and findings from MnROAD low cementitious content concrete test cells constructed in 2017.   + Provide overall conclusions and recommendations for implementation of findings.   + Estimated time: 3 months. Task to be completed after 3 years, unless all sections fail prior to this time.   + ***Deliverable: Draft final report and recommendations to NRRA Rigid Team and Technical Transfer Committee. To be presented at next scheduled bi-annual NRRA meeting.*** * **T8 – Final report**   + Create final report and publish according to MnDOT report standards.   + Disseminate final report to NRRA website and members.   + Estimated time: 1 month. Task to be completed no later than 4 years after construction.   + ***Deliverable: Final report and recommendations to NRRA Technical Transfer Committee.*** |
| Special notes: While some tasks for an outside contractor could be done shortly after construction, other tasks will not be able to be started until significant data collection has been accomplished, or a particular section shows significant distress. For timely findings, contract should not exceed 4 years in duration. |

**Potential Benefits for NRRA Members:**

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| A reduced cementitious mix will cost less up front than a standard mix. A 470 lb/CY mix would amount to a 1 bag reduction of cement and approximately a $6/CY savings.  Reducing the total amount of cementitious material would also reduce shrinkage cracking and ultimately extend the service life of the pavement. |

**How Does This Build Upon Previous Research?**

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| * Gudimettla, Crawford, Grove - Optimizing Paving Mixtures for Durable, Cost Effective, 2 and Sustainable Concrete, 2015 * Peter Taylor, National Concrete Pavement Technology Center, Iowa State University - An Innovative Approach To Proportioning Concrete Mixtures, March 2015 * Konstantin Sobolev, University of Wisconsin – Milwaukee - Laboratory Study of Optimized Concrete Pavement Mixtures, 2015 4. Larry Sutter, WisDOT Brief - Reducing Cement Content in Concrete Mixtures, December 2011 * Yurdakul, Ezgi, "Optimizing concrete mixtures with minimum cement content for performance and sustainability" (2010). Graduate Theses and Dissertations. Paper 11878. * Long-Term Plan for Concrete Pavement Research and Technology—The Concrete Pavement Road Map (Second Generation): Volume I, Background and Summary, FHWA-HRT-11-065, April 2012 * J.M. Ruiz, R.O. Rasmussen, and M. Simon, ACI, Performance-Based Paving Concrete Mixture Design and Optimization, 6/1/2005 * 8. IMCP Manual, Chapter 6, Development of Concrete Mixtures, August 2007 |