Spring 2020

INSPIRE Newsletter Spring 2020

Missouri University of Science and Technology. INSPIRE - University Transportation Center

TIER 1 UNIVERSITY
TRANSPORTATION CENTER (UTC)

Sponsored by the Office of the Assistant Secretary for Research and Technology in the U.S. Department of Transportation

INSPIRE

INSPECTING AND PRESERVING INFRASTRUCTURE THROUGH ROBOTIC EXPLORATION

VOL. 4 | ISSUE 1 | SPRING
INSPIRE-UTC Biannual Publication

In this issue:

Awarded in December of 2016 by the U.S. Department of Transportation, the five-year **INSPIRE UTC** is a Tier 1 University Transportation Center with a research priority of preserving the existing transportation system as part of the UTC Program (https://www.transportation.gov/utc/2016-utc-grantees) that was authorized under the Fixing America's Surface Transportation Act.

CONSORTIUM MEMBERS

Missouri S&T
The City College of New York
Georgia Tech
CU
UNLV
N
East Central College
Lincoln
Ozarks Technical Community College
St. Louis Community College

Director's Message

Greetings, colleagues and friends! Since our last newsletter, the INSPIRE UTC has completed the annual reviews and funding recommendations of Year 4 proposals. Each proposal was evaluated by at least one Department of Transportation/consulting engineer and one expert researcher in the proposed subject area. This round of the call for proposals has resulted in an award of 12 projects, including 10 new projects and two continuation projects from Year 3.

The INSPIRE team has completed four multi-phase research projects awarded in the previous years. For each completed project, a final technical report, a final data report, data files, and an educational module have been submitted and archived in the INSPIRE Center repository, which will be made accessible through the center website. These deliverables will meet various contractual requirements as summarized in the data management plan and technology transfer plan at the INSPIRE UTC.

The INSPIRE team has encountered research and operation challenges since early March 2020. Due to the unprecedented coronavirus pandemic, faculty and students lost their access to laboratories for experimental tasks and had to reschedule their projects to make maximum use of this difficult time for various computational tasks, literature reviews, and paper preparations.

The team continues to engage members of interest in transportation research. We will highlight a new Educational Module Series that serves as one lecture of each completed research topic for undergraduate students from community colleges. This initiative is targeted at a pipeline of workforce development in the area of transportation infrastructure inspection. We will also update the pooled-fund study for field validation of the advanced technologies developed at the INSPIRE UTC, which serves as a venue of technology transfer to practitioners through professional training.

This newsletter issue will feature three articles focusing on Forensic Study of Bridges with research led by INSPIRE researchers at the City College of New York and Missouri S&T. These forensic studies can help better understand the potential failure modes and mechanisms of bridge structures under service and extreme loads so that the inspection of similar bridges can be targeted at representative damage locations, levels, types, and working conditions. Other highlights will include the outreach activities of our members to promote transportation-related research in primary and secondary schools.

In addition, the Missouri S&T's envelope center of the INSPIRE UTC, Center for Intelligent Infrastructure (CII), recently continued the CII/Abbett Distinguished Lecture Series, developed an Envisioning a Digital City initiative and celebrated the establishment of the Missouri Center for Transportation Innovation

We hope you enjoy the featured articles and exciting news of the INSPIRE UTC and invite you to visit our website at **inspire-utc.mst.edu** for additional information

Sincerely,

Genda Chen, Ph.D., P.E., F. ASCE, F. SEI, F. ISHMII

Director, INSPIRE University Transportation Center
Director, Center for Intelligent Infrastructure

Envisioning a Digital City: Missouri S&T Could Lead to "Smart" Infrastructure

Dr. Genda Chen wants to make the city of the future more intelligent - able to build and repair its roads, bridges, electrical grids, power plants and other infrastructure through a network of robotics, sensors and data analytics that diagnose and identify the community's needs. Researchers at the Center for Intelligent Infrastructure (CII) at Missouri S&T are looking to create new infrastructure capabilities on a grand scale to lower construction and maintenance costs to improve worker safety.

"This is an ambitious project, and there are lots of challenges," says Chen, the Robert W. Abbett Distinguished Professor of Civil Engineering at Missouri S&T and CII's Director. "We are investigating a new frontier."

Chen says Missouri S&T's INSPIRE UTC has already developed the robotics technology that focuses on the inspection and maintenance of bridges. That technology could serve as a baseline for new technology coming out of CII, Chen says. He envisions a future where a digital stream of data from sensors could be used to run scenarios and help public officials determine policy and plan for potential infrastructure problems before they happen. For instance, the data could be used to predict damage to roads, rail lines and power grids in the event of a tornado or earthquake, possibly leading to improved construction techniques.

A robot can help inspect infrastructure and provide necessary data for decision-making of needed repair tasks. Robots could also be used in construction to help prevent injuries to people, Chen says. He says construction and maintenance involving robotics is currently used on a small scale, but nothing of the magnitude that the CII researchers envision.

The work is particularly important as the world's infrastructure ages. Chen says the advanced technology developed at the INSPIRE UTC enables faster and less expensive inspection to meet more frequent inspection requirements for aging infrastructure. He says the technology also allows for more accurate, safer assessments for infrastructure with limited remaining life or severe deterioration.

Working with Chen on the research project are Missouri S&T faculty members including Dr. Jenny Liu, professor of civil engineering; Dr. Suzanna Long, professor and chair of engineering management and systems engineering; and Dr. Sajal Das, professor and Daniel St. Clair Endowed Chair of computer science; as well as University of Missouri-Columbia professors Dr. William G. Buttlar, the Glen Barton Chair of Flexible Pavement Technology; and Dr. Glenn Washer, professor of civil engineering.

CII is funded by the Missouri S&T and the University of Missouri (UM) System as part of a multi-campus research initiative. Chen says he would like to see a few universities outside of the UM System get involved with CII to bring additional strengths to the team.

Original Version Posted December 13, 2019-Missouri S&T News and Events

PROVOST'S MESSAGE

I am honored to work with Dr. Chen to support his team to advance the mission of the INSPIRE University Transportation Center. The inspection and maintenance of transportation infrastructure are among our nation's most pressing challenges, and it is no surprise that the most creative solutions to the biggest problems such as these originate from the great minds of his team. I have had the privilege of observing Dr. Chen and his team demonstrate drone-enabled bridge inspection, and what struck me, in addition to the incredible innovation on display, was the sense of team-work and shared accomplishment that defines the INSPIRE researcher team. The INSPIRE group includes researchers which span young undergraduates to senior faculty and each stage of research progression in-between, and Dr. Chen has a gift for making sure every member is recognized and celebrated for their valuable contributions. The INSPIRE program is a model for Missouri S&T's commitment to solving the world's great challenges through innovation and experiential learning. There is no question that Missouri S&T is a national leader in transportation engineering, and will remain so for a very long time as capacity and innovation continue to advance with the members of the INSPIRE center.

Stephen Roberts, Ph.D.
Interim Provost, Missouri S&T

Missouri Center for Transportation Innovation Unveiled

MoDOT and the University of Missouri System announced in December 2019 the formation of the Missouri Center for Transportation Innovation (MCTI)- a research collaboration that will benefit both organizations and the citizens of Missouri.

The vision for MCTI is to establish Missouri as a showcase and a clearinghouse for safe, accessible, sustainable and resilient transportation, and moreover, to: Propel people...Connect their communities...and Energize their Economies. It will aim to increase Missouri's participation and influence in national research, perform practical research that can be implemented quickly, implement innovative technologies, produce future transportation engineers, and create an atmosphere that develops faculty and staff at the University and at MoDOT.

Missouri S&T faculty with MCTI Director (William G. Buttlar) and UM President (Mun Choi)

"At the rate that transportation technology is changing, if you can't stay ahead of the curve with your research initiatives, you'll quickly be passed by others,' MoDOT Director Patrick McKenna said. "With Missouri's historical position as a nationwide leader in transportation, we can't let that happen. The creation of MCTI positions us well for the future."

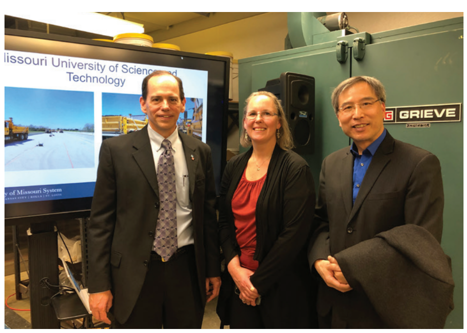
The Center, which will utilize the MoDOT laboratory in Jefferson City and laboratory facilities at the University's four campuses in Columbia, Rolla (Missouri S&T), Kansas City and St. Louis, is a partnership with the University of Missouri System and MoDOT in cooperation with the Federal Highway Administration and other transportation stakeholders.

"Combining the strengths of the UM System universities with MoDOT through the MCTI is a clear expression of our mission to foster research that benefits the people of Missouri, the nation and that world," UM System President Mun Choi said. "Building effective connections between our universities and the state will accelerate research breakthroughs and support economic development and improve transportation safety."

Bill Buttlar, an engineering professor at the University of Missouri-Columbia, will serve as the MCTI Director. The deputy director will be John Myers, an engineering professor at Missouri S&T. MoDOT Research Director Jen Harper will be a liaison to the state agency.

The INSPIRE UTC celebrated this occasion together with other transportation researchers and leaders from the University of Missouri (UM) System and MoDOT. It will help to streamline the connection among the universities, MoDOT, and the UTC Program in the US Department of Transportation.

Celebration on the establishment of the MCTI



MoDOT Chief Engineer (Ed Hassinger), MoDOT Research Director (Jennifer Harper), and INSPIRE UTC Director (Genda Chen)

MCTI
MISSOURI CENTER FOR
TRANSPORTATION
INNOVATION
PROPELLING PEOPLE · CONNECTING COMMUNITIES · ENERGIZING ECONOMIES

Posted December 17, 2019 — Missouri Department of Transportation

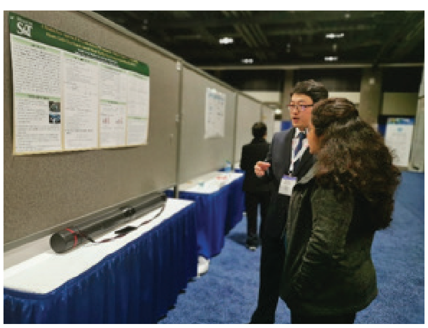
NEWS

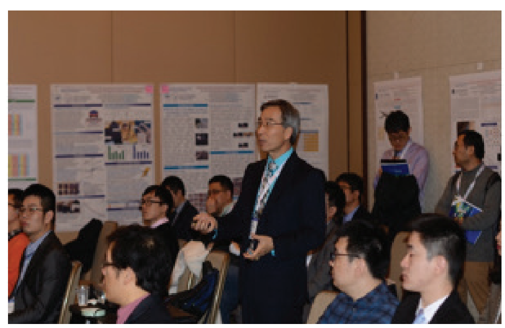
Researchers Presiding and Presenting at Transportation Research Board Annual Meeting

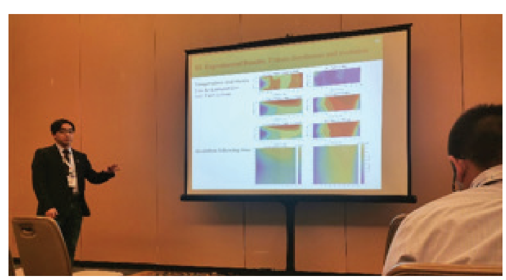
The 99th Transportation Research Board (TRB) Annual Meeting was held on January 12-16, 2020, at the Walter E. Washington Convention Center, in Washington, D.C. Missouri S&T was well represented at this annual meeting with its faculty making more than 10 presentations covering a wide range of topics on transportation infrastructure. Dr. Jenny Liu's group showcased their sustainable materials for transportation infrastructure use in cold regions.

Dr. Xiong Zhang's group focused on advanced testing techniques for geo-material characterization, soil structure interaction, advanced application of geotextile and unsaturated soil behavior. Dr. Xianbiao Hu's group demonstrated their research capabilities in traffic performance evaluation, traffic operation, incentive-based behavior, and traffic flow control.

S&T researchers also demonstrated their expertise and leadership in other professional venues in conjunction with the TRB annual meeting. Dr. Jenny Liu presided the ASCE Bituminous Material Committee annual meeting, and chaired the 10th International Association of Chinese Infrastructure Professionals (IACIP) Workshop. Drs. Xianbiao Hu and Hongyan Ma served as the session chairs and poster reviewers for the Workshop. Dr. Genda Chen delievered a keynote presentation entitled "Empowering and Rejuvenating Civil Engineering Profession with Informatics, Automation and Actuation". S&T students Hanli Wu, Jun Liu, Sara Fayek, and Xingxing Zou received poster awards at IACIP student poster competition.



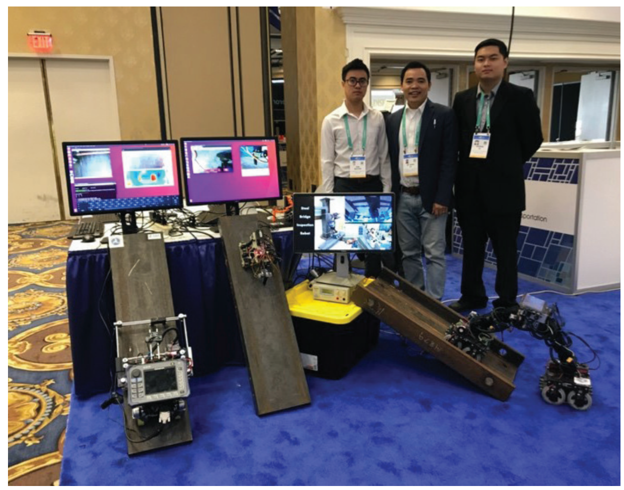




For more information, visit: www.trb.org/Annual Meeting

Consumer Electric Show in Las Vegas features University of Nevada Reno Advanced Robotics and Automation Laboratory

On behalf of the INSPIRE UTC, the Advanced Robotics Laboratory (ARA) led by Dr. Hung La demonstrated automated steel bridge inspection robots at the 2020 Consumer Electric Show (CES) in Las Vegas, Nevada on January 10, 2020. CES is the largest technology show in the world, attracting more than 4, 500 exhibitors each year. This year, the U.S. Department of Transportation hosted a 10' ×10' exhibition booth dedicated to highlighting transportation technologies developed by University Transportation Centers. The ARA Laboratory showcased three steel climbing robot prototypes: wheeled-mobile robot, tank-like robot, and inch-worm-liked robot. Steel members were setup to provide live demos to the CES audience. The ARA team successfully demonstrated the automated steel inspection robots that can climb on multiple-steel member assemblages and collect visual and eddy current data in real-time. This demonstration attracted more than 150 attendees.



For more information, visit: www.ces.tech

NEWS

CII Celebration at the 2019 Holiday Luncheon

CII celebrated its accomplishments during the Holiday Luncheon on December 11, 2019. Together with various campus supporters, staff, faculty, center research students and visiting scholars, guests enjoyed festive American and Chinese foods as well as dessert assortments.

CII/Abbett Distinguished Lecture Series

The Center for Intelligent Infrastructure (CII) at Missouri University of Science and Technology (S&T) proudly announces the establishment of a new CII Distinguished Lecture Series, starting Fall 2019. This series of lectures is continuation of the previous Abbett Distinguished Lecture Series established by the Department of Civil, Architectural, and Environmental Engineering in Fall 2014. The goal of this lecture series is to provoke intellectual discussion on scientific and engineering advances, innovative solutions, and grand challenges in the area of monitoring, assessment, preservation, resilience, and management of infrastructure subjected to aging deterioration and multiple hazards (earthquakes, winds/hurricanes/tornados, fires, floods, etc.). This goal will be achieved by hosting nationally and internationally renowned speakers to give presentations to the Missouri S&T faculty and broad community through webinars on topics of their choices that are related to the theme of the Center. We are anticipating presentations by a variety of eminent individuals, including senior professors (e.g., endowed chairs and research center directors) in academia, members of the National Academy of Engineering, and Program Directors of national funding agencies.

The lecture series is free of charge for students, faculty, and other participants. It is made possible through the support of the CII at Missouri S&T in collaboration with other on-campus organizations as appropriate. Details regarding the lecture series and its speakers will be forthcoming as they become available. For more information, please visit www.cii.mst.edu.

For more information, visit: www.cii.mst.edu

CII Laboratory and Office Renovation Completed at Missouri S&T

Founded on September 1, 2019, the CII is a Missouri S&T research center that crosses the boundary of academic departments and provides sustained administrative support to the operation of externally-funded centers, including the five-year INSPIRE UTC and Missouri S&T part of the Mid-America Transportation Center (MATC). Funded by the U.S. Department of Transportation, the INSPIRE UTC grant and MATC subcontract (2016-2022) are focused on the inspection, maintenance, and safety of transportation infrastructure.

The CII renovation was completed in February 2020 at Missouri S&T. The CII has an office space of approximately 200 m^2, housing about 24 students and visiting scholars with a desktop computer each. It also houses one high performance computer (Precision 7920 Tower with two Intel Xeon Gold 6148 cards) for computation-intensive simulation jobs. The CII manages the Robot Engineering and Application Laboratory (REAL), which has a floor area of approximately 45 m^2 and will support the development, application, and education of various types of robots, featuring robotic design, fabrication, testing and demonstration.

Dr. Anil Agrawal Received Torrens Award

Dr. Anil Agrawal was selected as the recipient of the 2019 Richard R. Torrens Award for outstanding performance as editor of the Journal of Bridge Engineering.

The Richard R. Torrens Award was created to honor the memory of Richard Torrens, who served the Publications Department for 17 years and was Manager of Professional and Technical Publications.

The award is made in recognition of Torrens' distinguished service and honors volunteer journal editors who have made outstanding contributions to the ASCE journals' program. Achievements in categories such as journal competitiveness, turnaround time, growth, and creativity and innovation shown by the editor are recognized among other measures of accomplishment.

Diane Murph Selected as Commencement Speaker

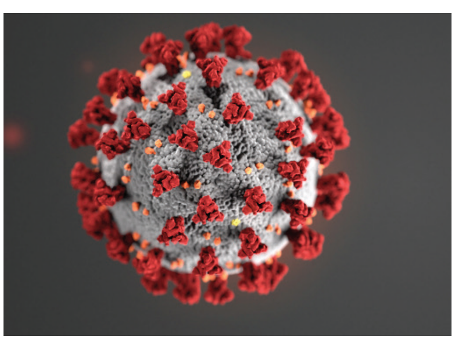
Diane Murph, graduate student of Dr. Jenny Liu, a key member of the Center of Intelligent Infrastructure at Missouri S&T, was selected as a Commencement Speaker at the December 2019 ceremony.

Diane earned her master's degree in Civil Engineering from Missouri S&T and represented graduate students at the ceremony. She was a graduate research assistant studying abrasion-resistant concrete designed for use in cold climates and membership chair for the Society of Women Engineers. She holds a Bachelor of Science degree in civil engineering from the University of Alaska Fairbanks. After graduation, she began her career as a civil engineer at the Bureau of Reclamation in Albuquerque, New Mexico.

Speakers must share their personal S&T experience and life lessons learned along the way in which they will be valuable to other endeavors in life. Speakers may self-nominate or be nominated by a faculty member or college dean. Selection is based on defined essay length and delivery time as well as a live audition.

Original Version Posted December 10, 2019-Missouri S&T News and Events

COVID-19 Impact on INSPIRE Projects



At the INSPIRE Center, the City College of New York, Georgia Institute of Technology, Missouri University of Science and Technology, the University of Nevada, Las Vegas, and the University of Nevada, Reno have been in telework mode since mid-March 2020. They closed campus and prohibited students from accessing laboratories. Project investigators re-scheduled their project tasks and used this unprecedented difficult time to complete computational modeling and simulations as well as literature search and paper preparation while holding off experimental works. Even the computational works are impacted when they require physical access to office computers and special software. In general, work efficiency of the research projects is at approximately 50% during the COVID-19 period.

LESSON LEARNED FROM THE FAILURE OF THE STEEL STRUT OF PASEO SUSPENSION BRIDGE

On January 22, 2003, the old Paseo Bridge (decommissioned in 2010) was hurriedly closed to traffic during the Wednesday afternoon rush hours when a pronounced gap (see Fig. 1) between sections of the bridge's deck sparked fears about the span's safety. At the time, temperatures were reported to have hit a record low of 9˚F below zero. During inspection the following day, the strut in the southeastern link anchorage assembly was found have fractured. Field inspectors found the lower pin in the southeastern hanger was frozen and did not allow for free movement of the superstructure. As a result, the strut was subjected to both tension/compression and bending. The damage of the strut was likely caused by one of the following reasons or their combination: overstressing, thermal contraction, fatigue, and reduction in fracture toughness at low temperatures.

The old Paseo Bridge was a self-anchored suspension bridge located in Kansas City, MO, spanning the Missouri River. The bridge supported Interstates I-29 and I-35 as well as US Highway

Fig. 1. Rise in southern span

71 with an average daily traffic volume of 89,000 vehicles in 2003. Built in 1952, the total length of the bridge was 1232 ft., consisting of two side spans measuring 308 ft. each, and a main span length of 616 ft. At each end of the bridge, two stiffening girders were independently tied down to a bridge pier with two vertical hangers or struts (see Fig. 2). Each hanger consisted of a lower and an upper link connected with bolts by a strut (S24×120). The links were connected with the stiffening girder and the bridge pier by two 11-inch diameter pins, respectively.

This article presents findings from a forensic investigation of the fractured strut (see Fig. 3) in combination with bridge characteristics and loading history to understand why the southeastern vertical strut of the bridge fractured after 50 years of service. Both standard material/fatigue tests on samples of the strut material and finite element modeling of the suspension bridge and strut under service loading conditions were conducted.

Fig. 2. Point of strut failure

Fig. 3. Fracture pattern of southeastern strut web

First, the residual crack initiation life of a perfect steel (A36) strut was evaluated using the strain-life method. The fatigue strength coefficient and exponent are 70.71 ksi and -0.066, respectively. The fatigue ductility coefficient and exponent are 0.0077 and -0.28, respectively. Fatigue tests on the fractured strut material (25 specimens) indicated an infinite life under normal service conditions when the strut were free to rotate, had no initial defects or small cracks inherent to steel structures.

Then, the critical flaw size at the design stress was determined as a function of the operating temperature using a fracture mechanics criterion. Charpy impact testing was conducted at nine temperatures since the thickness of specimens would be prohibitively large for direct fracture toughness testing. Based on testing of 45 specimens at temperatures ranging from -10º to 136ºF, the breaking energy of various specimens was related to the temperatures to which the specimens are exposed. The breaking energy was converted to the fracture toughness, which ranges from 24 to 110 ksi*in1/2.

Next, the life to fracture was determined given an initial crack length and known loading conditions. Five compact tension specimens were tested to establish the Paris crack growth law with two material constants: C=7×10-10 and m=2.8. Nearly 1,000,000 cycles (approximately 12 years) of 100% design loading or over 2,500,000 cycles of 50% design loading were required for an initial defect of 0.005 in. in the strut to propagate to a critical length (over 1.3 or 2.4 in.) causing sudden fracture under normal loading conditions if the pin were free to rotate. Since no visual cracks were recorded during the inspection two months prior to the failure, crack propagation was unlikely the reason for the failure. On the other hand, sudden fracture occurred as a result of the mechanically frozen pin condition at the lower link of the southeastern strut.

Next, loading and thermal effects on the failed strut as a result of a frozen pin condition were estimated. The dead plus live load on the failed strut was 145 kips in tension only when the pin was free to rotate. With a frozen pin condition, the dead plus live load included a tension force of 145 kips and a moment of 4,250 kip-in at a design temperature of 60ºF. When the temperature dropped to -10ºF at the time of strut failure, the thermal effects associated with the frozen pin condition amounted the load on the strut to 200 kips in tension and 40,800 kip-in in bending moment. From the traffic count records, each strut was subjected to approximately 230 cycles of live loading per day.

Finally, a detailed finite element model was established and the strut failure process was simulated as shown in Fig. 4. The model allowed for accurate calculation of the stress concentration (3.76) in the area of flange coping and the stress intensity factor as a function of crack length. Simulation results indicated that the strut would never have fractured even at low temperatures and with a 0.005-in initial defect if the pin in the lower link were free to rotate. Low temperature made the strut material behave more brittle with low fracture toughness and was thus a secondary contributor to the fracture of the strut after the pin was frozen. The load transferred through the web of the strut was likely 50% of design loading as supported by the fact that the strut did not fracture under the combined dead plus live load and thermal effect at a temperature of higher than 10ºF during the bridge inspection in November of 2002. This fact also suggested that the initial defect (crack) in the coping flange area of the failed strut seemed more than 0.001 in.

To sum up, the lack of preventative maintenance is the root cause of the failure. The overstressing, thermal contraction, fatigue, and reduction in fracture toughness associated with low temperatures were all real contributory conditions, but they would not have caused the failure if the preventative maintenance was done. Specifically, the mechanical freezing of the lower link pin has been attributed to salt and sand accumulation in the lower link housing, discovered during the bridge inspection two months prior to failure. This situation was associated with the lack of accessibility to the area of the fractured strut. Therefore, maintenance needs should be taken into account during design and construction phases.

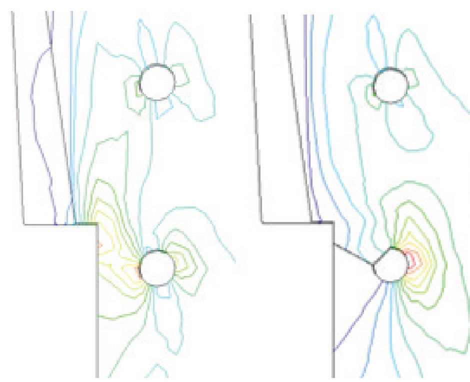


Fig. 4. Mises stress contours for crack initiation location (no initial crack) and crack propagation pattern after an initial crack

ABOUT THIS PROJECT

Led by Dr. Genda Chen, Professor and Abbett Distinguished Chair in Civil Engineering at Missouri University of Science and Technology, this study was supported by Missouri Department of Transporation. Detailed results are referred to the Technical Report MODOT RDT05-008: Failure Investigation of the Steel Strut of Paseo Suspension Bridge, July 2005 by Genda Chen, Christopher Courtright, Lokesh R. Dharani, and Bin Xu. For more information on this project, please contact Dr. Chen at inspire-utc@mst.edu or (573) 341-6114.

FOR MORE INFORMATION CONTACT:

Genda Chen
Professor and Abbett Distinguished Chair in Civil Engineering
Missouri University of Science and Technology
(573) 341-4462 | gchen@mst.edu

MARCH 2018 COLLAPSE OF THE PEDESTRIAN BRIDGE IN MIAMI, FLORIDA

A full article on the investigation of collapse of the Miami Pedestrian bridge has been published in the ASCE Journal of Bridge Engineering (Vol. 25, No. 1, January 2020) and can be accessed by the link below. ASCE has allowed free download of the article during the month of June 2020.

The collapse of the pedestrian concrete truss bridge in Miami, FL, on March 15, 2018, raised serious concerns on the safety of under-construction bridges, particularly those using accelerated bridge construction (ABC) technology. INSPIRE researchers, Dr. Agrawal and Dr. Cao, have been investigating the collapse of this bridge through computational forensic analysis in collaboration with Dr. Sherif El-Tawil of the University of Michigan. Their comprehensive research shows that the horizontal component of the re-tensioning force overcame the resistance of the northern end joint (cold-joint) and caused it to slide with respect to the deck. The evolving damage of the joint area by the dowel action prompted more sliding and led to a vicious cycle that culminated in the collapse of the entire bridge. The work provides important insights into the collapse mechanism and highlights lessons for preventing similar future collapses.
Fig. 1 shows the main span of the bridge after being transported and placed on the two piers. It was designed as a concrete truss bridge with a span length of 174 feet and weight of 950 tons. On March 15, 2018, 5 days after the relocation, it collapsed onto U.S. Route 41 (Fig. 2).

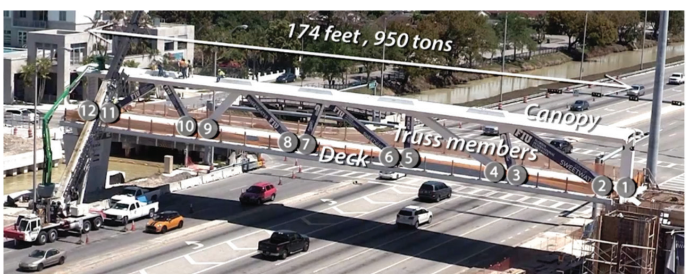


Fig. 1. Main span of the bridge before collapse

Fig. 2. Collapse scene of the pedestrian bridge

[1]https://www.osha.gov/doc/engineering/pdf/2019_r_03.pdf

According to NTSB, the collapse of the bridge was attributed to design errors in the joint at the northern end of the bridge. In particular, the demand on the nodal area was significantly underestimated and the capacity of the joint area was overestimated. The INSPIRE researchers have reviewed the as-built drawings and calculations by the designer and have identified several design flaws. For example, Fig. 3 shows the shear and compression forces calculated by the designer at the northern end joint of the bridge. Based on the geometry of the joint, the calculation of the forces acting on the joints in Fig. 3 do not seem to be correct. Hand calculations by the researchers have shown that the shear demand at the joint should be around 2,000 kips, which is approximately twice the shear force demand of 987 kips calculated by the designer. The compression force on the joint was calculated to be 1,239 kips by the researchers and is close to the design force of 1,233 kips. Per design drawings, the under-designed joint shown in Fig. 3 was a cold-joint, which means the truss members and the deck were not fully-monolithic and the joint had the tendency to slide under the diagonal compressive force. The shear demand at the joint interface was designed to be resisted by friction and shear rebars. Based on calculations, the researchers found the shear-friction and punching shear capacity of the cold-joint area were insufficient to resist the shear demand, even when considering a reliably roughened surface. In fact, the surface of the cold joints was found to be smooth and not intentionally roughened, as noted in the OSHA report on collapse investigation of the bridge[1] .

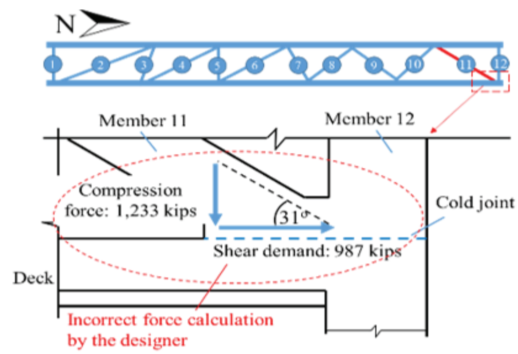


Fig. 3. Original Interface shear design of the northern end

The researchers developed a detailed finite element (FE) model of the collapsed span to investigate its failure mechanism., as shown in Fig. 4. Fig. 5 shows the simulation of development of cracks in the cold-joint area after relocation, matched the actual damage mode of the joint reasonably well. It can be seen that the joint area had already been severely damaged in the punching-shear mode before the collapse.

After observing cracks at the joint, a remediation plan of re-tensioning member 11 was being executed when the bridge collapsed.

The simulation results in Fig. 6 show that re-tensioning member 11 (m11) further aggravated the sliding situation at the cold-joint, and dowel action became fully mobilized, crushing and damaging the concrete in the joint area. The evolving damage of the joint prompted more sliding and led to a vicious cycle that culminated in the collapse of the entire bridge. Fig. 7 shows the punching-shear damage mode of the bridge diaphragm after the collapse.

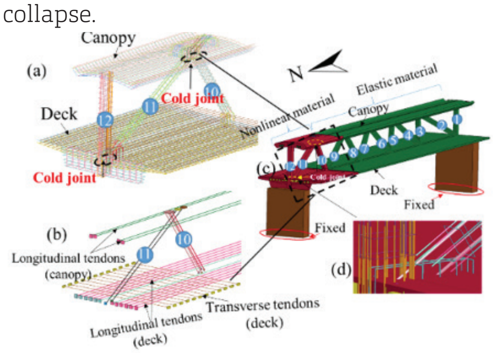


Fig. 4. Detailed Finite Element Model of the Bridge

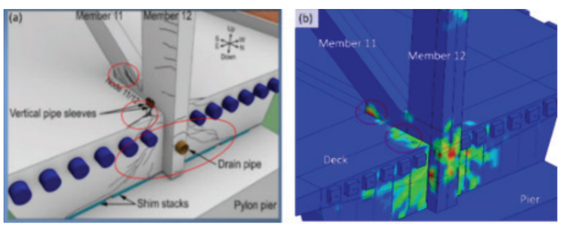


Fig. 5. Comparison of the damage mode at the northern end joint area before collapse: (a) accident, (b) simulation

The researchers further evaluated the influence of the shear capacity of the joint area by providing sufficient shear rebars to resist the actual shear demand. Fig. 8 shows the simulated damage mode of the northern end of the bridge with the original joint design, the modified one with sufficient rebars, and a third one in which there was no cold joint, although shear rebars were the same as designed. It is noted from Fig. 8 that the modified design significantly decreased sliding-induced damage at the heel of member 11. The concrete deck also suffered less damage, although there was still tendency of cracking associated with the punching failure mode (Fig. 8b). The monolithic joint (Fig. 8c) had the best performance in terms of localized cracking, although that also showed evidence of punch-related cracking atthe northern edge of the joint. These results indicate that, while providing sufficient shear connectors at the construction joint may have been effective in preventing sliding (and hence collapse), the joint zone was still vulnerable to localized cracking (due to small member sizes in the joint area).

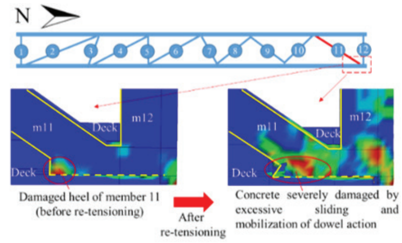


Fig. 6. Damage of the cold joint due to re-tensioning on member 11

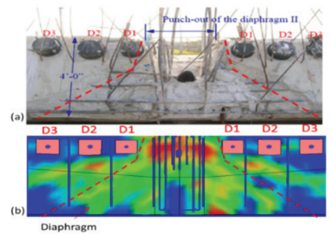


Fig. 7. Comparison of the punch-shear damage mode of the diaphragm after collapse: (a) accident (source: OSHA); (b) simulation

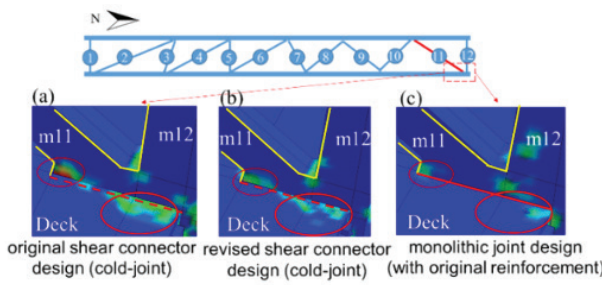


Fig. 8. Damage mode of the northern end of the bridge with different shear design

Results of the research show that the reliance of the designer on the shear friction to meet horizontal shear demand in the cold joint could be the primary cause of the collapse. Shear keys or some other explicit shear resisting mechanism in the cold joint could have met this demand more reliably. Cracks in the cold joint area should be viewed as a sign of certain and severe distress. The collapse doesn't necessarily imply that accelerated bridge construction (ABC) is risky, but certainly shows the need for comprehensive analysis simulating construction aspects such as the presence of cold joints or utility conduits. However, the most significant lesson is the risk of collapse associated with the nonredundant design and the use of concrete truss, which carries very high risk of cracking.

FOR MORE INFORMATION CONTACT:

Anil Agrawal
Herbert G. Kayser Professor in Civil Engineering
The City College of New York
(212) 650-8442 | agrawal@ccny.cuny.edu

FAILURE INVESTIGATION OF THE CARDINAL RAUL SILVA HENRIQUEZ STEEL-GIRDER BRIDGE DURING THE 2010 CHILE EARTHQUAKE

This article presents findings from a case study of the Cardinal Raúl Silva Henŕiquez Bridge that experienced significant damage during the February 27, 2010, M8.8 Chile Earthquake. The aim of this study is to investigate the failure mechanism of girders and end bearings at two abutments of the bridge. Both global and local three-dimensional finite element models were developed to simulate the bridge responses and the process of damage. It was found that the bridge damage was mainly caused by the excessive longitudinal seismic load of 11 continuous steel-girder spans and its eccentricity from the girder-to-abutment connection, resulting in a significant bending effect.

Built in 2002, the Cardenal Raúl Silva Henŕiquez Bridge is a 22-span, steel-girder structure crossing the Maule River near Constitución in the NE-SW direction (see Fig. 1). Each span length is 41.5 m. The bridge superstructure is comprised of two continuous 11-span-long segments with three expansion joints at the two ends and in the middle of the bridge. It is supported by two seat-type end abutments, and 21 intermediate bents through elastomeric pads to allow for longitudinal movement. At each abutment, the bottom flanges of three girders were welded to their bearing masonry plates that were embedded and anchored into the reinforced concrete (RC) abutment.

At the SW abutment, the fillet welds from the girder bottom flanges to the masonry plates fractured and the transverse stiffeners buckled as seen in Fig. 2. Supported on tall steel columns, the SW portion of the bridge overall performed well. At the NE abutment, the webs and bottom flanges of all three girders fractured, and both bearing stiffener and web buckled as depicted in Fig. 3. The cause of this type of damage is indicative of excessive longitudinal loads in the superstructure that were resisted by the weld bearing connection at the abutment. Supported on short RC columns, the NE portion of the bridge superstructure experienced significant transverse movement, resulting in significant deformation in the lateral steel stoppers and girder displacement from their supporting elastomeric pads as shown in Fig. 4.

Fig. 1. Partial view of the bridge structure

Fig. 2. Fillet weld fracture of the girder-to-masonry plate connection at the SW abutment

Fig. 3. Girder fracture at the NE abutment

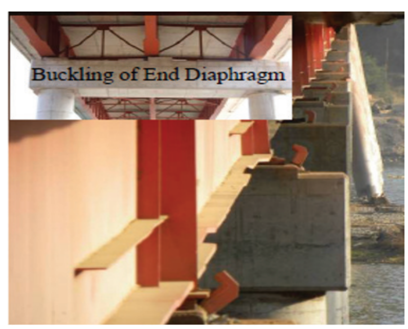


Fig. 4. Girder offset and cross frame buckling

The maximum axial force obtained at the end of girders from the global bridge model was divided into two components based on the weight ratio between the bridge deck and steel girders. Each component was uniformly distributed and applied on its respective deck or girder cross section.

To better understand the stress concentration around the fracture location of girders, the area of crack initiation, and the process of failure, a small portion of girder (including bearing stiffeners) was locally modeled with plate and solid elements for the steel girder and RC deck, respectively. Considering a 0.7 m fillet weld on the bottom flange of each girder at abutment or a 0.7 m bearing seat length, the local model was selected to be 1.7 m long (see Fig. 5). The portion of the bottom flange of the girder, welded on the masonry plate at abutments, was fixed in the fracture analysis of girders. The flange width and thickness of the girder are 0.28 m and 12 mm, respectively. The web and stiffener thicknesses are 12 mm and 20 mm, respectively.
To understand the crack initiation and damage process, three load cases were considered for elastic-plastic analysis: 130, 300 and 700 kN. Each load was applied at the centroid of the cross sectional area in the longitudinal direction. Representative von Mises stress distributions are presented in Fig. 6. At 130 kN, damage likely initiated at the bottom flange of the girder since the maximum stress at the end of the masonry plate was close to the yield strength (345 MPa) of the steel due to stress concentration. At 300 kN, the maximum stress occurred in the girder web at the location of observed damage. At 700 kN, a significant portion of the girder web was subjected to stress at the ultimate strength level or the girder experienced a web fracture as observed after the Chile earthquake. The load level corresponded to about 8% of the maximum axial load obtained from the response spectrum analysis. The web fracture was caused by the excessive longitudinal load, which was approximately 12 times the actual capacity of the steel girder bearing system.

In closure, this study demonstrated a few examples of classical failure modes (transverse stiffener buckling, girder web and flange buckling, girder web fracture, and girder-to-abutment weld fracture) that occurred in the real-world steel-girder bridge. The excessive longitudinal seismic force in the 11-span continuous bridge superstructure caused the weld fracture between the girder and steel masonry plate at the SW abutment, and the girder web fracture at the NE abutment as the attracted seismic force was transferred from the bridge girder to its supporting abutment in eccentricity. These examples would shed light on the type, severity, location, and causes of potential damage in future steel-girder bridges.

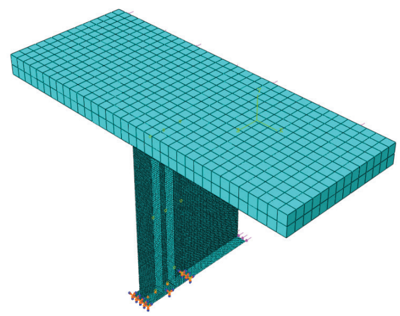


Fig. 5. Finite element model for fracture analysis

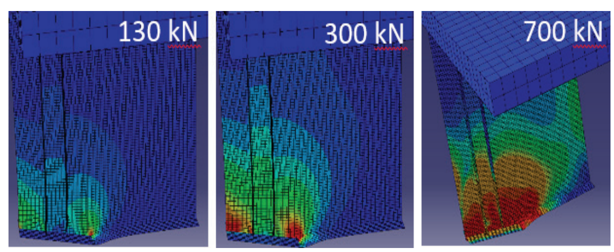


Fig. 6. Stress distributions under various axial loads

ABOUT THIS PROJECT

Led by Dr. Genda Chen, Professor and Abbett Distinguished Chair in Civil Engineering at Missouri University of Science and Technology, this study was supported by Federal Highway Administration (FHWA). Detailed results are referred to the Technical Report Publication No. FHWA-HRT-11-030: Post-earthquake Reconnaissance Report on Transportation Infrastructure Impact of the February 27, 2010, Offshore Maule Earthquake in Chile, March 2011 by Wen-Huei Phillip Yen, Genda Chen, Ian Buckle, Tony Allen, Daniel Alzamora, Jeffrey Ger, and Juan G. Arias. For more information on this project, please contact Dr. Chen at inspire-utc@mst.edu or (573) 341-6114.

FOR MORE INFORMATION CONTACT:

Genda Chen
Professor and Abbett Distinguished Chair in Civil Engineering
Missouri University of Science and Technology
(573) 341-4462 | gchen@mst.edu

TECHNOLOGY TRANSFER

EDUCATIONAL MODULE SERIES

SIGNAL PROCESSING AND SOUNDING DATA ANALYSIS FOR DETECTING CONCRETE DELIMINATION

BY PROFESSOR ANIL AGRAWAL, CITY COLLEGE OF NEW YORK

In this 50-minute lecture, the fundamental concepts such as digital sounding signal collection, filtering, and time-frequency analysis are introduced. The current practice of impact sounding techniques for delamination detection is explained, and the limitation and difficulty of the current practice are also presented. To make the impact sounding process more mechanical, several recent research activities are briefly mentioned. Based on an experiment on a concrete slab, the general process of collecting impact sounding data is presented in detail, including the use of hammer, microphone, and acoustic shield. Simple programming software is used to visualize the sounding wave collected from the concrete slab. An adaptive filtering method is introduced to filter out unwanted noise through data decomposition. The concept of Fourier transform is introduced and explained how it can transform the sounding signal from the time domain to frequency domain. A simple MATLAB program is written to perform power spectral density analysis based on the Fourier transform. The program is also used to extract the frequency-domain features of the impact sounding data. Based on the data analysis, the main features of sounding data collected from solid and damaged areas of the slab will be discussed. A damage index is defined based on the frequency-domain features obtained from power spectral density curves. For fast decision-making, a damage contour of the slab is generated using the calculated damage index from the impact sounding data.

MAGNETIC FIELD, MEASUREMENT, AND APPLICATION IN BRIDGE SCOUR MONITORING

BY PROFESSOR GENDA CHEN, MISSOURI S&T

In this 50-minute lecture, the fundamental concepts such as magnet, polarization, and magnetic field are introduced. The measurement principle and tool (magnetometer) of magnetic fields is developed. At a bridge site, sources of magnetic fields are simulated and the measured magnetic fields are used to identify their sources using a localization algorithm.

The theory and measurement principle of magnetic fields are applied into the design of 'smart' rocks with one or more magnets embedded in each concrete encasement for the monitoring of bridge scour, which is the main reason for the collapses of over 1,500 bridges in the U.S. Field tests and simulations are conducted to understand the change in magnetic fields as a smart rock moves to the bottom of the scour hole over time, and validate the localization algorithm of 'smart' rocks used in bridge scour mitigation.

INTRODUCTION TO LIGHT DETECTION AND RANGING

BY PROFESSOR PAUL OH, UNIVERSITY OF NEVADA, LAS VEGAS

In recent years, depth sensors have become consumer-level products. The Microsoft Kinect is an example for video gaming. For higher resolutions, day-night operations, and robustness despite obscurants (like fog or smoke), light detection and ranging is used. Called LIDAR, these have been around more than three decades. However the growth of robotics, advances in low-cost precision optics, and driveless car interests have all helped to accelerate LIDAR adoption.

This educational module will present the underlying theory of operation for LIDAR. This includes: one, two and three dimensional rangefinding; data visualization; and a lab to construct one's own LIDAR sensor with a laser pointer and USB webcam will also be presented to reinforce the theory.

WIRELESS PATCH ANTENNA SENSORS FOR STRAIN AND CRACK MONITORING

BY PROFESSOR YANG WANG, GEORGIA INSTITUTE OF TECHNOLOGY

This lecture introduces wireless patch antenna sensors developed for structural strain and crack monitoring. Toward the safety monitoring of civil structures, strain and crack propagation are among the most common indicators of excessive stress undergone by a structural component. The wireless sensors developed from this project can provide an alternative means of monitoring these critical indicators which is more convenient than conventional cabled approaches.

The lecture starts with the fundamental physics underlying the development of wireless patch antenna sensors for strain and crack monitoring. We review the concepts of antenna electromagnetic resonance and wireless interrogation through radio frequency identification (RFID). Based upon the underlying physics, two antenna sensor designs are introduced, including one passive and one dual-mode (passive + active) design. Multi-physics simulation results of the sensor behaviors are presented; prior to sensor fabrication, the simulation facilitates the fine-tuning of design parameters such as antenna dimensions. The lecture also presents experimental measurements performed by the designed antenna sensors upon fabrication. Both compression, tension, and crack test results are presented for the antenna sensors.

RECENT DEVELOPMENT OF THE SEVEN-STATE POOLED-FUND STUDY NO. TPF-5 (395):

TRAFFIC DISRUPTION-FREE BRIDGE INSPECTION INITIATIVE WITH ROBOTIC SYSTEMS

Progress in the above pooled-fund study has been made to select approximately 72 highway bridges and a few long-span bridges for field validation of the advanced technologies developed at the INSPIRE Center. Plan is underway to test steel-girder bridges in the state of New York, Virginia and Wisconsin, and prestressed concrete girder bridges in the state of Georgia, Texas, and California. In Missouri, both groups of girder bridges as well as long-span bridges are under consideration.

To support the pooled-fund study, Bridge Inspection Robot Deployment Systems (BIRDS) as part of the INSPIRE Center Initiative will be developed for the field inspection tasks of bridges. The BIRDS will be equipped with a number of remote sensing and non-destructive evaluation capabilities, such as high definition cameras, infrared cameras, hyperspectral cameras, light detection and ranging, giant magnetoresistance sensor array, magnetic field interference, ultrasonic transducer, ground penetrating radar, impact echo, impact sounding, and underwater acoustic imaging. The BIRDS may also support the field tasks for sensor installation and local bridge maintenance. In addition, the finite element model of a hybrid unmanned aerial and traversing vehicle as one of the BIRDS was established to optimize its structural design and understand its aerodynamic stability as the vehicle approached the bottom flange of a bridge girder. This understanding can help develop an effective and practical navigation strategy of the BIRDS in application, providing foundation for workforce training in vehicle operation.

INSPIRE UTC YEAR 4 FUNDED RESEARCH PROJECTS

The INSPIRE UTC is committed to addressing the research needs and projected research progress outlined in the original center proposal. Project proposals were reviewed and evaluated per the following criteria. Each reviewer assigned a total score on a scale of 0% (poor) to 100% (excellent). Total scores will be based on 50% technology advances, 35% innovative solutions, and 15% relevance to the goal of the center. The technology advances pertain to the understanding of the state of the art, technical soundness and feasibility of the proposed approach, capability to achieve the proposed outcomes within the proposed time frame, and expertise of the project team as applicable to the project. The innovative solutions pertain to importance of the problem addressed, practicality of the proposed solution, and advantages of the proposed solution over existing technologies. The goal of the INSPIRE UTC is to develop data-drive tools for decision making and robotics training tools for the next generation transportation workforce so that bridge inspection and maintenance can be done faster, cheaper and safer.

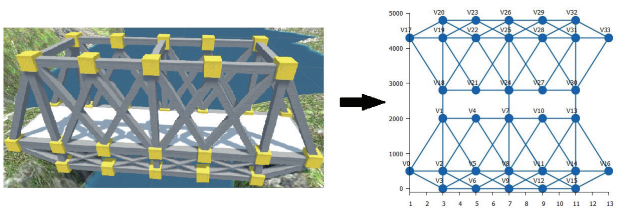
Reviews were submitted to the INSPIRE UTC Program/Project Coordinator and funding recommendations were made during an executive meeting with INSPIRE UTC Directors and External Advisory Committee Members in January 2020. Following completion of this review process, the INSPIRE UTC Director issued final approval of the following research projects for Year 4:

INSPIRE UTC - Year 4 Projects

Project	Principal Investigator	Co-Principal Investigators
Bridge Inspection Robot Deployment Systems (BIRDS)	**Dr. G. Chen,** Missouri S&T	**Dr. H. La,** University of Nevada-Reno, **Dr. Y. Wang,** Georgia Institute of Technology
An Interactive System for Training and Assisting Bridge Inspectors in the Inspection Video Data Analytics	**Dr. R. Qin,** Missouri S&T	**Dr. G. Chen** and **Dr. S. Long,** Missouri S&T
A Field Deployable Wall-Climbing Robot for Bridge Inspection Using Vision and Impact Sounding Techniques	**Dr. J. Xiao,** The City College of New York	**Dr. A. Agrawal,** The City College of New York
Autonomous Ultrasonic Thickness Measurement by a Magnet-Wheeled Robot	**Dr. Y. Wang,** Georgia Institute of Technology	**Dr. H. La,** University of Nevada, Reno
Health Inspection of Concrete Pavement and Bridge Members Exposed to Freeze-Thaw Service Environments	**Dr. H. Ma,** Missouri S&T	**Dr. G. Chen,** Missouri S&T
Data-Driven risk-Informed Bridge Asset Management and Prioritization across Transportation Networks	**Dr. I. Tien,** Georgia Institute of Technology	**Dr. G. Chen,** Missouri S&T
Nondestructive Data Driven Motion Planning for Inspection Robots	**Dr. H. La,** University of Nevada, Reno	**Dr. G. Chen,** Missouri S&T
Simulation Training to Work with Bridge Inspection Robots	**Dr. S. Louis,** University of Nevada, Reno	**Dr. H. La,** University of Nevada, Reno and **Dr. R. Qin,** Missouri S&T
Probability of Detection in Corrosion Monitoring with Fe-C Coated LPFG Sensors	**Dr. G. Chen,** Missouri S&T	**Dr. A. Agrawal,** The City College of New York
Augmenting Bridge Inspection with Augmented Reality and Haptics-Based Aerial Manipulation	**Dr. P. Oh,** University of Nevada, Las Vegas	**Dr. G. Chen,** Missouri S&T, and **Dr. H. La,** University of Nevada, Reno
Robot-Assisted Underwater Acoustic Imaging for Bridge Scour Evaluation	**Dr. G. Chen,** Missouri S&T	**Dr. H. La,** University of Nevada-Reno, and **Dr. J. Xiao,** The City College of New York
"Smart Sounding System" for Autonomous Evaluation of Concrete and Metallic Structures	**Dr. A. Agrawal,** The City College of New York	**Dr. J. Xiao,** The City College of New York

INSPIRE WEBINARS

RECENT WEBINARS



SIMULATION TRAINING AND ROUTE OPTIMIZATION FOR BRIDGE INSPECTION

Presented: December 4, 2019
Speaker: **Dr. Sushil Louis**
Professor of Computer Science and Engineering
University of Nevada, Reno

Veletzos et al., 2006

DATA TO RISK-INFORMED DECISIONS THROUGH BRIDGE MODEL UPDATING

Presented: September 25, 2019
Speaker: **Dr. Iris Tien**
Assistant Professor, School of Civil and Environmental Engineering
Georgia Institute of Technology

MOBILE MANIPULATING DRONES

Presented: June 17, 2020, 11:00 am (Central)
Speaker: **Dr. Paul Oh**
Lincy Professor of Mechanical Engineering
University of Nevada, Las Vegas (UNLV)
Register: **inspire-utc.mst.edu/webinars**

In the past few years, robotic limbs have been attached to rotorcraft drones to perform aerial manipulation. Unlike simple object pick-and-place, such mobile-manipulating drones are dexterous to perform tasks like valve-turning, hatch-opening, and tool-handling. This is a paradigm shift where such drones relatively interact with their environment rather than just passively surveil. Aerial manipulation is challenging because such interaction yields reaction forces and torques that destabilize the drone. This talk will provide an overview of aerial manipulation and showcase examples that could serve in infrastructure inspection, maintenance, and repair.

SPEAKER

Dr. Paul Oh is the Lincy Professor of Unmanned Aerial Systems in the Mechanical Engineering Department for the Howard R. Hughes College of Engineering. He is establishing an unmanned autonomous systems laboratory at UNLV, complete with a fleet of drones and several humanoid robots.

From 2000 to 2014, he served as the Mechanical Engineering Professor at Drexel University in Philadelphia and founded and directed the Drones and Autonomous Systems Laboratory (DASL).

Dr. Oh is the former director for robotics at the National Science Foundation where he managed a portfolio that supported almost all academic non-military robotics research in American universities. He has been a fellow of Boeing, and worked with the Office of Naval Research and NASA Caltech/ Jet Propulsion Lab.

RECENT KEYNOTE/INVITED PRESENTATIONS

- **"Investigation on Collapse of the Miami Pedestrian Bridge,"** Resilience, Safety, and Security of Bridges and Tunnels: U.S. and International Topics Workshop at the 99th Transportation Research Board Annual Meeting, Washington, DC, January 2020 (Anil Agrawal)
- **"Empowering and Rejuvenating Civil Engineering with Informatics, Automation and Actuation,"** 10th International Association of Chinese Infrastructure Professionals Annual Workshop at the 99th Transportation Research Board Annual Meeting, Washington, DC, January 2020 (Chen Chen)
- **"Robot-assisted Bridge Inspection and Maintenance,"** the 5th International Conference on Robotics and Artificial Intelligence, Singapore, November 2019 (Genda Chen)
- **"The Role of Infrastructure Systems in Community Resilience,"** National Academies Arab-American Frontiers of Science, Engineering, and Medicine Symposium in partnership with the Library of Alexandria and the Academy of Scientific Research and Technology, Cairo Egypt, November 2019 (Iris Tien)

WEBINAR ARCHIVES

2020

Non-Contact Air-Coupled Sensing for Rapid Evaluation of Bridge Decks
By Dr. Jinying Zhu, University of Nebraska, Lincoln, March 12, 2020

2019

Data to Risk-Informed Decisions Through Bridge Model Updating
By Dr. Iris Tien, Georgia Institute of Technology, September 25, 2019

A Performance-Based Approach for Loading Definition of Heavy Vehicle Impact Events
By Dr. Anil Agrawal, The City College of New York, June 5, 2019

Battery-Free Wireless Strain Measurement Using an Antenna Sensor
By Dr. Yang Wang, Georgia Institute of Technology, March 6, 2019

Assistive Intelligence (AI): Intelligent Data Analytics Algorithms to Assist Human Experts
By Dr. Zhaozheng Yin, Missouri S&T, January 30, 2019

2018

Toward Autonomous Wall-Climbing Robots for Inspection of Concrete Bridges and Tunnels
By Dr. Jizhong Xiao, The City College of New York, September 19, 2018

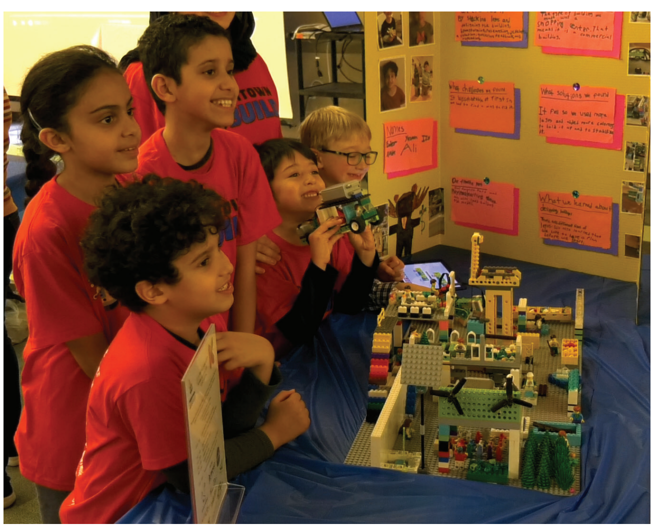
Climbing Robots for Steel Bridge Inspection and Evaluation
By Dr. Hung La, University of Nevada, Reno, June 21, 2018

Microwave Materials Characterization and Imaging for Structural Health Monitoring
By Dr. Reza Zoughi, Missouri S&T, March 15, 2018

VIEW COMPLETE LIST OF WEBINARS
scholarsmine.mst.edu/inspire_webinars

INSPIRE Supports 2020 FIRST LEGO Junior League at Kaleidoscope Discovery Center

In March 2020, the INSPIRE UTC provided support for the FIRST LEGO League (FLL) Junior Expo hosted by the Kaleidoscope Discovery Center (KDC) on the Missouri S&T campus in Rolla, MO. FLL Junior introduces robotics to students in grades K-4. The FLL Junior season culminates with an Expo where teams show off what they learn and create. The theme of the 2020 FLL Junior Expo was "BOOMTOWN BUILD", where participating students worked together to explore the growing needs and challenges of the people in our community. Teams created a building that solve a problem and makes life easier, happier, and more. The support provided by the INSPIRE UTC enabled the KDC to provide certificates to reward every student who competed the required task, and will help encourage even more students to take part in FLL Junior in the coming years.



For more information, visit: thekaleidoscope.org/first-robotics

Team Tangy Taki Town Wins INSPIRE Award at the Missouri State Future City Competition

The third annual Missouri Future City Competition, sponsored by Missouri American Water, was held January 25, 2020, on the Missouri S&T campus. The INSPIRE UTC provided support for the event that brought 6th-8th grade students from across the state to participate in the international Future City competition. Future City starts with a question—how can we make the world a better place? To answer it, students imagine, research, design, and build cities of the future that showcase their solution to a citywide sustainability issue. Past topics included stormwater management, urban agriculture, public spaces, and green energy. The 2019-2020 theme was Clean Water: Tap Into Tomorrow! Teams designed water-resilient cities that would address a wide range of risks including drought, flooding, population change, natural and man-made disasters, and economic recession.

This year Ph.D. student Xinzhe Yuan of the INSPIRE UTC research team, served as a judge for the event and gave a specialty award on behalf of the INSPIRE UTC. The INSPIRE award is granted to the team whose project design best incorporates structural functionality and feasibility, robustness, and resilience. Special consideration is given to teams who consider the concept of robotic exploration of the city's infrastructure. Team Tangy Taki Town from Rolla, MO was the recipient of this year's INSPIRE award. Each winner received an INSPIRE UTC award plaque and a $150 monetary award.

Missouri S&T Faculty and Students INSPIRE High School Students at NSBE Pre-College Initiative

Faculty and students from the INSPIRE University Transportation Center and Mid-America Transportation Center led a workshop for 17 Missouri high school students at the National Society of Black Engineers (NSBE) Pre-College Initiative (PCI) held February 29, 2020 at Missouri S&T.

The workshop was presented by Dr. Ruwen Qin, Associate Professor of Engineering Management and Systems Engineering, Ph.D. students Yu Li, Systems Engineering, Pengfei Ma, Civil Engineering and Xinzhe Yuan, Civil Engineering. Participants were engaged in a hands-on bridge engineering competition, and visited the Driving Simulation Laboratory for a demonstration of driver's behavior-related transportation research.

PCI is an on-campus visit program for African-American students who may be considering a future career in math, science, computing or engineering. PCI is sponsored by S&T's student chapter of the National Society of Black Engineers and the Student Diversity Initiatives department.

NSBE PCI Participants visited the Driving Simulation Laboratory led by Dr. Ruwen Qin.

For more information, visit: sdi.mst.edu

INSPIRE University Transportation Center
Missouri University of Science and Technology
112 Engineering Research Laboratory, 500 W. 16th St.
Rolla, MO 65409

Connect with INSPIRE UTC:

- **FACEBOOK: BIT.LY/2OXESW4**
- **TWITTER: BIT.LY/33jZW3r**

Contact Us

Phone: 573-341-6114 | Email: inspire-utc@mst.edu | Web: inspire-utc.mst.edu
Visit our website to follow us on social media

UPCOMING EVENTS

June 9-10, 2020
CUTC Summer Meeting
www.sptc.org/cutc

June 17, 2020
INSPIRE Webinar: "Mobile Manipulating Drones", by Dr. Paul Oh, University of Nevada, Las Vegas
inspire-utc.mst.edu/webinars

August 2020
INSPIRE UTC Annual Meeting (tentative)
inspire-utc.mst.edu/annualmeeting/

August 18-20, 2020
NDE/NDT Structural Materials Technology for Highways & Bridges, Sacramento, CA
https://asnt.org/MajorSiteSections/Events/Upcoming_Events/SMT_2020.aspx

September 15-16, 2020
1st International Conference on Unmanned Aerial Vehicles, Remote Control Vehicles for Onshore, Offshore and Subsea Asset and System Integrity, London, UK
https://www.asranet.co.uk/Conferences/DRONE

inspire-utc.mst.edu/events