PROGRAM PROGRESS PERFORMANCE REPORT #12

GRANT: DTRT13-G-UTC45
Reporting Period: 4/1/2019 – 9/30/2019

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.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
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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:

Several final project reports are in the final review stage and will be published by December 2019.

Project Updates

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

The final collective report with input from the RE-CAST consortium universities is being finalized will be submitted in December 2019.

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

The final pumping test was performed in April 2019. All tests are completed and analysis is ongoing. Detailed analysis procedures have been discussed within the group to ensure consistency over the entire data set. Analysis focuses on the changes induced by pumping. Spacing factor results indicate strong sensitivity for SCC mixtures with low air contents and could necessitate additional information in practical guidelines for pumping SCC.

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 and performance-based specifications were developed for field implementation. The final collective report with input from the RE-CAST consortium universities is completed and will be submitted in December 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 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 including performing falling weight deflectometer testing. The team also continued work on compiling the laboratory and field test testing results and writing the final report.

New York University - NYU team 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

SUBR - 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. One effort was made to monitor temperature inside the concrete using thermos couples and DAQ. The blanket curing kept the high temperature of the concrete cylinders compared to heated fan and ambient conditions.

The elastic modulus of developed concrete was measured. The bond strength between old concrete and newly developed concrete was measured in 24 hours for ambient condition and oven dry conditions, and oven dry resulted in higher bond strength.

The field implementation is planned to observe surface cracking and any other potential problems in the mixture and joint repair project. The field implementation will bring an idea to cover the repair surface with electric blanket to accelerate setting and strength gaining. The final report of this project will be submitted in Dec. 2019.

Project 2-B-2. Rapid Pavement Construction

SUBR - The VFC mixture modified by adding 36 oz. AC mixtures was used to study the various curing conditions. Four different curing methods (ambient room condition, heated blanket, blowing heated fan, and oven) were used to monitor the strength development in 24 hours. Oven curing was the most effective way to develop early high strength. The study suggested to having high capacity heated blanket or blowing heated fan can enhance the strength develop and consequently can be used in the field.

The final report of this project will be submitted in December 2019.

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

The main objective of this research was to develop high-performance Roller Compacted Concrete (RCC) with enhanced solid skeleton to secure greater workability, mechanical properties, and frost durability. The study involved the development of a mixture design methodology to select aggregate proportioning and particle-size distribution of combined aggregates that can secure high packing density and lead to enhanced performance. RCC mixtures with high packing density of aggregate combination and suitable fresh and hardened properties were used to introduce air-entraining agent (AEA) at different dosages. The effect of binder content, AEA dosage, workability level, adjusted by varying the water-to-solid ratio, mixer type, and compaction energy on RCC performance was evaluated. Test results indicate that the performance of RCC can be improved with the increase in packing density of aggregate skeleton. Higher packing density can enable the reduction of cement content through improved compacted structure of the solid particles. RCC mixtures made with 40% sand, 20% intermediate aggregate, and 40% coarse aggregate lad to the highest packing density and best workability and mechanical properties. A final report will be submitted by December 2019.

2-E. Compacted Concrete Pavement Evaluation

Missouri S&T - The study aims at determining the performance of compacted concrete pavement (CCP) mixtures for pavement construction. The CCP is comprised of similar proportions as that of RCC; however, it utilizes an admixture that enables better finishing and durable surface texture. The major difference in construction is that CCP has a longer "fresh" or "green" period and requires little or no rolling that makes the riding surface more uniform and consistent. The use of CCP technology is supposed to secure smooth texture during paving. A field implementation was carried out in fall 2018 in collaboration with MoDOT, MnDOT, and the NRRA for use of concrete compacted pavement (CCP) using concretes with and without synthetic fibers as part of a larger project that constructed in Scott County, Missouri. The project was undertaken to assess construction issues and characterize the long-term performance of the proposed CCP. The optimized concrete mixtures are found to satisfy strength requirements for pavement construction. The work included conducting laboratory tests on saw-cut and cored samples, namely compressive and flexural strength tests at 120 and 180 days, freeze-thaw durability, de-icing salt scaling resistance, and drying shrinkage. The work in progress during this reporting period is preparation of a summary and analysis of data from a periodic collection of load response data, including FWD and controlled truck loading of slabs with embedded sensors. The results of this research project aim to add value to the current state of practice related to the use of CCP, synthesize current technical knowledge, study the potential problems associated with using CCP in pavement construction in Missouri, and propose guidelines on how to avoid critical construction issues and poor quality issues. The study deals with practices recognized by MoDOT and MnDOT. The outcomes of the research will provide guidelines for the selection of proper ingredients, mixture optimization methodology, as well as suitable design features to ensure cost-effective and durable CCP.

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 FR-SWC 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.

University of Oklahoma - The OU research continued observing repairs to the I-244 Bridge over the Arkansas River and has begun writing the final report.

Rutgers University - The team completed testing of small scale and large scale specimens to evaluate various strengthening and repairing techniques of the beams including the fiber-reinforced self-consolidating concrete (FR-SCC) and fiber-reinforced ferro cement (FR-FC). The team started drafting the final report for this project.

New York University - The NYU team has developed and enhanced the proposed integrated LCCA-based approach for finding feasible maintenance, rehabilitation and replacement strategies at the project level and optimizing best project selection for transportation infrastructure network. A probabilistic multi-objective framework was developed for conventional and innovative construction material and technologies. The hypothetical improvement rate method introduced in project 1A and 3A is applied to provide a reasonable estimate of the performance for the new construction material and technology.

A comprehensive final report of the work carried out by the RE-0CAST consortium universities will be submitted by December 2019.

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 - Analysis of Missouri Bridge P0058 due to load testing has been completed during this reporting period and two conference papers have been completed and submitted. In addition a supplemental exterior long-term durability study has been added to the scope of the project work. These long-term exposure beams are currently completing fabrication and will be subjected to daily weathering close to campus in an offsite location in Rolla, Missouri. During the next reporting period, the research team will complete and submit the final report prior to the project end date this year.

University of Miami - The final report was completed and submitted for the University of Miami tasks. During the reporting period, the University of Miami has provided peer evaluation of the strengthening design for Missouri Bridge P0058.

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 15 to 20 years of service. During this past reporting period the S&T team has completed their laboratory work for evaluating GFRP bars extracted from field projects. In total 11 bridges have been sampled in collaboration with efforts through ACI SDC, the University of Miami, Penn State University and Owens Corning. The research team is currently completing the final report, which will be submitted prior to the project end date this year.

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

Project 3-E. Flexural Performance of Concrete Beams Strengthened using Different Repair Techniques

Rutgers University - The team completed the analysis of small and large scale beam testing and synthesized the results of beam testing to prepare final report. The report includes the development of new mix designs and evaluation of various materials to strengthen the damage beam. The final report will be submitted.

New York University - NYU team has investigated several recent studies on bridge beams and modified the proposed probabilistic multi-objective LCCA method for bridge beam/girder applications. To perform network-level LCCA, two methods utilizing AASHTO LRFD were proposed to estimate the number of girders for each bridge. Based on the laboratory results, a case study with five different scenarios using conventional repair technique and proposed Fiber reinforced self-consolidating concrete (FR-SCC) and Fiber reinforced ferrocement mortar (FR-FC) material are examined. The team continued to improve the interactive web-based tool to perform comprehensive probabilistic LCCA. Several new functionalities were added such as street view, map visualization in cluster/marker mode, and customized deterioration functions.

The draft 2D project final report has been submitted.

Project 3-F. Performance-Based Specifications of Fiber-Reinforced Concrete with Adapted Rheology to Enhance Performance and Reduce Steel-Reinforcement in Structural Members

Missouri S&T - The proposed project seeks to optimize the characteristics of concrete made with expansive agents (EA) and lightweight sand (LWS) to enhance mechanical properties, restrained shrinkage cracking, and

transport properties of mixtures developed in projects 1-A and 3-A. The system of EA-fiber characteristics-moist curing is systematically optimized to enhance shrinkage cracking resistance, improve mechanical properties (due to the chemically-pre-stressing condition) and transport properties (due to lower crack potential and crack width). In the second phase, steel reinforcement in structural members is partially replaced by means of steel fibers. A careful design of rheological properties of the fluid fibrous mixture was conducted to achieve efficient alignment of the fibers along the casting-flow direction. This can make the best use of fibers in the structural elements. The work in progress during this reporting period includes completing data analysis of mixtures to optimize the mixtures regarding compressive strength, flexural strength, as well as shrinkage. The statistical models are under development based on a factorial design approach to predict mechanical properties and shrinkage. The models take into consideration the mixture parameters, including the contents of the expansive agent (EA), saturated lightweight sand (LWS), and fiber-reinforcement (FR), as well as the duration of moist curing. The optimum contents for EA, LWS, and FR, and moist curing conditions will be identified and used for the final stage of the project. The tasks dealing with the assessment of corrosion resistance of reinforcing bars embedded in proven mixtures prepared with steel and synthetic fibers are in also progress.

3G. Performance of Synthetic Fiber-Reinforced Concrete with Adapted Rheology

Missouri S&T - The project seeks to reduce the cracking potential of concrete using EA, shrinkage reducing admixtures (SRAs), fibers, proper curing, including internal curing, and their combinations. Proper curing is provided through mixture design, use of lightweight sand, and/or external source (i.e., moist curing). In the first phase of this study, SRA-fiber system of self-consolidating concrete (SCC) and super workable concrete (SWC) mixtures from previous projects is optimized to achieve superior performance including autogenous shrinkage, restrained shrinkage, mechanical properties (tensile and compressive strength), frost durability, and transport properties. The investigation includes the SRA and two types of synthetic fibers from GCP applied technologies. Furthermore, the effect of rheological properties of fiber alignment along the casting-flow direction of structural elements is evaluated. Viscosity modifying agents and superplasticizers are used to improve the stability of the concrete mixture and distribution of the fibers. The project investigates the corrosion resistance of reinforcing bars in pre-cracked FR-SCC and FR-SWC mixtures. The cracking is controlled to achieve different widths for mixtures with different fibers. The transport properties of the concrete matrix is investigated. The enhancement in tensile/flexural toughness and shrinkage/crack resistance of FRC made with partially replacement of the steel reinforcement in flexural members with the optimized mixtures is also evaluated.

3-H. Enhanced Performance of Fiber-Reinforced Concrete for Construction and Repair

Missouri S&T - The purpose of this research is development a novel technique to enhance properties of Eco-Bridge-Crete and FR-SCC for higher crack resistance and improved flexural properties in construction and repair by taking advantage of hybrid fibers, chemical admixtures (shrinkage reducing agents and expansive agents) and lightweight sand. Binary and ternary system of EA, SRA and LWS with selected fibers were optimized to understand the tradeoff in the shrinkage and mechanical performance with varying the contents of EX, SRA, and LWS and curing time. The incorporation of fibers with EA, SRA and LWS can increase the flexural properties and help to replace a portion of steel reinforcement bars in flexural members or reduce thickness of repair overlays without compromising flexural strength/toughness and crack resistance. The work in progress during this reporting period involves identify optimum EX, SRA, and LWS contents, and curing duration for developing high shrinkage resistance self-consolidating concrete. The selected mixtures will be used in large-scale members to assess structural performance of Eco-Bridge-Crete and FR-SCC in construction and repair, respectively.

Education and Workforce Development (EWD) / Outreach Objectives Accomplished

1) At UIUC, Ph.D. student Ruofei Zou has progressed satisfactorily, completing his PhD coursework with strong grades and passed his Preliminary Exam on Jan 12, 2018. He anticipates completion of his PhD dissertation in May 2020.
2) Keynote Speaker: Dr. Kamal Khayat, International Congress on the Chemistry of Cement, ICCC2019, Prague, Czech Republic "Rheological Properties of Ultra-High-Performance Concrete – An Overview", September 16-20, 2019
3) Keynote Speaker: Dr. Kamal Khayat, 9th International RILEM Symposium on Self-Compacting Concrete, Dresden, Germany – opening keynote lecture, "Fiber-reinforced SCC –Recent advances and perspectives" September 8-11, 2019
4) Keynote Speaker: Dr. Kamal Khayat, International Conference on Innovative materials for Sustainable Civil Engineering (IMSCE), Nanjing, China, "Development and Performance of Cost-Effective UHPC for Sustainable Concrete Infrastructure Applications" August 27-29, 2019
5) LCCA with examples from RE-CAST has been taught as a course session during the two-day Fundamentals of Traffic Engineering workshop 2019 for employees of the New York City Department of Transportation (NYCDOT)
6) Dr. Nassif presented a keynote entitled "Development and Implementation of High Performance Concrete for NJTA Projects" during the NJ ACI lunch meeting held on 9/10/2019.

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, Ruofei Zou Ruofei participated at the American Ceramic Society Cements Division Meeting on June 16-18, 2019 at UIUC, and gave a poster presentation.
3) Several RE-CAST faculty presented keynote and invited presentations, as elaborated in part below.
4) S&T Transportation Infrastructure Conference – April 2020.
5) Dr. Kamal Khayat is the Co-Chair of the 2020 Gordon Research Conference, Advanced Materials for Sustainable Infrastructure Development, Feb. 23-28, 2020, Ventura Beach, CA.

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, 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. This graduate student has been awarded the Women's Transportation Seminar (WTS) Beverley Swaim Staley Leadership Legacy Award by WTS Greater New York Chapter in honor of outstanding academic performance.
4) This project supports the Lange Research Group which has 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 black female engineering students pursuing advanced degrees in Prof. Lange's research group, thus advancing diversity goals through the UTC program.

5) At UIUC, Nanaissa Maiga graduated with an MS in May 2020. She accepted a job at Magnusson Klemencic Associates in Seattle.

6) OU sponsored a summer internship for Kevin Lepissier, a minority Civil Engineering student. Kevin completed his B.S. in Spring 2019 and will began his M.S. studies in Fall 2019.

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:

- Three students from the Lange research attended the 2019 Fall Convention of the American Concrete Institute in Cincinnati. The students participate in ACI committee work.
- 7 students from the Lange research group will attend the American Ceramic Society Cements Division Meeting on June 24-26, 2020 at Northwestern University in Evanston, IL.
- Several post-docs and students attended the Fall ACI convention from the Missouri S&T RE-CAST team.
- Special Workshop on Composite Usage presented by Dr. John Myers will be offered at the 2020 Transportation Research Board Meeting in Washington, D.C. in January 2020.
- NYU has provided professional development and training on transportation economics (including LCCA and RE-CAST examples) via annual educational workshop to local transportation agency employees.

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

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 has been collaborating with the local transportation agency (New Jersey Turnpike Authority) to evaluate the long-term performance of two advanced cementitious materials (FR-HPC and HES-HPC) that have been implemented in major highways in NJ.

Dr. Nassif at Rutgers was invited to present the recent development of advanced cementitious materials.

The NYU team has developed informative video demo about the web-based LCCA tool and posters about the LCCA work and disseminated them to our partner, other colleagues, and on research exhibitions.

The OU research team presented the results of Project 3A to the Bridge Division of the Oklahoma Department of Transportation (ODOT). Based on field implementation project, ODOT is incorporating the FR-SCC repair material specifications into their specifications. There are plans for additional implementation of this concept to repair continuity joints and beam end regions on several prestressed concrete bridges in Oklahoma. Similar achievements have been achieved in Missouri where the team of Dr. Khayat has developed the first specification for FR-SWC for bridge deck replacement and carried out field implementation projects.

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 2019 in Las Vegas, Gordon Research Conference on Advanced Materials for Sustainable Infrastructure Development in Hong Kong (Khayat – Vice Chair of Conference), ACI Spring 2019 Convention in Québec City, QC, Canada, the annual ACERS Cements conference in State College, PA, as well as overseas, including the , International Conference on Innovative materials for Sustainable Civil Engineering (IMSCE), Nanjing, China, , 9th International RILEM Symposium on Self-Compacting Concrete, Dresden, Germany and International Congress on the Chemistry of Cement, ICCC2019, Prague, Czech Republic.

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

- Missouri S&T continued working on the design/construction of the **Advanced Materials and Construction Lab (ACML)**, which broke ground on October 12, 2018. Construction of a new $6.5 million lab that is expected to strengthen Missouri S&T's position as a national leader in addressing the challenges of aging public infrastructure. 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.
- The RE-CAST Center will continue to support of 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.
- In the next reporting period, all remaining final project reports will be posted and published.

2. PRODUCTS

2.A - Publications, Conference Papers, and Presentations

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

Galvez-Moreno, D., **Feys, D.** and Riding, K., 2019. "Characterization of Air Dissolution and Reappearance under Pressure in Cement Pastes by means of Rheology." Frontiers in Materials, 6:73, April 2019.

Galvez-Moreno, D., Riding, K. and **Feys, D.,** 2019, The Effect of Shear Rate on Air Dissolution in Cement Paste under Pressure, Proc. of the 9th Int. RILEM Symposium on SCC and the 2nd Int. Conference on Rheology of Construction Materials, Dresden, Germany.

Feys, D., Wehar, A., Galvez Moreno, D., Hutcheson, E., Riding, K., 2019, How pumping affects the spacing factor of self-consolidating concrete, Proc. of the 9th Int. RILEM Symposium on SCC and the 2nd Int. Conference on Rheology of Construction Materials, Dresden, Germany.

Kassimi, F., **Khayat, K.H.**, "Shrinkage of High-Performance Concrete with Adapted Rheology," Construction and Building Materials, 223, accepted Oct 12.

Gil, A.M., Tutikian, B.F., and **Khayat, K.H.**, An Experimental Approach To Design Self-Consolidating Concrete, Construction and Building Materials, 229, 116939, on-line Sept. 12, 2019.

Mehdipour, I., **Khayat, K.H.**, "Elucidating How Particle Packing Controls Rheology and Strength Development of Dense Cementitious Suspensions," Cement and Concrete Composites, 104, 103413, on-line Nov. 1, 2019.

Abdelrazik, A., **Khayat, K.H.**, "Effect of Fiber Characteristics on Fresh Properties of Fiber-Reinforced Concrete with Adapted Rheology," Construction and Building Materials, 230, 116852, on-line Sept. 23, 2019.

Fan, L., Meng, W., Teng, L., **Khayat, K.H.**, "Effect of Steel Fibers with Galvanized Coatings on Corrosion of Steel Bars Embedded in UHPC," Composite B, 177, 107445, on-line Sept. 14, 2019.

Khayat, K.H., Meng, W., Vallurupalli, K., Teng, L., "Rheological Properties of Ultra-High-Performance Concrete – An Overview," Cement and Concrete Research, 124F, October 2019, 105828, on-line Aug. 2, 2019.

Mechtcherine, V., Schröfl, C., Reichardt, M., Klemm, A.J., **Khayat, K.H.**, "Recommendations for Using Superabsorbent Polymers (SAP) for Improving Freeze-Thaw Resistance of Cement-Based Building Materials," Materials and Structures, 52 (75), on-line July 1, 2019.

Wu, Z., Shi, C., **Khayat, K.H.**, "Changes in Rheology and Mechanical Properties of UHPC with Silica Fume Content," Cement and Concrete Research, 123, September 2019, 105786.

Wu, Z., Shi, C., **Khayat. K.H.**, "Investigation of Mechanical Properties and Shrinkage of Ultra-High Performance Concrete: Influence of Steel Fiber Contents and Shape," Composite B: Engineering, 174, pp. 1-12, October 2019.

Kassimi, F., **Khayat, K.H.**, "Strategies to Mitigate Cracking of Self-Consolidating Concrete," ACI Materials Jr., May 2019, 116 (3), pp. 73-83.

Long, W.-J., Gu, Y.-C, Xing, F., and **Khayat, K.H.**, "Evaluation of the Inhibiting Effect of Graphene Oxide on Lead Leaching from Waste Cathode-Ray Tube Glass Incorporated in Cement Mortar," Cement and Concrete Composites, 104, 2019, 103337..

Zemour, N., Asadian, A., Ahmed, E.A., Benmokrane, B., **Khayat, K.H.**, "Experimental Study on Splice Strength of Glass Fiber-Reinforced Polymer Reinforcing Bars in Normal and Self-Consolidating Concrete," ACI Materials Jr., 116 (3), May 2019, pp. 105-118.

Hosseinpoor, M., Yahia, A., and **Khayat, K.H.**, "Modeling of Flow Performance of Self-Consolidating Concrete using Dam Break Theory and Computational Fluid Dynamics," Cement and Concrete Composites, 102, 2019, pp. 14-27.

Meng, W., Kumar, A., and **Khayat, K.H.**, "Effect of Silica Fume and Slump-Retaining Polycarboxylate-Based Dispersant on the Development of Properties of Portland Cement Paste," Cement and Concrete Composites, 99, May 2019, pp. 181-190.

D. Casteneda, K. Riding, **D.A. Lange**, "Prediction of Freezing Temperature inside Concrete Crossties at the Rail Seat," J. Mat. Civil Eng. (ASCE), doi.org/10.1061/(ASCE)MT.1943-5533.0002528, Vol 31, No. 1, 2019.

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.

Y.F. Silva, **D.A. Lange**, S. Delvasto, "Effect of incorporation of masonry residue on the properties of self-compacting concretes," Construction and Building Materials, Vol 196, pp 277-283, 2019.

Y. Song and **D.A. Lange**, "Crushing performance of ultra-lightweight foam concrete with fine particle inclusions," Applied Sciences, accepted 2019.

Z. Zhao, K. Wang, **D.A. Lange**, H. Zhou, W. Wang, and D. Zhu, "Creep and thermal cracking of ultra-high volume fly ash mass concrete at early age," Cement and Concrete Composites, (REF CECO3256), accepted 2019.

Alghazali, H.H., Aljazaeri, Z.R., **Myers, J.J.,** "Effect of Accelerated Curing Regimes on High Volume Fly Ash Mixtures in Precast Manufacturing Plants," Elsevier's Cement and Concrete Research, Submitted April 2019, Accepted September 2019, CEMCON_2019_377, In Press.

Al-Khafaji, A.F., **Myers, J.J.,** Wang, W. "Bond Evaluation of Steel Reinforced Polymer (SRP) Strengthening System Exposed to Several Harsh Conditions," Elsevier's Construction and Building Materials, Submitted March 2019, Accepted September 2019, In Press.

Hernandez, E., **Myers, J.J**., "Load Distribution of a Prestressed Self-Consolidating Concrete Bridge," Frontiers in Built Environment Journal, https://doi.org/10.3389/fbuil.2019.000966, Manuscript 438154, Vol. 5, Article 96, July 2019, pp 1-12.

Aljazaeri, Z.R., Alghazali, H.H., **Myers, J.J.,** "Effectiveness of Using Carbon Fiber Grid Systems in a Reinforced Two-way Concrete Slab System," ACI Structures Journal, Manuscript S-2018-402, Submitted September 2018, Comments Received, Accepted May 2019.

Al-Khafaji, A.F., **Myers, J.J.,** Alghazali, H.H., "Direct Service Temperature Exposure Effect on Bond Behaviour between NSM Composites and Concrete Masonry Units," 9th International Conference on Advanced Composites in Construction (ACIC 2019), University of Birmingham, Birmingham, England, UK, September 3-5, 2019, Submitted, 6 pages.

Al-Khafaji, A.F., **Myers, J.J.,** Alghazali, H.H., "The Evaluation of Bond-slip Behaviour of GFRP Bars in Conventional and Sustainable Concrete," 9th International Conference on Advanced Composites in Construction (ACIC 2019), University of Birmingham, Birmingham, England, UK, September 3-5, 2019, Submitted, 5 pages.

Hernandez, E.S., Alvarado-Contreras, J.A., Lopez, A.A., **Myers, J.J**., "Reinforced Masonry Retention Wall Model Using Artificial Neural Networks," 5th International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures (SMAR 2019), Potsdam, Germany, August 27-29, 2019. Submitted, 8 pages.

Hernandez, E.S., Alvarado-Contreras, J.A., Lopez, A.A., **Myers, J.J.,** "Modeling of Bimodulus Materials with Applications to the Analysis of the Brazilian Disc Test," 5th International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures (SMAR 2019), Potsdam, Germany, August 27-29, 2019. Paper Submitted, 7 pages.

Aljazaeri, Z.R., **Myers, J.J**., "Fatigue Performance of FRCM Strengthened RC Beams Subjected to Varied Fatigue Frequencies and Environmental Exposure," 5th International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures (SMAR 2019), Potsdam, Germany, August 27-29, 2019. Paper Submitted, 6 pages.

Al-Khafaji, A.F., **Myers, J.J.,** "Durability Evaluation of Embedded GFRP Rebars in Concrete Bridges after More Than Ten Years of Service," 5th International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures (SMAR 2019), Potsdam, Germany, August 27-29, 2019. Paper Submitted, 7 pages.

Al-Jaberi, Z., **Myers, J.J**., Chandrashekhara, K., "Bond Behavior between Externally Bonded FRP and CMU under Direct Service Temperature," Modeling, Testing, Design, Control and Health Monitoring of Masonry Structures Conference (MuRiCo6 2019), Bologna, Italy, June 26-28, 2019. Paper Submitted, 7 pages.

Al-Jaberi, Z., **Myers, J.J**., "Simplified Method for Predicting Flexural Behavior of Reinforced Masonry Walls Strengthened with FRP," 13th North American Masonry Conference (13NAMC 2019), Salt Lake City, Utah, June 16-19, 2019. Paper Submitted, 14 pages.

Janke, M., Hernandez, E., **Myers, J.J.,** Nanni, A. "Design and Installation of Cement Based Composite Technologies in the Strengthening of Missouri Bridge P0058," Bridge Engineering Institute Conference (BEI 2019), Honolulu, Hawaii, July 22-25, 2019. Paper Submitted, 4 pages.

Hernandez, E., **Myers, J.J.** "Experimental and Analytical Capacity Evaluation Before Strengthening of Missouri Bridge P0058," Bridge Engineering Institute Conference (BEI 2019), Honolulu, Hawaii, July 22-25, 2019. Paper Submitted, 4 pages.

Aljazaeri, Z.R., **Myers, J.J.,** "Flexural Evaluation of RC One-way Slabs Strengthened with Different Composite Materials," 14th Fiber Reinforced Polymer Reinforced Concrete Structures (FRPRCS-14), Belfast, Ireland, UK, June 4-7, 2019. 7 pages.

Aljazaeri, Z.R., **Myers, J.J**., "Fatigue Performance of FRCM Strengthened RC Beams Subjected to Environmental Exposure and Varied Fatigue Frequencies," 14th Fiber Reinforced Polymer Reinforced Concrete Structures (FRPRCS-14), Belfast, Ireland, UK, June 4-7, 2019. 5 pages.

Al-Khafaji, A.F., **Myers, J.J.,** Alghazali, H.H., "Bond-Slip Performance of Glass Fiber Bars Embedded in Conventional and High Volume Fly Ash Concrete," 14th Fiber Reinforced Polymer Reinforced Concrete Structures (FRPRCS-14), Belfast, Ireland, UK, June 4-7, 2019. 5 pages.

Benzecry, V., Brown, J., Yee, N., Al-Khafaji, A., **Myers, J.,** Haluza, R., Bakis, C., Nanni, A. "Durability Evaluation of Bridge-Extracted GFRP Bars," Fiber Reinforced Polymers in Reinforced Concrete Structures (FRPRCS-14), Belfast, UK, June 4-7, 2019. 5 pages.

Gao, J., Ozbay, K., Nassif, H., & **Kalan, O.,** "Stochastic Multi-Objective Optimization-Based Life Cycle Cost Analysis for New Construction Materials and Technologies." Transportation Research Record, June 2019.

Garcia, D., Arezoumandi, M., and **Volz, J.S**., "Experimental Study on Bond Performance of Eco-Crete and Reinforcing Steel," Construction and Building Materials, V. 215, Aug. 2019, pp. 475-481.

Presentations (in part):

Dimitri Feys

Galvez-Moreno, D., **Feys, D.** and Riding, K., 2019, The transient effect of pressure on the rheology of air entrained cement paste and its dependence on the applied shear rate, 10th Cements Division Annual Meeting, ACerS, Urbana-Champaign, IL.

Kamal H. Khayat

"Rheological Properties of Ultra-High-Performance Concrete – An Overview," International Congress on the Chemistry of Cement, ICCC2019, Prague, Czech Republic September 16-20, 2019, Keynote Speaker

"Fiber-reinforced SCC –Recent advances and perspectives," 9th International RILEM Symposium on Self-Compacting Concrete, Dresden, Germany – opening keynote lecture, September 8-11, 2019, Keynote Speaker

"Development and Performance of Cost-Effective UHPC for Sustainable Concrete Infrastructure Applications," International Conference on Innovative materials for Sustainable Civil Engineering (IMSCE), Nanjing, China, August 27-29, 2019, Keynote Speaker

John J. Myers

Al-Khafaji, A.F., **Myers, J.J**., "Durability Assessment of Non-steel Reinforcement after More Than Ten Years of Service," 7th International Conference on Structural Engineering, Mechanics and Computation (SEMC 2019), Cape Town, South Africa, September 2-4, 2019. Paper Submitted, 5 pages. Invited conference paper

Al-Jaberi, Z.K., **Myers, J.J.,** "Effect of Different Temperatures on Epoxy Adhesive Used in Near Surface Mounted FRP Bars Strengthened Concrete Masonry Unit Under Direct Shear Test," 7th International Conference on Structural Engineering, Mechanics and Computation (SEMC 2019), Cape Town, South Africa, September 2-4, 2019. Paper Submitted, 6 pages. Invited conference paper

Alghazali, H.H., Al-Jaberi, Z.K., Aljazaeri, Z.R., **Myers, J.J.,** "Flexural performance of Extremely Damaged Reinforced Concrete Beams after SRP Repair," 7th International Conference on Structural Engineering, Mechanics and Computation (SEMC 2019), Cape Town, South Africa, September 2-4, 2019. Paper Submitted, 6 pages. Invited conference paper

Hani Nassif

Keynote presentation at NJ ACI lunch meeting held on 9/10/2019 - "Development and Implementation of High Performance Concrete for NJTA Projects"

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
- APTIM
- 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
- **Corps of Engineers, Tulsa, OK**
- 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
- Euclid Chemical, Ohio
- Florida Department of Transportation
- Garver Engineering, Norman, OK
- GPI
- 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

- MnDOT
- MnRoad
- 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
- **Northeast Remsco**
- 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
- **Owens Corning**
- Penn State University
- 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. The implementation of FR-HPC mix design will help achieve the second theme area of RE-CAST Center "Durable Materials for Rehabilitation of Transportation Infrastructure".

We are delivering new, embedded sensor systems that support Structural Health Monitoring of transportation infrastructure 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 two-level LCCA framework provides an effective solution to probabilistically evaluate different alternatives on both project- and network-level. Project-level LCCA analysis is able to factor in costs incurred during the lifetime of a transportation asset, including future maintenance, repair and rehabilitation (MR&R), delays in traffic, and social-economic impacts. Network-level LCCA analysis is capable of evaluating different combinations of projects and treatments to yield maximum benefits in developing cost-effective investment strategies. This LCCA framework has been proved to be feasible to apply to bridge deck, bridge girder and pavement. Moreover, the customized interactive web-based LCCA software automates the data input process and provides a simple-to-use user interface for engineers and decision makers.

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 knowledge applies to other disciplines such as Materials Science as it relates to generic suspensions. Experimental work is being integrated in Artificial Intelligence and machine learning to predict material performance in other applications.

The NYU team is continue transferring the proposed probabilistic LCCA framework developed in RE-CAST to Intelligent Transportation System (ITS), especially in Connected and Autonomous Vehicle (CAV) deployment. It will help the cost benefit analysis and spare part inventory management in CAV field.

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, FY2018, FY2019 and FY2020. 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.

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 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. 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 supporting the local transportation agency (NJDOT) under a new major initiative entitled Bridge Resource Program (BRP). The team has shared new methodologies and techniques developed in this project as innovative materials to find future collaboration and implementation under BRP project. The field

performance of FR-HPC and HES-HPC compared to traditional Class A concrete or HPC helped the consortium team member, New York University, establish and validate the life-cycle cost analysis model for this project.

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 industry will gradually adopt the new technology and materials that the team collaborated with the local transportation agency and implemented to the field projects.

The NYU team has prepared a video that describes 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 NYU team has introduced the developed LCCA methodology, web-based LCCA software, and its potential application in ITS to a group of junior and senior engineers from the local transportation agency which might lead to greater societal impacts beyond this project as it provides an easy-to-access way for the engineers to perform LCCA estimation.

The developed mixture 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. Since the new materials are expected to enhance the service life of infrastructure and reduce the maintenance effort, the society will experience less congestion and traffic on the roadway.

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.