TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): ____Kansas DOT__________________________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project #	**Transportation Pooled Fund Program - Report Period:**
TPF-5(174)	☐Quarter 1 (January 1 – March 31) 2015 ☐Quarter 2 (April 1 – June 30) ☐Quarter 3 (July 1 – September 30) ☒Quarter 4 (October 1 – December 31)

Project Title:
Construction of Crack-Free Concrete Bridge Decks, Phase II

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Lead Agency Project ID:	**Other Project ID (i.e., contract #):**	**Project Start Date:** **July 1, 2008**
Original Project End Date: **June 30, 2013**	**Current Project End Date:** **August 31, 2016**	**Number of Extensions:** 1

Project schedule status:

☐ On schedule ☒ On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	**Total Cost to Date for Project**	**Total Percentage of Work Completed**
$995,000*	$952,695.64**	91%

Quarterly Project Statistics:

Total Project Expenses This Quarter	**Total Amount of Funds Expended This Quarter**	**Percentage of Work Completed This Quarter**
$13,892.23	$13,892.23	3%

*$1,545,000 including KUTRI, BASF, and SFA funds, **$1,505,477.62 including KUTRI, BASF, and SFA funds

Project Description:
Cracks in concrete bridge decks provide easy access for water and deicing chemicals that shorten the life of the deck. Both materials increase the effects of freeze-thaw damage, while the deicing chemicals lead to higher concentrations of chlorides, and subsequently, corrosion of reinforcing steel. Measurements taken on bridges in Kansas show that dense, high quality concrete can significantly slow the penetration of chlorides to the level of the reinforcing steel. However, measurements taken at cracks show that the chloride content of the concrete can exceed the corrosion threshold at the level of the reinforcing steel by the end of the first winter. The formation of cracks, thus, significantly lowers the effectiveness of other techniques that are used to increase the life of a deck.

Research, some of which dates back nearly 40 years, has addressed the causes of cracking in bridge decks in North America. The research includes three detailed bridge deck surveys carried out by the University of Kansas since 1993. The results of the studies provide specific guidance on modifications in materials and construction techniques that will reduce the amount of cracking in bridge decks. In spite of this accumulation of knowledge, only a small number of these findings have been used to implement changes in bridge deck design and construction procedures. In specific cases, on-site observations indicate that it is possible to develop nearly crack-free bridge decks, if "best practices" are followed. Even with these few successes, most bridge decks exhibit significant cracking, exposing the reinforcing steel to deicing chemicals and subsequent corrosion and increasing the degree of saturation, which increases the impact of freeze-thaw cycles. The current level of understanding, however, offers strong direction for constructing bridge decks with minimum cracking.

This improved understanding was put to use during the first phase of this study, in which 20 low-cracking, high-performance concrete (LC-HPC) bridge decks, with an equal number of control decks, were planned for construction. The decks involved the use of low cement and water contents, increased air contents, optimized aggregate gradations that produce pumpable, workable, placeable, finishable concrete with cement contents as low as 535 lb per cubic yard, temperature control during placement, limited finishing, and early curing. The study was successful in identifying low-cracking portland cement concrete mixtures. Several additional approaches, however, have been identified that have the potential to increase the benefits of the project, including using mineral admixtures, new sources of aggregate, and new approaches to finishing. These approaches could not be fully exploited in Phase I. Data indicates that, when coupled with internal curing (provided by fully or partially saturated KsDOT approved limestone with 2½ - 3% absorption), using blast furnace slag as a replacement for portland cement can reduce drying shrinkage by an additional 40%. Two other mineral admixtures, fly ash and silica fume (microsilica), are also under investigation, although with less advantageous results. They will continue to be evaluated, however, because of their widespread use and the desire to construct decks with minimum permeability (achieved using silica fume) and environmentally beneficial waste materials (fly ash). The new mixtures must be investigated for their shrinkage and freeze-thaw properties, as well as construction qualities, especially the ability to use pumps to place the new mixtures. Optimum procedures for concrete placement and fogging will continue to be areas of special emphasis. Finishing techniques have been restricted in the current study. Additional work is necessary to determine if some of the restrictions (principally on the placement and finishing equipment) may be lifted.

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

TASK 1: Update plans to construct bridge decks with minimum cracking by incorporating "best practices" dealing with materials, construction procedures, and structural design. This step involves improving techniques in use in Phase I and meeting with department of transportation personnel from multiple states, as well as other experts, to select the procedures to be used and the bridge types to which they will be applied.

This task was largely completed during the Annual Meeting of Pooled Fund Sponsors held in Kansas City, MO at the Kansas City Airport Hilton on July 24, 2008, as well as in meetings with KDOT officials as reported in the report for the 1st quarter of 2009. This task will remain open until the end of the project to allow for slight modifications to LC-HPC bridge deck specifications and additional LC-HPC bridge deck construction as warranted.

90% COMPLETE

TASK 2: Perform laboratory work to evaluate the effects of slag cement, fly ash, silica fume, shrinkage reducing admixtures, and internal curing on the performance of concrete mixtures for use on LC-HPC decks.

A number of mixtures are currently being analyzed for shrinkage, scaling resistance, freeze-thaw performance, settlement cracking, strength, and air void properties in hardened concrete.

Mixtures containing various dosages of SRA-5, a shrinkage reducing admixture (SRA), are currently undergoing free shrinkage tests. Freeze-thaw and scaling tests are complete for this series of mixtures. Air void analysis on hardened specimens will be performed in the future.

Mixtures containing various dosages of SRA-4 have been cast and are being tested for free shrinkage. Freeze-thaw and scaling tests are also complete for this series of mixtures. Air void analysis on hardened specimens will be performed in the future.

Mixtures containing SCA-2, a shrinkage compensating admixture (SCA), are currently undergoing free-shrinkage tests.; Results for freeze-thaw durability and scaling tests were summarized in previous reports.

Mixtures containing various dosages of SRA-5, SRA-4 and SCA-2 are currently being evaluated for free shrinkage including deformations within the first 24 hours - data that is not normally collected when testing in accordance with ASTM C57.

A settlement cracking test procedure has been developed. Specimens are 12” x 12” and 8” deep with a No. 6 reinforcing bar with 1.5” top cover (from center of the rebar). They are cast in two lifts and consolidated with vibration. The specimens are then air cured in a room with constant temperature (73º ± 3º) and humidity (50% ± 5%). After 24 hours they are checked for cracking. The tester uses their naked eye to find cracks in the area above the bar. When the widest crack is found, a crack comparator is used to determine the width of the crack in mils (0.001 in.). Finally the total length of the cracks is measured and recorded.

91% COMPLETE

TASK 3: Work with state DOTs, designers, contractors, inspectors, and material suppliers to modify designs, specifications, contracting procedures, construction techniques, and materials to obtain decks exhibiting minimal cracking.

This task was largely completed during the Annual Meeting of Pooled Fund Sponsors held in Kansas City, MO at the Kansas City Airport Hilton on July 23, 2009, as well as in meetings with KDOT officials as reported in the report for the 1st quarter of 2009. Additional decks have been added since 2009 –primarily decks containing synthetic fibers. This task will remain open until the end of the project to allow for modifications to LC-HPC bridge deck specifications, construction methods and materials as warranted.

90% COMPLETE

TASK 4: Select and schedule bridges to be constructed using “best practices,” and pre-qualify designers and contractors in application of the techniques. To date, 14 bridges in Kansas, two in South Dakota, four in Minnesota, and one in Missouri have been identified for construction. Twenty additional bridges are proposed for Phase II. Researchers from the University of Kansas and state DOT personnel will work closely with designers and contractors to achieve the desired results. Pre-qualification of designers and contractors includes the presentation of workshops sponsored by the University of Kansas to help educate and train engineers in implementing the “best-practices” identified in Tasks 1 and 3.

For Phase II, a total of seven LC-HPC bridge decks have been constructed to date. Four LC-HPC bridge decks have been constructed in Minnesota and three LC-HPC bridge decks have been constructed in Kansas, with the 3rd Kansas LC-HPC bridge deck completed on September 28, 2011. Details on the construction of the first two bridge decks can be found in the 4th Quarter report for 2010. Details on the 3rd deck can be found in the 3rd Quarter report for 2011. Additional bridges are planned in Minnesota and Kansas, although these will be constructed under the provisions of a follow-on Pooled-Fund Study.

Seven bridge decks containing fibers have been constructed in Kansas. Two of the seven were deck replacements of north and south bound I-635 over State Avenue located in Wyandotte County, each completed in two placements. Both decks contained polypropylene macrofibers and the south bound deck contained glass fiber-reinforced polymer reinforcement. The first deck was constructed in the third quarter of 2013 and the second deck was constructed in the fourth quarter of 2013. KU personnel were not present during construction of the first placement of the first deck while the other three placements were completed with KU personnel in attendance monitoring construction. The third deck is east bound US-24 over Union Pacific Road and contains polypropylene microfibers. KU personnel were not present during the construction of this deck. The fourth deck, east bound US-24 over Union Pacific Railroad, was constructed in two placements on August 19 and 26, respectively. The deck contained F-4 polypropylene microfibers, and was constructed with KU personnel in attendance. The fifth, west bound K-10 over North Canal located at Douglas County, was constructed on November 10 with KU personnel present at the site, this deck contained F-3 macrofibers, Class C fly ash and slag. The sixth (Haskell over K-10) and seventh (31st over K-10) decks, both located at Douglas county, were constructed on May 12 and June 1, respectively, with KU personnel present during the construction. These two decks contained concrete with F-3 macrofibers with type C fly ash and slag.

This task remains open until the end of the project to allow for additional bridge construction as requested.

91% COMPLETE

TASK 5: Perform detailed crack surveys on the bridge decks one year, two years, and three years after construction. The surveys are performed using techniques developed at the University of Kansas that involve identifying and measuring all cracks visible on the upper surface of the bridge deck. The majority of the early surveys will be done by the University of Kansas. As the project progresses, teams outside of the State of Kansas will be trained in the survey techniques. Three teams in South Dakota have been trained to date.

Annual crack surveys of LC-HPC and associated control decks were conducted during the summer. Crack densities for the LC-HPC decks were found to be lower than those observed for the control decks. Additional crack surveys were also conducted on bridges that were constructed with prestressed girders on US-59 south of Lawrence, KS. Bridge surveys were also performed on fiber and their control decks, including NB and SB I-635 over State Avenue, EB and WB US-24 over Union Pacific Railroad and Menoken Rd. 39 bridges were surveyed in total. Initial inspections on 3 newly constructed fiber decks in South Lawrence Trafficway (SLT) project were performed this quarter.

91% COMPLETE

TASK 6: Correlate the cracking measured in Task 5 with environmental and site conditions, construction techniques, design specifications, and material properties and compare with earlier data. Similar data from participating states, where it exists, will be incorporated in the analysis. Actual costs and future cost estimates will be compared with potential benefits.

The correlation of cracking with the factors listed above is completed when major summary reported are completed. The last correlation was made in January 2014 and is available at https://iri.drupal.ku.edu/sites/iri.drupal.ku.edu/files/files/pdf/SM%20107.pdf .

91% COMPLETE

TASK 7: Document the results of the study. A final report will be prepared and disseminated to participating states regarding the findings of Tasks 1-6.

The results of the study through 2012 are documented in:

Pendergrass, B. and Darwin, D., "Low-Cracking High-Performance Concrete (LC-HPC) Bridge Decks: Shrinkage-Reducing Admixtures, Internal Curing, and Cracking Performance ," *SM Report* No. 107, University of Kansas Center for Research, Inc., Lawrence, Kansas, January 2014, 625 pp. available at https://iri.drupal.ku.edu/sites/iri.drupal.ku.edu/files/files/pdf/SM%20107.pdf

In the report, the development, construction, and evaluation of LC-HPC bridge decks are described based on laboratory test results and experiences gained during the construction of 16 LC-HPC decks. Free shrinkage and durability of LC-HPC candidate mixtures are evaluated, with emphasis on internal curing and shrinkage reducing admixtures. A description of the construction and evaluation of LC-HPC and control bridge decks constructed in Kansas is presented in the report.

Crack survey data for 2011, 2012, and 2013 are presented in:

Bohaty, B., Riedel, E., and Darwin, D., "Crack Surveys of Low-Cracking High-Performance Concrete Bridge Decks in Kansas 2014-2015," *SL Report* 13-6, University of Kansas Center for Research, Inc., Lawrence, Kansas, December 2013, 153 pp. available at https://iri.drupal.ku.edu/sites/iri.drupal.ku.edu/files/files/pdf/SLR13_6.pdf

Crack survey data for 2014 and 2015 are presented in:

Alhmood, A., Darwin, D., and O'Reilly, M., "Crack Surveys of Low-Cracking High-Performance Concrete Bridge Decks in Kansas 2011-2013," *SL Report* 15-3, University of Kansas Center for Research, Inc., Lawrence, Kansas, September 2015, 116 pp. https://iri.ku.edu/sites/iri.ku.edu/files/files/pdf/SLR15_3.pdf

Results acquired after completion of Alhmood et al. (2015) will be documented in subsequent reports.

91% COMPLETE

TASK 8: Update the training program developed (and currently being presented) in Phase I to assist the participating states in implementing the findings of the study. The program consists of workshops to be held at the representative state DOT offices. These workshops are individually coordinated with each participating DOT. A technical committee, structured with one representative from each state providing funds, will oversee the project. A meeting of the committee will be held each year, as has been done for Phase I. The first meeting is scheduled for July 24, 2008.

Information was disseminated at the annual meeting on July 19th, 2012 at the Kansas City Airport Hilton. Meeting CDs were sent to all representatives.
100% COMPLETE

Anticipated work next quarter:

Tests evaluating settlement cracking will continue next quarter. Testing will continue on synthetic fibers mixtures to evaluate its effects on the workability, strength and settlement of concrete. The influence of concrete temperature, water to cement ratio and slump on settlement cracking will be evaluated.

Mixtures containing various dosages of SRA-6 will be tested for free shrinkage, scaling resistance, and freeze-thaw durability; air-void analysis of hardened specimens will be also performed.

Mixtures containing SCA-1 and SCA-2 are currently being evaluated for early-age deformation and free shrinkage, results will be presented in next quarter. The purpose of this study is to verify the effectiveness of shrinkage compensating admixtures.

Mixtures containing SRA-4 or SRA-5 that failed in scaling will be re-evaluated for free shrinkage, scaling, freeze-thaw, and hardened air-void analysis.

Air-void analysis on hardened concrete will continue. A selection of specimens will be tested by the KDOT lab using manual linear transverse method, the same specimens will then be tested at KU using automatic linear transverse method by RapidAir 457 to validate the automated test method.

A series of mixtures containing combinations of crack reduction technologies such as SCMs, LWA, different types of SCAs and SRA, and synthetic fibers will be evaluated for free shrinkage (including their early age deformation), freeze-thaw and scaling behaviors.

Significant Results this quarter:

<u>LABORATORY RESULTS:</u>

Concrete mixtures containing 8, 24 and 40 fl oz. per 100 lb of cement of SRA-5 are undergoing free shrinkage tests. After 140 days of drying, mixtures containing 8, 24 and 40 fl oz. of SRA-5 have an average drying shrinkage of 550, 510 and 355 microstrain, respectively. The control mixture has an average drying shrinkage of 515 microstrain. The mixture with 8 fl oz. of SRA-5 exhibits 35 microstrain greater shrinkage than the control mixture. The mixture with 24 fl oz. of SRA-5 exhibits shrinkage similar to the control mixture. The mixtures containing 40 fl oz. of SRA exhibit significantly lower shrinkage than the control mixture, with a shrinkage reduction of 160 microstrain. These observations suggest that this SRA is performing well at its higher recommended dosage (40 fl oz.) compared to when a dosage of 8 fl oz and 24 fl oz is used. The recommended dosage range for this SRA is 8-40 fl oz. per 100 lb of cement. The initial scaling tests on mixtures containing SRA-5 are complete. Test results indicate that the mixture with 8 fl oz. per 100 lb of cement maintained low mass loss through 56 freeze-thaw cycles (comparable to a control mixture with no SRA dosage); however, mixtures containing 24 and 40 fl oz. per 100 lb of cement failed the test, experiencing mass losses greater than the failure limit of 0.2 lb/ft^2 after 21 and 35 freeze-thaw cycles, respectively. Mixtures that failed the test will be re-tested to validate these findings. In freeze-thaw tests, all the mixtures containing SRA-5 passed the test by maintaining at least 99.8% of their initial dynamic modulus at the end of 300 freeze-thaw cycles according to ASTM C-666. Mixtures containing SRA-5 are currently being evaluated for free shrinkage while their early age deformation in first 24-hour is accounted for; the early age deformations measured starting at the final set (5 hours after casting) to end of the first day after casting of the two mixtures containing 40 fl oz and one containing 24 fl oz of SRA-5 exhibit expansions of 97, 60 and 80 microstrain, respectively.

Concrete mixtures containing 0.5% and 0.75% by weight of cement of SRA-4 are undergoing free shrinkage tests. Results indicate that after 230 days of drying, mixtures containing 0.5 and 0.75% of SRA-4 have an average drying shrinkage of 380 and 290 microstrain, respectively. The control mixture for this series has an average drying shrinkage of 380 microstrain. The results are indicative of a reduction of drying shrinkage (maximum of 90 microstrain compared to control specimen) in first 230 days of drying caused by this SRA, while the mixture with 0.5% of SRA-4 exhibits shrinkage similar to the control mixture. Scaling tests are complete on mixtures containing SRA-4; the results indicate that, the mixture containing either 0.5% or 0.75% of SRA-4 by weight of cement failed the test with mass losses higher than the failure limit of 0.2 lb/ft^2 after 35 and 21 freeze-thaw cycles, respectively. The control mixture, which did not contain SRA-4, exhibited low mass loss by the end of 56 freeze-thaw cycles. Mixtures that failed the test will be re-evaluated in the future. In freeze-thaw tests, all mixtures passed the test by maintaining at least 99.7% of their initial dynamic modulus at the end of 300 freeze-thaw cycles. A mixture containing 1% of SRA-4 is currently being evaluated for free shrinkage while the early age deformation in first 24-hour is accounted for; the early age deformation measured starting at the final set (5 hours after casting) to end of the first day after casting of the mixture containing 1% of SRA-4 shows a slight expansion, 17 microstrain.

Concrete mixtures containing 3%, 4.5%, and 6% by weight of cement of SCA-2, a Shrinkage Compensating Admixture, have undergone a year of drying shrinkage testing. Freeze-thaw and scaling tests are complete on this series of mixtures and were presented in the last quarterly report. Results indicate that, after 365 days of drying, mixtures containing 3, 4.5 and 6 % of SCA-2 exhibit average drying shrinkage of 523, 467 and 353 microstrain, respectively. The control mixture has an average drying shrinkage of 537 microstrain, indicating that SCA-2, when used in dosages greater than 3% by weight of cement, reduces the drying shrinkage. Because the initial measurement in these tests is taken at 24 hours, the early-age expansion of the concrete is not included in these results. Mixtures containing various dosages of SCA-2 (3 and 6%) are currently being evaluated for free shrinkage with the early age deformation in first 24 hours is accounted for; the early age deformation measured starting at the final set (5 hours after casting) to end of the first day after casting of the two mixtures containing 3% and 6% of SCA-2 shows an expansion of 93 and 270 microstrain, respectively, suggesting that SCA-2 causes significant expansion during the early hours after the final set. The mixture containing 6% SCA-2 showed the lowest mass loss among all specimens in this series, including the control mixture with no SCA-2. Freeze-thaw testing is complete for SCA-2 mixtures, all specimens maintained at least 98% of initial dynamic modulus, well above the failure limit of 95%. All the mixtures containing SCA-2 passed the scaling tests.

Tests to evaluate the settlement cracking performance of concrete are underway. Mixtures containing synthetic fibers perform better than control mixtures with the same slump. Testing will continue in next quarter.

Circumstances affecting project or budget. (Please describe any challenges encountered or anticipated that might the completion of the project within the time, scope and fiscal constraints set forth in the agreement, alon recommended solutions to those problems).

Nothing to report.