TriDurLE

National Center for Transportation Infrastructure Durability & Life-Extension

USDOT National University Transportation Center
Progress Performance Report #4

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1. ACCOMPLISHMENTS

1.1 What are the major goals and objectives of the program?

TriDurLE's strategic priority is to improve the durability and extend the life of transportation infrastructure with cost-effective innovations and holistic solutions to enhance multimodal infrastructure durability. The center is conducting multidisciplinary and multimodal research, education and workforce development, and technology transfer to directly support the USDOT's strategic goal of infrastructure durability and life extension while providing secondary benefits for other relevant strategic goals such as safety, mobility, environmental sustainability, and building a diverse transportation workforce.

The National UTC TriDurLE is concerned with the following strategic goals:

- Facilitating innovations in data modeling/management, analytical tools, and decision-making related to infrastructure durability and life-extension.
- Enhancing understanding of transportation infrastructure performance and asset management via condition monitoring and remote sensing.
- Extending the service life of transportation infrastructure and addressing durability issues through new materials and technologies and best practices.
- Leading the way in education, workforce development, capacity building, and technology transfer.

1.2 What was accomplished under these goals?

Research

TriDurLE is funding 51 research projects for years one (26 projects) and two (25 projects) combined. Most year one projects were granted a no-cost time extension because of delays due to the COVID-19 Pandemic. One university completed and submitted its final report. The following are reports from individual universities.

The research teams at the University of Colorado Denver (UCD) have a wide variety of project scopes ranging from transportation problems to structural problems, including computer-aided analysis. Three projects were funded to accomplish the research objectives. All PIs has been working hard and active publication activities are underway to translate research into practice. Researcher Wesley Marshall of UCD submitted the final report for his project titled "Evaluating Sidewalk Infrastructure & Prioritizing Investment" for this reporting period and also published two journal papers, one conference paper, and presented at two academic conferences.

The two research goals of University of Utah were: 1) performance of bridge columns constructed using accelerated bridge construction methods and the development of cost-effective retrofits when the columns are subjected to corrosion and seismic loading; and 2) the development of holistic methodologies for improving asphalt mix durability. Researchers completed analysis of the seismic performance of corroded columns and will be presenting the results at the TriDurLE Symposium. They have also begun construction of four columns with accelerated bridge construction methods and will soon be initiating accelerated corrosion for three of these columns. Also, testing was started to support the methodologies that are being proposed. A new MSc student started to work on the project January 2021. The results of the research are being processed and a presentation is also being prepared for the TRB conference. For goal two, UU has completed the first task of creating a comprehensive literature review and is in the process of summarizing it.

South Dakota State University developed an AI-based computer vision software that can perform preliminary and detailed serviceability assessments of RC bridge columns after earthquakes. A website was developed to

demonstrate the implementation of the post-event inspection/assessment tools. The most comprehensive experimental database of RC bridge columns was developed and is publicly available. The year-one project is almost complete, and a 30% progress was reported for two other projects from year-2 funding.

Alabama A&M developed a model to assess the properties of inundated collapsible soils that has been integrated into a general interactive soil-pile model. The inductive soil-pile model has the capabilities to evaluate the downdrag forces acting on the pile due to soil inundation. A computer code (software package) with a friendly graphics-user interface has been developed to implement the previously established soil-pile model. As a result, the user can determine and visualize the distribution of the axial force along the pile length including downdrag force (negative shin friction) along with the pile and the accompanying pile settlement.

Following the collection of ultrasonic data from a set of corroding samples, Florida Atlantic University completed an initial analysis to verify that the proposed model provided a reasonable match to the measurements. In the meantime, a graduate student was hired to continue with the data collection and simulation. With the help of a graduate student, researcher Beaujean is currently developing an optimization code to match simulated and measured data by adjusting the simulated physical properties of the reinforced concrete samples.

Washington State University researcher Haifang Wen reported that their investigators have designed a new butterfly double-wedge test specimen that could effectively be used in both strength tests and fracture tests. They have numerically analyzed the butterfly specimen's wedge angle (25-75 degrees) using commercial finite element software, ABAQUS, for tension, shear, fracture mode I, and fracture mode II loads. They have also designed a single test fixture to perform the said tests. This fixture is currently in the manufacturing stage and the team has conducted an online survey to identify the best practices in shotcrete, which was distributed among state DOTs and industry practitioners. Based on the literature review and the shotcrete survey, the investigators have decided to use direct shear and pull-off tests to compare the results of the butterfly test specimens. The investigators are currently retrieving 4" cylinders from shotcrete panels that have previously been cast for these tests.

Ji Yun Lee’s team at Washington State University has identified key variables in the corrosion process via correlation analysis. A database of time-dependent probabilistic capacity for deteriorating bridge columns has been created through section moment-curvature analyses using the fiber section modeling technique in OpenSees. Moment and curvature values at multiple limit states of sections including concrete cover cracking, rebar yielding, concrete cover spalling, concrete core crushing, and rebar snapping or buckling have been identified as output variables in the created database, together with environment, geometrical, and material variables as input variables. Based on the created database, various ML approaches such as multi-layer neural network, random forests, and gradient boosting trees have been optimized through multi-fold cross validation method to develop ML prediction models for time-dependent multi-state capacity models for the sake of fragility modeling. Possible sources of uncertainties in transportation network resilience assessment have been identified and quantitatively modeled. They include the parameters in the corrosion process; earthquake location, frequency, and intensity; traffic volumes; and the percentage of connected and autonomous vehicles in a mixed traffic environment. The reliabilities of information obtained from a set of monitoring and inspection techniques have been quantified and used to update the probability density function of each random variable at every discrete time step.

Xianming Shi’s team at Washington State University has made significant progress in the following TriDurLE projects: (Year one): Impacts of Magnesium Chloride Deicer on the Durability of Nanosilica-Modified HVA Concrete; Developing Enhanced Performance Curves of ITD Asphalt Pavements by Mining the Historical Data; Design of Long-Lasting Discrete Sacrificial Anode for Corrosion Mitigation of Reinforcement in Chloride Contaminated Concrete. (Year two): Design of Fly Ash-based Geopolymer Concrete-filled FRP Tube Composite for Highly Durable and Environmentally Friendly Infrastructure. Other projects have experienced significant

delays due to COVID-19 pandemic induced challenges in personnel and supply availability.)ne new Ph.D. student and one new postdoctoral researcher were hired during August 2021 to speed up the project progress.

Leadership

TriDurLE is organizing its first annual Symposium to take place virtually December 6-7, 2021. Currently there are 48 speakers and 4 keynote speakers as well as a student poster competition. Two industry sponsors will be funding speaker and poster cash awards.

At Washington State University (WSU), Dr. Xianming Shi won the following awards:

- 2021 Environmental Leadership Award (research category), Salt Symposium award committee.
- ASCE Publishing's Editor's Choice Paper, 2020

The following are some of Dr. Xianming Shi's other leadership experience during the reporting time period

- Director, Washington Transportation Research Center (TRAC), September 2021 – Present
- Interim Chair, Department of Civil & Environmental Engineering, Washington State University, August 2021 – Present
- Editor-in-Chief, *Journal of Infrastructure Preservation and Resilience,* by Springer-Nature, Jan. 2019 – Present
- Associate Editor, *Journal of Nondestructive Evaluation*, 2020-Present
- Editorial Board Member, *International Journal of Structural Integrity*, 2021-2024
- Editorial Board Member, *International Journal of Transportation Science and Technology*,2018-Present
- Organizing committee, 5th *International Conference on Transportation Infrastructure and* Materials, Oct. 21-22, 2021, Changsha, China.

Dr. Jenny Liu of Missouri University of Science & Technology

- was appointed as Associate Editor of ASCE Journal of Cold Regions Engineering
- was appointed Committee Communication Coordinator of TRB Committee on Pavement Preservation.
- served on the Scientific Committee, 5th International Conference on Transportation Infrastructure and Materials, Oct 21-22, 2021 (hybrid).
- Session Chair, 2021 Regional Conference on Permafrost and 19th International Conference on Cold Region Engineering, October 24–29, 2021(virtual).

Jenny Liu, Xiong Zhang, and Xianbiao Hu served as Session Chairs for Transportation Research Congress, November 5-7, 2021 Hangzhou, China (hybrid)

Xiong Zhang was a panelist at the TRB webinar on "Ensuring Construction Quality Assurance with Light-Weight Deflectometers" September 30, 2021.

Education and Workforce Development

Washington State University trained two postdoctoral research associates, six Ph.D. students, one M.S. student, and one undergraduate student. Some of the research associates and students have published journal articles and conducted presentations in collaboration with the project PI, as detailed in the later section. One research team has submitted a full-length international conference paper (ICOSSAR 2021-22).

Jun Liu, PhD student at Missouri S&T, received the 2020-2021 CEC Dean's PhD Scholar Award in recognition of his scholarly productivity.

South Dakota State University partially or fully supported three students under the UTC funding in the current reporting period.

University of Utah hired a new PhD student to work on the project since January 2021 and an undergraduate student began working on the project September 2021.

Florida Atlantic University's research on crack propagation detection using ultrasonics was presented during a seminar to external visitors in September 2021.Florida Atlantic University also presented a webinar to 15 graduate students (Graduate seminar Fall/2021 EML 5937 OME department, September 19, 2021), presenting the results of the on-going monitoring that provides evidence of corrosion of the rebar after initiation. Also, certain aspects of sound propagations in solids were covered in an undergraduate course (Underwater Acoustics) and its graduate counterpart (Ocean and Seabed Acoustics) and several aspects of the statistical analysis approach have been covered in an undergraduate course (Ocean and Environmental Data Analysis).

The CWRU team has submitted abstracts of two international conference papers (IABMAS 2022). Both research teams will disseminate the research results at international conferences in 2022.

University of Colorado Denver trained graduate students and technical staff members were exposed to state-of-the-art research environments, which would benefit their professional experiences.

Technology Transfer

The WSU team filed two provisional patents (detailed later) and the Case Western Reserve University research team has filed an invention disclosure with CWRU.

Diversity

TriDurLE is committed to engaging diverse and underrepresented groups with a goal of increasing interest in STEM disciplines and awareness of careers in the transportation fields. These efforts are focused on providing opportunities for minority students from high school through post-doc to participate in transportation-related research, providing funding for students to participate in symposiums and conferences that provide diversity-related workshops, and providing fellowships to graduate students pursuing transportation-related degrees. During this reporting period, TriDurLE has developed the following opportunities to promote diversity:

- Diverse Research Scholarship for High School and Undergraduate Students (awarded to 1 female student to date)
- Diversity Graduate Research Fellowship (awarded to 3 students)
- Diversity Travel Grant for Students (awarded to 3 students to date)
- Diversity Travel Grant for Faculty and Staff

See Table A3 for more detailed information about opportunities provided for diverse students by TriDurLE partners.

1.3 What opportunities for training and professional development has the program provided?

TriDurLE provided the following webinars for this reporting period and one on-campus lecture. Recordings were posted on the TriDurLE YouTube channel and linked to the TriDurLE website.

Table 1.1 TriDurLE Webinars

Date	*Speaker*	*Title*	*Attendance*
April 22, 2021	Henry V. Burton, Associate	Seismic Risk and Resilience Modeling of	YouTube: 30

	Professor, UCLA Civil & Environmental Engineering	Distributed Infrastructure Systems	
May 6, 2021	Xianming Shi, Director, TriDurLE	Durability of Concrete Materials in Cold Regions: Emerging Challenges and Countermeasures	Registrations: 64 YouTube: 38
June 9, 2021	Surendra Shah, Professor, Civil & Environmental Engineering, Northwestern University	Nanotechnology and Sustainability in Concrete Construction	Registrations for online viewing: 53 On-campus lecture attendance: 25 YouTube: 193
June 11, 2021	Larry D. Olson, President and Chief Engineer, Olson Engineering, Inc.	Advance NDE Methods for Condition Assessment and Imaging of Bridge Conditions	Registrations: 53 YouTube: 19
July 27, 2021	Francisco Presuel-Moreno, FAU Site Director and Professor, Dept. of Ocean and Mech. Engineering	Corrosion Propagation of Carbon Steel Rebars in Concrete	Registration: 44 YouTube: 57

1.4 How have the results been disseminated?

TriDurLE hosted monthly webinars and our universities submitted peer-reviewed publications, presentations at professional meetings, and research meetings with state DOTs to share preliminary results. TriDurLE is also active on social media sites Facebook and Twitter and has an up-to-date website for disseminating information.

1.5 What do you plan to do during the next reporting period to accomplish the goals and objectives?

Research projects will continue moving forward and progress made. Many year one projects that were granted a no-cost time extension will be completed in spring and summer 2022. Research findings will be generated and publications submitted to top-tier journals. When the pandemic subsides, active interactions with other researchers and engineers are expected. TriDurLE will host its first symposium in December 2021. This event will raise awareness of the Center and associated activities (research, diversity, education, workforce development, collaboration, and technology transfer).

University of Utah reported specifically that they anticipate results for both the corrosion and seismic testing in the next reporting period. To accomplish their goals they plan to complete construction of the four columns, initiate and complete the corrosion process for three of the columns and test all four columns under simulated seismic loads. In addition, the results of these tests will be disseminated through conference presentations and journal publications.

2. PARTICIPANTS AND COLLABORATING ORGANIZATIONS

2.1 Who has worked on the program?

A complete list of PIs and Co-PIs can be found at https://tridurle.wsu.edu/researchers/

Table 2.1 Program participants

Name & Institution	Program/ Project Role	Funding Support	Countries of foreign collaboration	Travel to foreign country and duration
Xianming Shi, Washington State University	Director, oversees all operations	WSU	China	None
Catherine Armwood, Tennessee State University	Site Director, Director of Diversity	TSU	None	None
Jenny Liu, Missouri University of Science & Technology	Site Director, Associate Director of Research	MST	China	None
Chris Pantelides, University of Utah	Site Director	UU	None	None
Mohamad Ashour, Alabama A& M	Site Director	AL A&M	China, South Korea	None
Yail Jimmy Kim, University of Colorado Denver	Site Director	UCD	None	None
Francisco Presuel-Moreno, Florida Atlantic University	Site Director	FAU	None	None
Mostafa Tazarv, South Dakota State University	Site Director	SDSU	None	None
Xiong (Bill) Yu, Case Western Reserve University	Site Director	CWRU	None	None
Dan Zollinger, Texas A&M University	Site Director	TAMU	None	None
Waheed Uddin (Deceased), University of Mississippi	Site Director	UM	None	None
Cheryl Reed, Washington State University	Outreach Coordinator	WSU	None	None

2.2 What organizations have been involved as partners?

Table 2.2 A List of Organizations Creating Partnerships with TriDurLE

Organization Name	Type / Location	Partners Contribution to Project				
		Financial/ Materials Support	In-kind Support	Facilities	Collaborative Research	Personnel Exchanges
Denver Streets Partnership	City/Denver, CO		X			
University of New Mexico	State/NM				X	
Northeast Forestry University	China				X	
Precast/Prestressed Concrete Institute	Chicago, IL	X				

Gage Brothers	Sioux Falls, SD		X	X		
Headed Reinforcement Corp.	Fountain Valley, CA	X	X			
Alabama Department of Transportation	State/AL		X			
Florida Dept. of Transportation	State/FL	X				
Missouri DOT	State/MO	X			X	X
Colorado Dept. of Transportation	State/CO	X			X	X
Tencate North America	Industry	X			X	
INSPIRE	Institution				X	
University of Tennessee	Institution					X
Missouri S&T	Institution	X				
WA State DOT	State/WA	X				
Washington Transportation Improvement Board	Institution/WA	X				
Conco	Industry/WA	X				
Washington State University	Institution/WA			X		X
Case Western Reserve University	Institution/			X		X
Utah DOT	State/UT				X	
GCP Applied Technologies, Inc.	Industry/MA	X				
Sika Corp.	Industry/NJ	X				
Ohio Flexible Pavement Association	Industry/OH				X	
Kokosing Materials Inc.	Industry/OH				X	
Ohio DOT	State/OH				X	
Politechnico di Milano	Industry/Italy	X	X		X	X

2.3 Have other collaborators or contacts been involved?

Nothing to Report

3. OUTPUTS

South Dakota State University developed an AI-based computer vision software that can perform preliminary

and detailed serviceability assessments of RC bridge columns after earthquakes. A website was developed to demonstrate the implementation of the post-event inspection/assessment tools. Researchers collected and digitized the most comprehensive experimental database of RC bridge columns, which is publicly available through The DesignSafe Data Deport, an NSF supported tool to store and publish data (https://doi.org/10.17603/ds2-1p5e-1v55). More information can be found at the research website (https://sites.google.com/people.unr.edu/mostafa-tazarv/research/post-event-serviceability).

WSU and CWRU's collaborative project led by Dr. Lee identified sensitive parameters in the capacity modeling of deteriorating reinforced concrete bridge columns help increase the knowledge in life-cycle analysis of deteriorating civil structures. The developed machine learning model significantly improves the existing technique, which helps engineers release their burden from the conventional time-consuming physics-based section moment-curvature analysis. A systematic procedure for uncertainty quantification, propagation, and reduction developed as part of a dynamic Bayesian network framework increases understanding of uncertainties existing in the parameters, theoretical and empirical models, monitoring and inspection techniques, as well as natural variabilities in transportation network resilience assessment.

3.1 Publications, conference papers, and presentations

Publications

[1] Fan, L., Shi, X. Techniques of Corrosion Monitoring of Steel Rebar in Reinforced Concrete Structures: A Review. *Structural Health Monitoring*, 2021, DOI: 10.1177/14759217211030911.

[2] Du, S., Zhao, Q., Shi, X. High-Volume Fly Ash Based Cementitious Composites as Sustainable Materials: A Review of Recent Advances. *Advances in Civil Engineering*, 2021, Article ID 4976169, DOI: 10.1155/2021/4976169.

[3] Li, Z., Shi, X. Effects of Nanomaterials on Engineering Performance of a Potassium Methyl Siliconate-Based Sealer for Cementitious Composite. *ASCE Journal of Materials in Civil Engineering*, 2021, DOI: 10.1061/(ASCE)MT.1943-5533.0004148.

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[12] Allan, K., & Phillips, A. R. (2021). Comparative Cradle-to-Grave Life Cycle Assessment of Low and Mid-Rise Mass Timber Buildings with Equivalent Structural Steel Alternatives. *Sustainability*, *13*(6), 3401.

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earthquake on schools. *Earthquake Spectra*, 8755293020988022.
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[30] Coppola, N. and Marshall, W.E. 2021. Sidewalk Static Obstructions and the Impact on Clear Width. Transportation Research Record (doi.org/10.1177/0361198121991833).
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Technical Reports

[1] Coppola, N. and Marshall, W.E. 2021. Evaluating Sidewalk Infrastructure & Prioritizing Investment. The National Center for Transportation Infrastructure Durability and Life-Extension (TriDurLE).
[2] Crockford, B., Gu, F., Im, S., Joshaghani, A., Liu, W., Luo, X., ... & Zollinger, D. (2021). *Develop Rapid Quality Control and Assurance Technologies for Pavements: Phase I* (No. FHWA/TX-16/0-6874-R1).
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[5] Kim, J., & Zollinger, D. G. (2021). *Portland Cement Concrete Pavement Joint Sealant Practices and Performance* (No. NCHRP Project 20-05, Topic 51-09).

Presentations

[1] Shi, X. Winter Road Maintenance Research Can Help Lower Salt Usage. Keynote Presentation for the 2021 Salt Symposium, August 4, 2021. Online.
[2] Shi, X. Value-added Renewable Additives for More Sustainable Anti-icing Operations on Roadways. An online presentation at the TRB Resource Conservation and Recovery Committee (AMS20) Summer Workshop, July 29, 2021.
[3] Shi, X. Durability of Concrete Materials in Cold Regions: Emerging Challenges and Countermeasures. Webinar for the National University Transportation Center TriDurLE, May 6, 2021.
[4] Nazari, M.H., Shi, X. A Laboratory Investigation on the Effect of Chloride Roadway Deicers on the Corrosion of Buried Pipes. A poster presentation (Marcel Pourbaix Category) at the Corrosion/2021 Conference, April 20, 2021, online.
[5] J. Galinmoghadam, J. Liu, X. Zhang, C. Lin, and Y. Guo, "Mitigating Pumping in Concrete Pavement Shoulder Using Wicking Geotextile: An Experimental Study", accepted for presentation at 101st TRB meeting.
[6] Riad, B., and Zhang, X. "Fully Characterizing the Elasto-Plastic Hydro-Mechanical Cyclic Behavior of Unsaturated Soils Using Constant Water Content Oedometer and Direct Shear Tests", accepted for presentation at 101st TRB meeting.
[7] Mamun, AA., Romero, P., and Asib, ASM.: Laboratory Simulation of HMA in a Cold Region: An Artificial Intelligence-Based Approach. Paper TRBAM-22-04180. Accepted for presentation at the 2022 meeting of the Transportation Research Board.

[8] Coppola, N. and Marshall, W.E. 2021. Pedestrian Peril? The Impact of Sidewalk Obstructions on Functional Width. ASCE International Conference on Transportation & Development.
[9] The Impact of Static Obstructions Spatial Data Evaluation of Sidewalk Clear Width and Pedestrian Planning (poster presentation by N. Coppola). ITE International Annual Meeting; July 2021.
[10] Hart, K., and Tazarv, M. (2021). "Repairable Precast Bridge Bents for Extreme Events," Presentation to Project Panel, Sept. 10, 2021
[11] [Presuel] Conference presentation during Corrosion/2021 Research in Progress symposium (Concrete and Architecture track)
[12] Zhang, X. "Recent Advances in Measuring Volume Changes of Soil Specimen during Triaxial Testing." Main Plenary Speaker, 3rd Pan-American Conferences on Unsaturated Soils, Rio de Janeiro, Brazil, July 25-28, 2021.
[13] Houston, S. and Zhang, X. "Review of expansive and collapsible soil volume change models within a unified elastoplastic framework." Keynote Lecture at the 3rd Pan-American Conferences on Unsaturated Soils, Rio de Janeiro, Brazil, July 25-28, 2021

3.2 Website(s) or other internet site(s)

SDSU Project Websites:
(1) Post-Earthquake Serviceability of RC Bridge Bents Using Visual Inspection
https://sites.google.com/people.unr.edu/mostafa-tazarv/research/post-event-serviceability
(2) Drone-Based Measurements for Bridge Field Testing,
https://sites.google.com/people.unr.edu/mostafa-tazarv/research/drone-based-measurement
(3) Repairable Precast Bridge Bents for Extreme Events
https://sites.google.com/people.unr.edu/mostafa-tazarv/research/repairable-bridge-bents

TriDurLE website: https://tridurle.wsu.edu

3.3 Technologies or techniques

A new software has been developed by Alabama A&M to implement the developed soil-pile model. The developed software package improves the designer's capacity to assess the effect of inundating the collapsible soil and its negative impact on the performance of the pile foundations. Unlike current practice (FHWA's procedure), the developed model couples the pile downdrag-settlement in the analytical process.

University of Utah has generated a software program in which corrosion of columns can be modeled using open source software to study the seismic performance of corroded columns constructed with accelerated bridge construction methods.

3.4 Inventions, patent applications, and/or licenses

The WSU team filed two provisional patents during this time period as follows: Shi, X. Long-lasting sacrificial anode and embedment method in repair mortar. Provisional Patent on August 24, 2021. Shi, X., Li, Z. Nano-modified waterproof sealer compositions and methods for concrete preservation. Provisional Patent on August 17, 2021.

Case Western Reserve University researchers have filed an invention disclosure with the university.

3.5 Other output

Nothing to report

4. OUTCOMES

4.1 Increased understanding and awareness of transportation issues

University of Utah's collaborative project has allowed for an improved process to develop asphalt mixtures that are capable of balancing the need for mechanical performance and durability. This is referred to as balanced mix design. The project has also produced increases in the body of knowledge, improvement of existing techniques, practices, and technologies.

4.2 Passage of new policies, regulation, rulemaking, or legislation

Nothing to report

4.3 Increases in the body of knowledge

UC Denver's work has had an impact on the students that are working on them in terms of providing an opportunity for research and the various research-related skill development. Work there is also finding research results that will make streets more accessible and equitable.

FAU research Increased the body of knowledge on how corrosion propagation of the reinforcing steel takes place embedded in binary and ternary concrete.

WSU's work has resulted in journal publications, scholarly presentations and patent applications, all of which not only increased the body of knowledge related to infrastructure durability but also contributed to student research experience, workforce development, and technology transfer.

CWRU results on fatigue behavior of FRCM composites has focused on the fatigue at a stress level prior to the yielding of the internal bars. The results indicate that the FRCM can increase the yielding point of the strengthened beam without being affected by the fatigue loading.

4.4 Improvement of existing techniques, practices, technologies

One of University of Utah's projects has increased the body of knowledge, improvement of existing techniques, practices, and technologies.

Alabama A&M: The presented model allows assessing the axial response of piles subjected to downdrag by combining both the soil and pile settlement profiles with the mobilized side-friction and end-bearing load-transfer relationships. Current practice (FHWA) determines the neutral plane's location solely based on the equilibrium of forces acting on the pile, while the pile settlement is calculated only using the soil settlement profile.

SDSU: Autonomous damage detection of bridge columns using the AI-based computer vision tool will significantly expedite the post-earthquake inspection and serviceability assessment of affected bridges. This technique is new for post-event bridge assessment, and the cloud-based inspection/assessment software is the-first-of-its-kind tool developed for bridges.

University of Utah's collaborative project has allowed for an improved process to develop asphalt mixtures that are capable of balancing the need for mechanical performance and durability. This is referred to as balanced mix design.

CWRU is Improving the design of thermochromic materials into asphalt pavement will modulate the effects of climate on pavement durability and provides a new strategy to mitigate climate impacts and enhance the durability and life extension of pavement. Also, Preliminary analyses of self-healing with microorganism demonstrate the promising potentials. The project team will continue to explore and advance the state of art.

4.5 Enlargement of the pool of trained transportation professionals

Nothing to report

4.6 Incorporation of new techniques, practices, technologies

Nothing to report

5. IMPACTS

5.1 What is the impact on the development of the principal discipline(s) of the program?

Alabama A&M's current study improves the reliability of the pile foundation analysis in inundated collapsible soil due to the consideration of the developing negative skin friction (i.e. downdrag force) that acts on deep foundations, and the employment of such an interactive model that couples the induced downdrag forces with pile settlement. Such a model enhances the safety and serviceability of the bridge foundations.

5.2 What is the impact on other disciplines?

Nothing to report

5.3 What is the impact on the development of transportation workforce development?

An FAU ocean engineer PhD student graduated with experience in corrosion of reinforcing steel in concrete. Alabama A&M has developed software that will be available to DOT engineers to test and investigate its capabilities. A training session can be offered by the software developer.

5.4 What is the impact on physical, institutional, and information resources at the university or other partner institutions?

Nothing to report

5.5 What is the impact on technology transfer?

The WSU team's two recent patent applications have obtained some interest from the private industry and there are ongoing technology transfer activities.

5.6 What is the impact on society beyond science and technology?

University of Colorado Denver projects seek to make streets more accessible and equitable, with the safe use of civil infrastructure as a primary interest.

The AI-based computer vision bridge serviceability assessment tool built by SDSU is expected to help the 16 seismic-prone states of the nation to quickly and safely evaluate affected bridges after earthquakes, which will save time, costs, and lives.

Alabama A&M's current study improves the reliability of the pile foundation analysis in inundated collapsible soil due to the consideration of the developing negative skin friction (i.e. downdrag force) that acts on deep foundations, and the employment of such an interactive model that couples the induced downdrag forces with pile settlement. Such a model enhances the safety and serviceability of the bridge foundations.

6. CHANGES/PROBLEMS

6.1 Changes in approach and reasons for change

Nothing to report

6.2 Actual or anticipated problems or delays and actions or plans to resolve them

FAU reported that COVID issues delayed or made the accessing of facilities not as regular as the pre-COVID conditions. The medical condition on a graduate student required him to stop working in the project, a new graduate student was identified shortly after, and the learning curve slowed some of the sample monitoring. No changes to the project.

WSU reported that the project teams requested a no-cost extension mainly due to difficulties related to the arrival of international graduate students.

UU had multiple delays caused in the execution of the experiments for both goals 1 and 2 due to COVID-19. However, the schedule is back to normal and the team is expecting to catch up in the next reporting period.

Case Western Reserve University reports that new graduate students recruited for projects can't arrive on campus due to COVID-19. The University policy does not allow them to work on the project outside US and get paid. These all had impacts on the implementation of the project activities.

6.3 Changes that have a significant impact on expenditures

Nothing to report

6.4 Significant change in use or care of animals, human subjects, and/or biohazards

Nothing to report

6.5 Changes of primary performance site location from that originally proposed

Nothing to report

6.6 Additional information regarding products and impacts

Nothing to report

7. SPECIAL REPORTING REQUIREMENTS

Nothing to report

APPENDIX A

Additional Performance Metrics

Table A1. Research Performance Metrics

Name	# of citations of UTC and projects on internet	# of implemented strategies, products, patent applications or techniques
FAU	1	1
UC Denver	5	0
SDSU	5	2
University of Utah	4	0
MST	5	0
Alabama A&M	2	2
WSU	75	2

Table A2. Leadership Performance Metrics

Name	Junior faculty receiving seed grant awards	Online seminars offered to future leaders	States in which research or implementation is active	Hours of technical assistance offered	Significant awards	Researchers serving as expert panelists or selected for major leadership positions
FAU	0	2	0	2	0	0
UC Denver	1	3	0	0	0	1
SDSU	3	1	0	2	0	5
UU	2	0	0	12	0	1
MST	1	10	0	80	0	14
Alabama A&M	3	1	0	2	0	5
WSU	0	1	0	24	1	2

Table A3. Education and Workforce Development Diversity Evaluation

Name	#students funded by TriDurLE and ethnicity	# supported students receiving degrees and ethnicity	# attendees at training sessions, ethnicity and affiliation	# of online course or webinar attendees	# of student participants in career-building activities and ethnicity	# of attendees in K-12 programs
FAU	1 Hispanic, 1 white	1 Hispanic, 1 white	3 Hispanic, 3 female, 6 white male	0	0	15
UCD	1 non-Hispanic, 1 white, 1 Arabic	1 non-Hispanic white	0	0	0	0
SDSU	2 white, 1 female Asian, 1 Italian, 1 Eastern Indian	0	0	0	0	0
UU	2	2	2	1	2	2
WSU	I female Indian 4 Asians 1 African American	4 Asians	100+	14	0	0

MST	1 female 3 Asian 3 middle eastern	1 MS and 1 PhD, both Asian	200+	500+	NA	NA
Alabama A&M	2 white males, 1 Asian female, 1 Italian male, 1 Indian male	2 white males, 1 Asian female, 1 Italian male	0	0	0	0

APPENDIX B

Year 2 Research Projects

Table B1. Year 2 research projects

	Research Project	**PIs and Co-PIs**	**University**
1	Using Deep Learning for Accurate Detection of Bridge Performance Anomalies	Farnoush Banaei-Kashani Chris Pantelides	University of Colorado Denver University of Utah
2	Design of Fly Ash-based Geopolymer Concrete-filled FRP Tube Composite for Highly Durable and Environmentally Friendly Infrastructure	Xianming Shi	Washington State University
3	Developing High-performance Nanocomposite Coating for Steel Reinforcement Protection in Chloride-rich Concrete	Xianming Shi	Washington State University
4	Development of Microcapsule-based Self-healing, High-strength Engineered Cementitious Composites (SHHS-EE)	Xianming Shi Liang Fan	Washington State University
5	Sustainable nHPC Mixtures for Durable Overlay of Concrete Bridge Decks in Cold Regions: Proof of Concept	Xianming Shi	Washington State University
6	Development of Stormwater Detention/Infiltration System for Urban Highways Using Permeable Light-weight Cellular Concrete, Phase I	Steven Bartlett Nigel Bruce Pickering	University of Utah Washington State University
7	Preparation of Pavement Infrastructure for Connected and Autonomous Vehicle Deployment – Phase I	Xianbiao Hu Jenny Liu	Missouri University of Science & Technology
8	Drone-based Measurements for Bridge Field Testing	Mostafa Tazarv Marco Ciarcia Kwanghee Won	South Dakota State University
9	Development of Holistic Methodologies for Improving Asphalt Mix Durability (Yr. 2)	Jenny Liu Pedro Romero Fujie Zhou	Missouri S&T University of Utah Texas A&M University
10	Performance of ABC Columns Cost-effective Retrofit Strategies Subjected to Synergistic Distress Resulting from Corrosion and Seismic Loading (Yr 2)	Yail Jimmy Kim Chris Pantelides	University of Colorado Denver University of Utah
11	Seismic Performance and Fragility of Retrofitted Reinforced Concrete Bridge Columns to Long-duration Earthquakes	Adam Phillips Chris Motter	Washington State University
12	Assessment and Evaluation of Post-liquefaction Lateral Spread Impact on Bridge Deep Foundations	Mohamad Ashour Sudip Bhattacharjee	Alabama A&M University
13	Use of Recycled Plastics in Asphalt Pavement (Yr 2)	Jenny Liu Xinhua Liang	Missouri S&T
14	AI-based Prediction Models for Transportation Infrastructure Asset Management Data Hub – Phase I	Xianbiao Hu Jenny Liu	Missouri S&T

15	Effects of Combined Carbonate and Biofilm on Shrinkage Cracking in Unsaturated Cementitiously Stabilized Soils Using Microcapsules	Xianming Shi	Washington State University
16	Repairable Precast Bridge Bents for Extreme Events	Mostafa Tazarv	South Dakota State University
17	UAV-enabled Structure-From-Motion Photogrammetry for Bridge Crack Detection and Characterization	Xiong Zhang Jenny Liu Genda Chen	Missouri S&T
18	A Multiple-camera System to Determine the Absolute Volume of Soil Specimen During Dynamic Triaxial Testing (Yr 1)	Xiong Zhang Jenny Liu	Missouri S&T
19	The (In)Equitable Distribution of Quality Bicycling Infrastructure	Wesley Marshall Nicholas Ferenchak	University of Colorado Denver University of New Mexico
20	Durability of Transverse Sawcut Joints in Midwestern Jointed Concrete Pavements	Dan Zollinger Jenny Liu	Texas A&M University Missouri S&T
21	Development of Infrastructure Research Weekly APP	Xianming Shi Kakan Dey	Washington State University West Virginia University
22	Developing Enhanced Performance Curves of ITD Asphalt Pavements by Mining the Historical Data	Xianming Shi	Washington State University
23	Comparing the Performances of Different Wicking Fibers for Water Removal for Transportation Applications	Xiong Zhang Xinhua Liang	Missouri S&T
24	Corrosion Propagation Monitoring Legacy Samples and Forensic Analysis on Selected Sample	Francisco Moreno-Presuel	Florida Atlantic University
25	Poro-Elastic Modeling and Measurement of Rebar Corrosion and Crack Formation Using High Frequency Ultrasonics	Pierre-Phillipe Beaujean	Florida Atlantic University