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*	$834,764.18**	82%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$49,527.00	$49,527.00	3%

*$1,545,000 including KUTRI, BASF, and SFA funds, **$1,321,363.05 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, strength, and air void properties in hardened concrete.

Mixtures containing various dosages of SRA-XT, a shrinkage reducing admixture (SRA) produced by Euclid Chemical, have been cast and are under curing. The specimens will be tested for free shrinkage, freeze-thaw durability, and scaling resistance. Air void analysis on hardened specimens will be performed in the future.

Mixtures containing Control 40, an SRA produced by Sika, are currently being re-evaluated (for the mixtures that failed the limits for scaling and freeze-thaw previously) for free-shrinkage and final results for scaling and freeze-thaw durability tests are obtained this quarter.

Mixtures containing Eclipse 4500, an SRA produced by W. R. Grace, are being re-evaluated to verify previous test results. Mixtures containing 1.50% and 2.25% of Eclipse 4500 by weight of cement failed both the scaling and freeze-thaw test in previous trials. Previous Eclipse 4500 mixtures are still under assessment for free shrinkage; air void analysis on hardened concrete is currently underway.

Mixtures containing Conex, a shrinkage compensating admixture (SCA) produced by Euclid Chemical, are currently undergoing free-shrinkage test; final results for freeze-thaw durability test are obtained this quarter, scaling test results are summarized in previous report.

One mixture containing 10% volume replacement of total aggregate with pre-wetted LWA, one containing 10% LWA with 30% weight replacement of cement with slag, and two containing 10% LWA, 30% slag and 3% replacement by weight of cement with silica fume are currently undergoing free-shrinkage evaluation. Freeze-thaw and scaling tests are complete on this series of mixtures.

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.

82% 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 under consideration in Minnesota and Ohio.

Seven bridge decks containing fibers either have been constructed or are planned for construction in Kansas. To date, five of the seven decks have been constructed. Two of the four 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 on the first placement during the construction; 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 completed deck, east bound US-24 over Union Pacific Railroad, was constructed in two placements on

August 19 and 26, respectively. The deck contained F70 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 Strux 90/40 Macrofibers, type C fly ash and slag. The remaining two decks are scheduled to be constructed in next quarter in Douglas County and will contain synthetic Macrofibers, KU is in contact with the project manager and will monitor the construction.

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

82% 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 completed last 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 completed on bridges on US-59 and on the I-635 over State Ave. deck replacements completed last year utilizing fibers. Nine bridge decks were surveyed in Virginia this quarter, five of which were constructed using an SRA, three that used a lightweight concrete, and one control deck. Funding for the surveys was provided by the ACI Foundation. It was initially thought that the lightweight bridge decks would involve some degree of replacing normalweight aggregate with lightweight aggregate to gain the benefits of internal curing. It was later found that the bridge decks had a conventional sand-lightweight concrete mixes. A report on the surveys has been completed.

82% 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 .

82% 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 through 2011, 2012, and 2013 is presented in:

Bohaty, B., Riedel, E., and Darwin, D., "Crack Surveys of Low-Cracking High-Performance Concrete Bridge Decks in Kansas 2011-2013," *SL Report* 13-6, University of Kansas Center for Research, Inc., Lawrence, Kansas, December 2013, 153 pp.

Results acquired after completion of Pendergrass and Darwin (2014) and Bohaty et al. (2013) will be documented in subsequent reports.

82% 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 Acti-Gel mixtures to evaluate its effects on the workability and settlement of concrete. Mixtures containing synthetic or steel fibers will be tested. The influence of concrete temperature, water to cement ratio and slump on settlement cracking will be evaluated.

Mixtures containing various dosages of Control-75 or Control-220, SRAs produced by Sika Corporation, will be tested for free shrinkage, scaling resistance, and freeze-thaw durability; air-void analysis of hardened specimens will be also performed.

Mixtures containing Eclipse 4500 will be retested using air entraining and water reducing admixtures from W. R. Grace. The purpose of this series of retests is to eliminate possible compatibility problems between admixtures (in previous tests admixtures were made by different manufacturers) that may have caused previous mixtures to fail in scaling and freeze-thaw tests.

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

Cracking surveys for LC-HPC, control, and fiber bridge decks will start in May. Cracking surveys for this year, 2015, will include five bridge decks that were constructed with fiber reinforced concrete, three of which will be surveyed for the first time. A report analyzing the cracking performance of the bridges based on the surveys conducted in 2014 and 2015 will be prepared by the end of 2015. Moreover, a KU team will be present during the construction of two remaining fiber decks that are located in Douglas County and planned to be poured in next quarter.

Significant Results this quarter:

<u>LABORATORY RESULTS:</u>

Concrete mixtures containing cement replacements of 30% slag and 3% silica fume and different dosages of Eclipse 4500 (0.75%, 1.5%, 2.25% by weight of cement) with and without a 10% replacement with pre-wetted lightweight aggregate (LWA) by volume of aggregate are currently undergoing free shrinkage testing. After 320 days of drying, mixtures with 0.75, 1.5 and 2.25% Eclipse 4500 (by weight of cement) have an average drying shrinkage of 427, 350 and 365 microstrain, respectively, while the control mixture has an average shrinkage of 600 microstrain. Additional testing is planned.

After 320 days of drying, the mixture with 10% replacement of pre-wetted LWA containing 0.75% of SRA has an average shrinkage of 463 microstrain. A mixture with no SRA, 10% pre-wetted LWA replacement, along with 30 and 3% fly ash and silica fume replacements of cement has an average shrinkage of 410 microstrain, while the same mixture without 3% silica fume replacement of cement has an average shrinkage of 490 microstrain, indicating an effect of silica fume addition on decreasing the drying shrinkage (about 80 microstrain). The mixture with a 10% replacement of LWA with no SRA has an average drying shrinkage of 565 microstrain indicating that the effect of slag and silica fume replacement of cement on reducing the drying shrinkage is superior (about 155 microstrain difference). Finally, the control mixture with no LWA and no SRA has an average drying shrinkage of 600 microstrain, the highest in this series.

Freeze-thaw testing is complete on mixtures containing Eclipse 4500 and mineral admixtures. Mixes containing 1.5% and 2.25% SRA by weight of cement failed the test, with only 93% and 91% of remaining dynamic modules, respectively. All other mixtures passed the test by maintaining at least 95% of initial dynamic modulus. One possible reason for the failure of high SRA dosage specimens is that the air entraining admixture and water reducing admixture used were not from same company as SRA and may have caused compatibility problem. To validate previous results, this series of mixtures will be re re-evaluated in next quarter with all mixtures supplied by W. R. Grace.

Scaling tests are complete on mixtures containing Control 40. The mixture with a 2% dosage rate of Control 40 experienced a mass loss greater than the failure limit of 0.31 lb/ft^2 specified in the scaling test (BNQ NQ 2621-900) before finishing 56 freeze-thaw cycles. Therefore, a retest of the 2% Control 40 mix was completed. Both the retested 2% Control 40 and the 1% Control 40 mixes passed, that is, they did not exceed the failure limit. The retested 2% Control 40 mix also passed freeze-thaw test by maintaining 96% of its initial dynamic modulus; the mixture containing 1% Control 40 is currently under freeze-thaw testing; after approximately 50 freeze-thaw cycles, no drop initial dynamic modulus has been observed.

Scaling tests are also under way for mixtures containing Acti-Gel and fly ash. Although these tests are not yet complete, none of the mixtures have exceeded the failure limit.

Concrete mixtures containing 3%, 4.5%, and 6% by weight of cement of Conex, an SCA produced by the Euclid Chemical Company, are currently undergoing free shrinkage test, scaling tests are complete on this series of mixtures. After 210 days of drying, mixtures containing 3, 4.5 and 6 % Conex SCA have average drying shrinkages of 490, 463 and 323 microstrain, respectively. The control mixture has an average drying shrinkage of 497 microstrain, indicating that Conex reduces the drying shrinkage. In the scaling test, all Conex mixtures exhibited low mass loss after 56 freeze-thaw cycles. The mixture containing 6% Conex showed the lowest mass loss among all specimens in this series, including the control mixture with no SRA. Freeze-thaw testing is complete for Conex mixtures, all specimens maintained at least 98% of initial dynamic modulus, well above the failure limit of 95%.

Mixtures containing 0.5, 0.75 and 1% of SRA-XT produced by Euclid Chemical are either in their initial stages of tests or their curing period. Results will be reported next quarter.

Tests to evaluate the settlement cracking performance of concrete are underway. After testing about forty batches representing control mixtures, the results indicate that, on average, cracking increases for the control mixtures as slump increases. In addition, mixtures containing Acti-Gel and Forta 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 affect 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.