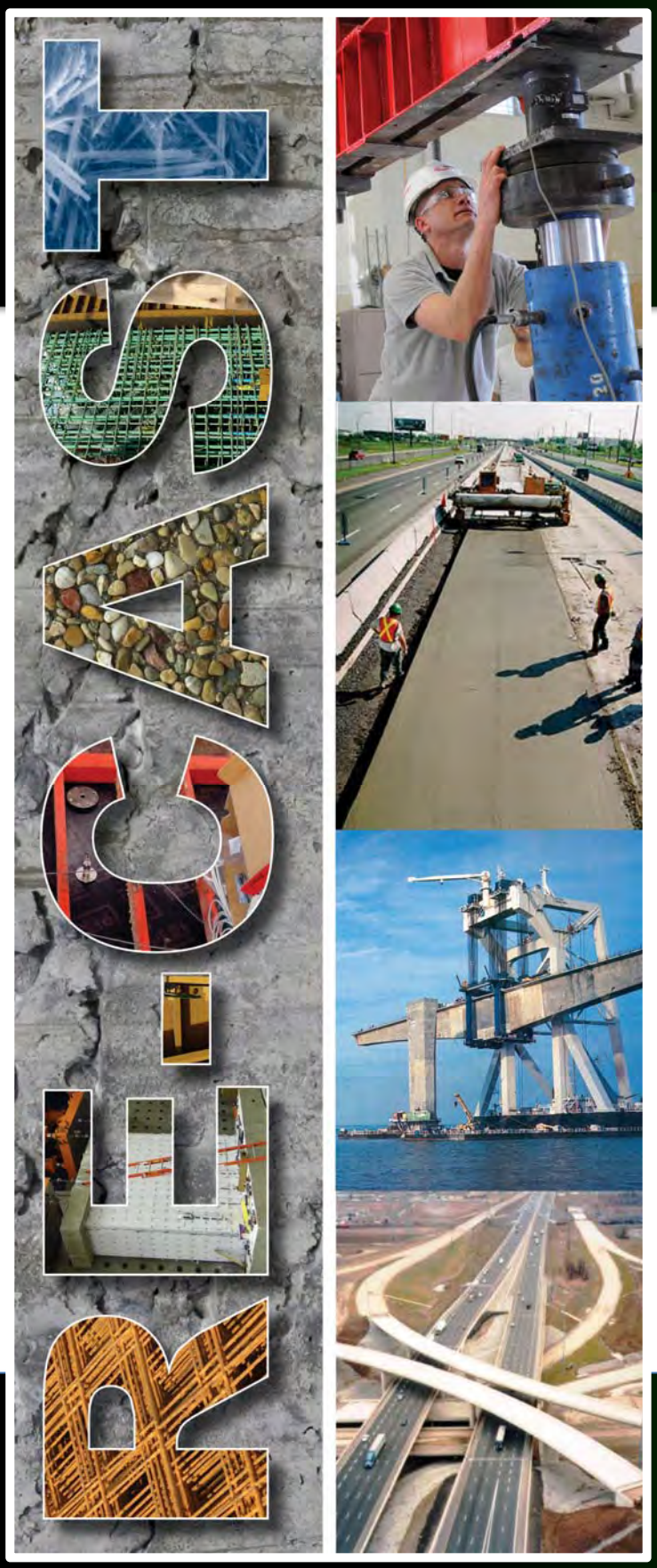
PROGRAM PROGRESS PERFORMANCE REPORT #7



GRANT: DTRT13-G-UTC45
Reporting Period: 10/1/2016 – 3/30/2017

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

TABLE OF CONTENTS

1. ACCOMPLISHMENTS 3

1.A - What Are The Major Goals And Objectives Of The Program? 3

1.B - What Was Accomplished Under These Goals? 6

1.C - What Opportunities For Training And Professional Development Has The Program Provided? 12

1. E - What Do You Plan To Do During The Next Reporting Period To Accomplish The Goals And Objectives? 13

2. PRODUCTS 13

2.A - Publications, Conference Papers, and Presentations 13

2.B - Website(s) or Other Internet Site(s) 17

2.C - Technologies or Techniques 17

2.D - Inventions, Patent Applications, and/or Licenses 17

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. 17

3. PARTICIPANTS & COLLABORATING ORGANIZATIONS 17

3.A - What Organizations Have Been Involved As Partners? 17

3.B - Have Other Collaborators Or Contacts Been Involved? 18

4. IMPACT 19

4.A - What Is The Impact On The Development Of The Principal Discipline(s) Of The Program? 19

4.B - What Is The Impact On Other Disciplines? 19

4.C - What Is The Impact On The Development Of Transportation Workforce Development? 19

4.E - What Is The Impact On Physical, Institutional, And Information Resources At The University Or Other Partner Institutions? 20

4.F - What Is The Impact On Technology Transfer? 20

4.G - What Is The Impact On Society Beyond Science And Technology? 20

5. CHANGES/PROBLEMS 20

5.A - Changes In Approach And Reasons For Change 20

5.B - Actual Or Anticipated Problems Or Delays And Actions Or Plans To Resolve Them 20

5.C - Changes That Have A Significant Impact On Expenditures 20

5.D - Significant Changes In Use Or Care Of Animals, Human Subjects, And/or Biohazards 20

5.E - Change Of Primary Performance Site Location From That Originally Proposed 20

6. SPECIAL REPORTING REQUIREMENTS 20

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
- 2.A. High-Volume Recycled Materials for Sustainable Pavement Construction
- 2.B.1 Rapid Pavement Rehabilitation
- 2-B.2 Rapid Pavement Construction
- 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
- 1-A.2/3-C.3 Use of Internal Curing Materials to Improve Performance of Concrete Infrastructure

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 project was completed and final report submitted:

Myers, J.J. and Rallabhandhi, S. "Ultra-high Performance Fiber-Reinforced Concrete (UHPFRC) for Infrastructure Rehabilitation - Volume 1: Evaluation of Ultra High Strength Concrete (UHSC) in Joints of Bridge Girders," Project #00047947, RE-CAST: Research on Concrete Applications for Sustainable Transportation, USDOT: GRANT: DTRT13-G-UTC45, Project Period: 8/1/2014 – 6/30/17

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. Research is currently in underway in evaluating life cycle assessment (LCA) of the proposed optimal concrete mixtures in conjunction with the New York University research team. The results have been compared with those of MoDOT reference mixtures designated for pavement and bridge applications. A Phase II project was also initiated to validate the performance of the developed concrete mixtures under actual field conditions. The research team is in contact with MoDOT to finalize transportation infrastructure element types and locations for field implementation.

University of Oklahoma

The OU research team completed the laboratory work and field implementation phases and has been working on data analysis and report which document the findings, recommendations, and guidelines.

Rutgers University

The research team has been evaluating the restrained shrinkage performance of fiber reinforced self-consolidating concrete (FRSCC) during this period. PSI Crimped steel fibers, 1.5 in. in length, were used to improve the resistance to shrinkage cracking of the paste-rich FRSCC. A control SCC mixture and four FRSCC mixtures with different steel fiber contents of 0.35%, 0.50%, 0.65% and 0.80%, by volume, were prepared for this objective. Two restrained shrinkage rings according to ASTM and AASHTO Standards were prepared to evaluate the resistance to shrinkage cracking. The results show that the use of steel fibers was not an effective way to delay the onset of cracking, but it tremendously helped in preventing larger cracks from forming and propagating, hence reducing crack width by up to 73% and reducing the total cracking area (= Σ(crack length × crack width)) by up to 73% also. Detailed results will be presented in progress reports and the final report.

New York University

Life Cycle Cost Analysis: Based on the information collected from the surveys and supplementary information from follow-up discussion with RE-CAST members, the NYU team extended the previous step-by-step case study to both pavement and bridge applications for multiple mixtures in Projects 1-A, 2-A and 3-A. Both deterministic and probabilistic approaches were tested and evaluated. In addition, sensitivity analysis for deterministic approach

was added as an optional feature for the proposed LCCA methodology that enables the analyst to examine the effect of the variability of the main input parameters. Enhanced cost-effectiveness analysis that evaluates cost effect on energy consumption and global warming potentials was applied to Project 1-A. The team continued to enhance the functionalities of the web-based LCCA software and added new features for conducting network LCCA in the future. Users are able to select multiple roadway links or bridges from the map interface. The team added input data validation, sensitivity analysis, visualization of deterioration curves and enhancement of work flow to the web-based app. These activities are carried out simultaneous with other projects, as indicated below.

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

UIUC students (Kavya Vallurupalli and Karthik Pattaje Sooryanarayana) supported by this project have developed many SCC mixtures and have tested rheological properties of these materials. The primary objective of this project is to understand the mechanisms responsible for the formwork pressure drop in SCC over time and to improve the methodology for the measurement and modelling of the formwork pressure. The current study involves preparing various concrete and mortar mixtues, studying the formwork pressure decay using PVC columns of different dimensions and understanding how the thixotropic properties of concrete/mortar influence pressure changes (in the formwork) over time.

Kavya has completed her MS thesis in time for graduation for the May 2017 commencement. Her work considers lateral pressure, temperature, and rheological properties variations over time measured for different SCC, mortar, and cement mixtures. The underlying mechanisms for the pressure, temperature, rheology changes are also discussed, and recommendations are given. Various models for predicting formwork pressure are considered.

The students have developed new column test apparatus for testing formwork pressure and have identified new sensors for measuring pressure in addition to the “traditional” HP sensor that has been used by Khayat, Lange, and others in the past. Rheological properties are measured routinely using an ICAR rheometer.

Materials range from mortars, pastes, and concretes; in addition to control material systems of non-concrete fluids. Material models are being developed using fluid mechanics theory based on “granular fluids” that are sensitive to the role of aggregate in the flowing concrete behavior.

The conclusions address mixture design parameters and sensitivity of formwork pressure to those variables. The impact of column dimensions and measurement variables is considered. Then recommendations are made related to modeling the behavior. The yield strength gain is due to reversible and irreversible changes in concrete/mortar. However, in the first few hours, the reversible changes dominate. The study of dynamic, static yield strength and temperature changes help to differentiate between the reversible and irreversible structural changes in concrete causing the pressure decay. Self-consolidating mortars exhibit strain hardening behavior, i.e., the yield stress value for disturbed mortar is higher than the stress value obtained in a fresh batch of mortar. The shear history influences the static yield stress data significantly.

Project 1-C. Influence of Casting Conditions on Durability and Structural Performance of High-Performance Concrete with Adapted Rheology

Project 1C-1: Dynamic segregation

In-situ compressive strength and ultrasonic pulse velocity results determined from precast beam elements cast using SCC mixtures with different dynamic segregation properties were analyzed to evaluate the homogeneity of the concrete. The beams were 9 and 18 m in length. Results reveal that the beams were less homogeneous in the vertical direction at the casting point, and at the bottom in the horizontal direction. Characterization of concrete sections is ongoing to determine aggregate and air content, and durability parameters.

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

For this project, discussions with ready-mix producers and pumping companies are underway to set up large-scale experiments. Critical testing parameters are being discussed with the partners (K. Riding, U. of Florida; L. Keller and S. Van Zetten, EllisDon). The pressure cell on the Anton Paar rheometer is finalized for testing under pressure.

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

Missouri S&T

Six different sources of recycled concrete aggregate (RCA) were incorporated in laboratory to investigate effect of RCA on mechanical properties, shrinkage, and durability of concrete designated for pavement construction. These mixtures were proportioned with two different water-to-cementitious materials ratios (w/cm) of 0.40 and 0.37. A binary composition of 75% Portland cement and 25% Class C fly ash, and a ternary composition with 50% Portland cement, 35% fly ash, and 15% slag were investigated. The concrete is tested for compressive, splitting tensile strength, and flexural strengths as well as elastic modulus, drying shrinkage, cracking resistance, and frost durability. Recommendations regarding the use of RCA in sustainable pavement are under development.

UIUC

The work undertaken at UIUC focuses on use of recycled fine materials for controlled low strength materials (CLSM) and Foam Cement. The team is using x-ray computed tomography to capture microstructural information in 3D. 3D printing technology was used to construct physical models of the foam system to aid interpretation. The modeling of crushing behavior is advancing well. Yu Song, PhD student, is using this topic for his PhD dissertation. Kate Hawkins and Jamie Clark are MS students involved in laboratory work related to modeling 3D structure. The work has produced models of structure and experiments on crushing behavior that is the subject of FEM models of fracture energy. These models will form the basis of materials design methodology in the future.

University of Oklahoma

The research team began work on the next phase of this project involving additional laboratory testing, mixture development, and further implementation of the eco-friendly pavement construction. This phase also includes durability testing of eco-friendly concrete, including freeze-thaw resistance, chloride ion permeability, and deicing salt scaling. Field implementation project involves construction of full-scale pavement sections for I-40 in Oklahoma County between mileposts 165 and 173. The team identified several recycled concrete aggregate (RCA) sources and performed standard aggregate tests and aggregate imaging to assess the angularity and surface roughness of the material. Durability testing and surface resistivity screening was performed on several candidate mixtures that utilized both RCA and fly ash, with total recycled content well over the target value of 50%.

New York University

Life Cycle Cost Analysis: Refer to project update in Project 1-A.

Project 2-B-1. Rapid PCC Pavement Rehabilitation

The research team continued on developing high early strength concrete (4,000 psi in 4 hours) to be used in rapid joint rehabilitation of PCC pavement. To minimize drying shrinkage and cracking, internal curing was adopted with lightweight aggregate and recycled concrete aggregate (RCA). The early-age strength was achieved to 3,500 psi with RCA, which below the target strength. RCA will be replaced with virgin limestone aggregate to further enhance the 4-hour strength to the target value. Repeatability of the mixture to produce early high strength concrete is under investigation. Field implementation is in planning and seeks to evaluate surface cracking of the optimized concrete used for rapid PCC pavement rehabilitation, including potential problems in joint repair.

Project 2-B-2. Rapid Pavement Construction

2-B.2. Rapid PCC Pavement Construction

Missouri S&T

Work is underway to evaluate thixotropy and workability loss of vibration-free concrete (VFC) in view of accelerating pavement construction by slipforming. Research on cement rheology has advanced significantly, narrowing suitable binder materials down to four constituents. Thixotropic development over time, as well as workability loss are monitored. It is also determined whether the thixotropic increase is reversible. Aggregate skeleton is being optimized, and production of testing equipment for "green" strength development is finalized. In the final stage, several concrete mixtures with different binder compositions and the optimized aggregate skeleton will be produced to investigate self-consolidation and "green: strength development.

SUBR

This follow-up project was initiated in June 2016 to apply VFC mixtures in rapid pavement construction. The first stage of the project aimed at developing VFC mixtures in collaboration with Missouri S&T. Plans are underway for pre-field and field implementation that should start soon.

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. Work is aiming at investigating ways to enhance frost durability of RCC. For selected mixtures, compressive strength at 7 and 28 days, surface resistivity, freeze and thaw resistance, deicing salt-scaling, and permeable voids have been measured. 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 and the City of Rolla.

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

Optimized FR-SWC that was developed in Phase I showed excellent performance for use in bridge construction will be used in field implementation for the replacement of bridge deck on the A8509 Bridge over Route 50 near Taos, Missouri. Casting of the bridge deck is scheduled in July 2017.The FR-SWC will be used to facilitate the casting of the bridge deck that will have two layers of longitudinal and transverse steel. The optimized FR-SWC is prepared using a combination of micro and macro steel fibers with a total content of 67 pcy, a binary cement with 70% Type I/II Portland cement and 30% Type C fly ash, by mass of binder, and 5% Type-G expansive agent, by mass of binder. A job special provisions document regarding the design and testing of the proposed FR-SWC has been produced in collaboration with MoDOT engineers. The concrete is expected to exhibit slump flow of 20-23 in. and will be air-entrained to secure 6%-9% air content. High stability of FR-SWC is required with VSI of 0. The difference between slump flow diameter and the modified J-Ring test flow diameter will be used to assess the passing ability and should be limited to 2 in. The optimized concrete should have a maximum drying shrinkage of 500 μstrain after 120 days of drying.

The research team will work with the concrete supplier and the contractor to prepare a mock-up placement and evaluate constructability issues with the FR-SWC. In-situ properties will be evaluated in six locations along the bridge deck. The research team will monitor variations of concrete strain, upper and lower steel rebar strains, concrete shrinkage, concrete temperature, relative humidity and maturity of concrete.

University of Oklahoma

The research team began work on the implementation phase of this project in Oklahoma, which involves transitioning the technology from the laboratory to the field. Working with the Oklahoma Department of Transportation (ODOT), the research team identified the implementation project as the I-244 Bridge over the Arkansas River. Constructed in 1967, recent ODOT evaluations classified the bridge structure as functionally obsolete, with an operating rating of 57.9 tons and an inventory ration of 35.0 tons. The main objective of the implementation phase is to evaluate the effectiveness of FR-SCC for the repair of bridge structures. The research team surveyed the I-244 Bridge and identified areas for repair. The team also developed repair specifications and drawings. This phase also includes testing of full-scale girders removed from the bridge. The research team identified the control bridge girder for testing, which was removed by the repair contractor and delivered to the OU Structures Lab. A detailed inspection of this girder revealed no signs of distress or deterioration. The girder underwent extensive instrumentation including load cells, LVDTs, concrete strain gages, prestressing slip gages, string pots, and laser survey points. Testing is scheduled for the next quarter.

Rutgers University

The team completely tested 10 full-scale beams with two layers (Class A substrate and FR-SCC repaired layer). The testing results were reviewed and analyzed to understand the sensitivity of each parameters that would affect the performance of FRSCC in structural repair application. The results show that the amount of fiber (regardless of fiber type- steel fiber or polypropylene fiber) affects the initial cracking capacity but does not affect the ultimate load. However, as anticipated, the initial cracking load was not reduced by the use of smaller diameter of reinforcing rebars. Therefore, it was concluded that the repair with FR-SCC could be an effective option to repair damaged beams and to increase cracking capacity. Additional efforts are needed to recover the original ultimate capacity of the beams when the rebar was degraded or damaged due to corrosion. The testing results and recommendations will be detailed described in the final report.

The team has collaborated with NYU Team to develop a deterioration model for FR-SCC repair material. The team reviewed the state-wide Weigh-In-Motion (WIM) data, National Bridge Inventory (NBI) database, and historical bridge maintenance reports. A typical deterioration curve for conventional Class A concrete for bridge deck was determined. Two stages of bridge deck deterioration were considered: Stage 1 is from rating 9 to rating 6 (crack onset to propagation); and Stage 2 is from rating 6 downward (crack propagation and corrosion). Although no long-term data about the new material are available, the FR-SCC is expected to significantly increase the crack and propagation resistance, toughness and long-term durability; as a result, team it can be assumed that there will be a significant improvement at Stage 1 of deck deterioration. The team will continuously collaborate with NYU Team for the development of deterioration model of this novel structural repair material.

New York University

Life Cycle Cost Analysis: Refer to project update in Project 1-A.

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

During this reporting period, one of the two structural testing and evaluation studies was completed and final report issued entitled “Evaluation of Ultra High Strength Concrete (UHSC) in Joints of Bridge Girders.” This research focused on using UHSC as joint filler material along with High strength self-consolidating concrete (HS-SCC) while studying the effects of using different continuity details and effects of surface preparation of beam in a reinforced concrete section subjected to high-moment loading using 22 test specimens. An investigation of non-prestressed MoDOT end girder detail using UHSC in the joint was also conducted. UHSC when used in the joints can be a viable solution making joints the stronger link holding the structure together.

The experimental work for the second portion of the work is completed, and the final reporting is expected to be issued by the end of summer 2017. The title of the report on this effort is entitled “Behavior of Ultra-High Strength

Concrete Bridge Deck Panels Compared to Conventional Stay-In-Place Deck Panels." This work investigates the performance of ultra-high-strength concrete (UHSC) stay-in-place (SIP) bridge deck panels subjected to high loads in both flexure and shear. The test matrix consisted of 12 half-scale panels that were 4 ft long and 2 ft wide. The variable parameters that were studied included thickness (i.e., 2 and 3 in.) as well as non-discrete reinforcement type, including conventional mild reinforcement, welded wire mesh and no reinforcement (UHPC). Control deck panels with conventional concrete (CC) were fabricated and tested to serve as a baseline. Results to date indicate that the UHPC panels had an improved performance compared to the conventional concrete panels. With respect to the panels tested in high shear loads, only the CC panel test resulted in a diagonal tension failure mode (i.e. traditional shear type failure). All of the other UHPC panels failed in flexure suggesting that the UHPC provided a high shear capacity. The results also showed a good correlation with selected empirical models.

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

Missouri S&T

During this reporting period, the experimental laboratory work has been completed. A PhD student working on the project has successfully defended her dissertation. The final report documenting is under development and it is expected to be published by the end of summer 2017. In terms of implementation of the new technology validated during the laboratory studies, the project Co-PI has successfully worked with the MoDOT to identify a four span candidate bridge for rehabilitation to serve as the implementation test bed. Presently, an extension request was submitted and approved to support the implementation work which includes pre- and post-strengthening load testing. Ideally, this implementation project will be initiated during the next reporting period.

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) RE-CAST hosted its **17th research seminar** on October 11, 2016 – see Attachment A.
2) RE-CAST hosted its **18th research seminar** on November 9, 2016– see Attachment B.
3) RE-CAST hosted its **19th research seminar** on November 17, 2016 – see Attachment C.
4) RE-CAST hosted its **20th research seminar** on February 23, 2017 – see Attachment D.
5) Dr. Volz at OU and his students presented papers on their RE-CAST projects at the 2016 Oklahoma Transportation Research Day as well as the 2nd Annual Region 6 Transportation-Climate Summit.
6) Prof. Khayat gave a keynote speech "Novel Applications of UHPC for Civil Infrastructure" at the 1rst International Conference on Ultra-High Performance Concrete (UHPC 2016), Changsha, China, Nov. 2016 and an invited lecture "Design and Performance of Sustainable Concrete Made with High Volume of Recycled Materials for Infrastructure Construction" at the International Symposium of Ceramics and Composites (ISCCO 2016), Medellin, Colombia, October, 2016.
7) Prof. Lange delivered a **Short course** at Southeast University in Nanjing China in Feb. 2017 *Innovation in Civil Engineering Materials*; SEU sponsor is Prof. Yamei Zhang. The short course covered SCC, recycled materials, foamed cements, and other topics that are within the scope of RE-CAST research program. The course was attended by 50 students and included eight lectures and lab exercise.

Technology Transfer Objectives Accomplished

1) Social media (**Facebook and LinkedIn**) pages have been utilized to publicize on-going research, training, and technology transfer events.

2) The RE-CAST **website has been updated** to contain links to listing of upcoming technology transfer events, educational seminars and workshops, presentations, and project reports.
3) The 11th quarterly **newslette**r was published in October 2016 – see Attachment E.
4) The 12th quarterly **newslette**r was published in January 2017 – see Attachment F.
5) The 5th annual Missouri S&T/MoDOT Transportation Infrastructure Conference took place in Rolla, MO on Friday, November 18th, 2016. Keynote speakers included Dr. Atorod Azizinamini of the ABC-UTC, as well as Dr. Ghassan Al-Chaar of the US Army Construction Engineering Research Laboratory, Tom Blair from MoDOT's Road to Tomorrow Statewide Initiative and Paul White, an industry speaker from LaFargeHolcim.
6) Several RE-CAST faculty presented keynote and invited presentations, as elaborated in part below.

Diversity Objectives Accomplished

1) U. of Miami continued support of two minority undergraduate students as part of commitment to diversity.
2) Southern University and A&M College will be hosting **Summer Transportation and Energy Institute** (STEI) in 2017. Dr. Alex Shin of RE-CAST is planning to give a lecture on RE-CAST projects and provide financial support to buy teaching materials.
3) The University of Oklahoma added two new undergraduates performing research from traditionally underrepresented groups. The first is Candace Alsenay, a female Native American civil engineering student. The second is Alejandro Sotomayor, who participated in undergraduate research through the McNair Scholars Program and is also a civil engineering student.
4) UIUC student Jamie Clark, an African American female student, is in Prof. D. Lange's group working with partial support from RE-CAST funding.

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

1. The RE-CAST has provided **four research seminars** as professional development opportunities. The topics/dates of those seminars are:

1. Date: October 11, 2016
   - Presenter: Dr. Hani Nassif, Professor of Civil Engineering, Rutgers University
   - Topic: *Structural Health Monitoring (SHM) of Corrosion Potential in Concrete Bridge Decks*
   - Recorded and posted on RE-CAST website
2. Date: November 9, 2016
   - RE-CAST Presenter: Dr. Antonio Nanni, University of Miami
   - Topic: *The Role of Cementitious Materials in the Next Decade - Joint workshop offered with CESTiCC and ACI*
3. Date: November 17, 2016
   - Presenter: Dr. Raissa Ferron, Asst. Prof. of Civil Engineering, The University of Oklahoma
   - Topic: *Engineering smart, stimuli-responsive cementitious composites*
   - Recorded and posted on RE-CAST website
4. Date: February 23, 2017
   - Presenter: Dr. Jeffery Volz, Assoc. Prof. of Civil Engineering, University of Texas at Austin
   - Topic: *Concrete Pavement Containing High Volumes of Recycled Materials*
   - Recorded and posted on RE-CAST website
5. Shortcourse in Nanjing, China.

1.D - How Have The Results Been Disseminated?

Recordings of previous seminars are available on the RE-CAST website. A summary of all RE-CAST activities are outlined in the Center's quarterly newsletter, which is distributed electronically to approx. 1200 recipients.

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 2016 in Las Vegas, 2016 TRB Meeting in Washington, D.C., ACI Fall 2016 Convention in Philadelphia, ACI Spring 2017 Convention in Detroit, as well as overseas, including the 1^{rst} Int. Conference on Ultra-High Performance Concrete, in Nov. 2016 in Changsha, China.

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

- Publish 11th and 12th newsletters
- Schedule 21st, 22nd and 23rd bi-monthly research seminars
- **Summer Transportation Institute at SUBR** - Southern University and A&M College will host National Summer Transportation Institute (NSTI) 2017. 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. H. 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 subjects.
- **S&T Transportation Infrastructure Conference -** Planned for winter of 2017.
- External funding for pumping experiments has been secured, and at least 25 concrete mixtures will be pumped with different parameters. Lubrication layer study will be continued as Jan Vosahlik, Ph-D candidate at Kansas State University will be spending two weeks in our laboratory.
- In the next reporting period: ACI Field Technician Certification at Missouri S&T. 4 undergrads and 6 graduate students will hopefully be certified. Activity in collaboration with the local ACI chapter.
- The Rutgers University team will compile the restrained shrinkage testing results of FR-SCC with steel and polypropylene fiber and promote the best mixtures to a field implementation. Accordingly, a technical specification of FR-SCC will be prepared for the field implementation. The team will closely work with the local transportation agencies to draft the technical specification and will implement the new material (FR-SCC) and technical specification. The team will coordinate with the team at Missouri S&T for field implementation of FR-SWC for bridge deck replacement in MO.

2. PRODUCTS

2.A - Publications, Conference Papers, and Presentations

1) **17th research seminar** on October 11, 2016 – see Attachment A.
2) **18th research seminar** on November 9, 2016– see Attachment B.
3) **19th research seminar** on November 17, 2016 – see Attachment C.
4) **20th research seminar** on February 23, 2016 – see Attachment D.
5) **11th quarterly newslette**r published in October 2016 – see Attachment E.
6) **12th quarterly newslette**r published in January 2017 – see Attachment F.
7) **Journal Publications** (in part):

Geert De Schutter, **Dimitri Feys**, "Pumping of Fresh Concrete: Insights and Challenges," RILEM Technical Letters 1 (2016), 76-80.

Gooranorimi, O., **Myers, J.J**., Nanni, A., GFRP Reinforcements in Box Culvert Bridge: A Case Study after Two Decades of Service, Journal of ASTM International, Manuscript STP1601-2016-0119, in Press.

Alghazali, H.H., **Myers, J.J.**, A Study of Elastic Shortening Losses of High-Strength Self-Consolidating Concrete Prestress Girders, Int. Journal of Research in Engineering and Science, **4**(9), 2016, pp. 06-16.

Aljazaeri, Z.R., **Myers, J.J.**, Fatigue and Flexural Behavior of Reinforced Concrete Beams Strengthened with a Fiber Reinforced Cementitious Matrix, American Society of Civil Engineering – Journal of Composites for Construction, **21**(1), February 2017, pp. 1-7.

Abeol Seoud, M.A., **Myers, J.J.**, Durability of Hybrid Composite Beam (HCB) Bridges Subjected to Various Environmental Conditioning, American Society of Civil Engineering – Journal of Composites for Construction, **20**(6), December 2016, pp. 1-13.

Mehdipour, I., **Khayat, K.H.**, Effect of Particle-Size Distribution and Specific Surface Area of Different Binder Systems on Packing Density and Flow Characteristics of Cement Paste, *Cement, Concrete and Composites*, **78**, 2017, pp. 120-131.

Meng, W., Valipour, M., **Khayat, K.H.**, Optimization and Performance of Cost-Effective Ultra-High Performance Concrete, *Materials and Structures*, **50**:29 (1), Feb. 2017, pp. 1-16.

Naji, S., **Khayat, K.H.**, Karray, M., Assessment of Static Stability of Concrete Using Shear Wave Velocity Approach, *ACI Materials Jr.*, on-line Dec, 2016, DOI: 10.14359/51689244.

Esmaeilkhanian, B., Diederich, P., **Khayat, K.H.**, Yahia, A., Wallevik, Ó.H., Influence of Particle Lattice Effect on Stability of Suspensions: Application to Self-Consolidating Concrete, *Materials and Structures*, **50** (39), Jan. 2107, pp. 39.2016.

Meng, W., **Khayat, K.H.**, Mechanical Properties of Ultra-High-Performance Concrete Enhanced with Graphite Nanoplatelets and Carbon Nanofibers, *Composites Part B: Engineering*, Dec., 2016, pp. 113-122.

Foudazi, A., Mehdipour, I., Donnell, K.M., **Khayat, K.H.**, Evaluation of Steel Fiber Distribution in Cement-Based Materials Using Active Microwave Thermography, *Materials and Structures*, **49**(12), 2016, pp. 5051-65.

Ghafari, E., Feys, D., **Khayat, K.H.**, Feasibility of Using Natural SCMs in Concrete for Infrastructure Applications, *Concrete and Building Materials Jr.*, 127, Nov., 2016, pp. 724-732.

Sadati, H., **Khayat, K.H.**, Field Performance of Concrete Pavement Incorporating Recycled Concrete Aggregate, *Construction & Building Materials Jr.*, 126, Nov. 2016, pp. 691-700.

Vanhove, Y., **Khayat, K.H.**, Forced Bleeding Test to Assess Stability of Flowable Concrete, *ACI Materials Jr.*, **113** (6), Nov.-Dec. 2016, pp. 753-758.

Meng, W., Lunkad, P., Kumar, A., **Khayat, K.H.**, Influence of Silica Fume and PCE Dispersant on Hydration Mechanisms of Cement, *Journal of Physical Chemistry C*, Nov. 2016, **120** (47), pp. 26814-26823.

Feys, D. De Schutter, G., **Khayat, K.H.**, Verhoeven, R., Changes in Rheology of Self-Consolidating Concrete Induced by Pumping, *Materials and Structures*, **49** (11) Nov. 2016, pp. 4657-4677.

Zhao, S., Van Dam, E., **Lange**, **D.A.** Sun, W., "Abrasion Resistance and Nano-Scratch Behavior of an Ultra-High Performance Concrete, ASCE J. Mat. Civil Eng., 2016, in press.

Song, Y., Zou, R., Castaneda, D., Riding, K.A., **Lange**, **D.A.**, Advances in Measuring Air-Void Parameters in Hardened Concrete Using a Flatbed Scanner, ASTM J. Testing and Evaluation, 45(5), 2017.

Gooranorimi, O., **Nanni**, **A.**, GFRP Reinforcement in Concrete after 15 Years of Service, ASCE JCC, March 2017, DOI: 10.1061/(ASCE)CC.1943-5614.0000806, 04017024-1 to 9.

Spagnuolo, S., Meda, A., Rinaldi Z., **Nanni**, **A.**, Precast Concrete Tunnel Segments with GFRP Reinforcement, ASCE JCC, March 2017, DOI: 10.1061/(ASCE)CC.1943-5614.0000803, 04017020-1 to 10.

Gooranorimi, O., Suaris, W., Dauer, E. **Nanni**, **A.**, Microstructural Investigation of Glass Fiber Reinforced Polymer Bars, Composites Part B: Engineering, Vol. 110, Feb. 2017, pp. 388–395.

Pino, V., **Nanni, A.**, Arboleda, D., Roberts-Wollmann, C., Cousins, T., Repair of Damaged Prestressed Concrete Girders with FRP and FRCM Composites, ASCE JCC, Nov. 2016.

Nanni, A., Claure, G., Caso, F. De, and Gooranorimi, O., Concrete and Composites Pedestrian Bridge, Concrete International, Nov. 2016, pp. 53-59.

Ebead, U.A., K.C. Shrestha, M.S. Afzal, El Refai, A., **Nanni**, **A.**, Effectiveness of FRCM in Strengthening Reinforced Concrete Beams, ASCE J. Compos. Constr., 2016.

Conference Papers (in part):

Wu., Z., Shi, C., **Khayat, K.H.**, Zhu, D., Optimization of Microstructure and Pullout Behavior of Fibers in Ultra-high Strength Concrete with the Help of Nano-particles and Heat Curing, Proc. UHPC 2016 Conference, Oct. 27-30, 2016, Changsha, China, pp. 476-488.

Aljaberi, Z., **Myers, J.J.**, Contribution of Externally Bonded FRP to Flexural Capacity of Reinforced Masonry Walls Subjected to Out-Of-Plane Load, Proc. 8th Int. Conf. on Fiber Reinforced Polymer (FRP) Composites in Civil Engineering (CICE-16), Hong Kong, China, December 14-16, 2016, 6 pages.

Wang, W., **Myers, J.J.**, Assessment of Existing FRP Bridge Structures Exposed to Field Conditioning, Proc. CICE-16, Hong Kong, China, December 14-16, 2016, 6 pages.

Aljazaeri, Z., **Myers, J.J.**, Durability Performance of FRCM Composite Bonded to Concrete Under Different Environmental Ageing Conditions, Proc. CICE-16, Hong Kong, China, December 14-16, 2016, 8 pages.

Hernandez, E., **Myers, J.J.**, Initial Response of a Prestressed Self-Consolidating Concrete (SCC) Bridge Using Diagnostic Load Tests, Proc. CICE-16, 5th Int. Symp. on Life-Cycle Civil Engineering (IALCCE 2016), Delft, The Netherlands, October 16-19, 2016, 8 pages.

8) **Presentations** (in part):

Dimitri Feys

Ley Hernandez, M., Feys, D., Hartell, J.-A., How Bad Placement Can Hinder Concrete Performance, Missouri S&T/MoDOT Transportation Infrastructure Conference, Rolla, MO, November 2016.

Ley Hernandez, M., Feys, D., Hartell, J.-A., How Dynamic Segregation Influences Performance of Self-Consolidating Concrete Pre-stressed Beams, ACI Fall Convention, October 2016.

Feys, D., SCC Air Quality after Pumping, ACI Fall Convention, October 2016.

Kamal H. Khayat

Hosseinpoor, M., Yahia, A., **Khayat, K.H.**, Numerical Simulation of Dynamic Segregation of SCC under Restricted & Non-Restricted Flow Conditions, ACI Spring 2017 Convention, March 2017.

Khayat, K.H., Novel Applications of UHPC for Civil Infrastructure, 1rst Int. Conf. on Ultra-High Performance Concrete (UHPC 2016), Changsha, China, Nov. 2016 (keynote).

Wu, Z., Shi, C., **Khayat, K.H.**, Optimization of Microstructure and Pullout Behavior of Fibers in Ultra-High Strength Concrete Using Nano-Particles and Heat Curing, UHPC 2016, Changsha, China, Nov. 2016.

Khayat, K.H., To What Degree Does Slump Affect the Performance of Underwater Concrete? ACI Fall 2016 Convention, Oct. 2016.

Khayat, K.H., Design and Performance of Sustainable Concrete Made with High Volume of Recycled Materials for Infrastructure Construction, Int. Symp. of Ceramics & Composites, Colombia, Oct. 2016.

David Lange

Prof. Lange delivered a **keynote address** at the Int. Conf. on Advances in Sustainable Construction Materials & Civil Engineering Systems (ASCMCES-17), held at the University of Sharjah, United Arab Emirates, 18-20 April 2017. The presentation featured RE-CAST research. There were about 200 in attendance.

John J. Myers

GFRP Reinforcements in Box Culvert Bridge: A Case Study after Two Decades of Service, Transportation Research Board (TRB) 2017 Annual Meeting, Committee AAF80, Washington, DC, January 9, 2017.

Innovative Infrastructure Developments and Long-term Performance Assessment, Rolla Lion's Club Featured Dinner Speaker, Rolla, Missouri, January 5, 2017.

An Overview of the United States Protocols on Structural Assessment Using Load Testing: ACI 437.1R-07, ACI 437.2-13 and ACI 342R-16, 5th Int. Symp. on Life-Cycle Civil Engineering (IALCCE 2016), Delft, The Netherlands, Oct. 17, 2016.

Durability Assessment of FRP Bars Extracted from FRP Bridge Structures Exposed to Field Conditions, 8th Int. Conf. on Fibre-Reinforced Polymer Composites in Civil Engineering (CICE 2016), Hong Kong, Dec. 14, 2016.

Durability Performance of FRCM Composite Bonded to Concrete Under Different Environmental Ageing Conditions, 8th Int. Conf. on Fibre-Reinforced Polymer Composites in Civil Engineering (CICE 2016), Hong Kong, Dec. 14, 2016.

Contribution of Externally Bonded FRP to Flexural Capacity of Reinforced Masonry Walls Subjected to Out-of-Plane Load, 8th Int. Conf. on Fibre-Reinforced Polymer Composites in Civil Engineering (CICE 2016), Hong Kong, Dec. 14, 2016.

GFRP Reinforcements in Box Culvert Bridge: A Case Study After Two Decades of Service, American Society of Testing Methods International Symposium (ASTM Symposium 2016), Orlando, Florida, December 7, 2016.

Experimental Study on Flexural Behavior of Reinforced Masonry Walls Strengthened with FRCM Composite or NSM with Cementitious Adhesive, American Concrete Institute (ACI) 2016 Fall Conference, Philadelphia, Pennsylvania, Oct. 25, 2016.

Bond Behavior of High Performance Self-Consolidating Concrete, American Concrete Institute (ACI) 2016 Fall Conference, October 25, 2016, 2016.

Initial Response of a Prestressed Self-Consolidating Concrete (SCC) Bridge Using Diagnostic Load Tests, 5th International Symposium on Life-Cycle Civil Engineering (IALCCE 2016), Delft, The Netherlands, October 17, 2016.

Antonio Nanni

Gooranorimi, O., G. Claure, F. De Caso, W. Suaris, A. Nanni, GFRP Reinforcements in Box Culvert Bridge: A Case Study after Two Decades of Service, ASTM Symposium on Concrete Pipes and Box Culverts, Orlando, FL, Dec. 2016.

Jeffery Volz

Volz, J.S., Concrete Pavement Containing High Volumes of Recycled Materials, 2016 Oklahoma Transportation Research Day, Oklahoma City, OK, October 2016.

Drury, J.T., Volz, J.S., Durability Performance of High Volume Recycled Concrete Pavements, 2nd Annual Region 6 Transportation-Climate Summit, Norman, OK, November 2016.

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-6626216?trk=anet_ug_hm&gid=6626216&home=

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
- Bowman, Barrett and Associates, Chicago, IL, financial support
- CBM-St-Mary's Toronto
- Chicago Department of Aviation
- City University of New York
- Clayton Concrete Materials and Ready Mix, Edison, NJ
- Chicago Bridge and Iron Company (CB&I), Trenton, NJ
- Coreslab Structures Inc., Marshall, MO
- Dewberry, Bloomfield, NJ, financial support
- Dolese Bros. Co., Oklahoma City, OK financial support

- Eastern Concrete Materials and Ready Mix, Bogota, NJ
- EllisDon, Toronto
- Euclid Chemicals, East Brunswick, NJ
- Garver Engineering, Norman, OK
- Grand River Dam Authority, Vinita, OK
- Greenman Pedersen, Inc. (GPI), Lebanon, NJ, financial support
- Hanyang University (Korea)
- K-FIVE Construction Corp., Lemont, IL
- Kansas State University
- Kyunghee Univ. (Korea)
- LaFarge North America (Cement Plant), Whitehall, PA
- Louisiana Transportation Research Center (LTRC), Baton Rouge, LA, financial support
- Missouri Department of Transportation, Jefferson City, MO, financial support
- Missouri University of Science and Technology, Rolla, MO, in-kind support
- New Jersey Department of Transportation Research Division, West Trenton, NJ, financial support
- New Jersey Turnpike Authority, Woodbridge, NJ, financial support
- New York City Department of Transportation
- New York State Department of Transportation
- New York University Polytechnic School of Engineering, Brooklyn, NY, financial support
- Noblis
- O'Hare Modernization Program, Chicago, IL, financial support
- Oklahoma Department of Transportation, Oklahoma City, OK
- Oklahoma City, Norman, and Tulsa, OK, City Planning Departments
- Oklahoma State University
- Oklahoma Turnpike Authority, Oklahoma City, OK
- Small Modular Reactor Research and Education Consortium, financial support
- **Southeast University, Nanjing, China**
- State University of New York Maritime College
- State University of New York at Stony Brook
- Structural Technologies, Hanover, MD, financial support
- University of Illinois, Urbana-Champagne, Champaign, IL, in-kind support
- University of Miami, Coral Gables, FL, financial support
- University of Nevada, Las Vegas
- University of Oklahoma, financial and in-kind support
- University of Sao Paulo (Brazil)
- University of Sherbrooke (Canada)
- Virginia Center for Transportation Innovation and Research (via VirginiaTech) Charlottesville, VA
- **Wallace Engineering, Tulsa, OK**
- 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 Department of Transportation, 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, New York, **NY***
Harvey DeFord, Ph.D., Structural Materials Research Specialist
*Florida Department of Transportation State Materials Office, Gainesville, **FL***
Chiara "Clarissa" Ferraris, Ph.D., Physicist
*National Institute of Standards and Technology, Gaithersburg, **MD***
Jim Myers, P.E., Senior Staff Engineer
*Coreslab Structures, Inc., Marshall, **MO***
Karthik Obla, Ph.D. P.E., Vice President, Technical Services
*National Ready Mix Concrete Association, Silver Spring, **MD***
Zhongjie "Doc" Zhang, Ph.D., Pavement Geotechnical Research Administrator
*Louisiana Transportation Research Center, Baton Rouge, **LA***

4. IMPACT

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

We are delivering strategies for new materials with self-consolidating characteristics, and materials with recycled fine material from concrete crushing operations that would otherwise be landfilled. The new materials are Foam Cement and Controlled Low Strength Materials that are suitable for backfill for construction projects around the airport.

The field demonstration project at Rutgers University can be used as a case study that shows the applicability of new mix design developed by the RECAST members for concrete bridge decks or other application.

The customized LCCA tool created by the NYU team combines the proposed LCCA methodology with unified database, online map service and interactive charts and summary reports. Besides the availability of extracting information from state's road shape files, it allows users to create hypothetical scenarios with customized data.

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.

The customized LCCA tool created by the NYU team is capable to perform probabilistic cost-effectiveness analysis that evaluates cost effect on material's energy consumption and global warming potentials. This function applies to other disciplines such as Environmental Engineering.

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 and FY2017. For the undergraduate students, working with graduate students and world-renown faculty helps them with experiential learning activities and raise their interest in the transportation field.

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

The customized LCCA methodology and web-based tool created by the NYU team is expected to be easier to use and thus more people will be able to use it.

The technical specifications for use of FR-SCC will help transportation agencies understand the feasibility and adoption of FR-SCC in various infrastructure applications.

4.E - What Is The Impact On Physical, Institutional, And Information Resources At The University Or Other Partner Institutions? - Nothing to report at this time.

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

Several invited speakers/keynote speaker lectures are scheduled for the Winter/Spring of 2017/2018, many of which will report on some of the research findings of RE-CAST projects.

The FR-SCC Technical Specification will be developed and shared between the transportation agencies and the consortium universities as a case study of field implementation. As soon as the field implementation is planned, the team will share the field experience of FR-SCC.

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 recently at Missouri S&T as one of four strategic areas for future growth in education and research on campus.

With the predicted increase in infrastructure funding, the developed LCCA methodology and the web-based tool will help agencies and companies to make better investment decisions and this increase societal benefits of their infrastructure investment.

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.