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 # *TPF-5(174)*		**Transportation Pooled Fund Program - Report Period:** ☐Quarter 1 (January 1 – March 31) ☐Quarter 2 (April 1 – June 30) XQuarter 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 X 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*	$739,553.84	76%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$118,272.16	$118,272.16	3%

*$1,545,000 including KUTRI, BASF, and SFA funds, **$1,226,152.71 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 Control 40, a shrinkage reducing admixture (SRA) produced by Sika, are currently being re-evaluated for free-shrinkage, scaling resistance and freeze-thaw durability to validate previous test results. Some mixtures containing Control 40 failed the scaling test in previous trials.

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 the scaling test in previous trials. Previous Eclispe 4500 mixtures are still under assessment for free shrinkage and freeze-thaw durability; air void analysis on hardened concrete will be performed in the future.

Mixtures containing Conex, a shrinkage reducing admixture (SRA) produced by Euclid Chemical, are currently undergoing free-shrinkage and scaling tests; freeze-thaw testing will be performed in the next quarter.

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 tests will be performed in the next quarter.

A consistent settlement cracking test procedure has been developed. Specimens are 12" x 12" and 8" deep with a No. 6 bar with ¾" clear top cover. 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 unaided vision 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. Finally, the total length of cracks along the bar is measured and recorded.

Preliminary testing is underway to establish the repeatability of this test procedure. Mixtures containing varying dosages of fibers (Forta and Euclid 1.5 in.) have been evaluated for settlement cracking performance, as have mixtures containing Acti-Gel, a rheology modifier and anti-settling agent produced by Active Minerals International, LLC Mixtures containing Acti-Gel are also evaluated in the plastic state using a rheometer to determine the effect Acti-Gel has on the workability of concrete.

76% 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. 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, four 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 Menoken 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 polypropylene microfibers and was constructed with KU personnel in attendance. The three remaining decks are in Douglas County and will contain synthetic macrofibers; the first one is scheduled early next quarter and KU personnel will attend the construction, the other two decks are scheduled to be constructed in 2015.

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

76% 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 this quarter. Crack densities for the LC-HPC decks were found to be lower than those observed for the control decks. Additional crack surveys were completed this quarter 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. The data is still being analyzed and will be presented in a comprehensive report at the end of the next quarter.

76% 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 .

76% 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

76% 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 of concrete. Mixtures containing synthetic or steel fibers will be tested. The influence of concrete temperature and slump on settlement cracking will be evaluated.

Freeze-thaw testing will continue on a series of mixtures containing varying dosages of Eclipse 4500 with and without pre-wetted LWA and a series of mixtures containing 10% volume replacement of total aggregate with pre-wetted LWA, with and without 30% and 3% weight replacement of cement with slag and silica fume respectively. Testing will begin on mixtures containing Conex.

Mixtures containing SRA-XT, an SRA produced by Euclid Chemical, are also scheduled for testing on free-shrinkage, freeze-thaw resistance, scaling durability and air-void analysis.

Mixtures containing 1.5% and 2.25% of Eclipse 4500 will be re-evaluated in the next quarter to verify previous results.

Testing to evaluate air-void properties of hardened concrete will begin. Mixtures to be evaluated include mixtures containing varying dosages of PREVent-C (2.5, 5, and 7.5% by weight of cement) with 20 and 40% replacements by volume of cement with Type C and Type F fly ash, mixtures containing varying dosages of Acti-Gel (0.05, 0.075, and 0.15% by weight of total dry material), with and without Type C fly ash (20 and 40% replacements by volume of cement), mixtures made with Tstrata, a pre-packaged material produced by Structural Technologies, mixtures containing different dosages of Eclipse 4500 with and without pre-wetted LWA, and mixtures containing different dosages of Conex.

Significant Results this quarter:

<u>LABORATORY RESULTS:</u>

After 350 days of drying, mixtures containing 0.15% Acti-Gel by weight of cement with 0, 20 and 40% replacement of cement with fly ash have an average shrinkage of 537, 613 and 753 microstrain, respectively. Mixtures containing 0.075% Acti-Gel by weight of cement with 0, 20 and 40% replacement of cement with fly ash have an average shrinkage of 660, 607 and 643 microstrain, respectively, and mixtures containing 0.05 % Acti-Gel by weight of cement with 0, 20 and 40% replacement of cement with fly ash have an average shrinkage of 590, 433 and 643 microstrain respectively. The control mixes (no Acti-Gel with 0, 20 and 40% replacement of fly ash) have an average shrinkage of 617, 510 and 580 microstrain respectively.

Freeze-thaw testing is complete on mixtures containing different dosages of Acti-Gel (0.05, 0.075, and 0.15% by weight of total dry material), with and without Type C fly ash (20 and 40% replacements by volume of cement). All but one of the mixtures passed the test by maintaining at least 95% of their initial dynamic modulus as specified by ASTM C666; the mixture that didn't pass the test contained 0.15% Acti-Gel by weight of cement and 20% replacement of cement with fly ash and failed after about 160 freeze-thaw cycles.

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 180 days of drying, mixtures with 0.75, 1.5 and 2.25% Eclipse 4500 (by weight of cement) have an average shrinkages of 477, 353 and 360 microstrain, respectively, while the control mixture has an average shrinkage of 385 microstrain. Additional testing is planned.

After 180 days of drying, the mixture with 10% replacement of pre-wetted LWA containing 0.75% of SRA has an average shrinkage of 420 microstrain. A mixture with no SRA, 10% pre-wetted LWA replacement, along with 30 and 3% fly ash and silica fume replacement of cement has an average shrinkage of 395 microstrain, while the same mixture without 3% silica fume replacement of cement has an average shrinkage of 457 microstrain, indicating an effect of silica fume addition on decreasing the drying shrinkage (about 70 microstrain). The mixture with a 10% replacement of LWA with no SRA has an average drying shrinkage of 545 microstrain indicating that the effect of fly ash and silica fume replacement of cement on reducing the drying shrinkage is superior (about 150 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.

Scaling tests are underway on mixtures containing Eclipse 4500. To date, mixtures with 1.50% and 2.25% of Eclipse 4500 experienced mass losses 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. All other mixtures maintained low mass losses by the end of 56 freeze-thaw cycles. Mixtures that failed the scaling test will be re-evaluated in the next quarter. Comparative control mixtures with no LWA or SRA exhibited lower mass loss than both mixtures containing SRA only and mixtures containing both SRA and LWA. Mixtures containing higher dosage of SRA have higher mass loss. Freeze-thaw testing is currently underway on mixtures containing Eclipse 4500 with and without the addition of LWA. Through about 130 freeze-thaw cycles, all the mixtures maintained at least 98% of their initial dynamic modulus.

Concrete mixtures containing 3%, 4.5%, and 6% by weight of cement of Conex, an SRA produced by the Euclid Chemical Company, are currently undergoing free shrinkage and scaling tests. After a month of drying, mixtures containing 3, 4.5 and 6 % Conex SRA have average drying shrinkages of 397, 373 and 210 microstrain, respectively. The control mixture has an average drying shrinkage of 413 microstrain, indicating Conex SRA reduces the drying shrinkage. In the scaling test, mixtures with 3% and 4.5% Conex exhibited low mass loss in their early ages; further test results will be included in the next report. Freeze-thaw testing will also be performed in the next quarter.

Mixtures containing FORTA fibers at 3 and 7.5 lb/yd^3 have been tested. Mixtures with the higher dosage rate of 7.5 lb/yd^3 performed consistently better than control mixes without fibers and mixtures with the lower dosage rate of 3 lb/yd^3. Mixtures with the lower dosage rate did not consistently outperform control mixes without fibers.

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.