news

MISSOURI S&T

CENTER FOR TRANSPORTATION INFRASTRUCTURE AND SAFETY

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From the desk of the Director

Stone sculptures on snowy S&T campus

As 2013 comes to a close and a new year of opportunity and growth begin, CTIS Director, Dr. K. Khayat is very pleased to report the next step in the future of transportation research endeavors at Missouri S&T. The University has been selected to lead a consortium of four universities sharing in a new Tier-1 University Transportation Center. Missouri S&T will share this two-year grant with Rutgers University, Southern University, University of Illinois at Urbana-Champaign and University of Miami. *"We are honored to be selected to lead this effort,"* says Dr. Khayat. *"This consortium has the opportunity to do great things. We have assembled a wonderful team of researchers, staff and students — this grant will give them the opportunity to shine."* This new UTC, named RE-CAST (Research on Concrete Applications for Sustainable Transportation), will focus on developing the next generation of cement-based construction materials. *"The ultimate goal of the proposed research program is to fast-track the acceptance of these technologies and develop national standards and guidelines for their use for the reconstruction of the nation's infrastructure for the 21st Century,"* says Khayat.

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FEATURED PROJECT:

Examining system dynamics to study maritime transportation system

- Dr. Suzanna Long, Asst. Professor, Engineering Management and Systems Engineering, Missouri S&T
- Dr. Heather Nachtmann, Professor, Industrial Engineering, University of Arkansas
- Lizzette Perez-Lespier, PhD Candidate, Missouri S&T
- Furkan Oztanriseven, PhD Candidate, University of Arkansas

Figure 1. U.S. Maritime System

In the last decades, a number of factors have re-shaped the shipping industry, including the growth of international trade, the emergence of new markets, and the development of multimodal supply chains. This has made Maritime transportation, defined as ocean and coastal routes, inland waterways, railways, roads, and air-freight, a critical part of the global supply chains and global freight transportation systems. The volume of maritime freight is steadily growing and the freight distribution getting more complex with time because of its many origins, destinations and supply chains. Due to the complexity and interconnectivity of the MTS system, traditional models limit the ability to evaluate all factors of the system. The feasibility of a system dynamics approach is considered to determine its ability to simulate maritime transportation and its integration between the different modes of transportation. In the initial phase of this research, an integrative literature review of applications of system dynamics in the maritime transportation system was conducted. This literature review was used to define research questions in an emerging area and evaluate a proposed methodology against the state of the literature in terms of rigor, efficacy, and ability to generate valid results.

The results of this early research provide an overview of the applicability of system dynamics models in the maritime transportation system and suggest a path to develop a system dynamic framework model.

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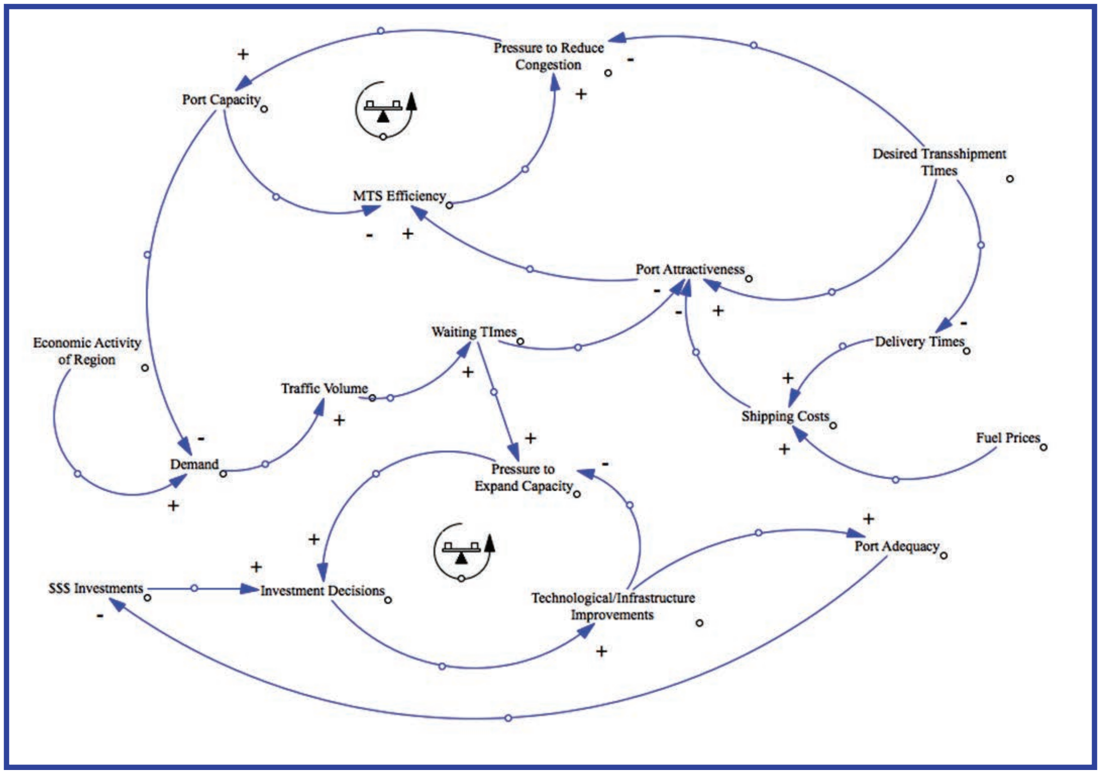

Figure 2. MTS Causal Loop Diagram

Further, results show that system dynamics has the ability of overcoming the drawbacks of time-series and statistical models currently in use. The system dynamics simulation takes causality into account, allows what-if scenario analysis, and can be adapted to fundamental changes in the system. Sensitivity analysis can be conducted within the model, which can help policy makers better analyze the outcomes of a policy change.

An initial framework model was built in order to understand the integration of system dynamics methodology into the maritime transportation field. The model shown in Figure 2 is a map of the MTS system. In the causal loop (map), variables are linked with arrows from cause to effect with a plus (+) or minus (-) sign at the end of the arrow to identify if the effect that each variable has on the other one is a positive or a negative one. This specific model forecasts the impact on system efficiency that investments in port infrastructure and maintenance of the maritime system will produce; these investments and maintenance are assumed to alleviate time delays, capacity and congestion disruptions and aid in the improvement of port attractiveness and port capacity. All variables are interconnected and have an impact on the system's overall efficiency. For example, depending on the input for 'desired transshipment times', even if the input is designed to produce the best possible (shorter), this will result in an opposite behavior in the 'pressure to reduce congestion'. Subsequently, the pressure congestion impacts the 'port capacity' positively and so forth. The loop continues with modifying decisions until the desired state of the system is achieved. At the end of the process, decision makers will benefit from understanding how these investments have an impact on the MTS's efficiency over time.

Preliminary system dynamics models may be combined with agent based modeling simulations in future research to better evaluate the change environment best suited for efficient movement of goods along the U.S. Maritime System.

FEATURED PROJECT:

Modelling the geomorphology of an active landslide

- Norber Maerz, Associate Professor, Department of Geological Science and Engineering, Missouri S&T

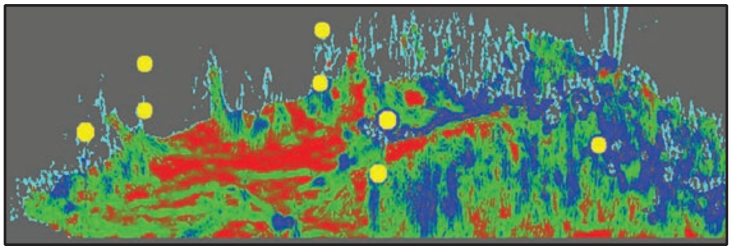

Figure 1. Development of a recursive sphere center finding algorithm on the LIDAR

Soft slope movement is a big problem near highways. Since the movement is not always predictable, having to inspect the slope visually is not necessarily the safest approach. If it can be done remotely with a laser scanner the observer will remain safe and may also be able to detect movement not readily noticeable, unlike tension cracks or scarp development.

The focus of this project is to determine millimeter/sub-millimeter movement within a slide body using high precision terrestrial LIDAR (LIght Detection And Ranging, a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light) and artificial targets. The preliminary tests have used a smaller slope at a closer distance than the target slide in Branson, Missouri. The goal of the study is to model how a landslide deforms over time. Using different lengths of rebar (3, 4, and 5 feet) driven vertically into the slide area and two 4 inch Styrofoam balls placed onto each rebar in a network over the slide body, consecutive scans will be taken during the winter season. A total of 54 pieces of rebar with two balls each will be placed over the slide. An additional 6 pieces of rebar with one ball per piece will be used as control points and therefore placed outside of the movement area.

Using a sphere finding algorithm, the initial location of each ball will be recorded and referenced against all later scans. After several consecutive scans of the landslide area, a map will be generated

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Modelling the geomorphology of an active landslide (continued)

Figure 2. Test site in landslide in Branson MO. Rebar with 4" targets will be positioned on yellow markers (outside of the slide) for control, and at each intersection of the grid within the slide.

using displacement vectors to show how the slide body has deformed. Having two balls on each of the rebar and knowing the total length of the rebar a 3 dimensional model can be created, to not only measure downslope movements but also characterize the rotational movements.

To date, several test scans have been performed using varying distances and different LIDAR units. The raw data points have been analyzed in ArcScene to determine the magnitude of accuracy and scan point deviation.

Field Trip to Holcim, Inc.

Ste. Genevieve, MO

December 18, 2013

The CTIS organized a one day trip for faculty and students to visit the world's largest cement factory: Holcim, Inc., in Ste. Genevieve, MO. The plant produces 12,500 metric ton per day of cement and supplies this material to 22 states. It is one of the most environmentally-efficient cement plants in the Holcim Group. Ste. Genevieve, Missouri was chosen as the best site for this new plant for several reasons: a plentiful supply of good-quality limestone, a high-quality workforce, and good access to target markets via key transportation networks including waterway, rail and road which serves ten of the twenty largest cities in the United States.

FEATURED PROJECT:

Application of active microwave thermography to structural health monitoring

- Kristen M. Donnell, Asst. Professor, Dept. of Electrical and Computer Engineering, Missouri S&T
- Mohammad Tayeb Ghasr, Asst. Research Professor, Dept. of Electrical and Computer Engr., Missouri S&T
- Edward C. Kinzel, Asst. Professor, Dept. of Mechanical and Aerospace Engineering, Missouri S&T

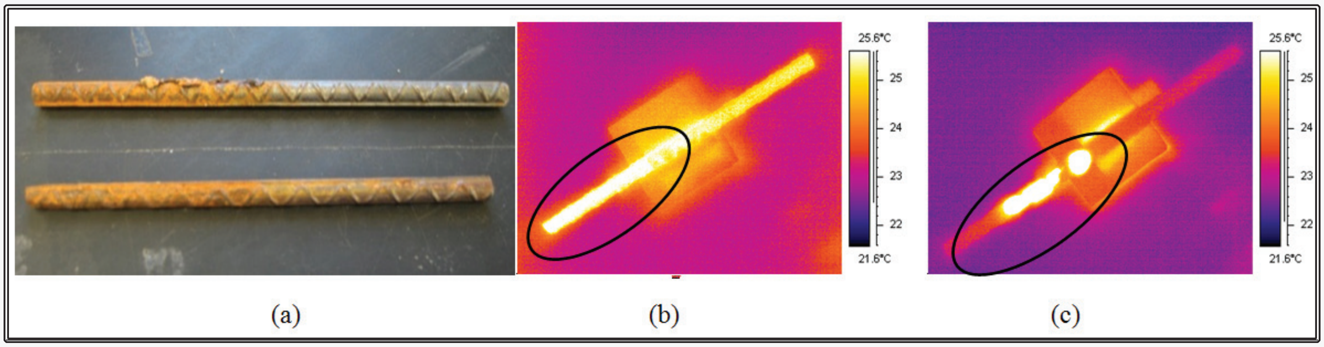

Figure 1. (a) Rebar with localized significant (top), and light corrosion (bottom). Thermal image of rebar with (b) light corrosion, and (c) localized corrosion.

Health monitoring of infrastructure is very important in the transportation and infrastructure industries. Many nondestructive testing (NDT) techniques have been applied for structural health monitoring including microwave NDT, ultrasound, thermography, etc. Due to the complex materials (composites, concrete, etc.) commonly used, it may be difficult to thoroughly inspect a structure using one method alone. Thus, hybrid NDT methods have been developed. Recently, the integration of microwave NDT and thermography, herein referred to as Active Microwave Thermography (AMT), has also been considered as a potential structural health monitoring tool. This hybrid method utilizes microwave energy to heat a structure of interest, and then the thermal surface profile is measured using a thermal camera.

Thus far, this project has focused on the application of AMT to detection of corrosion on reinforcing steel bars (rebars), and inspection of rehabilitated cement-based structures for delaminations under carbon-fiber-reinforced-polymer (CFRP) patches.

Detection of Corroded Rebar

To investigate the potential of AMT for detection of corroded rebar, two rebar samples were obtained; one with light corrosion along half of its length, the other with localized significant corrosion on a portion of its length. These rebar samples are shown above in **Figure 1a**. Each sample was exposed to microwave energy (frequency of 2.45 GHz) for 5 sec, and immediately following, imaged using a thermal camera, shown above in **Figure 1 b-c** (corroded area indicated in the black oval).

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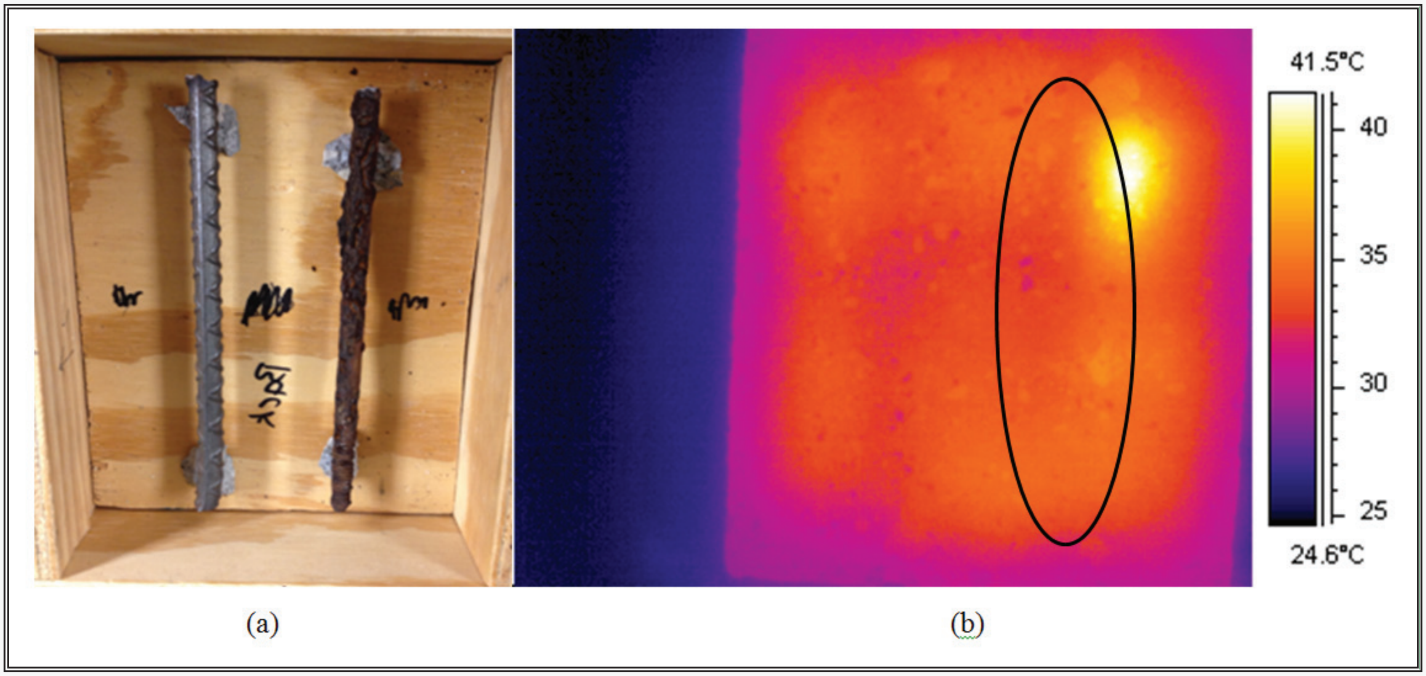

Figure 2. (a) photograph of clean (left) and corroded (right) rebar, and (b) thermal image of concrete block surface after microwave heating (location of corroded rebar indicated in the black oval).

As can be seen in **Figure 1b-c**, for both light and significant corrosion, the corrosion exhibited increased heating as opposed to the clean rebar. For the case of the lightly-corroded rebar, the temperature increase was nearly 600° mC (well above the sensitivity of the thermal camera used, 100° mC). In addition and as expected, more heat was generated in the localized significant corrosion (nearly 3000° mC), as compared to the light corrosion. While these results are quite encouraging, it is also important to more accurately replicate what may be found in practice. To this end, a concrete sample (dimensions of 17 × 15 × 5 cm^3) containing clean and corroded rebar embedded ~2.5 cm in the concrete was cast.

Measurements were performed using this sample as well. The sample mold and rebars are shown in **Figure 2a**. After allowing the sample to cure (~1 week) the sample was exposed to 15 sec of microwave energy. Then, using the same thermal camera as above, an image was captured of the sample, as shown in **Figure 2b**. Clearly (and as indicated by the black oval), the corroded rebar is detectable in the thermal image after microwave heating. The clean rebar is also evident in the image as well (left of the black oval), appearing as a lower-temperature line.

Delamination Detection

In order to study the potential of AMT for detection of delamination in rehabilitated structures, a coupled microwave-thermal simulation was conducted using CST Microwave Studio® and MPHYSICS Studio®. The simulation is completed in two parts; first, the electromagnetic response of the structure under test under planewave illumination is determined. Then, based on the electromagnetic response, the thermal response (i.e., heat generation and diffusion, etc.) of the structure is calculated. To begin, a small concrete sample with dimensions of 30×30×5 (cm^3), partially covered by a CFRP sheet, was considered. The CFRP sheet has dimensions of 20×20×0.2 (cm^3), and contains an offset delamination with cross sectional area of 4×4 (cm^2) and a depth of 2 (mm). The geometry of the structure is illustrated in **Figure 3** (see next page).

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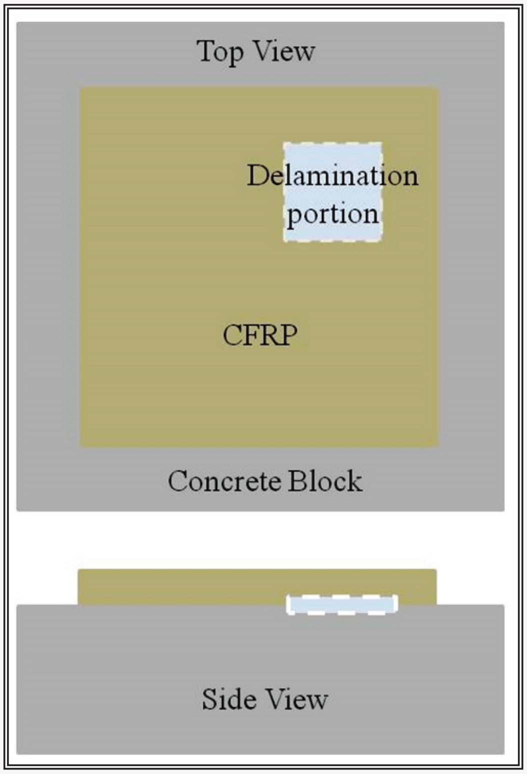

Figure 3. Top and side views of the SUT covered by CFRP.

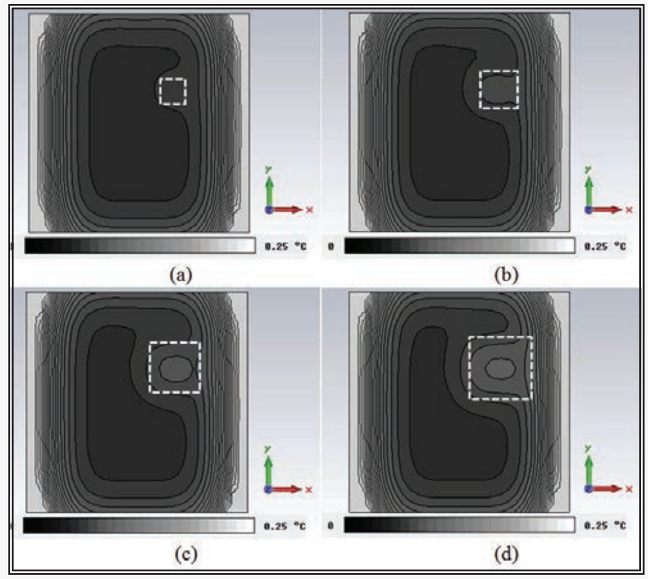

Figure 4. Surface temperature distribution for delamination dimensions of (a) 2, (b) 3, (c) 4, and (d) 5 cm (location of delamination is indicated by the white dashed line).

Under microwave illumination, currents will be induced in the CFRP and will operate as a heat source, adding to any dielectric heating that may occur (relative dielectric properties, εr, of the concrete are assumed to be $\varepsilon r = 10 - j4$). The presence of a delamination will affect the thermal response of the structure resulting from the AMT-induced heat.

This simulation allowed the effect of delamination size on the temperature distribution to be studied. To this end, different cross-sectional areas of the delamination were considered, and the resulting change in temperature at the top surface of the CFRP analyzed. For these simulations, an incident power level of 50 (W) (frequency of 2.45 GHz) and microwave excitation time of 5 (sec) was assumed. The surface temperature profile for 4 different cross-sectional areas, 2×2 to 5×5 (cm^2), is shown below in **Figure 4**. A thermal measurement sensitivity of 10 mK is assumed for all cases.

As shown in **Figure 4**, the dimensions of the delamination clearly have an effect on the surface temperature distribution. For example, in **Figure 4a** (2×2 (cm^2) delamination), the temperature distribution is just beginning to provide an indication of the presence of the delamination. This indication becomes increasingly stronger as the delamination dimensions increase, as shown in **Figure 4c-d**.

Future Work

Thus far, the preliminary measurements and simulations indicate that AMT has significant potential as a new structural health monitoring tool. To continue the development of AMT, a small AMT system is currently under construction in the Applied Microwave Nondestructive Testing Laboratory (*amntl*) at Missouri S&T. Upon completion of the AMT system, the next step in the project will focus on preliminary delamination detection measurements.

FEATURED PROJECT:

Innovative concrete bridge to open in 2014 near Jefferson City, MO

- Mindy Limback, Assistant Director, Communications, Missouri S&T

Figure 1. Final bridge girder for Span 2 with instrumentation being placed.

Just east of Jefferson City, MO, sits a construction site that will soon be home to one of the nation's first bridges to incorporate an unusual concrete mix in its girders and support structure.

The three-span bridge, which is scheduled to be completed this fall on Highway 50, will also be outfitted with various sensors and instrumentation to collect data on how well the bridge performs over time.

It's another milestone for Dr. John J. Myers, a professor of civil, architectural and environmental engineering at Missouri University of Science and Technology working with the Missouri Department of Transportation and Missouri S&T's National University Transportation Center. Myers has spent the past decade studying and testing high-strength concrete and other innovative concrete systems for implementation.

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Figure 2. Bridge girder with instrumentation being set.

"In 2012, we completed a two-year study that examined overall behavior of self-consolidating concrete, or SCC, using locally available materials including natural river sands, dolomitic limestone aggregates and river gravels," Myers says. The study examined the concrete and steel reinforcing material's shear strength, transfer and development length, creep and shrinkage as well as key durability attributes.

Myers and his team found that using high-strength self-consolidating concrete, or HS-SCC, can either extend the span length of the HS-SCC girders, a structure's main support member, or reduce the number of girder lines needed in a given span.

"That's because this material can allow for additional prestressing tendons, which can increase the girder's load-carrying capacity," says Myers.

Myers says they also expected the material to have reduced maintenance costs and an extended service life compared to conventional concrete due to the HS-SCC's improved durability behavior. Concrete typically has four key components: portland cement, water, fine aggregate like sand and course aggregate or rock. In HS-SCC, the course aggregate is finer and chemical admixtures are added to increase its flow rate. That allows it to flow into every corner of a form work, by its own weight, eliminating the need for vibration or other types of compacting effort that requires more labor at the precast plant or job-site.

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Figure 3.
Missouri S&T graduate students Eli Hernandez and Alex Griffin attaching Data Acquisition System to bridge girder.

"It's a more efficient use of the material," Myers says. "With its increased strength, it can extend a span's length by 20 percent or more."

The new bridge will combine three different types of concrete grades in the girders. The first 100-foot span will use traditional concrete. The second, 120-foot span, will use high-strength, self-consolidating concrete. The final span will use self-consolidating concrete. Using sensors embedded in the material, researchers will monitor to see any differences as they occur. The bridge also includes instrumentation that will allow the research team to collect important data during load testing and normal in-service conditions.

"The advantage of having one bridge demonstrating four to five types of concrete throughout the entire bridge is that you know the exposure conditions, salts, temperatures, weather conditions are all identical," Myers explains.

In addition, one intermediate support will use concrete with a high-replacement level of fly ash, fine particles from coal are the by-product of a power plant's combustion process. During the manufacture of traditional cement, limestone and other materials are heated to extreme temperatures, releasing of CO^2 from both chemical reactions and the heating process. By replacing half of the cement with fly ash, the mix not only reduces the amount of fly ash that ends up in landfills but will cut CO^2 emissions as well. It also will make for a more cost-effective concrete mix, which will reduce construction costs.

The state's first bridge to use high-strength, self-consolidating concrete was constructed in 2009 in Rolla and led by Myers' research group. The bridge, designed for rapid construction, was one of two built to demonstrate the mechanical and material properties of high-strength concrete and high-strength, self-consolidating concrete. County Materials Corp. in Bonne Terre, Mo., was responsible for fabrication of the prestressed-precast girders. Iron Mountain Construction Services of Maryland Heights, Mo., was responsible for the overall construction of the bridge project.