PROGRAM PROGRESS PERFORMANCE REPORT #5

GRANT: DTRT13-G-UTC45
Reporting Period: 10/01/2015 – 03/31/2016

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? 5

1.C - What Opportunities For Training And Professional Development Has The Program Provided? 13

1. E - What Do You Plan To Do During The Next Reporting Period To Accomplish The Goals And Objectives? 14

2. PRODUCTS 14

2.A - Publications, Conference Papers, and Presentations 14

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? 19

4.F - What Is The Impact On Technology Transfer? 19

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

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 at different locations: (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 construction

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:

University of Miami successfully completed the first year project and published the following report:

Pino, V. and A. Nanni, "FRCM and FRP Composites for the Repair of Damaged PC Girders," Project #00042134-04, RE-CAST: Research on Concrete Applications for Sustainable Transportation, USDOT: GRANT: DTRT13-G-UTC45, Project Period: 1/1/2014 – 12/31/16

Project Updates

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

Missouri S&T

The project seeks to develop and validate the behavior of a new class of environmentally friendly and cost-effective high-performance concrete (Eco and crack-free HPC) with the aim of reducing cement content and high resistance to shrinkage cracking designated for pavement (Eco-Pave-Crete) and bridge desk constructions (Eco-Bridge-Crete). Based on the obtained results from Phases 1, 2, 3, and 4 of the project, the effect of different binder compositions, aggregate characteristics, and shrinkage mitigating materials were incorporated to design and optimize the Eco and crack-free HPCs and evaluate key fresh and hardened properties. The research program will proceed for the evaluation of the shrinkage deformation and structural behavior of optimized Eco and crack-free HPC for members, including slab and beam elements. The elements will be tested to determine shrinkage deformation, cracking, and structural performance in order to develop performance-based specification for field implementation of these sustainable mixtures.

University of Oklahoma

The research team developed mix designs for the control concrete, an ODOT Class AA mix, and two versions of the Eco-Bridge-Crete mix. The Eco-Bridge-Crete mixes used an optimized aggregate gradation to minimize the cementitious materials content to 470 lb/cu. yd. One of the mixes used a monofilament microsynthetic fiber, while the other mix used a combination of microsynthetic and macrosynthetic fibers. The research team constructed and tested full scale beam specimens for bond and shear.

Rutgers University

In response to concrete deck cracking issues observed at early ages due to truck traffic traveling in lanes adjacent to fresh concrete, the research team responded by developing and implementing a high early strength-high performance concrete (HES-HPC). The HES-HPC mix is optimized to attain higher strength at early ages within 12 hours while maintaining lower shrinkage strain at later ages. This mix is optimized to minimize the concrete cracking potential when the concrete is subjected to live load in adjacent lanes. The mix was developed based on laboratory as well as plant-produced by two concrete suppliers prior to being implemented in a bridge deck rehabilitation project under contract. Based on results from the laboratory and plant mixes, detailed technical and construction specifications have been written and implemented in the Newark Bay Hudson County Extension (NB-HCE, I-78) deck replacement project. Field implementation included the use of maturity method for acceptance and quality control of concrete. Surveys of concrete decks show that the HES-HPC mix reduced the deck cracking potential at early age.

The team is also developing a low cracking (LC) HPC mix designs based on the current HPC as well as HES-HPC mixes used for New Jersey Turnpike Authority. This mix utilizes a blended aggregate with optimized gradation and various supplementary cementitious materials (SCMs) to minimize the Portland Cement content that will help reduce the shrinkage strain of bridge deck.

New York University

Life Cycle Cost Analysis: The research team continued to develop our probabilistic methodology for new and existing materials. They implemented this methodology in the Python programming environment. They will be adding "social costs" such as environmental costs of manufacturing used construction material and other vehicle

related costs such as noise and emissions. They have also developed a full detailed example and a survey of information needed for others to use as guidance. They are working with the Rutgers team to perform their own LCCA using this example. They have also made major progress towards the development of a web based LCCA calculator that is based on our developed methodology. They are planning to complete this in early summer. Over the coming month, the team plans to improve our probabilistic LCCA to extend it to a network-wide framework. This is a major extension and will require considerable effort and improve the web based tool to incorporate methodological extensions. These activities are carried out simultaneous with other projects, as indicated below.

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

Experimental work and material models are being advanced using fluid mechanics theory based on "granular fluids" that are sensitive to the role of aggregate in the flowing concrete behavior. Granular fluids models capture important characteristics of fresh concrete such as depth-dependent viscosity and change of measured yield stress when the fresh concrete is flowing or vibrated. The granular structure of concrete is an essential part of understanding concrete flow, and in extension, formwork pressure.

The preplaced aggregate method for rapid repair of light cans embedded in O'Hare runways continues in 2016 with trial projects. These are scheduled to occur in Summer 2016 in collaboration with our ORD partners.

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

Project 1C-1: Dynamic segregation

From the laboratory work, a clear relationship between the rheological properties and the dynamic segregation index in self-consolidating concrete has been observed. Balancing yield stress and viscosity appears essential. The only mix design factor which causes a deviation from the observed rheology – segregation relationship is the sand-to-total aggregate ratio. From the field, a 9th beam has been cast with SCC which had a 60 ft length. More than 150 cores have been sampled from all nine beams, at different distances from the casting point and at different heights to investigate the changes in compressive strength, ultrasonic pulse velocity, aggregate content, sorptivity and hardened air void system. Bond strength measurements between SCC and prestressing strands were also performed.

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

In collaboration with Kansas State University, a large-scale pumping test was set up early November. Three KDOT approved mixtures were pumped, with different configurations of the boom and different flow rates. The changes in slump, fresh concrete air void system, rheology, tribology, strength and hardened air void system are being analyzed.

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

Missouri S&T

Work is currently underway on second round of concrete mixture optimization, development of eco-friendly concrete for single layer pavement, and development of eco-friendly concrete for double layered pavement. The main goal at this step is to investigate the durability of concrete proportioned with various RCA contents, water-to-cementitious materials ratios (w/cm) of 0.4 and 0.37, and a total cementitious materials content of 545 lb/yd3. A detailed evaluation of frost durability, deicing-salt scaling, and abrasion resistance, drying, shrinkage, and strength development is underway. Analysis of the data enables the research team to select concrete mixtures with the greater RCA replacement levels that could still meet the desired mechanical, physical, and durability requirements of pavement concrete. The team is planning to undertake field demonstration in summer 2016 using various mixtures made with RCA in pavement construction.

UIUC

The research team is conducting experiments on recycled fine materials for controlled low strength materials (CLSM) and lightweight foamed materials. We are studying how material design and admixtures provides for controlled set and strength control. We are developed a new method for measuring moisture content of very small particle systems for which standard methods of obtaining "saturated surface dry" specimens are unsatisfactory. The new methods use electrical properties to assess moisture content. We are also advancing experimental studies of Engineered Material Arresting Systems (EMAS) which are used at the end of runways at airports. We believe that CLSM concepts can be used for EMAS applications, providing airports with sustainable and locally constructed options which have potential for cost savings.

University of Oklahoma

The research team developed mix designs for the control concrete, an ODOT Class A mix, as well as several eco-friendly mix designs for the single layer pavement option. After thorough testing and refinement, the team maximized the percentage of recycled material and arrived at a mix that utilized 100% recycled concrete aggregate and 50% fly ash. The research team then participated in the instrumentation, construction, and monitoring of several pavement sections as part of the Decatur Avenue Concrete Pavement Project. These sections included vibrating wire strain gages to monitor thermal, shrinkage, and truck loading strains.

New York University

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

Project 2-B-1. Rapid PCC Pavement Rehabilitation

The research team worked on developing high early strength concrete to be used in rapid joint rehabilitation of PCC pavement. Source of early age cracking and related parameters are being identified. Some of feasible materials were used in the development of crack-free early strength concrete and their material properties were measured. Internal curing using recycled aggregate and light weight aggregate were used in the mixture design. The target strength of 4,000 psi within four hours has not been achieved yet, and trying to use different combination of the mixtures. Silica fume is also considered to increase early age strength.

To finalize the mixture design with recycled aggregate, light weight aggregate, and internal curing to get the target strength. It will be further explored how the silica fume can increase early age strength and long term strength. The effect of internal curing on the strength development will be studied.

Project 2-B-2. Rapid Pavement Construction

2-B-2-1. Research on Thixotropy and Workability Loss of Vibration-free Concrete in View Accelerating Pavement Construction by Slipforming

Several experiments were executed on cement-paste level to investigate thixotropic build-up, breakdown and workability loss. It has been observed that the rheological properties (yield stress and plastic viscosity) decrease with an increase in applied shear rate, in a non-linear fashion. This is in line with observations in literature on the influence of mixing and pumping on rheology. Furthermore, the influence of w/cm, SP content and binder composition on reversible and non-reversible build-up is being investigated. Additional experiments will be necessary to decouple some effects, as the results are more complex than anticipated.

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

RCC mixtures were developed with optimized aggregate combinations to minimize the void between solid skeleton; leading to a mixture with minimum cement content. The target strength was satisfied in all tested concrete mixtures; the research team focus on characterizing durability of RCC.

The current task Optimization of Mixture with Adequate Air-Void System, is focusing on producing adequate air-void system in roller compacted concrete (RCC). The goal of this task is to develop production and mixture

design techniques to provide and adjust the amount of air entrainment in RCC. The compaction and uniformity of the air-void system were investigated according to ASTM C 457. Dosage of air-entraining admixtures, workability level, mixer type, compaction technique, and binder volume were adjusted. Almost every optimized mix design provided an adequate air-void system based on the spacing factor, air content, and specific volume values measured using the ASTM C 457 linear traverse method. Mixer type and compaction method were found to not have significant impact on the air-void system, while other parameters (dosage of air-entraining admixtures, workability level, binder type) did.

Currently, samples from successful mixtures are being prepared for determining the freeze and thaw resistance (ASTM C 666, Procedure A), deicing salt-scaling resistance (ASTM C 672), and permeable void (ASTM C 642) properties. The goal of this subtask is to develop a comprehensive investigation of the mixture parameters that can affect the quality of RCC in order to prepare RCC mixtures for Field Implementation. The testing should conclude in July this year.

Project 3-A. Performance of Fiber Reinforced Self-Consolidating Concrete for Repair of Bridge Sub-Structures and fiber-reinforced Super-workable Concrete for Infrastructure Construction

Missouri S&T

The project involved mixture optimization of fiber-reinforced self-consolidating concrete (FR-SCC) and super-workable concrete (SWC) with fibers. In total, 24 concrete mixtures were investigated to optimize mixture proportioning, including the content and type of supplementary cementitious materials (mainly fly ash) and expansive agent (EA). The concrete mixtures were tested for workability and rheology, compressive and splitting tensile strengths. Mixtures with 30% class C fly ash replacement and 4% Type-G EA showed optimum fresh properties and mechanical properties.

The next phase of the investigation involves the testing of 10 SCC and eight SWC) mixtures to select efficient fiber types. Four fiber types were selected for further evaluation of the FR-SWC (ST1, 5D, STST, and STPL). The fibers were incorporated at 0.75%. The STPL fiber was eliminated due to poor workability at higher fiber volume. The remaining mixtures with steel fibers ST1, 5D, and STST achieved the targeted fresh and mechanical properties. Four mixtures out of 12 mixtures were evaluated for drying shrinkage, restrained shrinkage, and freeze/thaw resistance. Eight more mixtures will be used to evaluate the flexural behavior of reinforced concrete beams. In total, 36 beam cages are assembled with strain gauges attached to the steel reinforcement at the mid-span. To date, 20 beams have been cast. Eight will be sampled to evaluate drying shrinkage, restrained shrinkage, frost durability and develop performance-based specifications for field demonstration projects that is being planned for the second part of 2016.

University of Oklahoma

The research team developed mix designs for the control concrete, an ODOT Class AA mix, and two fiber-reinforced, self-consolidating concrete (FR-SCC) mixes. The FR-SCC mixes utilized a macrosynthetic fiber and a Type K expansive cement to improve the crack resistance of the repair material. One FR-SCC mix utilized 10% substitution of the expansive cement while the other utilized 15%. The research team constructed full scale beam specimens to evaluate the FR-SCC repair material. The first set were monolithic beam specimens using the Class AA mix design, which served as control specimens. The next sets involved construction of partial beams using the Class AA mix that would then be repaired with the FR-SCC mixes. Three specimens were constructed for each repair material and were subsequently tested to failure. Initial review of the test data indicated that both repair materials restored the full structural capacity of the beam elements.

Rutgers University

Repaired Beam Testing with FR-SCC: The research team finalized the testing program of the repaired beams with FR-SCC to evaluate the flexural performance under two-point loading. The team tested nine (9) beams and

each beam has two layers of concrete; typical class A was used for existing concrete layer, and the FR-SCC was used as the repair material for the bottom layer. Each beam was equipped with a series of sensors, such as foil strain gauges, vibrating wire strain gauges, and linear variable differential transformers. Currently, the research team is compiling testing results of repaired beams as well as other laboratory tests, and finalizing the data processing and analysis from all measured data of various sensors.

Creep Testing on FR-SCC: The research team has started the testing program to perform the creep testing of the FR-SCC. The team has performed the creep testing of control SCC mix, and is currently mixing various FR-SCC mixes with different volume of steel as well as propylene fibers to perform additional creep testing.

New York University

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

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

The research team continues to develop mix designs for ultra-high performance concrete (UHPC) to enhance crack resistance, tensile strength, and ductility. The effect of different shrinkage compensating materials on autogenous and drying shrinkage, cracking potential, and mechanical properties of UHPC was evaluated. The shrinkage compensating materials included expansive agents (CaO- and MgO-based), shrinkage-reducing admixtures, and lightweight sand. In addition, different micro steel and synthetic fibers were evaluated with the aim of enhancing both post-cracking behavior and early-age cracking resistance. Selected mixtures from this task were subjected to different moist-curing durations to investigate the influence of initial moist curing period on the shrinkage and mechanical properties of UHPC.

The team also investigated the effects of using highly dispersed carbon nano materials combined with micro steel fibers to enhance the performance of UHPC. Graphene nanoplatelets (GNPs) and carbon nanofibers (CNFs) were efficiently dispersed in the mixing water using ultrasonic energy and a commercially available surfactant. The enhancement due to the incorporating contents of GNPs and CNFs were demonstrated by fracture resistance properties of the UHPC. Direct tensile tests and four bending tests were conducted.

The research team concluded the experimental and analysis phases and the results clearly indicate that UHPFRC when used in connections subjected to high-moment successfully surpassed the performance of high strength self-consolidating concrete (HS-SCC) and attained the peak load behavior similar to a monolithically cast control specimen. Three different continuity details (straight lap, hairpin, and anchored) were studied. When used in the connections and straight lap performed the best when used with UHPFRC. Effects of different surface preparations (smooth, roughened, and sandblasted) on beam-joint interface indicated that in flexural testing, no significant increase in performance can be observed.

Another Phase of this research studied the use of UHPFRC in non-prestressed MoDOT end girder detail in a composite deck-girder system subjected to high-moment. The results indicated that UHPFRC when used in these connections, clearly surpassed the monolithic control specimen's behavior it was concluded that UHPFRC increase the peak load capacity and also makes the connections much more ductile while utilizing the full capacity of the reinforcement used.

This study investigated the performance of ultra-high strength concrete (UHSC), which is a similar concrete, stay-in-place (SIP) bridge deck panels subjected to high loads in both flexure and shear. The test matrix consisted of twelve (12) half-scale panels that were 4 feet long and 2 feet wide. The variable parameters that were studied included thickness (i.e., 2-in. and 3-in.) as well as non-discrete reinforcement type, including conventional mild reinforcement, welded wire mesh and no reinforcement (UHSC only). Control deck panels with conventional concrete (CC) were fabricated and tested to serve as a baseline for comparison. The results indicated that the UHSC 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 UHSC panels failed in flexure suggesting that the UHSC provided a high shear capacity. The results also showed a good correlation with selected empirical models.

A cost study was also investigated. It was concluded that, even with the high difference between the prices per cubic yard of both concretes, the difference can be significantly lower when compared with the prices per ultimate load capacity.

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

Missouri S&T

After fatigue cyclic testing on RC beams strengthened externally with PBO-FRCM composite for 2 million cycles, flexural testing was preceded on those beams. Both fatigue and flexure tests' results revealed the effectiveness of the PBO-FRCM composite in restraining the RC beams against higher fatigue cracks and increasing their flexural capacities. The flexural capacities enhancements were in a range of 20% to 60 % based on the number of the PBO-FRCM plies. As well known, increasing in the load carrying capacity of RC beam would increase its shear load. If the beam would be loaded to the level beyond its shear capacity, then, a shear failure will be the control one. This type of failure is undesired failure mode in RC beams where sudden failure could influence the continuity of loading transformations between the RC beams and led to concentrated local damages. For that, we conducted an experimental study on the behavior of reinforced concrete beams strengthened in shear using an externally applied fiber reinforced cementitious matrix. The first aim of the study was to investigate the effectiveness and the performance of the PBO-FRCM composite for shear strengthening. The second aim was to study the shear performance of the PBO-FRCM composite in terms of the availability and absence of internal transverse shear reinforcements. Two series of five RC beams were casted. Series A consisted of RC beams with internal shear reinforcements. Series B consisted of RC beams without internal shear reinforcements. Two strengthening configurations were used, continuous U-wrapped PBO- FRCM over the shear span and U-wrapped strips of 4-in width. Each series had one control beam, two beams strengthened with one and four continuous U-wrapped FRCM's plies, and the other two beams strengthened with one and four U-wrapped strips of FRCM's plies. All of the beams were tested under four point loading. For beams in series A, the control beam and the strengthened RC beams with U-Wrapped FRCM strips failed under a diagonal shear cracks. While the other two beams with continuous U-wrapped FRCM failed due to shear-flexure cracks. All beams in series B failed under single diagonal shear crack. The strengthened RC beams in series A had a substantial increase in shear load by 20% to 33% out of the control beam for one and four FRCM plies, respectively. In contrast, the strengthened RC beams in series B were partially nulled. After peeling the PBO-fabric to observe the cracks, it was clear that the wide single crack in RC beams was passed through the adhesive cementitious matrix. In such a case, there was no load transferred through the PBO- fabric. That concluded two features. The first feature, the fragile tensile capacity of the cementitious matrix lowered the PBO-FRCM composite's effectiveness in shear strengthening in the absence of the internal transverse reinforcements. The second feature, the internal transverse shear reinforcements had an important role in distributing the shear stresses along the shear span and transferring the shear load through the PBO-FRCM composite proportionally. In summary, the continuous U-wrapping revealed better ductile failure with an increase in the shear load for RC beams in availability of internal shear reinforcements due to its stiffer performance in terms of increasing both the flexure and shear loads.

University of Miami

Design and casting of the 16 beams for PBO and Carbon FRCM systems was completed in fall 2015. Casting of a new set of 16 beams, identical to the previous lot, to be strengthened with AR Glass FRCM was completed in winter 2016. Testing of beams in two groups A and B is almost complete. Nine additional beams were tested. Four of them strengthened with PBO FRCM so the testing matrix for this material is complete: two PBO-FRCM (1 ply

and 5 ply) strengthened and tested statically, and two PBO-FRCM (1 ply and 5 ply) strengthened under fatigue load in the range 20-76% of steel yield.

The other five beams are strengthened with Carbon FRCM, two tested under static-displacement control (1- and 2-ply), one virgin static-displacement control, one virgin fatigue for 20-75% of the static yield and one fatigue (2-ply) for 20-80% of the static yield.

In summary, by the end of this reporting period 23 beams have been tested. The tests for Carbon FRCM strengthened beams are ongoing while those with PBO FRCM are completed. The latter include: two static virgin beams, two virgin beams subject to fatigue (20-76% yield); three static PBO-FRCM (1, 3, and 5-ply); and, ten PBO-FRCM (1, 3, and 5-ply) subject to fatigue [one 20-91%, one from 20-87%, two 20-81%, two 20-76%, and two (1 and 5-ply) 20-76%]. The combined results were summarized in the form of S-N curves for PBO-FRCM system.

Education and Workforce Development (EWD) Objectives Accomplished

1) RE-CAST hosted its **10th research seminar** on October 22, 2015 – see Attachment A.
2) RE-CAST hosted its **11th research seminar** on December 1, 2015 – see Attachment B.
3) RE-CAST hosted its **12th research seminar** on February 10, 2016 – see Attachment C.
4) Demonstration of SCC technology in undergraduate materials class (CE 3116) at Missouri S&T
5) Training session for Repair of Runway Lights at O'Hare International Airport
    - October 2, 2015
    - Related to UTC project on CLSM and high flow grouts with recycled mat.
    - Presented procedures for repair
    - Executed demonstration project
    - Led by UIUC
    - 10 participants from Chicago Department of Aviation
    - 3 graduate students from UIUC participated
6) Southern University at Baton Rouge hired one graduate and one undergraduate student during the report period. The students have been involved in developing high early strength concrete to be used in rapid pavement repair and construction.
7) 2015 Student of the Year: Daniel Ivan Castaneda, a Ph.D. candidate under the supervision of Dr. David Lange, RE-CAST Associate Director at UIUC, was selected as the 2015 RE-CAST Outstanding Student of the Year. He was recognized at the 25th Annual Outstanding Student of the Year Awards ceremony that took place as part of the Council of University Transportation Centers (CUTC) annual banquet on Saturday, January 9, 2016 in Washington, D.C.

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 seventh quarterly **newsletter** was published in October 2015 – see Attachment D.
4) The eighth quarterly **newsletter** was published in January 2016 – see Attachment E.
5) A. Nanni offered a one-day workshop in Spanish on November 14, 2015, entitled "Diseño y Construcción de Sistemas FRP para el Reforzamiento de Estructuras Existentes. (Design and construction of FRP Systems for Strengthening Existing Structures)" with more than 100 participants.

6) The research team is planning to organize a structural health-monitoring (SHM) workshop in Fall 2016 similar to what has been done at Rutgers University in May of 2015. This workshop will help RECAST students understand the fundamentals as well as the actual applications of SHM.

Diversity Objectives Accomplished

1) UIUC student Nanaissa Maiga, a black female student with French citizenship, will participate as undergraduate researcher in Prof. D. Lange's group in Summer 2016 as she did in the past. She works on concrete materials testing under the supervision of graduates sponsored by RE-CAST.
2) The College of Engineering at the Southern University and A&M College at Baton Rouge will host **2016 Summer Transportation Institute (STI)** during June 6 through 30, 2016. The STI will invite 20-30 high school students in the level of 10th and 11th grade. The students will have broad introduction of transportation engineering and site trips. In addition, students will have hands on experience on science and engineering application during the event. Dr. Shin will present on the RE-CAST activities and projects that is progressing in Southern University and partner universities.
3) The University of Oklahoma (OU) added two new graduate students to the RE-CAST projects, both females, Lexis Allen and Amy Crone. Both students are pursuing a M.S. degree in Civil Engr.

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

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

1. Date: Thursday, October 22, 2015
   - Presenter: Charles Hanskat, P.E., Executive Director, American Shotcrete Association
   - Topic: *Shotcrete for Repair and Rehabilitation of Highway Facilities*
   - Recorded and posted on RE-CAST website
2. Date: Tuesday, December 1, 2015
   - Presenter: Dr. Julie Hartell, Assistant Professor of Civil Engineering, Oklahoma State University
   - Topic: *The Use of Resistivity Testing to Improve Concrete Quality*
   - Offered jointly with the Southern Plans Transportation Center (SPTC)
3. Date: Wednesday, February 10, 2016
   - Presenter: Dr. Saverio Spadea, Research Fellow, University of Bath (UK), Visiting Fulbright Scholar, University of Miami
   - Topic: *Bespoke FRP Reinforcement for Optimized Concrete Structures*
   - Recorded and posted on RE-CAST website
4. Developed repair methods and transferred these methods to Chicago CDA personnel related to rapid repair of light cans embedded in runways.
5. Shortcourse at Southeast University in Nov 2016 on Innovation in Civil Engineering Materials; SEU sponsor is Prof. Yamei Zhang
6. S&T Transportation Infrastructure Conference
   - December 4, 2015 at St. Louis University, in collaboration with MoDOT, with RE-CAST faculty members giving invited lectures.

1.D - How Have The Results Been Disseminated?

The recordings of the 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 to approx. 1200 recipients.

Initial 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 Spring 2016 Convention in Milwaukee, and ACI Fall 2015 Convention in Denver, as well as overseas, including the 14th International Congress on Cement Chemistry, ICCC 2015, in Nov. 2015 in Beijing, China.

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

- Publish ninth and tenth newsletters
- Schedule 14th, 15th and 16th bi-monthly research seminars, as follows:
  - Date: Wednesday, April 6, 2016
    - Presenter: Dr. Maria Juenger, Prof. of Civil Engineering, The Univ. of TX at Austin
    - Topic: *The Future of Concrete may be in its past*
    - Recorded and posted on RE-CAST website
  - Date: June 2016
    - Presenter: Dr. Kaan Ozbay, NYU
    - Topic: TBD
  - Date: August 2016
    - Presenter: TBD
- **Summer Transportation Institute at SUBR** - Southern University and A&M College will host National Summer Transportation Institute (NSTI) 2016. 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 Fall 2016
- **Brown Bag Seminar** on Rehab and Repair at O'Hare Int'l Airport - Planned for June 2016
- UM plans to complete projects two and three and initiate the preparation of the respective final reports. UM researchers will develop publications for referred journals and deliver presentations. Additionally, UM personnel will continue education activities targeting the K-12 pipeline.
- The **first International Interactive Symposium on UHPC** will be held July 18-20, 2016 in Des Moines, Iowa. A student team from Missouri S&T representing the RE-CAST Center will compete at this competition with an objective of designing, fabricating, and testing UHPC in the form of a structural load carrying beam. RE-CAST member Prof. John J. Myers is serving as the team faculty advisor.

2. PRODUCTS

2.A - Publications, Conference Papers, and Presentations

1) **10th research seminar** on October 22, 2015 – see Attachment A.
2) **11th research seminar** on December 1, 2015 – see Attachment B.
3) **12th research seminar** on February 10, 2016 – see Attachment C.
4) October 2015 **newsletter** – see Attachment D.
5) January 2016 **newsletter** – see Attachment E.
6) Journal Publications:

Abeol Seoud, M.A., **Myers, J.J.**, *"Durability of Hybrid Composite Beam (HCB) Bridges Subjected to Various Environmental Conditioning,"* ASCE Journal of Composites for Construction, February 2016, in Press.

Aissoun, B., Hwang, S.D., and **Khayat, K.H.**, Influence of Aggregate Characteristics on Workability of Superworkable Concrete, Materials and Structures, 49 (2), 2016, pp. 597-609.

Albhaisi, S., **Nassif, H**. (2015) "Simple Approach to Calculate Displacements and Rotations in Integral Abutment Bridges," Transportation Research Record: Journal of the Transportation Research Board, No. 2522, TRB of the National Academies, Washington, D.C., 2015, pp. 39–46.

Cao, Q., Hwang, S.D., **Khayat. K.H.**, and Morcous, G., Mixture Development and Evaluation of Self-Consolidating Concrete Bridge Application, Journal of Materials in Civil Engineering, March 2016.

D. Lange, "Models and Mechanisms for Evaluating Form Pressure of SCC," ACI Spring Convention, April 12, 2015. (recording available ACI website)

D. Walker and **A. Shin**, "Development of Rapid PCC Pavement Repair Materials," accepted in the international conference paper and will be presented in the 4th Sustainable Construction Materials and Technologies (SCMT4) conference, August 7 -11, 2016, Las Vegas, NV.

Feys, D. De Schutter, G., **Khayat, K.H.**, and Verhoeven, R., Changes in Rheology of Self-Consolidating Concrete Induced by Pumping, Materials and Structures, Feb. 2016.

Feys, D., **Khayat, K.H.**, and Khatib, R., How do Concrete Rheology, Tribology, Flow Rate and Pipe Radius Influence Pumping Pressure? Cement and Concrete Composites, Composites, 66, 2016, pp. 38-46.

Foudazi, A., Mehdipour, I., Donnell, K.M., and **Khayat, K.H.**, Evaluation of Steel Fiber Distribution in Cement-Based Materials Using Active Microwave. Thermography, Materials and Structures, March 2016.

Ghadban, A., Albahttiti, M., Riding, K.A., **Lange, D.,** ìThe Effect of HRWR and AEA on the Air System of Vibrated Concrete,î Proceedings of the Joint Rail Conference 2015, San Jose, CA, March 23-26, 2015, Technical Publication JRC2015-5788, 2015.

Griffin, A., **Myers, J.J.**, "Shear Behavior of High-strength Self-consolidating Concrete in NU Bridge Girders," Prestressed-Precast Concrete Institute Journal, Accepted, November 2015, in Press.

Hernandez, E.S., **Myers, J.J.**, "Use of Self-Consolidating Concrete and High Volume Fly Ash Concrete in Missouri Bridge A7957," ACI SP, Sustainable Performance of Concrete Bridges and Elements Subjected to Aggressive Environments: Monitoring, Evaluation & Rehabilitation, Vol. 304, October 2015, pp 85-100.

I. You, J. Choi, G. Zi, **D.A. Lange**, "Pozzolanic reaction of waste glass sludge incorporating precipitation additives," Computers and Concrete, Vol. 17, No. 2, (DOI: 10.12989.cac.2016.17.2.000), 2016.

J. Henschen, A. Amirkhanien, J. Roesler, **D.A. Lange**, "Field Evaluation of Alternative Isolation Joints at O'Hare International Airport," FAA Worldwide Airport Technology Transfer Conference, Galloway, N.J., August 5-7, 2014.

J. Xiao, C. Sun, **D.A. Lange**, "Effect of joint interface conditions on shear transfer behavior of recycled aggregate concrete," Construction and Building Materials 105 (2016).

Lou, P., **Nassif, H**., Su, D., and Truban, P. (2015) "Effect of Overweight Trucks on Bridge Deck Deterioration Based on Weigh-In-Motion Data," Transportation Research Record: Journal of the Transportation Research Board (TRB), TRB of the National Academies, Washington, D.C., (in Press).

M. Albahttiti, A. Ghadban, K. Riding, **D. Lange**, "Air Entrainment and the Fabrication of Concrete Railroad Ties," Proceedings of the Joint Rail Conference 2015, San Jose, CA, March 23-26, 2015, Technical Publication JRC2015-5671, 2015.

Meng, W., and **Khayat, K.H.**, Experimental and Numerical Studies on Flexural Behavior of Ultra-High Performance Concrete Panels Reinforced with Embedded Glass Fiber-Reinforced Polymer Grids, TRB Record, **No.** 2592, DOI 10.3141/2592-05, pp. 38-44, January 2016.

Miguel Ferreira, **David Lange**, Markku Leivo, Hannele Kuosa, "On the Effect of Freeze-thaw Exposure on Chloride Ingress in Concrete," Cement and Concrete Composite, submitted 2015.

R. Serpell, J. Henschen, J. Roesler, **D.A. Lange**, "Relative Proportioning Method for Controlled Low-Strength Material," ACI Materials Journal, Vol. 112, No. 2, pp 179-188, 2015.

Rallabhandhi, S., **Myers, J., J.**, "UHPC in Non-prestressed Reinforced Concrete (RC) Continuous Girders for Bridge Elements," First Interactive Symposium on UHPC, Des Moines, Iowa, 2016. (Accepted)

Sadati, S., Arezoumandi, M., **Khayat, K.H.**, and **Volz, J.S**., "Shear Performance of Reinforced Concrete Beams Incorporating Recycled Concrete Aggregate and High-Volume Fly Ash," Journal of Cleaner Production, 115:284-293.

Soliman, N., **Khayat, K.H.**, Karray, M., and Omran, A., Piezoelectric Ring Actuator Technique to Monitor Early-Age Properties of Cement-Based Materials, Cement and Concrete Composites, Cement and Concrete Composites, Composites, 63, 2015, pp. 84-95.

Wallevik, O.H., Feys, D., Wallevik, J.E., and **Khayat, K.H**., "Avoiding Inaccurate Interpretations of Rheological Measurements for Cement-Based Materials," Cement and Concrete Research, Vol. 78, Part A, pp. 100-109, Dec. 2015.

Wallevik, O.H., Feys, D., Wallevik, J.E., and **Khayat, K.H.**, Avoiding Inaccurate Interpretations of Rheological Measurements for Cement-Based Materials, Cement and Concrete Research; 78, Dec. 2015, pp. 100-109.

Xia, Y., **Nassif, H**., and Su, D., "Early Age Cracking in High Performance Concrete Decks of a Curved Steel Girder Bridge," American Society of Civil Engineers (ASCE) Journal of Aerospace Engineering, Jan. 2016.

Y. Song, R. Zou, D. Castaneda, K.A. Riding, and **D.A. Lange**, "Advances in Measuring Air-Void Parameters in Hardened Concrete Using a Flatbed Scanner," ASTM J. Testing and Evaluation, submitted 2016.

7) Keynote/Invited Presentations:

Kamal H. Khayat

2015 keynote speaker, International Congress on Cement Chemistry, ICCC 2015, Nov. 2015, Beijing, China

David Lange

American Concrete Institute; Presentation on "Stability and Retention of Entrained Air in Vibrated Concrete," by D. Lange, J. Koch, D. Castaneda, and R. Ewoldt

Shortcourse at Southeast University in Nov 2016 on Innovation in Civil Engineering Materials; SEU sponsor is Prof. Yamei Zhang

Antonio Nanni

"Long Term Performance of FRCM Strengthened Beams Subject to Fatigue" - Presentation given to the Center for Integration of Composites into Infrastructure (CICI) Industrial Advisory Board (IAB) Meeting in Miami, FL, Feb 22, 2016

Hani Nassif

2015 ACI Ambassador, Invited as part of the ACI delegation to attend the Joint-ACI-JCI Seminar held at the 50th Anniversary of the Japan Concrete Institute (JCI), Tokyo, Japan, July 11-14.

2015 American Concrete Institute Chapter of Eastern Pennsylvania and Delaware, Philadelphia, PA, Sept. 24.

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 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
- 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**
- **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
- 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)
- Virginia Center for Transportation Innovation and Research (via VirginiaTech) Charlottesville, VA
- 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***

The group met 12/18/15 from 1-3 PM CST to discuss projects and the future direction of the Center's activities.

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 that utilize recycled fine material from concrete crushing operations that would otherwise be landfilled. The new materials are Controlled Low Strength Materials that are suitable for backfill for construction projects around the airport.

The customized LCCA tool created by the NYU team will enable prospective users to do their own LCCA without major effort. In case of the availability of their state's road shape files, they can easily extract information from these files. We are now capable of doing this automated data extraction from NJ shape files.

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 will have an impact on all the disciplines of the program since it will help decision makers to compare alternative technologies / materials.

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, FY204, and FY2016. 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 Summer/Fall of 2016, many of which will report on some of the research findings of RE-CAST projects.

SCC2016, an international conference focusing on the Design and Use of Self-Consolidating Concrete, is being supported by RE-CAST. This event will attract engineers, architects, government officials, researchers, academics, students, contractors, and industry professionals from around the world. The international conference is help in conjunction with the 11th annual International Concrete Sustainability Conference (2016 ICSC). The combined conferences (Flowing toward Sustainability) will involve five parallel sessions with nearly 225 technical papers presented over three days. The conference should provide learning opportunities on the latest advances, knowledge, research, tools and solutions for sustainable concrete manufacturing, design and construction. Engineers, architects, government officials, researchers, academics, students, contractors, and industry professionals are invited to share their knowledge.

The development of the FR-SCC technical specifications will be based on the research results that will be shared with transportation infrastructure agencies and other institutions as a model for transferring the knowledge gained through implementation and demonstration. Workshops and training sessions will be held to assist contractors, concrete producers, design consultants, and academic institutions, learn more about the potential of FR-SCC and its applications.

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.

The possibility of having a simple yet scientifically sound way of quantifying LCCA of new materials / construction techniques can help decision makers to adopt these more easily. This will have far bigger implication in terms of introducing new technologies to our infrastructure at large.

UM continues to engage K-12 students and provide them hands on activities. This April, 37 first graders participated in a morning session on "the fun of concrete."

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 at this time.

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.

6. SPECIAL REPORTING REQUIREMENTS - Nothing to Report.

APPENDIX A

RE-CAST October 22, 2015 Webinar:
Shotcrete for Repair and Rehabilitation of Highway Facilities

WEBINAR

Shotcrete for Repair and Rehabilitation of Highway Facilities

ABSTRACT

This seminar presented by the **American Shotcrete Association** (ASA) will give the owner, design engineer, project specifier, field inspector, and general contractors an overview on how shotcrete can be efficiently, and cost effectively used for structural repair and rehabilitation of concrete bridges and associated structures. We will provide a basic overview of the shotcrete process, cover the design, specifying and detailing considerations for shotcrete repairs.
Next, we will use specific project case studies from a variety of projects across the USA to illustrate field considerations and the sustainability benefits gained when using shotcrete for repair including reduced formwork needs and scheduling advantages. We will also discuss achieving quality of shotcrete addressing field inspection, specific placement techniques, nozzleman certifications, and contractor qualifications. We will wrap up with a discussion of new ASA programs for shotcrete inspector training, and contractor qualification as well as providing a listing of appropriate references and resources on use of shotcrete for structural concrete repair.

Presented by:

Charles Hanskat, P.E.

Executive Director
American Shotcrete Association

::

Thursday
October 22

Time:
11 am - 12 pm CDT

RE-CAST

APPENDIX B

RE-CAST December 1, 2015 Webinar:
The Use of Resistivity Testing to Improve Concrete Quality

WEBINAR

The Use of Resistivity Testing to Improve Concrete Quality

ABSTRACT

The physical and chemical nature of concrete makes it particularly sensitive to electrical conductivity. Recently, investigations have demonstrated that electrical methods, such as the surface resistivity and bulk resistivity methods, are cost effective and accurate means for assessing the durability performance of a concrete mixture. The latter was established through comparative relationship analysis with the standard method of testing ionic conductivity, the rapid chloride permeability test (RCPT). Many procedures and recommendations have been published which led to the developments of new AASHTO and ASTM standards. And, since their introduction, resistivity has been used in the industry for the past decade as a viable means to assess the quality of concrete mixtures with respect to durability performance.

Moreover, resistivity properties of a concrete mixture at a specific age may provide insight on its physical and chemical properties. This principle is currently being investigated at Oklahoma State University to determine whether the method can be utilized to discern undesirable mixture variations. In this case, resistivity testing could be used to improve the current process of concrete mixture approval and site acceptance. The presentation will address the operating concepts and theory behind the testing method; along with a comprehensive discussion on the procedures, result interpretation, application and limitations.

Presented by:

Prof. Julie Hartell

Asst. Professor of Civil Engineering

Oklahoma State University

Tuesday, Dec. 1

Time:
11 am - 12 pm CST

SOUTHERN PLAINS TRANSPORTATION CENTER

SPONSORS:

MISSOURI S&T · MIAMI · RUTGERS

RE-CAST

APPENDIX C

RE-CAST February 10, 2016 Webinar:
Bespoke FRP Reinforcement for Optimized Concrete Structures

WEBINAR

Bespoke FRP Reinforcement for Optimized Concrete Structures

Presented by:

Dr. Saverio Spadea

Research Fellow

University of Bath (UK)

Visiting Fulbright Scholar

University of Miami

REGISTER &
VIEW BIO:

http://recast.mst.edu/webinars

ABSTRACT

With the goal of achieving sustainable design, being able to combine optimized geometries with durable construction materials is a major challenge for civil engineering. New research at the University of Bath and the University of Miami aims to solve these problems for the first time by completely replacing internal steel reinforcement in complex optimised concrete structures using a knitted cage made of fibre reinforced polymer (FRP) reinforcement. By fabricating the reinforcement in the desired geometry, it will be possible to provide the required strength exactly where needed, thereby reducing the amount of concrete required to resist internal forces and capitalising on the extraordinary possibilities offered by both concrete and FRP construction materials.

Wednesday, Feb. 10, 2016

Time:
12 pm - 1 pm CST

SPONSORS: FULBRIGHT

Missouri S&T · Miami · Rutgers

RE-CAST

APPENDIX D

RE-CAST October 2015 Newsletter

Research on Concrete Applications for Sustainable Transportation

RE-CAST

MISSOURI S&T

Vol. 2 :: Issue 4 :: OCTOBER 2015

In this issue:

- Director's Message
- Featured Projects
- Meet the Summer Interns
- Youth Transportation Conference
- Leadership Spotlight
- Upcoming Events

CONSORTIUM MEMBERS:

Missouri University of Science and Technology

University of Illinois at Urbana-Champaign

Rutgers, The State University of New Jersey

University of Miami

Southern University and A&M College

Director's Message

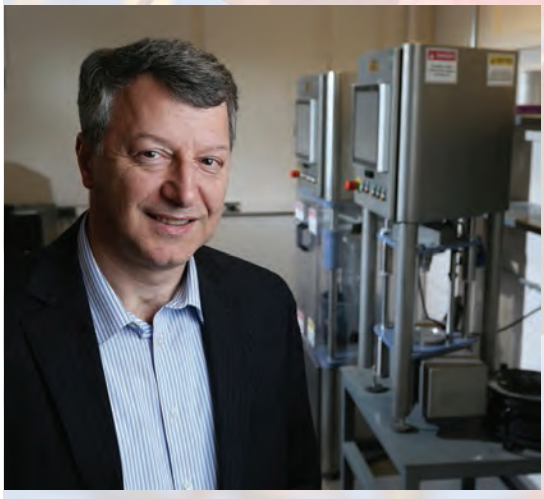
As fall colors cover the Missouri S&T campus, RE-CAST has many exciting updates to report.

In this issue we provide some featured project updates, including an exciting field project that took place at the O'Hare International Airport in Chicago as well as some Life Cycle Cost Analysis work that our team is working on.

We are happy to report that our summar internship program was a success. This summer we also sponsored a MoDOT Youth Transportation Conference, which entailed 30 underrepresented students coming to the Missouri S&T campus to learn about transportation engineering and to participate in some hands-on learning.

On Oct. 22, the RE-CAST Center offered a webinar presented by Charles Hanskat, Executive Director of the American Shotcrete Association entitled "*Shotcrete for Repair and Rehabilitation of Highway Facilities.*"

RE-CAST is offering another webinar on Dec. 1 by Julie Hartell from the University of Oklahoma that will be jointly hosted with Southern Plains Transportation Center. Please watch our website for other upcoming webinars and events.



-Kamal H. Khayat
RE-CAST Director

FEATURED PROJECT

Rapid Repair Method for O'Hare International Airport Runway Light Cans

- David A. Lange, Ph.D., Prof. of Civil Engineering, University of Illinois at Urbana-Campaign
- Jihwan Kim, Ph.D., Post-Doctoral Fellow, University of Illinois at Urbana-Campaign
- Yu Song, Ph.D. Candidate, University of Illinois at Urbana-Campaign
- Ruofei Zou, Ph.D. Candidate, University of Oklahoma

Figure 1. A 42 in. diameter core is used to extract the original runway light can.

Runway lighting is critical to safe flight operations, so it was a major concern to engineers at the Chicago Department of Aviation when light receptacles embedded in the concrete pavement began to show a tendency to displace downward over time. The problem was found to be related to how the original installation process failed to provide sufficient doweling to transfer shear load between the light cans and the pavement under the vertical loading from airplane wheel loads. Some of the displacements were more than 1 in., thus creating a "small pothole" over which the airplane gear had to travel. The nighttime repair concept required that the light cans be removed and replaced within eight hours, allowing normal airplane traffic at 6:00 am the next morning.

UIUC researchers supported by RE-CAST and the O'Hare International Airport proposed a repair method using pre-packed aggregate that would be grouted to create a solid and durable concrete repair.

- Continued Next Page -

FEATURED PROJECT

Rapid Repair Method for O'Hare International Airport Runway Light Cans *(continued)*

Figure 2. Lifting the core out of the pavement required clever teamwork.

Figure 3. The new light can is installed with conduit for electrical connections.

The pre-packed aggregate method offered advantages of providing reliable early structural support much like ballast supporting rail for trains. The use of a rapid set grout transforms the pre-placed aggregate into a concrete mass. The benefit of this method over the use of other rapid set concrete options is that the entire repair can be installed and positioned, and load carrying at early hours is made reliable by the certain rock-to-rock contact created by the packed ballast.

On October 2, 2015, a team consisting of Chicago Department of Aviation, K-FIVE Construction Corp., and University of Illinois personnel joined in a demonstration project to explore the procedural details required to execute this repair method. A 42 in. diameter core was used to remove the original light can, electricians immediately worked to install conduit to the new light can, the aggregate was placed, and then grout was used to saturate the pre-paced aggregate.

The repair was completed, and the demonstration proved valuable in identifying necessary changes in procedural details.

- Continued Next Page -

FEATURED PROJECT

Rapid Repair Method for O'Hare International Airport Runway Light Cans *(continued)*

Figure 4. Grout is mixed on site using practical and field-appropriate methods.

Figure 5. Grout is placed to saturate the pre-packed aggregate bed.

Figure 6. A rapid set topping mortar mix is used to finish the surface.

CONCLUSION:

Overall, the repair was shown viable as an alternative that O'Hare will consider as they face the replacement of about 100 problematic light cans without interrupting flight operations by using nighttime repairs.

OUTREACH/WORKFORCE DEVELOPMENT

Meet the 2015 RE-CAST Summer Interns

Sarah Vanhooser

summer intern at Missouri S&T

Sarah Vanhooser, a senior civil engineering undergraduate student, was involved with research on dynamic segregation with Dr. Feys during her summer internship. Sarah was involved in the experimental work in the laboratory and during the field work at Coreslab Structures. She also attended the 6th Advances in Cement-based Materials Conference with graduate student Margarita, who presented the results.

Heitor Fernandez Oliveira De Melo

summer intern at Missouri S&T

Heitor Fernandez Oliveira De Melo is an undergraduate civil engineering student who visited S&T during the summer semester. During his internship, he participated in the following RE-CAST projects:

- Development of ultra-high-performance oncrete for thin overlay
- Eco- and crack-free high-performance concrete with adapted rheology
- High-volume recycled materials for sustainable pavement construction

Alex Harris

summer intern at Missouri S&T

Alex Harris is an undergraduate student in civil engineering at Missouri S&T. As part of his RE-CAST summer internship experience, he assisted graduate students in completing their research in the S&T structures lab and materials lab. He helped setting up beams with external fiber reinforcement to be tested in a two point load configuration. He worked with mixing self-consolidating eco-friendly mortar as well as UHPC containing various supplementary cementicious materials, chemical admixtures, and steel fibers.

Arnaud Lozachmeur

summer intern at Missouri S&T

Arnaud Lozachmeur is an second year civil engineering student who visited S&T for the summer semester. During his internship, he assisted many RE-CAST graduate students in the laboratory in order to gain practical experience in the area of advanced construction materials.

- Continued Next Page -

OUTREACH/WORKFORCE DEVELOPMENT

Meet the 2015 RE-CAST Summer Interns *(continued)*

Kyrah Williams

summer intern at University of Miami

Kyrah Williams is an undergraduate student at the University of Miami pursuing her bachelor's degree in Architectural Engineering. She is currently the President of National Society of Black Engineers. After Kyrah graduates, she hopes to pursue her Masters in Architecture.

Catherine Alexis Wells

summer intern at University of Miami

Alexis Wells is pursuing a bachelor's degree in mechanical engineering at the University of Miami. She participated in the RE-CAST research internship program and her area of focus was FRCM composites as a strengthening material for concrete.

Matthew Kesler

summer intern at University of Miami

Matthew Kesler is an undergraduate student at the University of Miami. Matthew is a member of Chi Epsilon, the civil engineering honor society, where he serves as marshall. Upon graduation, Kesler plans to pursue a M.S. in structural engineering. As a RE-CAST intern, he assisted with the material characterization of novel fiber reinforced composites along with a variety of other research.

- Continued Next Page -

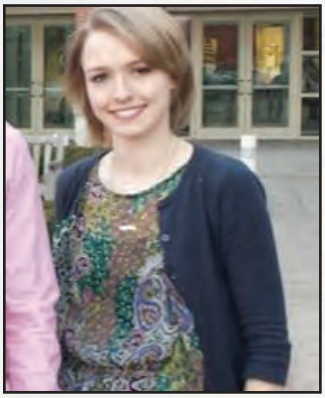
OUTREACH/WORKFORCE DEVELOPMENT

Meet the 2015 RE-CAST Summer Interns *(continued)*

Nischal Pradhan

summer intern at University of Oklahoma

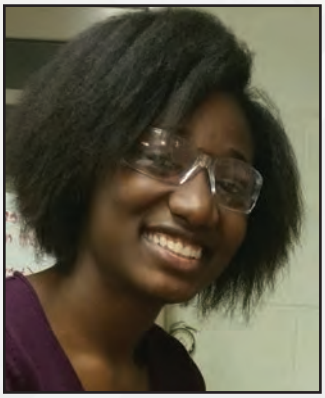
Nischal Pradahna, a native of Kathmandu, Nepal, is an undergraduate student studying civil engineering at the National Institute of Technology, Warangal, India. During his internship, Nischal was involved in the design and testing of concrete mixtures for several RE-CAST projects.



Alixandra Bradford

summer intern at University of Oklahoma

Alixandra Bradford is a female undergraduate civil engineering student at the University of Oklahoma. Alix was involved in the design and testing of concrete mixtures for several RE-CAST projects.



Nanaissa Maiga

summer intern at University of Illinois at Urbana-Champaign (UIUC)

Nanaissa Maiga is a undergraduate student UIUC. She participated as an undergraduate researcher in Prof. D. Lange's group. She worked on concrete materials testing under the supervision of graduate students sponsored by the RE-CAST UTC funding.

FEATURED PROJECT

Life Cycle Cost Analysis: A Probabilistic Approach to Evaluate Novel High-performance Materials

- Kaan Ozbay, Ph.D., Professor of Civil and Urban Engineering, New York University
- Jingqin Gao, Ph.D., Candidate, Civil and Urban Engineering, New York University

The Rutgers-NYU team has been developing a novel probabilistic approach to the life cycle cost analysis (LCCA) in comparing the life cycle cost of conventional and high-performance materials to assist decision-makers in finding optimum investment strategies with budget constraints.

Aging facilities along with growing demand in terms of operational and environmental requirements as well as increasing costs associated with maintaining our transportation infrastructure have led agencies to seek the development of innovative materials and construction technologies. However, reliable decision-making tools for the selection of the best combination of existing and new materials and / or construction methods are needed. Life cycle cost analysis is one of such decision-making tools that take into consideration the life cycle cost of the entire project, including future maintenance and repair costs, vehicle operation costs, work-zone delay cost, and socio-economic impacts resulting from all of these activities.

Clearly, it is not trivial to predict the actual field performance of a brand new construction material or technology that has either being tested in a laboratory environment or underwent a very limited field deployment. Its performance prediction must thus rely on these limited tests or deployment results combined with expert opinions for the most likely values of its behavior under real-world conditions. This approach increases the uncertainty of such predictions. As a result, these uncertainties demand the use of a probabilistic approach to appropriately apply LCCA. Furthermore, the fact that these uncertainties can also vary in time creates the need for a robust stochastic treatment of the individual scenarios that will be evaluated as part of the proposed LCCA methodology.

In the light of all these complications, two different hypotheses are proposed:

1) Apply a hypothesized improvement rate to the deterioration functions of existing and well-known materials to represent the expected enhanced performance of a new material compared with a conventional material with relatively similar characteristics;

2) Utilize the correlation function between the results of laboratory tests and field performance of known materials to predict the expected performance of a new material based only on its laboratory tests.

- Continued Next Page -

Life Cycle Cost Analysis: A Probabilistic Approach to Evaluate Novel High-performance Materials *(continued)*

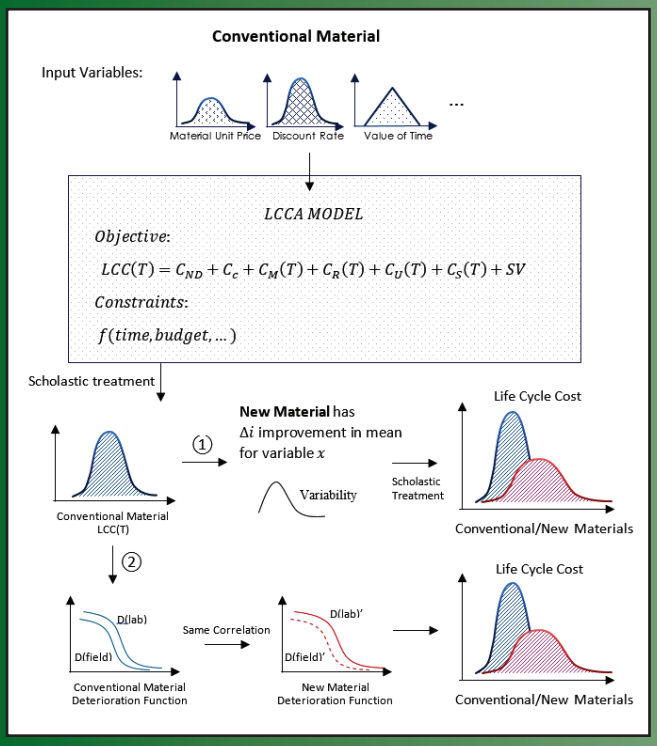


Figure 1. Two hypothesis approaches

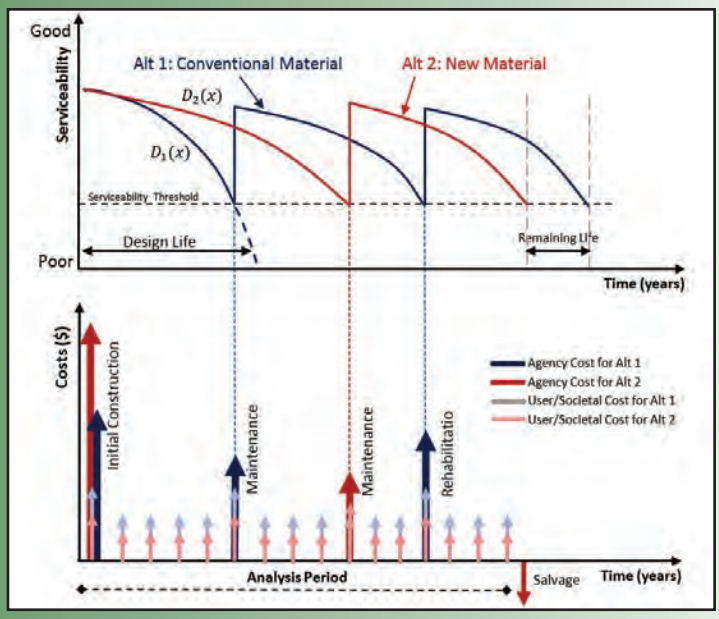


Figure 2. Life cycle of conventional/new material alternatives and corresponding expenditure stream

Figure 1 illustrates the proposed methodology of the two approaches. Stochastic treatment proposed for both approaches is needed to evaluate performance of the new material that has high level of uncertainty. As more information and field data becomes available in the near future, "hypothesized performance functions" will continue to be re-evaluated and improved.

Figure 2 is the representation of the life cycle of analysis approach and its corresponding costs of two different types of materials, namely conventional and new. As seen in this figure, an assumption about the performance of novel and sustainable materials similar to those under development by RE-CAST researchers will have to be made.

The proposed approaches to predict the performance of new materials are further described on the following page to illustrate the way they will be adopted in this study.

- Continued Next Page -

Life Cycle Cost Analysis: A Probabilistic Approach to Evaluate Novel High-performance Materials *(continued)*

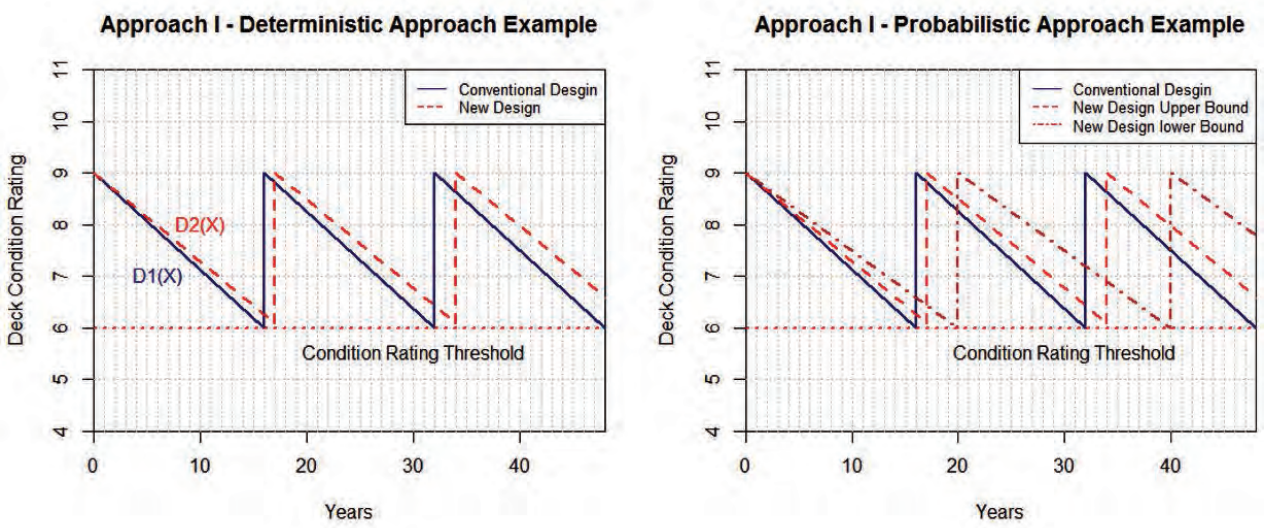


Figure 3. Hypothetical Example of Approach I: Improvement Rate

1) Improvement rate approach

Normally, estimated values or models based on historical data are used as input to life-cycle analysis when quantifying costs. However, for a new material or construction technology, there may not be adequate data to describe its real-world performance. An interim solution is to define metrics for the new material / technology as a percent improvement rate with respect to a current conventional material with a known performance function. Then, this percent improvement rate is applied deterministically or probabilistically to this known performance function. **Figure 3** shows an hypothetical example of the life cycle of a traditional versus new material in terms of maintenance and replacement actions. Both deterministic and stochastic approaches are illustrated in **Figure 3** for the same hypothetical example.

2) Correlation approach

There have been considerable amount of research efforts conducted to develop "performance tests" that can link performance of parameters measured in the laboratory to actual in-situ pavement or bridge performance. This proposed approach is focused on such a correlation methodology between laboratory results and the available correlation values from published data based on actual field performance. If a correlation function between laboratory and field performance of a well-known material exists, one can assume that this relationship remains the same for the new material as well. This same correlation methodology can be used to estimate the field performance of new material. This correlation function may include coefficient of thermal contraction, Poisson's ratio, complex modulus, resilient modulus, relaxation modulus and so on.

- Continued Next Page -

Life Cycle Cost Analysis: A Probabilistic Approach to Evaluate Novel High-performance Materials *(continued)*

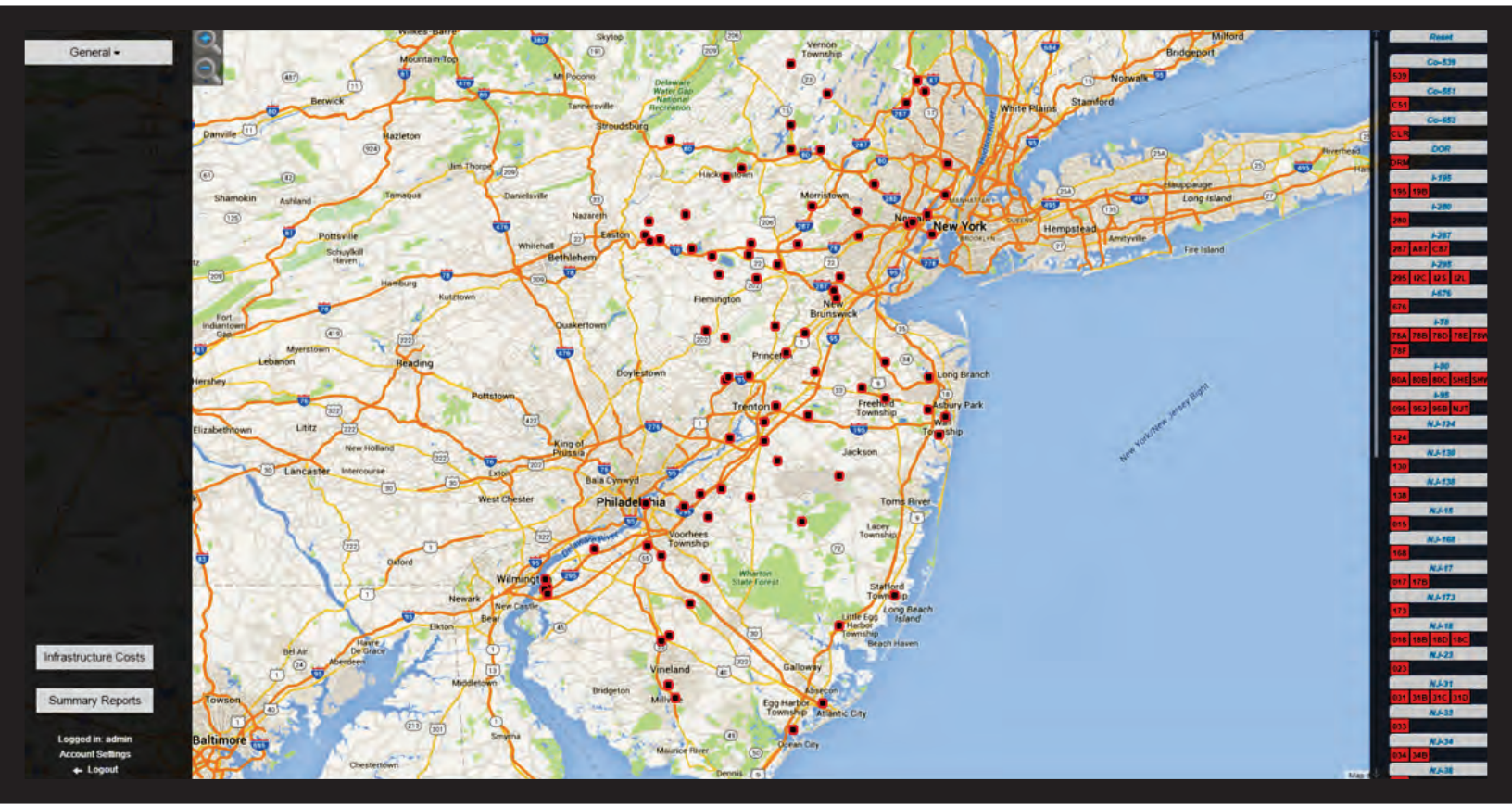


Figure 4. Sample screen shot of the web-based LCCA tool developed in this study

LCCA web-based software tool

In addition to the probabilistic LCCA methodology described above, a web-based software tool that can access state-wide infrastructure data is being developed. This tool is able to automatically extract road and traffic data for each link. This data is needed to calculate life cycle costs of each individual link using the proposed LCCA methodology for different scenarios. We will incorporate a flexible interface to define performance functions specific to the construction materials/technologies used. This will be in addition to default performance functions for conventional construction materials/ technologies. This tool is also envisioned to serve as a database of performance functions. Moreover, the advantage of a web-based tool is that it can be used by any user without having to install additional software (and possibly data) on their own computers. This simplifies the process of using the developed software by a large number of users who just need to have access to a web browser.

In the near future, the research team will start testing the proposed LCCA approach using real-world and laboratory data.

DIVERSITY AND OUTREACH

MoDOT 2015 Annual Youth Transportation Conference

The Missouri Department of Transportation (MoDOT) sponsors an annual Youth Transportation Conference each summer. Thirty students are selected from across the state to attend this conference in Jefferson City, Missouri. The six-day conference is free to 9th, 10th, 11th, and 12th graders.

The conference exposes students from across Missouri to the numerous career opportunities in the field of transportation and is packed with fun and exciting academic, career development, and social activities. Students apply math, science, and computer concepts learned in school to transportation related problems.

RE-CAST sponsors this activity by providing assistance with a bridge building activity, shown below, that took place during the field trip to Missouri S&T on July 22nd. This Youth Transportation Conference is a great outreach opportunity for the RE-CAST Center to attract new entrants into the transportation field from local secondary schools and highlight the numerous opportunities of a STEM education.

"*RE-CAST is very pleased to support this annual youth conference. I believe opportunities such as these are essential for generating excitement at an early age for the next generation of transportation leaders.*"
- K. H. Khayat, RE-CAST Director

Pictured center:
Jason Cox, RE-CAST technician,
helps students test bridge structures

Pictured below:
Iman Mehdipour, RE-CAST Ph.D. student,
with camp participants

LEADERSHIP SPOTLIGHT

RE-CAST Director named RILEM Fellow

Dr. Kamal H. Khayat, RE-CAST Director, has been named a Fellow of RILEM, the International Union of Laboratories and Experts in Construction Materials, Systems and Structures.

"The award of a RILEM Fellowship is a rare honor," says RILEM president Mark Alexander. "It is given for exceptional contributions to the work of RILEM and includes aspects such as scientific contributions and developmental contributions."

Khayat is one of only 64 named Fellows in the RILEM organization.

RE-CAST Associate Director invited to present in Bogota

Dr. Antonio Nanni, RE-CAST Associate Director, was invited to present "**Case Studies on Strengthening of Concrete and Masonry Structures**" by the ACI Columbian Chapter and Columbia Association of Seismic Engineering during their seminar entitled "Strengthening of Concrete and Masonry Structure with FRP". The seminar took place in Bogota, Columbia on July 23, 2015.

"We below that your participation will lead to the success of the seminar given your recognized expertise on this topic and active participation in the ACI 440 Committee "Fiber Reinforced Polymer Reinforcement", one of the most prominent technical groups in the world working on the development of guidelines for the use of FRP for strengthening of concrete and masonry structures." - Pedro Nel Quiroga and Juan Francisco Correal, seminar organizers

FEATURED PROJECT / COLLABORATION

Self-Consolidating Concrete (SCC) for Connecting Precast Concrete Deck Panels and Bridge I-Girders

- George Morcous , Ph.D., P.E., Professor, Durham School of Architectural Engineering and Construction, College of Engineering, University of Nebraska - Lincoln

Figure 1. SCC slump flow

Full-depth precast concrete deck systems have several advantages over traditional cast-in-place (CIP) concrete decks in bridge construction, such as improved construction quality, reduced construction time and impact on traveling public, possible weight reduction, and lower bridge life-cycle cost. Existing full-depth precast concrete deck systems use either open channels or open pockets at 2 ft spacing for connecting to supporting girders to achieve a composite system. These channels and pockets are typically grouted and then overlaid to cover the exposed surface, which negatively affect construction duration and cost.

Recent development in full-depth precast concrete deck systems allowed using covered individual pockets at 4 ft spacing to simplify fabrication and eliminate the need for deck overlays, which speeds up construction and enhances deck durability and economy. However, this development requires the use of specially proportioned flowable concrete to completely fill the blind pockets as well as the gap between precast concrete deck panels and supporting girders. A research project was conducted with researchers at Missouri S&T, in collaboration with University of Nebraska-Lincoln to develop a self-consolidating concrete (SCC) mixture for this specific application and to experimentally investigate its constructability using small-scale and full-scale mock ups. Results indicated the excellent performance of the developed

- Continued Next Page -

FEATURED PROJECT / COLLABORATION

Self-Consolidating Concrete (SCC) for Connecting Precast Concrete Deck Panels and Bridge I-Girders *(continued)*

Figure 2. Placing SCC

Figure 3. Completed bridge deck

mixture in both fresh and hardened conditions in addition to its economy, which led to the implementation of this new generation of full-depth precast concrete deck systems in the construction of Kearney East Bypass bridge project in Kearney, NE.

The project consists of twin bridges over US-30 and Union Pacific rail road: south bound bridge constructed using conventional CIP deck; and north bound bridge constructed using the new precast concrete deck system. Each bridge is 41 ft 8 in. wide and 332 ft long and has two equal spans with five prestressed concrete girders in each span at 8 ft 6 in. spacing. The bridge deck consisted of 28 full-width panels, each panel is 12 long and 8 in. thick. After installing the deck panels, grouting transverse joints, and post-tensioning deck panels longitudinally, a total of 120 cubic yards of the developed SCC was placed through 4 in. diameter grouting/inspection holes located at 4 ft spacing on the deck surface using an innovative process to ensure the complete filling of the shear pockets and the gap between the deck and girders in an efficient manner. **Figures 2 and 3** show the slump flow of the SCC (averaged 28 in.), placing apparatus used to funnel the pumped SCC into the holes, sand buckets used to cover the filled pockets and force SCC to flow to the next ones, and the completed deck. This process was very successful and efficient as it resulted in a continuous placement that took approximately 1 hour for each girder line. A video of SCC placement process can be watched at: https://www.youtube.com/watch?v=wFC8zxpVDp8. The use of workability retaining admixtures and 3/8 in. nominal maximum aggregate size assisted in maintaining concrete flowability for over an hour and ensured full encapsulation of reinforcing bars and strands in very tight spaces. This successful implementation has proven that SCC can be used as an economical and superior alternative to commercial grouts in bridge construction.

WEBINAR SERIES

Visit our Webinar Library at: recast.mst.edu/webinars

October 22, 2015 at 11am CDT

Presenter: Charles Hanskat, P.E.

Executive Director, American Shotcrete Association

"*Shotcrete for Repair and Rehabilitation of Highway Facilities*"

This seminar, presented by the American Shotcrete Association (ASA), will give the owner, design engineer, project specifier, field inspector, and general contractors an overview on how shotcrete can be efficiently, and cost effectively used for structural repair and rehabilitation of concrete bridges and associated structures. We will provide a basic overview of the shotcrete process, cover the design, specifying and detailing considerations for shotcrete repairs. Next, we use specific project case studies from a variety of projects across the USA to illustrate field considerations and the sustainability benefits gained when using shotcrete for repair including reduced formwork needs and scheduling advantages. We also discuss achieving quality of shotcrete addressing field inspection, specific placement techniques, nozzleman certifications, and contractor qualifications. We wrap up with a discussion of new ASA programs for shotcrete inspector training, and contractor qualification as well as providing a listing of appropriate references and resources on use of shotcrete for structural concrete repair.

December 1, 2015 at 11am CDT

Presenter: Julie Hartell, Assistant Professor

Civil and Environmental Engineering

Oklahoma State University

Topic Coming Soon

Presented in partnership with Southern Plains Transportation Center (SPTC) at University of Oklahoma

UPCOMING TECHNOLOGY TRANSFER EVENTS

4th Annual Transportation Infrastructure Conference

Date: Friday, December 4, 2015 **Location: St. Louis University**

SCC2016 - "Flowing Towards Sustainability"

Dates: May 15-18, 2016 **Location: Washington, DC**

Overview: The conference combines the 8th RILEM Symposium on SCC and the 6th North American Conference on the Design and Use of SCC and will be held jointly with the National Ready Mix Concrete Association (NRMCA) International Concrete Sustainability Conference The conference is supported by Missouri S&T, the RECAST Center, NRMCA, the Center for Advanced Cement-Based Materials (ACBM), as well as RILEM and ACI.

For more information, visit: **www.scc2016.com**

STAY INFORMED
STAY CONNECTED

Contact Information:

Website:
http://recast.mst.edu

Email:
re-cast@mst.edu

Director:
Kamal H. Khayat - khayatk@mst.edu

Coordinator/Newsletter Editor:
Abigayle Sherman - abigayle@mst.edu

Social Media:

Facebook:
facebook.com/RECASTCenter

LinkedIn:
'RE-CAST University Transportation Center' listed under Groups

APPENDIX E

RE-CAST January 2016 Newsletter

Research on Concrete Applications for Sustainable Transportation

RE-CAST

MISSOURI S&T

Vol. 3 :: Issue 1 :: JANUARY 2016

In this issue:

- Director's Message
- RE-CAST Student of the Year
- Featured Projects
- Workshop with FRP Repair Market
- RE-CAST presents Down Under
- Student Spotlight
- Events

CONSORTIUM MEMBERS:

Missouri University of Science and Technology

University of Illinois at Urbana-Champaign

Rutgers, The State University of New Jersey

University of Miami

Southern University and A&M College

Director's Message

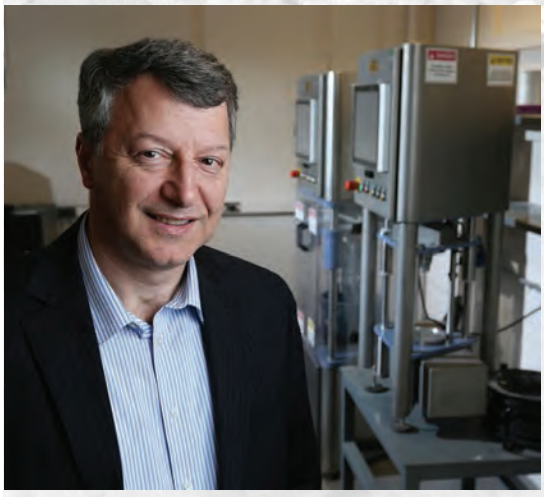
First, I would like to take a moment and wish our readers a Happy New Year! I hope that everyone has enjoyed the holidays and is re-energized for a new year full of innovation and progress.

In this issue, we provide some featured project updates, highlighting some of the recent progress our faculty and students have made.

We are happy to report that Daniel Ivan Castaneda, a Ph.D. candidate under the supervision of Dr. David Lange, RE-CAST Associate Director at UIUC, was selected as the 2015 RE-CAST Outstanding Student of the Year. More information about Daniel and his work can be found in the following pages.

On Dec. 1, the RE-CAST Center offered a webinar presented by Dr. Julie Hartell, Assistant Professor at Oklahoma State University on "*The Use of Resistivity Testing to Improve Concrete Quality.*" Please watch our website for other upcoming webinars and events.

This issue includes some activities at the University of Miami on the "*Design and Construction of Externally Bonded FRP Systems for Strengthening Existing Structures*", as well as activities at far reaching at Australia.



Best wishes for the New Year.

Kamal H. Khayat
RE-CAST Director

OUTREACH/WORKFORCE DEVELOPMENT

2015 RE-CAST Student of the Year: Daniel Castaneda

2015 RE-CAST Outstanding Student of the Year, Daniel Castaneda, pictured with USDOT Office of the Assistant Secretary, Gregory Winfree (left) and CUTC President, Mr. Joel Volinski (right)

For the past 24 years, the U.S. Department of Transportation (USDOT) has honored an outstanding Student from each University Transportation Center (UTC) at a special ceremony held during the Transportation Research Board (TRB) Annual Meeting. This year, the RE-CAST University Transportation Center selected Mr. Daniel Castaneda as its Outstanding Student of the Year. He was recognized at the 25th Annual Outstanding Student of the Year Awards ceremony that took place as part of the Council of University Transportation Centers (CUTC) annual banquet on Saturday, January 9, 2016 in Washington, D.C. Mr. Castaneda was selected for his outstanding academic performance as well as the technical merit and national importance of his research. Additional information on Mr. Castaneda's qualifications for this award are outlined on the following page.

- Continued Next Page -

OUTREACH/WORKFORCE DEVELOPMENT

Student of the Year Award *(continued)*

2015 Outstanding UTC Student of the Year Awardees

Daniel Ivan Castaneda is a Ph.D. Candidate in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign, one of the RE-CAST consortium partners. His research seeks to understand the consequence of design, handling, and placement of fresh materials as they relate to the long-term durability of civil infrastructure. His work includes examining the loss of air-entrainment in extensively vibrated fresh concrete with adapted rheology; investigating bond of repair materials in non-ideal placement conditions; thoughtful selection of sorptive aggregates to control diffusion processes in alternative, sustainable binder systems; development of a field-test to measure residual stresses in plain concrete pavements and structures; and instrumentation of recycled aggregate pavements. Daniel is originally from southern California and attended the University of California, Berkeley, where he completed his B.S. in 2008. Thereafter, he worked as a systems analyst in Silicon Valley where he drafted analytical solutions for the Federal Aviation Administration regarding aircraft excursions out of protected Class B airspace. Throughout Daniel's academic and professional career, he has been strongly motivated to increase the number of qualified women and underrepresented persons in STEM fields and has been involved in numerous outreach and retention efforts. He intends to continue as a researcher of civil engineering materials after he defends his dissertation in early 2016. His adviser, David A. Lange, believes that this award affirms Daniel's contributions to RE-CAST's themes on adapted rheology of high performance concrete and utilizing recycled materials in new construction; and it summarily recognizes Daniel's overall accomplishments.

FEATURED PROJECT

Flexural behavior of UHPC panels reinforced with GFRP grids

- Weina Meng, Ph.D. Candidate, Civil Engineering, Missouri S&T
- Kamal H. Khayat, Ph.D., Civil Engineering, Missouri S&T

The use of glass fiber reinforced polymer (GFRP) grids in reinforced concrete construction offers several advantages, such as high tensile strength and excellent corrosion resistance. Experimental and numerical studies to investigate flexural performance of ultra-high performance concrete (UHPC) panels reinforced with GFRP grids (GFRP-UHPC panel) were carried out. Such panels can be prefabricated and used as stay-in-place formwork for various types of structural elements, especially elements subjected to severe environmental conditions. The flexural performance of panels containing different reinforcement configurations was evaluated in three-point bending tests. A three-dimensional non-linear finite element model was established using ABAQUS, which incorporates the concrete damage plasticity (CDP) model and can be used to predict the post-fracture behavior. The numerical model was experimentally validated using the three-point bending test results. The proposed GFRP-UHPC panel system is shown to be promising for the development of lightweight, high-performance permanent formwork system. Such formwork can be used in accelerated construction of critical infrastructures to enhance the crack resistance and extend service life of the concrete structure.

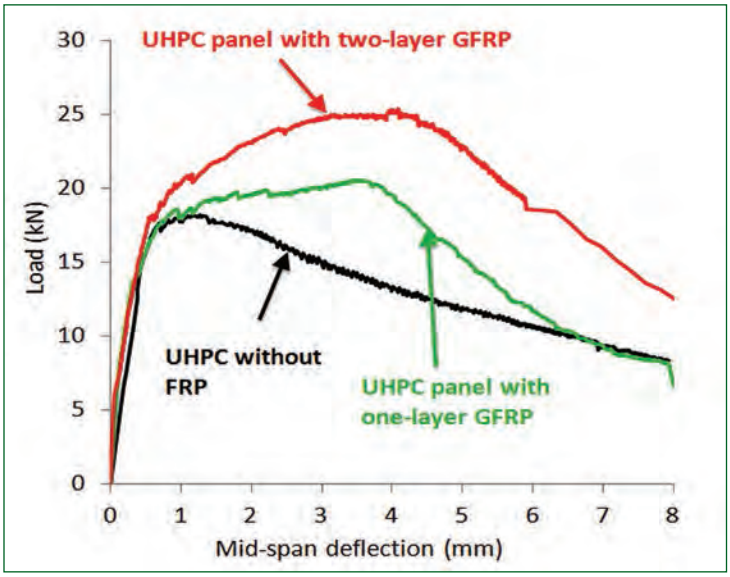


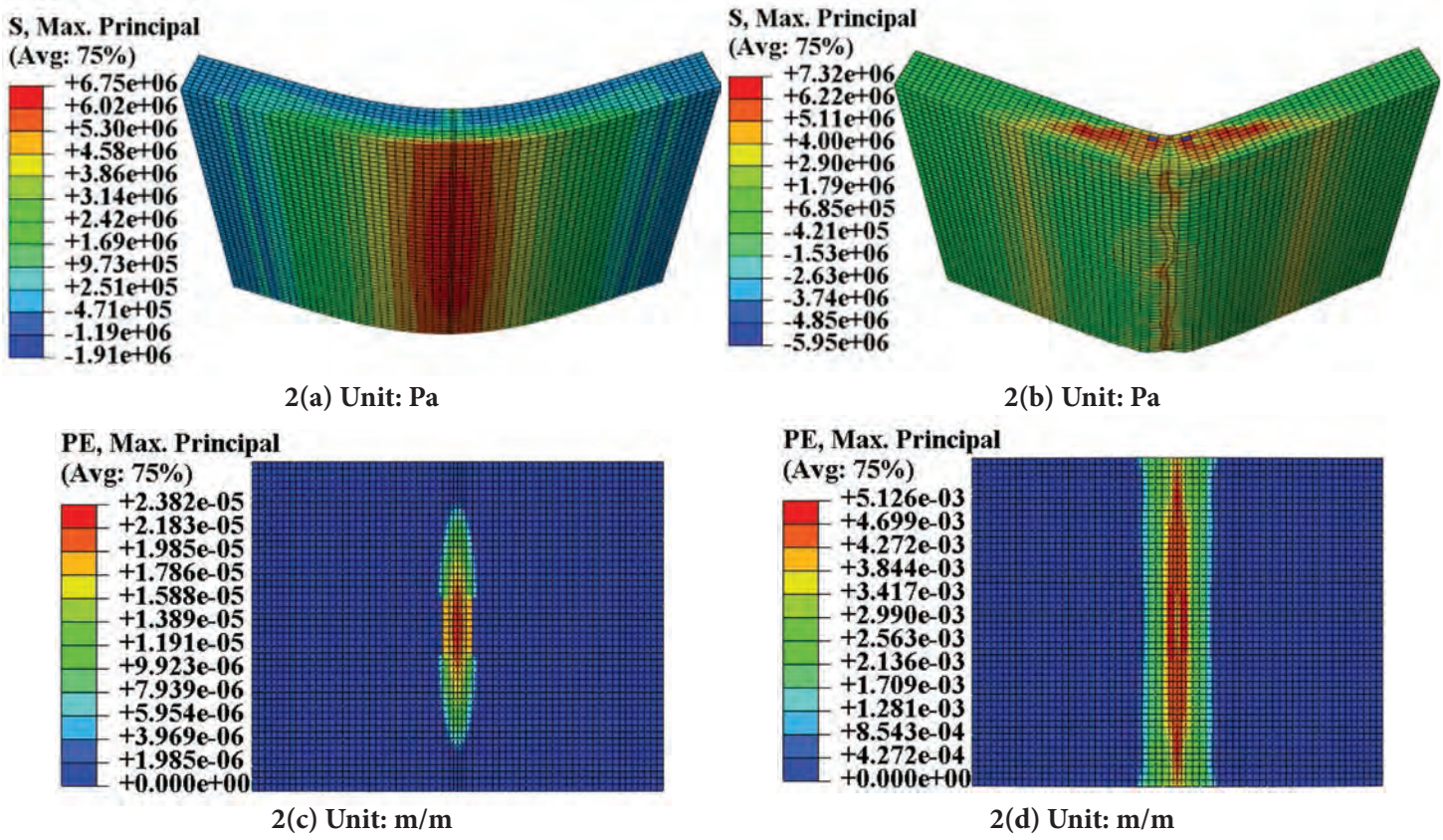
Figure 1. Load-deflection relationships

The load-deflection relationships of the tested panels are compared in **Figure 1**. The peak loads of the single-layer and the dual-layer GFRP reinforced UHPC panels were shown to increase by 20% and 23%, respectively, compared to the reference panel. The thermal toughness was increased by 12% and 59%, for the single-layer and dual-layer GFRP grids, respectively.

- Continued Next Page -

FEATURED PROJECT

Flexural behavior of UHPC panels reinforced with GFRP grids *(continued)*



2(a) Unit: Pa **2(b) Unit: Pa**

2(c) Unit: m/m **2(d) Unit: m/m**

Figure 2. Simulation results of stress: (a) distribution of MPS before cracking (scale factor: 500), (b) distribution of MPS after cracking (scale factor: 10), (c) distribution of PS at 0.1-mm mid-span deflection, and (d) distribution of PS at at 0.5-mm mid-span deflection

Figures 2(a) and (b) show the distribution of maximum principle stress in the panel. Before the occurance of cracking, the maximum principal stress (MPS) was located at the bottom of the panel at mid-span. The deflection curve was in a parabolic shape. However, after cracking that occurs at mid-span, the MPS can relocate to the region near the top. **Figures 2(c) and (d)** show the development of plastic strain (PS, strain larger than the elastic strain limit) with the increase of the mid-span deflection. The PS first appeared at the center of the panel, and then propagated along the mid-span.

FEATURED PROJECT

Flexural behavior of UHPC panels reinforced with GFRP grids *(continued)*

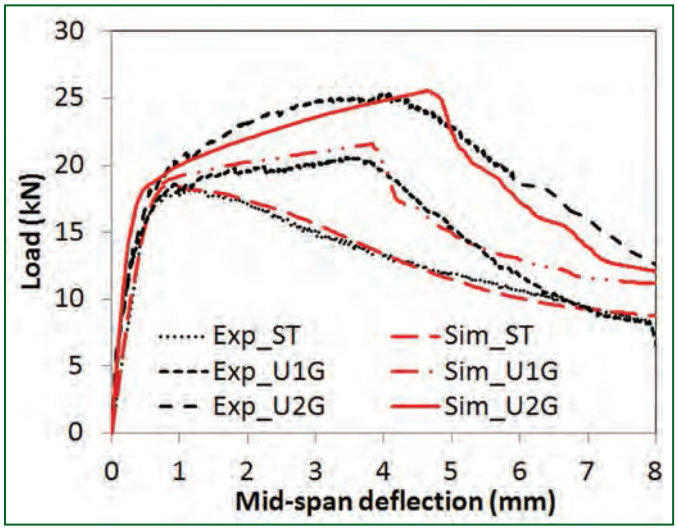


Figure 3. Load-deflection relationships of the panels with 40-mm thickness

Figure 3 compares the experimental (Exp_ST, U1G, and U2G) and numerical (Sim_ST, U1G, and U2G) results. Both results are in good agreement, thus validating the validity of the numerical model. For the elastic stage before cracking occurs, the experimental and numerical results were in excellent agreement (up to 1% error).

Based on the results obtained to date, the use of the GFRP grids can significantly enhance the peak load and energy dissipation, and therefore, the panel's load carrying capacity can be enhanced.

OUTREACH/TECHNOLOGY TRANSFER

Workshop to connect with the Latin American FRP repair market

A one-day workshop on **"Design and Construction of Externally Bonded FRP Systems for Strengthening Existing Structures"** in Spanish Language was held on Saturday, November 14, 2015 at the University of Miami with over 100 registered participants representing 15 countries.

The main objective of this workshop was to present to the Spanish-speaking technical communities of Latin American countries and South Florida the Spanish version of CNR-DT 200 R1/2013, the guide for design and construction of externally bonded FRP systems to existing structures that that has been recognized as one of the most advanced and technically-sound documents on the subject in the world. A guideline, by its nature, is not a binding regulation, but represents an aid for practitioners. The availability of this guide is intended to complement existing regulations where they exist or be the basis for design/construction where they lack.

The second objective was to learn from experts in the Americas about the most compelling challenges to the maintenance and repair of the built stock including case histories and experiences in relevant projects. The workshop concluded with a visit to lab facilities and exhibits from FRP suppliers, contactors, and designers.

OUTREACH/TECHNOLOGY TRANSFER

RE-CAST work makes its way down under

- John J. Myers, Ph.D., P.E., Professor of Civil and Architectural Engineering, Missouri S&T

Dr. Myers presenting at the PLSE 2015 Conference in December 2015

This past December and November, RECAST Investigator, Dr. John J. Myers, gave a series of five technical presentations at the **Second International Conference on Performance-based and Life-cycle Structural Engineering (PLSE 2015)** in Brisbane, Queensland, Australia and the E**ighth International Structural Engineering and Construction Conference (ISEC-8)** in Sydney, New South Wales, Australia. His technical presentations extended RE-CAST work to a broad new audience and included presentations on Strengthening of Reinforced Concrete Beams in Shear with Fiber Reinforced Cementitious Matrix, the Creep and Shrinkage of Ecological Self-Consolidating Concrete, the Effect of Accelerated Curing on Abrasion Resistance of HVSCM-SC, the Influence of Near-Surface mounted (NSM) FRP with Cementitious Material on the Out-of-Plane Behavior of Reinforced Masonry Walls, and the Live-Load Distribution Factors and Service Response of Missouri Bridge A7957. These presentations and technical papers included Missouri S&T Ph.D. student co-authors Zena Aljazaeri, Hayder Alghazali, Zuhair Al Jaberi and Eli Hernandez.

FEATURED PROJECT

Fatigue performance of reinforced concrete beams strengthened with fabric reinforced cementitious materials

- John J. Myers, Ph.D., P.E., Professor of Civil and Architectural Engineering, Missouri S&T
- Zena R. Aljazaeri, Ph.D. student, Missouri S&T

One of the most important aspects for a structural element in bridge applications is its ability to resist the oscillatory loads through its entire life. For that, Dr. John Myers and his graduate student, Zena Aljazaeri, have been studying the fatigue performance of FRCM composite in strengthening RC beams as part of RE-CAST program Project 3C. The study parameters were the FRCM's reinforcement ratio, the environmental exposure, and the fatigue frequency. The experimental work included testing of 12 RC beams. Two beams served as control beams. Five beams strengthened with one ply of the FRCM composite and the other five beams strengthened with four plies of the FRCM composite. The test matrix was divided into three groups based on the exposure conditions. Group 1, beams were tested under laboratory conditions. Group 2, beams were subjected to severe environmental conditions such as freezing and thawing cycles, high temperature and humidity cycles. Within the environmental chamber cycling regime, some beams were under their self-weight and the others were subjected to sustained stress.

Figure 1. Beams inside Environmental Chamber

STUDENT SPOTLIGHT

RE-CAST student wins second place at 4th annual Missouri S&T/MoDOT Transportation Infrastructure Conference poster competition

RE-CAST Ph.D. student, Zena R. Aljazaeri with RE-CAST Director and Conference Chairman Dr. Kamal H. Khayat

Zena Aljazaeri with MoDOT Research Administrator and Conference Co-Chairman Mr. William Stone

RE-CAST Ph.D. student, Zena R. Aljazaeri won second place at the 4th Annual Missouri S&T / MoDOT Transportation Infrastructure Conference poster competition. Her poster presented the work she has preformed under the RE-CAST project entitled "**Fatigue and Flexural Behavior of Reinforced Concrete Beams Stregnthened with Fiber Reinforced Cementitous Matrix.**"

The conference was held on December 4, 2015 at the St. Louis University Campus in collaboration with MoDOT. Nearly 100 participants attended the event which featured presentations of cutting edge research and field implementation projects in transportation infrastructure engineering.

This year's conference showcased recent findings in the areas of advanced construction materials, non-destructive testing and structural health monitoring of transportation infrastructure.

This was the first year that a student poster competition was held, which attracts 15 students from three area universities to compete. Three judges from the Missouri Department of Transportation met with each student to discuss thier poster and chose three winners. RE-CAST is proud of the recognition that Zena recieved at this event.

FEATURED PROJECT

Fatigue behavior of FRCM strengthened RC Beams

- Vanessa Pino, Ph.D. candidate, Department of Civil Engineering, University of Miami
- Houman A. Hadad, Ph.D. candidate, Department of Civil Engineering, University of Miami
- Antonio Nanni, Ph.D., Department of Civil Engineering, University of Miami

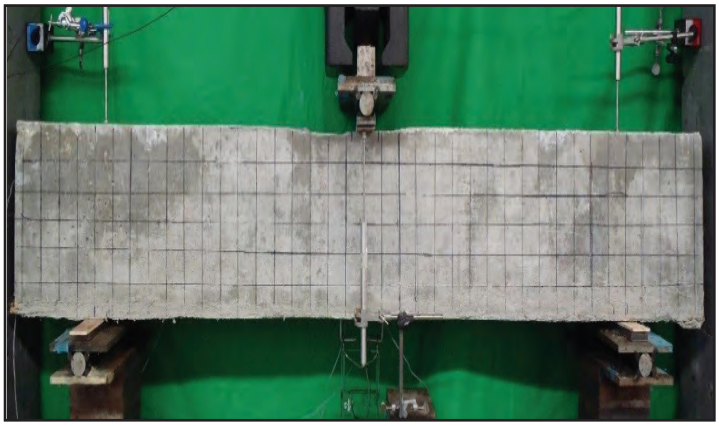


Figure 1. Test Set-up and Instrumentation

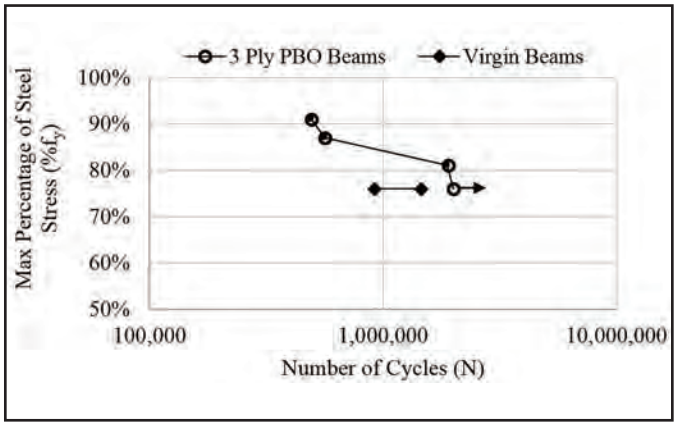


Figure 2. Load-deflection curves for control and PBO-FRCM 3 ply

Fabric reinforced cementitious matrix (FRCM) is a comparably novel composite strengthening system for existing reinforced concrete (RC) and masonry structures. Existing externally bonded strengthening technologies based on organic matrices referred to as Fiber reinforced polymers (FRP), and more novel solutions based on inorganic matrices known as FRCM systems have proven to successfully increase and restore strength in RC structures. FRCMs are deemed suitable for the repair of RC and masonry because of the excellent compatibility between the cementitious matrix and substrate.

Some concrete structures, such as bridges, experience high traffic volumes and varying vehicle axle weights causing repeated cyclic loading throughout their lifetime. Cyclic loading may cause damage to the structure, a phenomenon known as fatigue. Due to the novelty of FRCM technology, there is a lack of research regarding the long-term performance of FRCM systems when used to strengthen members subject to cyclic loads.

This study investigates experimentally some of the parameters that affect the fatigue behavior of FRCM strengthened RC beams subject to cyclic loading (**Figure 1**). The stress ration vs. number of cycles (S-N) curve depicted in **Figure 2** is obtained herein as it is typically used in fatigue-related studies to reflects the longevity limit of the member under fatigue. Failure mode, fatigue life, and the serviceability behavior of beams during cyclic loading are investigated, and preliminary results seem to show that FRCM provides an increase in strength, yield point and stiffness for a RC beam and can potentially increase its fatigue life. In addition, it was observed that the level of minimum and maximum stresses in reinforcing steel are of great importance among the other parameters in the fatigue life of RC beams strengthened with FRCM.

WEBINAR SERIES

Visit our Webinar Library at: recast.mst.edu/webinars

October 22, 2015 at 11am CDT

Presenter: Charles Hanskat, P.E.

Executive Director, American Shotcrete Association

"Shotcrete for Repair and Rehabilitation of Highway Facilities"

December 1, 2015 at 11am CDT

Presenter: Julie Hartell, Assistant Professor

Civil and Environmental Engineering

Oklahoma State University

"The Use of Resistivity Testing to Improve Concrete Quality"

Presented in partnership with Southern Plains Transportation Center (SPTC) at University of Oklahoma

SCC2016 - "Flowing Towards Sustainability"

Dates: May 15-18, 2016 **Location: Washington, DC**

Overview: The conference combines the 8th RILEM Symposium on SCC and the 6th North American Conference on the Design and Use of SCC and will be held jointly with the National Ready Mix Concrete Association (NRMCA) International Concrete Sustainability Conference The conference is supported by Missouri S&T, the RECAST Center, NRMCA, the Center for Advanced Cement-Based Materials (ACBM), as well as RILEM and ACI.

Register today at: **www.scc2016.com**

STAY INFORMED
STAY CONNECTED

Contact Information:

Website:
http://recast.mst.edu

Email:
re-cast@mst.edu

Director:
Kamal H. Khayat - khayatk@mst.edu

Coordinator/Newsletter Editor:
Abigayle Sherman - abigayle@mst.edu

Social Media:

Facebook:
facebook.com/RECASTCenter

LinkedIn:
'RE-CAST University Transportation Center' listed under Groups