PROGRAM PROGRESS PERFORMANCE REPORT #10

GRANT: DTRT13-G-UTC45
Reporting Period: 4/1/2018 – 9/30/2018

REsearch on Concrete Applications RE-CAST:
REsearch on Concrete Applications for Sustainable Transportation
Tier 1 University Transportation Center

Consortium Members:

Missouri University of Science and Technology
Rolla, MO

University of Illinois at Urbana-Champaign
Urbana, IL

Rutgers, The State University of New Jersey
Piscataway, NJ

University of Miami
Coral Gables, FL

Southern University and A&M College
Baton Rouge, LA

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1. ACCOMPLISHMENTS

1.A - What Are The Major Goals And Objectives Of The Program?

The overall goal of this grant is to develop the next generation of cement-based construction materials that are essential to address the growing technical and environmental requirements of the transportation infrastructure. The research program aims to fast-track the acceptance of these technologies and develop national standards and guidelines for their use in the reconstruction of the nation's infrastructure for the 21st Century.

Research Goals

The RE-CAST program goal stated above will be accomplished by performing the following research projects:

- 1-A. Ecological and Crack-Free High-Performance Concrete with Adapted Rheology
- 1-B. Formwork Pressure Measurements and Prediction of High-Performance Concrete with Adapted Rheology
- 1-C. Influence of Casting Conditions on Durability and Structural Performance of High-Performance Concrete with Adapted Rheology
- 1-C-1. Optimization of Self-Consolidating Concrete to Guarantee Homogeneity during Casting of Long Structural Elements
- 1-C-2. Changes in Workability and Air-Void System of Concrete Due to Pumping
- 2-A. High-Volume Recycled Materials for Sustainable Pavement Construction
- 2-A-2. Passive Wireless Sensors for Monitoring Behavior of Recycled Aggregate Concrete
- 2-B-1. Rapid Pavement Rehabilitation
- 2-B-2. Rapid Pavement Construction
- 2-B-2-2. Roller Compacted Concrete for Rapid Pavement Construction
- 2-C. Development of Rapid PCC Pavement Repair Materials and Construction Techniques
- 2-D. Flexural Performance of Concrete Beams Strengthened using Different Repair Techniques
- 3-A. Performance of Fiber Reinforced Self-Consolidating Concrete for Repair of Bridge Sub-Structures and fiber-reinforced Super-workable Concrete for Infrastructure Construction
- 3-B. Ultra-High Performance Fiber Reinforced Concrete for Infrastructure Rehabilitation
- 3-C. Performance of Reinforced Concrete Decks Strengthened with Fabric-Reinforced-Cementitious-Matrix Composites
- 3-C-2. FRP Reinforcement for Concrete: Performance Assessment and New Construction
- 3-C-3. Use of Internal Curing Materials to Improve Performance of Concrete Infrastructure
- 3-D. Durability of GFRP Bar Reinforcement Extracted from In-service Concrete Structures
- 3-E. Flexural Performance of Concrete Beams Strengthened using Different Repair Techniques
- 3-F. Performance-Based Specifications of Fiber-Reinforced Concrete with Adapted Rheology to Enhance Performance and Reduce Steel-Reinforcement in Structural Members

Education and Workforce Development (EWD) Goals

The main goal of RE-CAST's Education and Workforce Development program is to develop a workforce trained in the interdisciplinary scholarship needed to understand and address the complex issues facing the implementation of a durable, reliable, and sustainable infrastructure. This is to be achieved by creating multidisciplinary educational opportunities for undergraduate and graduate students in the theme areas of the Center, as well as outreach activities for practitioners.

Education Objectives:

1) RE-CAST faculty members will collaborate to create the following courses related to the major thrust areas of the Center:

- Fundamentals of Rheology and Self-Consolidating Concrete (S&T and UIUC)
- Structural Health Monitoring Applied to Transportation (Rutgers University and SUBR)
- Repair Materials and Strategies for Civil Infrastructure (Multiple Universities)

2) RE-CAST is to collaborate with national laboratories and DOT research entities, such as NIST and MoDOT-R&D, to host students on scholarly efforts.

3) The Center will actively contribute to annual conferences in the transportation field organized by the consortium Universities, including the Transportation and Highway Engineering Conference and the Structural Engineering Conference at UIUC as well as the Transportation Infrastructure Conference at S&T.

Workforce Development / Outreach Objectives:

A. Outreach Activities to Attract New Entrants into the Transportation Field
   1) RE-CAST members will seek opportunities to invite junior faculty from complementary fields, such as engineering management, mechanical engineering, chemical engineering and chemistry to team up with RE-CAST faculty on various research projects.
   2) *Graduate Research Assistantship in Transportation Areas (GRATA)* - RE-CAST will provide graduate research assistantships to highly qualified Ph.D. students.
   3) *Invited Speakers and Field Trip Visits* – RE-CAST will collaborate with the CIES at S&T and student societies at the participating Universities, including ASCE and ACI to organize bi-monthly seminars featuring invited speakers from industry
   4) *ACI / Portland Cement Association (PCA) / Prestressed Concrete Institute (PCI) Co-Funded Scholarships* – RE-CAST will explore the possibility of providing matching funds to the scholarship programs that these organizations currently offer on a nation-wide basis for Fellowship students
   5) *Student Competition* – RE-CAST will work with professional student societies to organize a new competition on sustainable construction materials.
      1. Two competitions will be organized: (a) design of concrete with a minimum of 50% of recycled materials with the highest strength at Rutgers University/SUBR; and (b) development of fiber-reinforced thin elements with minimum fiber content and maximum ductility at UM/S&T.
   6) *UTC Student of the Year* – Each year, RE-CAST will select a Student of the Year based on scholarly merit and academic achievement.

B. Primary and Secondary School Transportation Workforce Outreach
   1) RE-CAST will support the *Minority Introduction to Technology and Engineering* MITE summer program.
   2) *Proposed Activities with Career Technical Education System* – RE-CAST will reach out to local technical trade schools to offer short courses for students in construction-related degree programs to showcase recent developments within their trade.

Technology Transfer Goals

The main goal of RE-CAST related to technology transfer is to work towards advancing transportation proficiency through technology transfer and educational opportunities and to make research results available to potential users in a form that can be implemented.

Technology Transfer Objectives:

A. Partnerships Across Sectors to Move Research into Practice
   1) RE-CAST will collaborate with MO-LTAP and LA-LTAP to introduce and deliver new materials related

to RE-CAST research themes that can be incorporated into workshops and technology transfer activities to service providers and professionals from the transportation industry.

2) RE-CAST will work with the Louisiana Transportation Research Center (LTRC) on technology transfer.

B. Technical Assistance to Others in Applying Research Results

1) The Center's website will publish detailed documentation of special construction procedures through videos and photos and will also provide data from the research investigations.
2) Faculty from RE-CAST as well as technical staff will be available to provide technical assistance to practicing engineers and state and local agencies in the design and construction of the various materials developed by the RE-CAST program.
3) RE-CAST faculty will actively disseminate knowledge and develop guidelines and standards through numerous technical committees (TRB, ACI, ASCE, PCI, ACerS, RILEM, and CSA).
4) RE-CAST faculty members will also organize sessions at the technical conventions (e.g., TRB, ACI, ASTM, and ASCE) to disseminate the latest findings in the theme areas of sustainable materials, NDE and monitoring of infrastructure, service life prediction, and LCCA of transportation infrastructure.
5) RE-CAST will also collaborate with various technical committees (e.g., ACI) to develop certification programs on special test methods dealing with the characterization of the materials developed in the research program, including rheological properties, dynamic segregation, and pumpability of HPC-AR.
6) RE-CAST will also collaborate with other UTCs working in the State of Good Repair focus area as well as other national/regional centers, including the NSF Industry/University Coop. Research Center for the Integration of Composites into Infrastructure (CICI) at UM and the Infrastructure Monitoring and Evaluation (RIME) Group at Rutgers University.

C. Technology Transfer Mechanisms/Creation of New Business Entities

1) The RE-CAST research team will work with the Technology Transfer and Economic Development Center (TTED) at S&T to develop marketing plans and subsequent commercialization of any product(s) and deliverables that can stem from the research program.

D. Information Exchanges

1) The team will publish the findings of the proposed research in joint publications involving the different faculty and their students from the partnering consortium members.
2) Social media (Facebook and LinkedIn) will be utilized to publicize on-going research, training, and technology transfer events, including field demonstrations, webinars, and educational videos stemming from research activities.
3) Research outcomes of the RE-CAST program will be uploaded into the U.S. DOT Research Hub in a timely manner.
4) A website with links to a listing of upcoming technology transfer events, educational seminars and workshops, presentations, and project reports.
5) Quarterly newsletters highlighting project updates, featured faculty and students, and field implementations of research projects.

Diversity Goals

The main goal of RE-CAST with regard to Diversity is to broaden participation and enhance diversity of the students, researchers, and practitioners involved in transportation-related activities and careers. In the consortium Universities, many initiatives have been created to ensure an inclusive environment related to race, ethnicity, gender, gender identity, sexuality, disability, economic class, religion, and country of origin.

Diversity Objectives:

1) Summer Internship for Underrepresented Students - SUBR and Rutgers University, through collaborative

projects among faculty members of the Center, will offer summer internship programs to undergraduate students to undertake internship programs at partner institutions.

2) RE-CAST will provide support in educational and outreach activities and financial aid in the form of scholarships to bring underrepresented students into transportation engineering-learning opportunities through the following programs:
    - The *Women's Leadership Program* at S&T
    - The *Summer Transportation Institute* at SUBR
    - *The Gates Millennium Scholars Program* at UM
    - The *Hammond Scholars Program* at UM

1.B - What Was Accomplished Under These Goals?

Research Objectives Accomplished:

In this reporting period, the following projects were completed and final reports submitted:

Lange, D., "Passive Wireless Sensors for Monitoring Behavior of Recycled Aggregate Concrete," Project 00042134-02-2A-2, Research on Concrete Applications for Sustainable Transportation, USDOT: GRANT: DTRT13-G-UTC45, Project Period: 5/15/2017 – 6/30/18.

Khayat, K., Meng, W. Hopkins, M., "Use of Internal Curing Materials to Improve Performance of Concrete Infrastructure," Project 00055456, Research on Concrete Applications for Sustainable Transportation, USDOT: GRANT: DTRT13-G-UTC45, Project Period: 7/1/2016 – 7/31/18.

Project Updates

1-A. Ecological and Crack-Free High-Performance Concrete with Adapted Rheology

Missouri S&T - This project seeks to develop and validate the behavior of a new class of ecological and crack-free high-performance concrete (Eco- and crack-free HPC) with the aim of reducing cement content and high resistance to shrinkage cracking designated for sustainable pavement (Eco-Pave-Crete) and transportation infrastructures (Eco-Bridge-Crete). The optimized Eco- and crack-free HPCs were used to cast some large scale slab sections and reinforced concrete beams to evaluate the shrinkage deformation and flexural performance of the optimized Eco-Pave-Crete and Eco-Bridge-Crete. Based on the laboratory investigation and full-scale structural evaluation, recommendations were established for the use of Eco- and crack-free HPC for pavement and transportation infrastructure applications. The final report was submitted to MoDOT in May 2017. The team is collaborating with MoDOT to carry out field implementation of Phase I work in Spring 2019. The final report is completed and will be submitted in November 2018.

University of Oklahoma - In May 2017, the research team submitted the final report for their portion of research Project 1A, documenting their findings, recommendations, and guidelines.

Rutgers University - The Rutgers team prepared the additional high-performance concrete mixes with fiber (FR-HPC) with blended aggregate to evaluate the restrained shrinkage performance in accordance with AASHTO Standards. The results show that the macro synthetic fibers have reduced the crack intensity by up to 31.2%. The team also performed the creep testing for SCC and FR-SCC mixes. The results show that the fibers have an effect on the creep performance - the fibers increase the specific creep by up to 6 times with 1.5" PPE.

New York University - NYU team extended the previous literature review on network-level Life Cycle Cost Analysis (LCCA) studies and identified the goals for an ideal network-level optimization model. The team was able to integrate the developed project- and network-level LCCA models into a two-level bottom-up tool. At the project-level, the tool can identify all feasible maintenance, repair and rehabilitation strategies for multiple facility

based on project-level constraints. At the network level, the tool is able to solve the multi-objective optimization problem to find the best combination of projects to meet network-level goals by choosing among project candidates found in the project-level model.

Project 1-B. Formwork Pressure of High-Performance Concrete with Adapted Rheology

This project is complete and a final report was published, as noted previously.

Project 1-C-1. Optimization of Self-Consolidating Concrete to Guarantee Homogeneity during Casting of Long Structural Elements

This project has been completed and a final report was submitted.

Project 1-C-2. Changes in Rheology and Air Void System in SCC Due To Pumping

A total of 14 concrete mixtures have been evaluated by means of full-scale pumping tests. Most of the mixtures exhibit a loss of 0-2% air content due to pumping, but no correlations between mixture design and pumping conditions could yet be established. Freeze-thaw, scaling and hardened air-void analysis studies are still ongoing. Experiments on rheology under pressure show a quick dissolution and re-appearance of air with pressure change. A hypothesis that shearing may affect the rate of dissolution and reappearance of air bubbles is being verified.

Project 2-A. High-Volume Recycled Materials for Sustainable Pavement Construction

Missouri S&T - Results obtained from laboratory investigation of various concrete mixtures were analyzed and candidate mixtures were proposed for field implementation. The research team is working along with the Missouri Department of Transportation to secure proper job sites for field implementation phase of the project in Spring 2019.

UIUC - This study considers recycled fine materials for controlled low strength materials (CLSM) and foam cement. We are using x-ray computed tomography to capture microstructural information in 3D. 3D printing technology has been used to construct physical models of the foam system to aid interpretation.

The modeling of crushing behavior is advancing well. Yu Song is a PhD student who is using this topic for his PhD dissertation. Kate Hawkins and Karthik Pattaje are MS students involved in laboratory work related to materials incorporating recycled fines with adapted rheology for sue in additive manufacturing and 3D printing.

The work has produced models of structure and experiments on crushing behavior that is the subject of dynamic (LS-DYNA) models of crushing behavior. These models form the basis of materials design methodology.

Jamie Clark completed her MS thesis in December 2017 with thesis entitled “Characterization of the Cellular Structure of Foamed Cement using X-ray computed tomography [2017]. The thesis represents a major report of results of this project.

University of Oklahoma - The OU research team continued monitoring the concrete pavements from the field implementation phase. The team has also begun writing the final report that will be published in Spring 2019 with research findings of the other consortium universities.

New York University - NYU team extended the previous literature review on network-level Life Cycle Cost Analysis (LCCA) studies and identified the goals for an ideal network-level optimization model. The team was able to integrate the developed project- and network-level LCCA models into a two-level bottom-up tool. At the project-level, the tool can identify all feasible maintenance, repair and rehabilitation strategies for multiple facility based on project-level constraints. At the network level, the tool is able to solve the multi-objective optimization problem to find the best combination of projects to meet network-level goals by choosing among project candidates found in the project-level model.

Project 2-A-2. Passive Wireless Sensors for Monitoring Behavior of Recycled Aggregate Concrete

This project was completed and the final report was published.

Project 2-B-1. Rapid PCC Pavement Rehabilitation

The research team continued on improving the high early strength concrete (4,000 psi in 4 hours) to be used in rapid joint rehabilitation of PCC pavement. Effort was made to monitor temperature inside the concrete using thermos couples and DAQ. The addition of accelerator was optimized for the strength development and temperature development. One of parameters to prevent strength development at early age was moisture inside the concrete. Some trial tests to put concrete samples in an oven with the temperature of 105°F should positively impact to quickly develop strength, and is being further monitored to evaluate impact on other properties.

Field implementation is underway to observe surface cracking and any other potential problems in such mixtures used in rapid PCC pavement repair.

Project 2-B-2. Rapid Pavement Construction

SUBR - Candidate vibration free concrete (VFC) mixtures and the measurement of hardened concrete properties were developed. The VFC mixtures were modified to achieve high early strength. Some of the mixtures were promising to gain early strength within 24 hours, and will continue to gain high strength in overnight construction.

With selected mixtures, the bond strength test between VFC repair concrete and old concrete is planned. Dr. Shin is planning for slab testing in the laboratory this Spring.

2-B-2-2. Roller Compacted Concrete for Rapid Pavement Construction

The research project seeks to develop guidelines for the use of RCC for rapid construction of concrete pavement. Work progress concentrated on the optimization of aggregate combinations to achieve maximum packing density, determining proper production techniques to adjust the air-void system in RCC. The optimized concrete mixtures are found to satisfy strength requirements for pavement construction. Work is under way to prepare for field implementation in collaboration with MoDOT, MnDOT, and the NRRA for use of concrete compacted pavement (CCP) using concretes with and without synthetic fibers.

Project 3-A. Performance of Fiber Reinforced Self-Consolidating Concrete (FR-SCC) for Repair of Bridge Sub-Structures & Fiber-Reinforced Super-workable Concrete (FR-SWC) for Infrastructure Construction

Missouri S&T – In summer 2017, the RE-CAST team at Missouri S&T cast FRSWC to replace a bridge deck in MO. After data were collected up to 260 days, and a 3D finite element model (FEM) was developed to predict the structural strain values in the concrete deck developed due to the weight of the bridge. A typical 12-in. (305 mm) mesh element was used for the FEM of the bridge deck, girders, and diaphragm. The applied loads were limited to the self-weight of the bridge. Modeling was conducted for the bridge deck at three different ages of 3, 56, and 260 days with the corresponding material properties that varied with time. The estimated strain values were compared to those recorded by the in-situ sensors in the longitudinal and transverse directions.

In the longitudinal direction, the stresses were shown to reach the maximum positive values at the points of contact of the girder with the diaphragm. The values decreased gradually along the span of the bridge to reach the maximum negative values at the mid-span of the bridge deck. In the transverse direction, the tensile stresses were positive near the diaphragm given the fact that the slab is acting as a top flange for the diaphragm. Away from the diaphragm the stresses were positive above the girders and negative in between adjacent girders. The area under consideration, where the towers are located, was in complete tension in the longitudinal and transverse directions. The highest tensile strain values reached 2100 micro-strain at the intersection of the intermediate bent with one of the pre-cast concrete girders.

A strain model was proposed to evaluate the strain data collected from the embedded sensors. The model represents the total strain as a summation of strains due to thermal deformation, drying and autogenous shrinkage, and structural deformation. The model was used to evaluate strains and estimate values of the concrete shrinkage during the first 30-36 hours, which corresponded to the time of demolding of the shrinkage samples. The load distribution factor, defined as the ratio between the portion of the load carried out by the concrete slab to the total load carried out by the slab and stay-in-place corrugated sheet formwork as well as the supporting girders, was estimated from the proposed strain model. Findings indicated that the load distribution factor increased with concrete age reaching a value of 0.98 at 260 days. The concrete shrinkage during the first 30-36 hours was then estimated to be 75 micro-strain. A final report highlighting the performance of FR-SWC for bridge deck reinforcement will be submitted in Fall 2018.

University of Oklahoma - The OU research team tested a full scale AASHTO Type II bridge girder repaired using the fiber-reinforced, self-consolidating concrete mixture design developed for this project. The girder, part of the I-244 Bridge over the Arkansas River, was repaired on site, removed from the bridge, and transported to the Donald G. Fears Structural Engineering Lab at OU for testing. Results indicated that the girder was repaired to 94% of its original capacity

Rutgers University -The team finished evaluating various strengthening and repairing techniques of the beams including the fiber-reinforced self-consolidating concrete (FR-SCC) and fiber-reinforced ferro cement (FR-FC). Different mix proportions in terms of fiber type and dosage as well as different meshes in terms of material and grid size were evaluated. The team performed vast number of small-scale beam testing to evaluate their strengthening performances. In addition, a number of 2-span continuous beams were prepared at large scale (10 ft long). The beams were repaired by the FR-SCC and FR-FC while the beams were pre-stressed with bonded and unbonded tendons

New York University - NYU team worked closely with Missouri S&T team on updating the previous LCCA using field data collected from a new bridge that was cast using FR-SWC in summer 2017. A project-level LCCA was conducted and a draft report was submitted. In addition, the research team continued to enhance the web-based software with the two-level bottom up approach that combines project- and network-level LCCA.

Project 3-B. Ultra-High Performance Fiber Reinforced Concrete for Infrastructure Rehabilitation

This project has been completed, and a final report was submitted.

Project 3-C. Performance of Reinforced Concrete Decks Strengthened with Fabric-Reinforced-Cementitious-Matrix Composites

Missouri S&T - The experimental laboratory work has been completed. A PhD student working on the project has successfully defended her dissertation during the last reporting period and presently a MS Student and Post-Doc student are working on the field implementation (Phase II) of this work. During this reporting period the strengthening design for the demonstration bridge project was completed. Working with industry partners, the repair materials have been received and work has initiated on the preparation of said materials. During the reporting period, a load test of the bridge was also completed, prior to installation of the strengthening materials to obtain a baseline on bridge behavior prior to installation. Installation of the strengthening materials in the field was scheduled to begin in September 2018, when a key staff member had health issues that is the expert in installation of strengthening materials delaying the field installation by at least two months. It is uncertain at the present time if the fall weather will cooperate (i.e., temperatures stay above freezing) to install the innovative strengthening materials in November of if the installation will occur in early spring. The project is scheduled to be completed by June 2019.

University of Miami - The final report was completed and submitted for the University of Miami tasks.

Project 3-C-2. FRP Reinforcement for Concrete: Performance Assessment and New Construction

Volumes I and III of III of the final report was completed and submitted. Volume II was finalized and published.

Project 3-C-3. Use of Internal Curing Materials to Improve Performance of Concrete Infrastructure

The effect of different curing regimens was explored to establish the beneficial effect of internal curing using lightweight sand. Different lightweight sands coupled with external water curing regimes were investigated. The project was finished during this reporting period and a final report has been submitted.

Project 3-D. Durability of GFRP Bar Reinforcement Extracted from In-service Concrete Structures

Missouri S&T - This study is evaluating the durability of fiber reinforced polymer (FRP) reinforcing bars as internal reinforcement of existing concrete bridge extracted from FRP RC Bridges after 10 or more years of service. The state of Missouri has had a number of FRP projects that FRP reinforcing bars serve as internal reinforcement. Validation of the long-term durability performance and the comprehensive development criteria/guidelines are needed before FRP system will gain widespread acceptance throughout the engineering and civil infrastructure community in the United States. The work includes: (1) some concrete core samples with GFRP bars will be extracted from different bridges; (2) a series of tests will be performed including Scanning Electron Microscope (SEM), Energy-dispersive X-ray Spectroscopy (EDX), short beam shear test, etc. During the reporting period a series of FRP samples were extracted from bridges in Missouri, Texas, Iowa, Florida, and Ohio. This project includes collaboration with both the University of Miami and Penn State University as well as industry (Owens Corning) and the ACI Foundation. One PhD Student and an Undergraduate Student have been working on this project. Evaluation of the samples will be on going during the next reporting period with a Final Report expected upon completion in 2019.

University of Miami - During the reporting period, the final report was completed and submitted for the University of Miami tasks.

Education and Workforce Development (EWD) / Outreach Objectives Accomplished

1) In early May 2018, 2 Ph.D. students from Missouri S&T assisted in demonstrating Materials Science aspects of concrete to 40 2nd-5th grade kids at Salem Elementary in MO. Discussions included basic principles of density, viscosity, load-deflection and concrete fabrication.
2) Keynote presentation "Performance of FRF and FR-SCC in Repair of Damaged Beam" on Wednesday, 12/13/2017. (H. Nassif)
3) Webinar presented by Dr. Hani Nassif, Rutgers University, Ferro18 Belo Horizonte, MG, Brazil, July 16-18, 2018. (H. Nassif)
4) Presentation for FES PDH Days. "Non-Corrosive Composite Bars for the Durability of Reinforced Concrete (1 PDH)" • Learn how new materials are implemented to improve the sustainability of the built infrastructure August 30, 2018. (A. Nanni)
5) Magna Lecture at FERRO12, July 16, 2018. (A. Nanni)
6) Keynote Speaker, International RILEM Workshop on Rheological Measurements of Cement-Based Materials, Arras, France, May 2018. (K. Khayat)
7) Keynote Speaker, 4th Int. Symposium on Design, Performance and Use of Self-Consolidating Concrete, Changsha, China, May 2018. (K. Khayat)

Technology Transfer Objectives Accomplished

1) The RE-CAST website contains links to listing of upcoming technology transfer events, educational seminars and workshops, presentations, and project reports.
2) A UIUC student participated at the American Ceramic Society Cements Division Meeting on June 10-12, 2018 at Penn State. He presented an oral presentation feature the work of this project.
3) Several RE-CAST faculty presented keynote and invited presentations, as elaborated in part below.

Diversity Objectives Accomplished

1) Missouri S&T has made progress to enhance diversity in the graduate and undergraduate team helping with the large scale pumping tests. They have recruited one female undergraduate for a 1-semester research program, have recruited a Hispanic M.Sc. student and have a paid African-American undergraduate student. A female post-doc fellow and a female PhD candidate joined Dr. Khayat's RE-CAST team in Fall 2018.
2) Rutgers University has recruited female and minority undergraduate students to help test beams.
3) NYU has a female graduate student conducting the LCCA research portions of the RE-CAST projects.
4) Southern University and A&M College hosted the **Summer Transportation and Energy Institute** (STEI) in the summer 2018. Dr. Alex Shin of RE-CAST gave lectures on RE-CAST projects and provided financial support for teaching materials.
5) At UIUC, the Lange Research Group which has 10 students with diverse background, including underrepresented groups. In the group of 10 students, there are four women. UIUC students Nanaissa Maiga (MS) and Jamie Clark (PhD) are African American female engineering students pursuing advanced degrees, thus advancing diversity goals through the UTC program.
6) OU sponsored a summer internship for Maranda Leggs and Michelle Manwarren, female undergraduate civil engineering students at OU. Both students were involved in the testing of the full-scale AASHTO Type II girder repaired as part of Project 3A.

1.C - What Opportunities For Training And Professional Development Has The Program Provided?

The RE-CAST has archived a library of webinars provided by the Center in the Missouri S&T Scholars Mine. The webinars are available to the public at no charge.

The RE-CAST funding provides partial support for many conferences and symposia including the following:

- 10 students from the Lange's research group attended the 2018 International Crosstie and Fastening System Symposium held in Urbana, IL on 15-17 May 2018.
- 9 students from the Lange's research group attended the American Ceramic Society Cements Division Meeting on June 10-12, 2018 at Penn State. The research and transportation was supported by the RE-CAST funding.
- Five students from the Lange's research attended the American Concrete Institute Spring Convention in Las Vegas, NV. The students participate in ACI committee work.
- Several post-docs and students attended the Fall ACI convention from the Missouri S&T RE-CAST team.

The RE-CAST program supports students who are active in the ACI Student Chapter. A RE-CAST student currently serves as President.

For the full-scale pumping tests, (senior) undergraduates and graduates are encouraged to help the research team, exposing the students to field testing of concrete, concrete mixing, transport and placement, etc. So far, 10 undergraduate and 7 graduate students have been involved in the testing.

1.D - How Have The Results Been Disseminated?

Prof. D.A. Lange is serving as ACI President in 2018-19 and will be reporting on RE-CAST through the year during his many presentations to ACI Chapters in the U.S. and elsewhere.

The Rutgers team provided two technical specifications to a local transportation agency (New Jersey Turnpike Authority). The specifications are the fiber-reinforced high-performance concrete (FR-HPC) and high-early strength HPC (HES-HPC), and both mixes and specifications were implemented on the major highway bridges.

Similar achievement was done in the Missouri S&T team of Dr. Khayat that developed the first specification for FR-SWC for bridge deck replacement.

Key findings of various research projects are being compiled to prepare scientific papers and technical presentations at various conventions. Some these findings have already been disseminated at the World of Concrete 2018 in Las Vegas, Gordon Research Conference on Advanced Materials for Sustainable Infrastructure Development in Hong Kong (Khayat – Vice Chair of Conference), ACI Fall 2018 Convention in Las Vegas, NV, the annual ACERS Cements conference in State College, PA, June 2018, the 12th UTC Spotlight Conference in Washington D.C., as well as overseas, including the 10th International Conference on Cement and Concrete, ISCC2018, China.

1. E - What Do You Plan To Do During The Next Reporting Period To Accomplish The Goals And Objectives?

- **Summer Transportation Institute at SUBR -** Southern University and A&M College will host National Summer Transportation Institute (NSTI) 2019. The College of Engineering will serve as the housing facility for the institute's classroom based activities and construction projects. Up to 20 high school participants (9th and 10th grades) will be selected from parishes in Louisiana. Dr. Shin from RE-CAST will participate in the NSTI as the speaker. He will present the Center's on-going research on rapid pavement repair and related RE-CAST research subjects.
- **S&T Transportation Infrastructure Conference –** January 28, 2019.
- Missouri S&T continued working on the design/construction of the **Advanced Materials and Construction Lab (ACML)**, which broke ground on October 12. Construction of a new $6.5 million lab that is expected to strengthen Missouri University of Science and Technology's position as a national leader in addressing the challenges of aging public infrastructure officially begins Friday with a ceremonial groundbreaking. Phase I of this project was funded by UTC Grant DTRT06-G-0014, which funded the $2.25M of specialized research equipment that will be housed in this new lab.
- In the next reporting period, the Missouri S&T and University of Miami teams will continue to work on Phase II of Field Implementation Project involving field strengthening and rehabilitation and reporting on final reports of implementation projects.
- The RE-CAST Center will continue to support of all students involved in RE-CAST research, encourage professional development via conferences and workshops, and reward students through financial support and travel support for their professional service activities. Our next months will focus on closure of the project and remaining technical objectives. UIUC will commission a new freeze-thaw chamber is to help accomplish its goals.

- The Rutgers team will finish the testing of large-scale beams and propose the best techniques to strengthen the damaged beams. The team will study the applicability of such techniques to actual bridge projects. The team will prepare the final report of this project and will submit it prior to project end date.
- The New York University team will continue to work on the implementation of integrated multi-objective optimization based LCCA model and incorporate it into the web-based LCCA software. User tests on the web-based LCCA software will be conducted. The team will continue to collaborate with Rutgers team on implementing LCCA for the new materials and repair techniques proposed in Project 2-D.
- In the next reporting period, SUBR plans to: Finalize concrete mixtures satisfied the target strength focusing on the repeatability of the mixture by controlling moisture conditions on LWA and RCA; Oven dry and blanket dry of concrete specimen will be explored to expedite strength development; Apply the early strength concrete to the pre-field and field implementation; Measure hardened properties of vibration free concrete (VFC) mixes provided by Missouri S&T; Fabricate bond strength specimens with the selected VFC mixes and identify the mixes that can be used in bonded concrete overlay and apply in pre-filed test; Using the measured physical properties and performance, a numerical model will be developed to predict the performance of bonded concrete overlay.

2. PRODUCTS

2.A - Publications, Conference Papers, and Presentations

1) **Journal Publications** (in part):

Vosahlik, J., Riding, K.A., **Feys, D.**, Lindquist, W., Keller, L., Van Zetten, S. and Schulz, B., 2018. Concrete pumping and its effect on the air void system. Materials and Structures, 51(4), p.94.

Asghari, A.A., **Feys, D.** and De Schutter, G., 2018. Time Evolution of Rheology of Cement Pastes Affected by Mixture Design and Mixing Procedure. ACI Materials Journal, 115(5).

Kassimi, F., **Khayat, K.H.**, Development of Methodology to Evaluate Passing Ability and Test Sample Preparation for Superworkable Concrete, Construction and Building Materials, Sept. 20, 2018, 183, pp. 356-364, on line July 5 2018, https://doi.org/10.1016/j.conbuildmat.2018.06.140.

Long, W.-J., Wei, J.-J., Xing, F., and **Khayat, K.H.**, Enhanced Dynamic Mechanical Properties of Cement Paste Modified with Graphene Oxide Nanosheets and its Reinforcing Mechanism, Cement and Concrete Composites, Oct. 2018, 93, pp. 127-139, online July 6, 2018.

Megid, W.A., **Khayat, K.H.**, Effect of Concrete Rheological Properties on Quality of Formed Surfaces Cast with Self-Consolidating Concrete and Superworkable Concrete, Cement and Concrete Composites Jr., Oct. 2018, 93, 2018, pp. 75-84, on line June 26, 2018 https://doi.org/10.1016/j.cemconcomp.2018.06.016.

Meng, W., **Khayat, K.H.**, and Bao, Y., Flexural Behavior of Ultra-High Performance Concrete Panels Reinforced with Embedded Fiber-Reinforced Polymer Grids, Cement, Concrete and Composites, Oct. 2018, 93, pp. 43-53, on line June 21, 2018 https://doi.org/10.1016/j.cemconcomp.2018.06.012.

Valipour, M., **Khayat, K.H.**, Coupled Effect of Shrinkage-Mitigating Admixtures and Saturated Lightweight Sand on Shrinkage of UHPC for Overlay Applications, Construction and Building Materials, Sept. 30, 2018, 184, pp. 320-329, on line July 5. https://doi.org/10.1016/j.conbuildmat.2018.06.191

Mehdipour, I., **Khayat, K.H.**, Effect of Shrinkage Reducing Admixture on Early Expansion and Strength Evolution of Calcium Sulfoaluminate Blended Cement, Cement and Concrete Composites, Sept. 2018, 92, pp. 82-91, on line June 6, 2018, https://doi.org/10.1016/j.cemconcomp.2018.06.002.

Wu, Z., Shi, C., **Khayat, K.H.**, and Xie, L., Effect of Nano-Particles on Static and Mechanical Properties of UHPC, Construction and Building Materials, Sept. 10, 2018, 182, pp. 118-125, on line June 19, 2018.

Wu, Z., **Khayat, K.H.**, and Shi, C., How do Fiber Shape and Matrix Composition Affect Fiber Pullout Behavior and Flexural Properties of UHPC? Cement and Concrete Composites, 90, 2018, pp. 193-201.De

J. Koch, D. Castaneda, R.H. Ewoldt, and **D.A. Lange**, "Vibration of fresh concrete understood through the paradigm of granular physics" Cement and Concrete Research, Volume 115, pp 31-42, 2019.

D. Casteneda, K. Riding, **D.A. Lange**, "Prediction of Freezing Temperature inside Concrete Crossties at the Rail Seat," J. Mat. Civil Eng. (ASCE), accepted 2018.

Henschen, J.D., Castaneda, D.I., **Lange, D.A.**, Formwork pressure model for self-consolidating concrete using pressure decay signature, ACI Materials Journal, 115(3), pp. 339-348, 2018.

Santis S., H. Akbari, F. De Caso y Basalo; G. de Felice and **A. Nanni**, "Acceptance Criteria for Tensile Characterization of Fabric Reinforced Cementitious Matrix (FRCM) Systems for Concrete and Masonry Repair," ASCE JCC, 2018, 22(6): 04018048-1 to 14.

Spagnuolo S., A. Meda, Z. Rinaldi and **A. Nanni**, "Residual behavior of glass FRP bars subjected to high temperatures," Composite Structures, Vol. 203 (July 2018), pp. 886–893.

Gooranorimi, O., G. Claure, W. Suaris and **A. Nanni**, "Bond-Slip Effect in Flexural Behavior of GFRP RC Slabs," Composites Structures, 193 April 2018, pp. 80-86. https://doi.org/10.1016/j.compstruct.2018.03.027

Wang, W., O. Gooranorimi, JJ. Myers and **A. Nanni**, "Microstructure and Mechanical Property Behavior of FRP Reinforcement Autopsied from Bridge Structures Subjected to In Situ Exposure," Taha M. (ed.) International Congress on Polymers in Concrete (ICPIC 2018). ICPIC 2018. Washington D.C., April 29-May 1, 2018, pp 585-591.

Wirkman, C., Arezoumandi, M., and **Volz, J.S**., "Performance of Fiber-Reinforced Self-Consolidating Concrete for Repair of Bridge Substructures," Structures, V. 15, Aug. 2018, pp. 320-328.

Looney, T.J. and **Volz, J.S.**, "Bond Performance of Mild Reinforcing Steel in Fiber-Reinforced Cement-Limiting Concrete (FRCLC)," International Journal of Engineering and Science Invention," V. 7, No. 6, June 2018, pp. 35-42.

Steele, A., Arezoumandi, M., and **Volz, J.S.**, "Evaluation of the Bond Strengths Between Concrete and Reinforcement as a Function of Recycled Concrete Aggregate Replacement Level," Structures, V. 16, Nov. 2018, pp. 73-81).

Presentations (in part):

Dimitri Feys

"Rheology: The Link between Mix Design, Placement and Performance of Concrete Research" seminar at University of Illinois at Arkansas, Fayetteville, AR (April 2018)

Daniel Galvez Moreno, Dimitri Feys, Kyle Riding, "The Effect of Pressure on the Rheological Properties of Air-Entrained Cement Paste," ACERS Cements Division Conference, State College, PA (June 2018)

Kamal H. Khayat

Keynote Speaker, International RILEM Workshop on Rheological Measurements of Cement-Based Materials, Arras, France, May 2018.

Keynote Speaker, 4th Int. Symposium on Design, Performance and Use of Self-Consolidating Concrete, Changsha, China, May 2018.

Shen, W., Shi, C., **Khayat, K.H.**, Yuan, Q., Zeng, R., Wu, Y., and Lao, L., An Investigation on Structural Build-up of Cement Paste Containing Superplasticizers and Fly Ash under Different Temperatures, RILEM Proc. 122, Proceedings of the Fourth Int. Symposium on 4th Inter. Symposium on Performance and Use of Self-Consolidating Concrete, SCC'2018, June 019, Changsha, China, pp. 100-112.

David Lange

A. Werner and **D.A. Lange**, "Mechanisms affecting Bond to Porous Media", 2018 Masonry Symposium: Innovations in Collaborative Research, Development and Applications, San Diego, CA, June 2018.

John J. Myers

Myers, J.J. "Microstructure and Mechanical Property Behavior of FRP Reinforcement Autopsied from Bridge Structures Subjected to In-situ Exposure," 16th International Congress on Polymers in Concrete 2018 (ICPIC 2018), Washington, DC, Apr. 29 – May 1, 2018. (invited)

Myers, J.J. "Bond Performance of Steel Reinforced Polymer (SRP) Subjected to Environmental Conditioning and Sustained Stress," 16th International Congress on Polymers in Concrete 2018 (ICPIC 2018), Washington, DC, Apr. 29 – May 1, 2018. (invited)

Myers, J.J. "Strength Evaluation of Prestressed Concrete Bridges by Load Testing," 9th International Conference on Bridge Maintenance, Safety, and Management (IABMAS 2018), Melbourne, Australia, July 13, 2018 (co-presenter).

Myers, J.J. "In-service Stress and Strain Behavior of Missouri Bridge A7957," 9th International Conference on Bridge Maintenance, Safety, and Management (IABMAS 2018), Melbourne, Australia, July 13, 2018 (co-presenter).

Myers, J.J. "Effect of Long-term Environmental Exposure on EB FRP or FRCM Reinforced Masonry System," 10th International Masonry Conference, Milan, Italy, July 9, 2018.

Antonio Nanni

Akbari Hadad, H. and **A. Nanni**, "Structural Performance of SRG Strengthened Concrete Slabs," Proceedings of FERRO12, Eds. C.S. Rodrigues and S.N. Bonifacio, 12th International Symposium on Ferrocement and Thin Reinforced Cement Composites, July 15-18, Belo Horizonte, Minas Gerias , Brazil, pp. 47-55.

Akbari Hadad, H. and **A. Nanni**, "Mechanical Properties of Glass FRCM," Proceedings of FERRO12, Eds. C.S. Rodrigues and S.N. Bonifacio, 12th International Symposium on Ferrocement and Thin Reinforced Cement Composites, July 15-18, Belo Horizonte, Minas Gerias , Brazil, pp. 77-85.

Rossini, M, F. Matta, S. Nolan, W. Potter, **A. Nanni**, "AASHTO Design Specifications for GFRP-RC Bridges: 2nd Edition," Italian Concrete Days, Giornate aicap 2018 Congresso CTE, Lecco, 13-15 June, 2018.

Rossini, M, T. Cadenazzi, **A. Nanni,** "SEACON and Resilient FRP-RC/PC Solutions: The Halls River Bridge," Italian Concrete Days, Giornate aicap 2018 Congresso CTE, Lecco, 13-15 June, 2018.

Hani Nassif

Nassif, H. "Performance of Fiber Reinforced Ferrocement (FRF) and Fiber Reinforced Self Consolidating Concrete (FR-SCC) in Repair of Damaged Beam," Ferro18 Belo Horizonte, MG, Brazil, July 16-18, 2018.

Abdulhameed, H. **Nassif, H.** and **Khayat, K.** "Use of Fiber-Reinforced Self-Consolidating Concrete to Enhance Serviceability Performance of Damaged Beams," TRB 2018.

Kaan Ozbay

J. Gao, **K. Ozbay, H. Nassif**, and O. Kalan, "Stochastic Multi-Objective Optimization-Based Life Cycle Cost Analysis for New Construction Materials and Technologies".

2.B - Website(s) or Other Internet Site(s)

Website: http://recast.mst.edu

Facebook: https://www.facebook.com/RECASTCenter

LinkedIn: https://www.linkedin.com/groups/RECAST-University-Transportation-Center

2.C - Technologies or Techniques - Nothing to Report.

2.D - Inventions, Patent Applications, and/or Licenses - Nothing to Report.

2.E - Other Products, Such As Data Or Databases, Physical Collections, Audio Or Video Products, Software Or Netware, Models, Educational Aids Or Curricula, Instruments, Or Equipment.

Nothing to Report.

3. PARTICIPANTS & COLLABORATING ORGANIZATIONS

3.A - What Organizations Have Been Involved As Partners?

The main consortium members of this University Transportation Center remain the same as the proposal:

- Missouri University of Science and Technology, Rolla, MO - LEAD
- University of Illinois at Urbana-Champaign, Urbana, IL
- Rutgers, The State University of New Jersey, Piscataway, NJ
- University of Miami, Coral Gables, FL
- Southern University and A&M College, Baton Rouge, LA

As stated in the proposal, the RE-CAST team is also partnered with Dr. H. Celik Ozyildirim, as a consultant, from the Virginia Center for Transportation Innovation and Research, Charlottesville, VA. Dr. Ozyildirim's main implication is to provide input for field implementation and development of specifications and standards.

In addition to the main consortium members, two additional universities are collaborating with RE-CAST, due to faculty moving to those universities after the proposal was submitted. Those new partners are:

- The University of Oklahoma, Norman, OK (Dr. Jeffrey Volz)
- New York University Polytechnic School of Engineering, Brooklyn, NY (Dr. Kaan Ozbay)

Several state governments and industrial partners are involved in RE-CAST projects and are providing financial and in-kind support to the research program. The highlighted agencies are new in this reporting period:

- AIG
- American Concrete Pavement Association, Oklahoma and Arkansas Chapter
- **American Concrete Institute**
- **American Society of Civil Engineering**
- Bekaert Corp. - Arkansas
- BASF - Joseph Dazcko and Tim Filer
- Bowman, Barrett & Associates, Chicago, IL
- Capital Holdings - MO
- CBM-St-Mary's Toronto
- Chicago Department of Aviation
- City University of New York

- Clayton Concrete Materials and Ready Mix, Edison, NJ
- Chicago Bridge & Iron Co., Trenton, NJ
- Cole County Industries – MO
- Coreslab Structures Inc., Marshall, MO
- Dewberry, Bloomfield, NJ
- Dolese Bros. Co., Oklahoma City, OK
- Eastern Concrete Materials and Ready Mix, Bogota, NJ
- EllisDon, Toronto
- Euclid Chemicals, East Brunswick, NJ
- Florida Department of Transportation
- Garver Engineering, Norman, OK
- Grace Construction Products, MA
- Grand River Dam Authority, Vinita, OK
- Greenman Pedersen, Inc., Lebanon, NJ,
- Hanyang University (Korea)
- K-FIVE Construction Corp., Lemont, IL
- Kansas State University
- Kyunghee Univ. (Korea)
- LaFarge North America, Whitehall, PA
- Louisiana Transportation Research Center
- Missouri DOT
- Missouri S&T
- New Jersey DOT Research Division, West Trenton, NJ
- New Jersey Turnpike Authority, NJ
- New York City DOT
- New York State DOT
- New York University Polytechnic School of Engineering, Brooklyn, NY
- Noblis
- O'Hare Modernization Program, IL
- Oklahoma DOT, Oklahoma City, OK
- Oklahoma City, Norman, and Tulsa, OK, City Planning Departments
- Oklahoma State University
- Oklahoma Turnpike Authority, OK
- Philips Hardy Inc., MO
- Port Authority of New York and New Jersey (PANYNJ)
- **Prestressed Concrete Institute**
- Small Modular Reactor Research and Education Consortium
- Southeast University, Nanjing, China
- State University of NY Maritime College
- State University of NY at Stony Brook
- **The Masonry Society**
- **Transportation Research Board**
- University of Miami, Coral Gables, FL
- Structural Technologies, Hanover, MD
- University of Florida, Kyle Riding
- UIUC
- University of Jinan (China)
- University of Nevada, Las Vegas
- University of Oklahoma
- University of Sao Paulo (Brazil)
- University of Sherbrooke (Canada)
- VirginiaTech, Charlottesville, VA
- Wallace Engineering, Tulsa, OK
- Webcor Corp. - CA
- Qatar Foundation

3.B - Have Other Collaborators Or Contacts Been Involved?

The Research Advisory Committee (RAC) is composed of the following individuals:

William Stone, Research Administrator, P.E. (RAC President) - *Missouri DOT, Jefferson City, **MO***
Ross Anderson, Senior Vice President - *Bowman Barrett & Associates, Chicago, **IL***
Casimir Bognacki, Chief of Materials Engineering - *Port Authority of New York and New Jersey, **NY***
Harvey DeFord, Ph.D., Structural Materials Research Specialist – *FLDOT State Materials Office, **FL***
Chiara "Clarissa" Ferraris, Ph.D., Physicist - *NIST, Gaithersburg, **MD***
Jim Myers, P.E., Senior Staff Engineer - *Coreslab Structures, Inc., Marshall, **MO***
Karthik Obla, Ph.D. P.E., Vice President, Technical Services - *NRMCA, Silver Spring, **MD***
Zhongjie "Doc" Zhang, Ph.D., Pavement Geotechnical Research Administrator -*LTRC, Baton Rouge, **LA***

4. IMPACT

4.A - What Is The Impact On The Development Of The Principal Discipline(s) Of The Program?

The field demonstration project in NJ, IL, MO, OK and FL can be used as case studies that shows the applicability of advanced materials and technologies developed by RE-CAST members for the construction of durable and sustainable concrete bridge decks and pavements using HPC and FRP.

We are delivering new, embedded sensor systems that support Structural Health Monitoring of transportation pavements and structures that can allow better prediction of service life and enable better management of the infrastructure.

The FR-HPC mix designs that were developed by the RECAST consortium members can be widely used for the bridge deck construction and rehabilitation. This mix design will minimize the cracking and therefore prolong the service life of the deck. This improvement will have a major impact on the development of the principal disciplines of the program by reducing the maintenance fee and schedule.

The developed comprehensive bottom-up methodology based on LCCA to integrate project- and network-level analysis will provide an effective solution to many issues that have not been completely addressed in the past, including the trade-off between multiple objectives, effect of time, uncertainty and outcome interpretation.

In addition, the customized LCCA software allows more non-technical users to apply LCCA using hypothetical data or real-data from various projects conducted by our RE-CAST partners. This is an important improvement over previous effort where testing and validation with various data from different projects were limited.

4.B - What Is The Impact On Other Disciplines?

Our work involves laboratory studies of flow and rheology of cement based systems, and the work involves fluid mechanics models of suspensions where properties are related to particle size and shape. This general knowledge applies to other disciplines such as Materials Science as it relates to generic suspensions. Experimental work is also being integrated in Artificial Intelligence and machine learning to predict material performance that be employed in other applications.

There are many similarities between LCCA of novel materials and Intelligent Transportation System (ITS) technologies. The NYU team has extended the probabilistic LCCA approach to Connected and Autonomous Vehicle deployment analysis.

The general knowledge applies to other disciplines such as Materials Science as it relates to generic applications where field testing is conducted and portable equipment and embedded sensors are valued.

The field demonstration and SHM of FR-SCC deck will help the transportation agencies understand the benefits of FR-SCC applications and adopt such materials in future designs or repair and maintenance projects. Both demonstration projects can be used as case studies that show the applicability and encourages implementation of FR-SCC for concrete bridge decks.

4.C - What Is The Impact On The Development Of Transportation Workforce Development?

Several graduate and undergraduate students have been recruited to staff the RE-CAST projects for FY2014, FY2015, FY2016, FY2017 and FY2018. For the undergraduate students, working with graduate students and world-renown faculty helps them with experiential learning activities and raise their interest in transportation.

We have been involved in training activities related to new repair methods at the Chicago O'Hare Airport.

The web-based LCCA tool has been presented as C2SMART Showcases Research at ITS-NY.

The technical specifications for use of FR-SCC, RCA, RCC, SCC and UHPC will help transportation agencies understand the feasibility and adoption of FR-SCC in various infrastructure applications. The use of new mixture designs (FR-HPC and HES-HPC) helps the transportation agencies offer more durable bridges with less cost to the tax payers.

The field implementation of FR-HPC mixture can be used as a case study for the lessons learned for future similar projects. Then the case studies can be compiled to be used as a presentation for workshop or class that will have an impact on the transportation workforce development. Major findings of research are also used in preparing webinars.

4.E - What Is The Impact On Physical, Institutional, And Information Resources At The University Or Other Partner Institutions?

The Rutgers team has been closely collaborating with NYU team in the context of a new major initiative in New Jersey entitled Bridge Resource Program (BRP) for the state transportation agency (NJDOT). We are planning to use some of the new methodologies and techniques developed in this project in the new aforementioned BRP initiative.

The web-based LCCA tool has been presented as a showcase in 2018 New York University's Annual Research EXPO.

4.F - What Is The Impact On Technology Transfer?

The technical specifications of two mixtures (FR-HPC and HES-HPC) have been providing the understanding of new technologies to the contractors as advanced materials.

The NYU team is planning to prepare a video that will describe the new LCCA software tool.

Technical Specification of new materials have been developed, and field implementation results are being shared between the transportation agencies as well as the consortium universities as a case study of RE-CAST project. Such information will help other transportation agencies learn the new mix designs and encourage to use them for the field implementation.

4.G - What Is The Impact On Society Beyond Science And Technology?

The RE-CAST projects are developing the next generation of cement-based construction materials to address the growing technical and environmental requirements of the nation's transportation infrastructure. The ultimate goal of the RE-CAST program is to fast-track the acceptance of these technologies and develop national standards and guidelines for their use in the reconstruction of the nation's infrastructure for the 21st Century, which will have a lasting impact on our nation's society. This research theme addresses a Grand Challenge for our society and has been recognized at Missouri S&T as one of four strategic areas for future growth in education and research.

The developed on-line LCCA tool will be used by a larger group of engineers and students when it is ready for open access. The fact that we are incorporating new methodologies for LCCA estimation in the case of new materials and technologies, this tool might have greater societal impacts beyond this project. By introducing the developed on-line LCCA tool to a larger group of engineers and students in the near future might lead to greater societal impacts beyond this project since the tool is capable of LCCA estimation in the case of new materials and technologies. We will be able to facilitate the adoption of new technologies by providing agencies with important LCCA information for more informed decision making.

The use of developed mix designs will offer more reliable and safety bridge decks by reducing the crack severity and extending the service life. Such improvement will reduce the maintenance schedule and therefore save a vast of fund to repair the infrastructure.

The consortium continues to engage K-12 students and provides them hands on activities.

5. CHANGES/PROBLEMS

5.A - Changes In Approach And Reasons For Change

Nothing to report at this time.

5.B - Actual Or Anticipated Problems Or Delays And Actions Or Plans To Resolve Them

Nothing to report.

5.C - Changes That Have A Significant Impact On Expenditures

Nothing to report at this time.

5.D - Significant Changes In Use Or Care Of Animals, Human Subjects, And/or Biohazards

N/A

5.E - Change Of Primary Performance Site Location From That Originally Proposed

No Change to Report.

5. SPECIAL REPORTING REQUIREMENTS

Nothing to Report.