TriDurLE

National Center for Transportation Infrastructure Durability & Life-Extension

USDOT National University Transportation Center
Progress Performance Report #5

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1. ACCOMPLISHMENTS

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

The strategic priority of TriDurLE is to enhance the durability of transportation infrastructure of the US and extend its service life with cost-effective innovations and holistic solutions. 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 56 research projects for year one (26 projects), year two (26 projects) and year three (4 projects) combined. Most year-one and year-two projects were granted a no-cost time extension because of delays caused by the COVID-19 Pandemic. Ten universities have completed and submitted their final project reports.

The following are research reports from individual universities.

The research teams at the University of Colorado Denver (UCD) have a wide variety of project scopes. Dr. Jimmy Kim studied the behavior of reinforced columns confined with composite sheets. By examining the complicated responses of these members under mechanical loadings, an in-depth understanding of repaired ABC (accelerated bridge construction) members in the field can become available. Dr. Marshall and his team continued with their research efforts and published a conference paper at TRB. They also disseminated their research via several presentations at conferences as well as a webinar. Dr. Banaei-Kashani and his team followed their previous work and accomplished the rest of the project objectives, which included evaluation of the developed anomaly detection methods, starting a new project of developing a software tool, including the proposed anomaly detection methods in undergraduate and graduate level courses, and submitting a manuscript to TRB 2023 Annual Meeting.

The research teams at Missouri University of Science & Technology are making progress according to the research tasks proposed in the proposals. Some results were shared with sponsors including state DOTs (e.g., Missouri, Kansas, and Colorado DOTs) and industry companies.

In Case Western Reserve University, a separate research of Dr. Xiong (Bill) Yu continued to explore a self-healing concrete technology based on fungi mycelium to improve the strength and mitigate deterioration due to water infiltration. He also continued the research of exploring a thermochromic asphalt technology that would improve the durability of asphalt pavement by dynamically modulating the solar radiations. Dr. Yue Li targeted three tasks to accomplish Objective 2, which included developing a physics-based finite element model, surrogating models of probabilistic responses, and

parameterizing seismic fragility curves of deteriorating bridges. Dr. Christian Carloni conducted research to investigate the effect of the bonded length in pull-out on the bond behavior of FRP bars.

At Alabama A&M University, Dr. Mohamad Ashour's research targets the evaluation of the serviceability of the bridge deep foundations that could be at high risk due to the vulnerability to unexpected and underestimated post-liquefaction lateral soil spread destructive forces. The research work quantifies the mobilized damaging forces acting on the bridge foundation pile groups with caps as a result of the post-liquefaction triggered lateral soil spreading.

At Florida Atlantic University, a non-linear solver using the Trust-Region Reflective (TRR) algorithm is used to match a set of synthetic data to the Biot-Stoll model. Synthetic data is produced separately using set values in a script that functions purely as a table of constants. Ultrasonic data acquisition and rebar potential data collection has been completed using a new set of reinforced concrete samples, showing various degrees of corrosion and cracking.

At the University of Utah, several specimens were prepared for large-scale testing and a numerical model was developed to model the control specimen. Currently a numerical model is being developed for the slightly corroded specimen and the final report is under writing.

At Washington State University, a new mode-II fracture-mechanics based test method was developed to evaluate the overlay-to-substrate interface bond performance in concrete repairs. The said method was successfully used to characterize long-term and short-term performance of the concrete-to-shotcrete interface bonds.

Leadership

Dr. Xianming Shi continued to serve as the Chair of the Department of Civil and Environmental Engineering at Washington State University. He continued to serve as the Editor-in-Chief for the *Journal of Infrastructure Preservation and Resilience* (by Springer Nature) and as the Director of Washington State Transportation Center. Dr. Shi started to serve on the Board of Directors for ITS Washington since April 2022. He continued to serve as an Associate Editor for the *Journal of Nondestructive Evaluation*, and an Editorial Board Member for the *International Journal of Structural Integrity* and *International Journal of Transportation Science and Technology*.

Dr. Jimmy Kim virtually attended the conventions of the American Concrete Institute (ACI) in Spring 2022 and moderated four special sessions: Developments, Applications, and Case Studies in UHPC for Bridges and Structures, Parts 1 to 4 (Spring 2022). He also participated in several technical committee meetings as a voting member. Dr. Kim also delivered an invited presentation for the members of the Korea Concrete Institute (Translation of Research into Practice for Concrete Bridges and Buildings in the United States, Feb. 2022) and moderated the KCI Presidential Lecture series (Strategies for Enhancing Resiliency of Modern Concrete Structures under Fire Hazard, Mar. 2022).

Drs. Jenny Liu and Xiong Zhang were both named James A. Heidman Professors of Civil Engineering at S&T effective on September 1, 2022.

Dr. Xiong (Bill) Yu delivered a few invited talks based on this research. Dr. Christian Carloni discussed the results of his research in ACI 440K/ASTM D.30.10 Leadership to improve current standards and possibly implement a new formula in the ACI code.

Collaboration

Section 2 of this report details the extensive collaboration of TriDurLE researchers with industries and universities. In addition, several of the TriDurLE research projects are collaborative within the consortium, such as Washington State University and Case Western Reserve University, and Texas A&M University and Missouri University of Science & Technology.

Education and Workforce Development

At Washington State University, outstanding graduate students have been recognized by multiple awards. These include: **Ayumi Manawadu,** Named a CEE Rising Star by Carnegie Melon University (MIT CEE Rising Stars Program); Winner, WTS International Paula Hammond Leadership Legacy Scholarship; WSU Woman of Distinction – Graduate Student; ITE Washington Chapter Graduate Student Scholarship Winner; Graduate Collegiate Research Competition Winner - WE Local, Buffalo, NY Conference, 2022. **Ali Mahmoodi**, Howard

and Hermina Hallgarth Scholarship, 2022. **Seth Owusu Tawiah**, 2022 Michael L. Condon Civil Engineering Scholarship, by Deep Foundations Institute (DFI) Educational Trust. **Chuang Chen**, First-place Winner in the 2022 Long-Term Infrastructure Performance (LTIP) Student Data Analysis Contest (Pavement). **Zhipeng Li**, Dissertation Award, for both the Dept. of Civil & Environmental Engineering and the WSU Voiland College of Engineering and Architecture; John F. Orsborn Outstanding Graduate Student Award; Perteet Engineering Graduate Fellowship in Civil Engineering; Graduate & Professional Student Travel Grant, WSU Graduate & Professional Student Association (GPSA), 2022. **Mehdi Honarvar Nazari**, 2022 Outstanding Research Assistant Award, selected by the WSU Department of Civil & Environmental Engineering.

The research projects at UCD trained graduate students in terms of project planning, conducting technical tasks, collecting & interpreting collected data, and understanding physical outcomes. Through these fundamental approaches, their understanding of structural behavior was improved, which would be a great asset for their professional career. An undergraduate research assistant, Ryan Cheng, has been trained under this project and has made key contributions. They have also included discussion of the proposed anomaly detection methods in undergraduate and graduate level courses to advance education through training students on the topic and results of our project.

Dr. Xiong Yu has involved a few graduate students in research activities. He continued to introduce the research progresses into course modules for classes and for K-12 outreach activities. Dr. Christian Carloni hired a PhD student and a master's student to work on TriDurLE projects.

Dr. Francisco Presual of FLA reports that a master's student has successfully completed his thesis proposal and was scheduled to receive his degree in August 2022. Two graduate students (one on each project) started their master program in the summer of 2022. An undergraduate student was trained and started working in Dr. Presuel's lab.

Two master's students are working on Dr. Steven Bartlett's project at UU. One PhD student is currently working on Dr. Chris Pantelide's project and three high school students were hired to work on this project during the summer of 2022. The student working on Dr. Pedro Romero's project has graduated and joined the workforce.

At South Dakota State University, seven graduate students (three PhD students and four MS students) and one undergraduate student were supported under the UTC funding.

Diversity

TriDurLE has awarded several diversity initiatives for students, staff, and faculty, including travel grants to meetings that promote diversity, graduate research fellowships for students from underrepresented groups, and high school/undergraduate scholarships for students from underrepresented groups to work under the tutelage of TriDurLE researchers. Three students were awarded the Waheed Uddin Diversity Graduate Research Fellowship: Sara Fayek from Missouri S&T University; Rodrigo Teixeira Schlosser from Case Western Reserve University, and Vishnupriya Jonnalagadda of Washington State University. One undergraduate student, Thippapha Aloundeth, from Washington State University received the Balasingam Muhunthan Diverse Research Experience Scholarship. Four travel grants were awarded to students to attend conferences. In addition:

- In Missouri University of Science and Technology, a female undergraduate research assistant named Allison Poe is hired to working on the TriDurLE project during the summer of 2022

- Alabama A&M University is a Historically Black College and University (HBCU).

- The projects at Florida Atlantic University hired two new graduate students with the minority background of African American and part native American, respectively.

- The project of Dr. Haifang Wen funded a female international engineering graduate student, Ayumi Manawadu, in her doctoral studies.

Technology Transfer

At Washington State University, the following non-provisional patent was filed by Dr. Xianming Shi and Dr. Jing Zhong: Graphene oxide fine aggregate in cement composites (filed on April 19, 2022).

The PIs at University of Colorado Denver have started a new collaboration with Colorado Department of Transportation, to tech transfer their findings to practice. Both research professionals and practitioners were targeted to share their learning.

The TriDurLE project at Alabama A&M University is integrated into a software package that can detect the development of soil liquefaction, subsequent lateral spreading and variation of porewater pressure. The software package will be available to designers.

Dr. Steven Bartlett is seeking the participation and potential commercialization of the PLCC with Holcim and CRH Companies. These relationships are still being discussed.

Dr. Xiong Yu of Case Western Reserve University has filed an invention disclosure with the University Tech Transfer office on the self-healing concrete technology.

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

The TriDurLE monthly webinars have been promoted via multiple channels to professional groups likely interested in transportation infrastructure preservation and life-extension. These are open to the public, particularly of value to the local and state transportation agencies, as well as to industry practitioners and researchers. These monthly Invited Speaker Series Webinars are presented by leading experts in the field. All the webinars are recorded and posted on our website, and Professional Development Hour Certificates are available upon request.

The TriDurLE second annual symposium will take place on November 10th and 11th, featuring four keynote speakers, 32 presentations, and 10 student poster presentations from scholars and professionals worldwide who are conducting research on transportation infrastructure. There would also be online virtual sessions during the two-day event. All presentations will be recorded and posted on our YouTube channel and website.

1.4 How have the results been disseminated?

As detailed in Section 3, TriDurLE researchers and students have disseminated the results of their work through journal publications, conference papers, technical reports, thesis presentations, and oral presentations at professional conferences and workshops. Many TriDurLE researchers would also present their study at the coming annual symposium and through monthly webinars.

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

The following tasks are planned to accomplish the goals and objective of TriDurLE.

- Hold monthly meetings with executive committee (Site Directors); and hold quarterly Zoom Meetings w/ fiscal staff members and outreach coordinator
- Hold the 2022 Annual Symposium of the National UTC, Nov. 9-11, 2022, Honolulu, Hawaii.
- Plan for the 2023 Annual Symposium of this National UTC, likely to be held in late fall 2023.
- Continue efforts in research, leadership, education, workforce development, diversity, and technology transfer, on behalf of the National UTC TriDurLE.
- Continue to explore opportunities of collaboration to pool resources and expand the scope of previous success. Continue to develop a diverse collaboration network with different state and local government agencies, private sector, educational and professional organizations (and their student chapters), other university transportation centers (UTCs), FHWA offices, and universities in the U.S. and abroad. Expand our collaboration with the Journal of Infrastructure Preservation & Resilience (JIPR) and Bridge Engineering Institute (BEI).
- Maintain a robust website and publish a quarterly e-newsletter
- Work with partners to pursue commercialization and licensing opportunities
- Continue to update the website, Facebook, Twitter, LinkedIn and YouTube pages, particularly those related to publications, presentations, monthly webinars, collaborations, and events/activities related to diversity, leadership, collaboration, education, workforce development, or technology transfer.
- Consortium universities are report complete their research and final reports for years one and year two research projects as specified in their project reports.

2. PARTICIPANTS AND COLLABORATING ORGANIZATIONS

2.1 Who has worked on the program?

Table 1 lists the site directors of TriDurLE and in addition to the site directors, all the researchers who have worked on the program during this reporting period are listed on our website at https://tridurle.wsu.edu/researchers/

Table. 1 TriDurLE Site Directors

University	Name	Contribution to Program
Alabama A&M University	Mohamad Ashour	Site Director
Case Western Reserve University	Xiong (Bill) Yu	Site Director
Florida Atlantic University	Francisco Presuel-Moreno	Site Director
Missouri University of Science & Technology	Jenny Liu	Site Director, TriDurLE Director for Research
South Dakota State University	Mostafa Tazarv	Site Director
Tennessee State University	Catherine Armwood	Site Director, TriDurLE Director for Diversity
Texas A&M University	Dan Zollinger	Site Director
University of Colorado Denver	Yail Jimmy Kim	Site Director
University of Mississippi	Hakan Yasarer	Site Director
University of Utah	Chris Pantelides	Site Director
Washington State University	Xianming Shi and Jialuo He	Center Director and Assistant Director

2.2 What organizations have been involved as partners?

Table 2 summarizes the organizations that have partnerships with TriDurLE

Table. 2 A list of organizations that have partnerships with TriDurLE

Organization	Type/Location	Contribution to Projects				
		Financial Support	In-kind Support	Facilities	Collaborative Research	Personnel Exchange
Alabama A&M University	Government/ Alabama	X	X	X		
Denver Streets Partnership	Government/ Colorado		X		X	
Libyan North American Scholarship Program	Government/ Canada		X			
Case Western Reserve University	Government/ Ohio		X	X	X	X
Colorado DOT Accelerated Bridge Construction (ABC)	Government/ Colorado		X		X	
Emulsion Products, Inc.	Industry/Alaska					X
Florida Atlantic University	Government/Florida		X	X		X
Florida DOT	Government/Florida	X				
Geneva Rock Products	Industry/Utah		X		X	
Illinois DOT Bureau of Materials	Government/ Illinois		X			

Kansas DOT	Government/ Kansas		X			
KeraKoll Group	Industry/Italy		X			X
Kokosing Materials, Inc.	Industry/Ohio		X			
Missouri S&T	Government/ Missouri		X	X	X	X
Missouri DOT	Government/ Missouri	X			X	X
City of Rolla, Missouri	State/Missouri					X
MYK Latikrete	Industry/India					
Northeast Forestry University	Government/ China	X			X	X
Ruregold SRL	Industry/Italy		X			
SBIR/STTR	Federal					
Sika USA	Industry		X		X	
SNS Dempers	Industry/Utah		X			
South Dakota State University	Government/ South Dakota	X	X	X		
Tencate North America	Industry	X			X	
Texas A&M University	Government/ Texas		X	X	X	
The Polytechnic University of Milan	Government/ Italy		X		X	
University of Maryland, College Park	Government/ Maryland				X	
University of Mississippi	Government/ Mississippi		X	X		
University of Utah	Government/ Utah		X	X	X	X
Washington State University	Government/ Washington	X	X	X	X	X
Washington State DOT	Government/ Washington	X	X			
Idaho Transportation Department	Government/ Idaho	X				
Simpson Strong-Tie, Co.	Industry/ California		X			
Precast/Prestressed Concrete Inst.	Industry/Illinois	X				
Gage Brothers	Industry/ SD		X	X		
Headed Reinforcement, Corp	Industry/CA		X			
National Road Research Alliance (NRRA)	Pooled Fund/MN					

2.3 Have other collaborators or contacts been involved?

- Inspecting and Preserving Infrastructure through Robotic Exploration (INSPIRE) UTC
- Hughes Brothers (currently Dow Corning) and are waiting for their response to initiate collaboration.
- City and County of Denver
- Bike Denver
- Bicycle Colorado

- Walk Denver
- Colorado Cross-Disability Coalition
- Groundwork Denver Community/Environmental Organization
- All in Denver Affordable Housing Organization
- American Heart Association
- Journal of Infrastructure Preservation & Resilience (JIPR, by Springer Nature)
- Bridge Engineering Institute (BEI)
- Alabama Department of Transportation (ALDOT)
- Dr. Yongcheng Ji, Northeast Forestry University
- Seal/No Seal Group
- Crafco, Inc.
- Dow Chemical Company
- Dr. Nick Ferenchak, Assistant Professor of Civil Engineering, University of New Mexico
- Micah Silberman, project executive, The Conco Companies, Kent WA
- Jesse Espy: Pre-mix Inc, Pullman WA
- Dr. Tommaso D'Antino, Politecnico di Milano, Italy
- Dr. Francesco Focacci, E-Campus University, Italy
- Dr. Danny Xiao, University of Wisconsin-Platteville
- Dr. Jing Zhong, Harbin Institute of Technology
- Dr. Hui Peng, Changsha University of Science and Technology

3. OUTPUTS

3.1 Publications, conference papers, and presentations

Publications

[1] Wang, J. and Kim, Y.J. 2022. Durability of a bridge column under marine environments, ACI Special Publication on Durability, service life, and long-term integrity of concrete materials, bridges, and structures (ACI-SP-351), American Concrete Institute (ACI), 70-82

[2] B. Raid, X. Zhang, J. Liu, and D. Wang, "State of the Art Review on Compaction Quality Assurance Specifications of Unbound Materials", ASCE Journal of Transportation Engineering Part B: Pavements (accepted).

[3] D. Wang, J. Liu, and J. Liu, "Integrating Quality Assurance in Balance Mix Designs for Durable Asphalt Mixtures: State-of-the-Art Literature Review", ASCE Journal of Transportation Engineering Part B: Pavements (accepted).

[4] U. Bakhbergen, C. Shon, D. Zhang, J. Kim, and J. Liu, "Optimization of Mixture Parameter for Physical and Mechanical Properties of Reactive Powder Concrete Exposed to Three Different Temperatures and Sodium Sulfate Concentrations Using Taguchi Method", Construction & Building Materials, 352 (2022) 129023.

[5] J. Galinmoghadam, J. Liu, X. Zhang, C. Lin, and Y. Guo, "Mitigating Pumping in Concrete Pavement Shoulder Using Wicking Geotextile: An Experimental Study", Transportation Research Record

[6] H. Wu, D. Wang, X. Zhang, and J. Liu, "Impacts of Lightweight Aggregates Interlayers for Air Convection Embankment on Pavement Thermal Profile and Pavement Performance in Alaskan Permafrost Regions", Transportation Research Record

[7] J. Liu, B. Huang, H. Wang, and X. Luo, "Special Collection Announcement - Sustainable Innovations in Pavement Infrastructure", ASCE Journal of Transportation Engineering Part B: Pavements

[8] D. Murph, J. Liu, and J. Liu, "Mix Designs of Abrasion Resistant and Durable Concrete Made with SCMs for Cold Climates", ASCE Journal of Transportation Engineering Part B: Pavements, 148(2), 04022017, 2022.

[9] A. Zhu, H. Wu, and J. Liu, "Feasibility Study on Novel Fire Resistant Coating Materials", ASCE Journal of Materials in Civil Engineering, 34(6), 04022080, 2022.

[10] J. Liu, D. Wang, F. Saberi, and J. Liu, "Impact of deicers on low-temperature performance of Missouri pavements", International Conference on Transportation & Development 2022 Pavements, edited by H. Wei, May 31- June 3, 2022, 258-268.

[11] Riad, B., and Zhang, X. (2022). "Fully Characterizing the Elasto-Plastic Hydro-Mechanical Cyclic Behavior of Unsaturated Soils Using Constant Water Content Oedometer and Direct Shear Tests." Transportation Research Record.

[12] Zaman, M. W., Han, J., and Zhang, X. (2022). "Evaluating Wettability of Geotextiles with Contact Angles." Geotextiles and Geomembranes. Available online 5 April 2022.

[13] Xia, P., Deng, W., Shao, L.*, and Zhang, X. (2022). "Role of Elastic Upper Limit in Shakedown Study for Granular Soils." Transportation *Geotechnics*. Volume 34, May 2022, 100746.

[14] X Zhang, Y Li, X Fan, G Wnek, YTT Liao, X Yu (2022). Development and characterization of novelly grown fire-resistant fungal fibers, Scientific Reports.

[15] X Zhang, J Hu, X Fan, X Yu (2022). Naturally grown mycelium-composite as sustainable building insulation materials, Journal of Cleaner Production 342, 130784

[16] Zhao, X., Rahman, M.M., D'Antino, T., Focacci, F., Carloni, C. (2022). Effect of Bonded Length on the Load Response and Failure Mode of Pull-out Tests of GFRP Bars Embedded in Concrete. Construction and Building Materials, 347, 128425.

[17] Rahman, M.M., Zhao, X., D'Antino, T., Focacci, F., Carloni, C. (2022). Fracture Behavior and Digital Image Analysis of GFRP Reinforced Concrete Notched Beams. Materials, 15(17). 10.3390/ma15175981.

[18] Brogden M., "Estimation of the Physical Properties of Corroding Rebar in Reinforced Concrete using Biot-Stoll Model Inversion", Master's thesis, Florida Atlantic University, 2022.

[19] Tazarv, M., Won, K., Jang, Y., Hart, K., and Greeneway, E. (2022). "Post-Earthquake Serviceability Assessment of Standard RC Bridge Columns Using Computer Vision and Seismic Analyses," Engineering Structures, In Press.

[20] Asib, ASM., Romero, P., and Safazadeh, F. (2022). "Relating Laboratory and Natural Aging of Asphalt Mixtures Based on Low-Temperature Performance." Journal of Cold Regions Engineering, 36(4), 04022007

[21] Q. Mao, Y. Li, K. Liu, H. Peng, X. Shi (2022) "Mechanism, characterization and factors of reaction between basalt and alkali: Exploratory investigation for potential application in geopolymer concrete" Cement and Concrete Composites, 130, 104526

[22] X. Wang, D. Feng, X. Shi, J. Zhong (2022) "Carbon nanotubes do not provide strong seeding effect for the nucleation of C3S hydration" Materials and Structures, 55(7), 1-17

[23] D. Lu, X. Shi, H. Wong, Z. Jiang, J. Zhong (2022) "Graphene coated sand for smart cement composites" Construction and Building Materials, 346, 128313

[24] D. Lu, X. Shi, J. Zhong (2022) "Interfacial bonding between graphene oxide coated carbon nanotube fiber and cement paste matrix" Cement and Concrete Composites, 134, 104802

[25] D. Lu, X. Shi, J. Zhong (2022) "Nano-engineering the interfacial transition zone in cement composites with graphene oxide" Construction and Building Materials, 356, 129284

[26] Y. Zhang, Y. Deng, X. Shi (2022) "Model development and prediction of anti-icing longevity of asphalt pavement with salt-storage additive" Journal of Infrastructure Preservation and Resilience, 3(1), 1-28

[27] H. Peng, Y. Yang, Y. Ge, Y. Li, X. Shi (2022) "Metakaolin-Based Geopolymer Features Different Pore Structure Characteristics from Ordinary Portland Cement Paste: A Mechanistic Study", Journal of Materials in Civil Engineering ASCE, 34(12), 04022321

[28] F. Ma, J. Lee, D. Camenzind, M. Wolcott (2022) "Probabilistic Wildfire risk assessment methodology and evaluation of a supply chain network" International Journal of Disaster Risk Reduction, 82, 103340

[29] Ji Yun Lee, Fangjiao Ma, Yue Li (2022) "Understanding homeowner proactive actions for managing wildfire risks" Natural Hazards, 114, 1525-1547

Technical Reports

[1] J. Liu, F. Zhou, P. Romero, Y. Wang, and B. Lin, "Development of Holistic Methodologies for Improving Asphalt Mix Durability", TriDurLE Final Report, Missouri S&T, MO, 2022.

[2] X. Hu, Q. Tang, and J. Liu, "Analyzing the Impact of Autonomous Maintenance Technology to Transportation Infrastructure Capacity for Condition Monitoring and Performance Management", TriDurLE Final Report, Pennsylvania State University, PA, 2022.

[3] Ashour, M. and Abbas, A. "Evaluation of Downdrag Loads on Bridge Pile Foundations in Inundated Collapsible Soils." TriDurLE Final Report, Alabama A&M University, AL, 2022.

[4] Hart, K. and Tazarv, M. "Repairable Precast Bridge Bents for Seismic Events," TriDurLE Final Report, South Dakota State University, SD, 2022.

[5] Romero, P. and VanFrank, K. "Multi-Laboratory Testing of IDEAL-CT." Report No UT-22.15. Utah Department of Transportation Research and Innovation Division. July 2022

[6] Y. Deng, C. Chen, X. Shi "Prediction of Traffic Mobility Based on Historical Data and Machine Learning Approaches" CAMMSE-UNCC-2022-UTC-Project-15, August 2022

[7] J. Lee, J. Zhao "Effect of Connected and Autonomous Vehicles on Supply Chain Performance" CAMMSE-UNCC-2021-UTC-Project-10, August 2022

[8] J. Lee, G. Yan "Rebuilding after a tornado: the role of homeowners insurance in recovery" Natural Hazards Center Mitigation Matters Grant Report, September 2022

Presentations

[1] Shi, X., Zhang, Z., Li, Z., He, J. High-Strength Engineered Cementitious Composites with Nanosilica Incorporated: Mechanical Performance and Autogenous Self-Healing Behavior. ACI Fall Convention, Dallas, TX, Oct. 23-27, 2022.

[2] Shi, X. "Nanotechnology is Key to More Sustainable and Durable Concrete Infrastructure" invited presentation by Sellen Construction Company, Seattle, WA. July 14th, 2022.

[3] X. Zhang. "Recent Advances in Measuring Volume of Soil Specimen in Triaxial Testing", TriDurLE webinar series, July 29th, 2022.

[4] J. Liu. "Impacts of Lightweight Aggregates ACEs on Pavement Performance in Alaskan Permafrost Regions", International Conference on Transportation & Development, May 31- June 3, 2022.

[5] J. Liu. "Impact of Deicers on Low-temperature Performance of Missouri Pavements", International Conference on Transportation & Development, May 31- June 3, 2022.

[6] X. Zhang. "Automated Detection and Characterization of Cracks on Concrete Using Remote Sensing", International Conference on Transportation & Development, May 31- June 3, 2022.

[7] X. Zhang. "Measuring Full Field Displacement of Soil Specimen during Triaxial Testing", International Conference on Transportation & Development, May 31- June 3, 2022.

[8] Fungi-mediated/-inspired rapid self-healing of concrete to restore water tightness and recovery strength, BRACE program idealization workshop, April 2022

[9] M.M. Rahman, A Study on the Bond between GFRP Bars and Concrete: Fracture Tests of Notched Beams. Case Western Reserve University

[10] Dr. Presuel gave a presentation at the 12th Annual Structures Research Update Meeting, Florida Department of Transportation, on August 9, 2022

[11] Tazarv, M., Hart, K., Sjurseth, T. "Precast Buildings and Bridges with Replaceable Fuses," ASCE Structures Congress, Atlanta, GA, April 22nd, 2022.

[12] Tazarv, M., Won, K., Jang, Y., Hart, K., and Greeneway, E. "Post-Earthquake RC Bridge Column Assessment Using Computer Vision and Seismic Analysis," ASCE Structures Congress, ASCE Seismic Effects Committee, Atlanta, GA, April 20th, 2022.

[13] Tazarv, M. "UAS Innovations in South Dakota – Academic Perspective," South Dakota Unmanned Aerial Systems (UAS) Workshop, Virtual Workshop, April 20th, 2022.

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

TriDurLE Website: https://tridurle.wsu.edu
BEI Website: http://www.beibridge.org
SDSU Project Websites:
Post-Earthquake Serviceability of RC Bridge Bents Using Visual Inspection
https://sites.google.com/people.unr.edu/mostafa-tazarv/research/post-event-serviceability
Drone-Based Measurements for Bridge Field Testing,
https://sites.google.com/people.unr.edu/mostafa-tazarv/research/drone-based-measurement
Repairable Precast Bridge Bents for Extreme Events
https://sites.google.com/people.unr.edu/mostafa-tazarv/research/repairable-bridge-bents

- It is noteworthy that the following news story from Washington State University: "Disposable masks could be used to make more durable concrete (April 27, 2022)" resulted in great visibility of the research worldwide, covered by 100+ news articles. The work was based on: Li, Z., Zhang, Z., Fei, M. E., & Shi, X. (2022). Upcycling waste mask PP microfibers in portland cement paste: Surface treatment by graphene

oxide. *Materials Letters*, *318*, 132238. One year three project at WSU will continue this line of research and extend the upcycling of used medical masks to the upcycling of waste clothes in concrete. This work has brought great visibility to the National UTC TriDurLE.

3.3 Technologies or techniques

- Dr. Banaei-Kashani has developed adaptations and extensions of 5 time-series anomaly detection methods for early detection of anomaly in bridge performance.
- Dr. Haifang Wen developed the Mode-II fracture test for cementitious bi-material interface
- Dr. Mostafa Tazarv developed the autonomous damage detection software for RC bridge columns using AI-based computer vision.
- Dr. Pierre-Phillipe Beaujean employed a non-linear solver using the Trust-Region Reflective (TRR) algorithm to match a set of synthetic data to the Biot-Stoll model.
- Dr. Mohamad Ashour developed the software package of pile-drag computer program for piles under downdrag forces

3.4 Inventions, patent applications, and/or licenses

- At Washington State University, the following non-provisional patent was filed by Dr. Xianming Shi and Dr. Jing Zhong: Graphene oxide fine aggregate in cement composites (filed on April 19, 2022).

- The University Tech Transfer office of Case Western Reserve University has pursued patent application process on the self-healing concrete technology of Dr. Xiong (Bill) Yu

3.5 Other output

Nothing to report.

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4. OUTCOMES

4.1 Increased understanding and awareness of transportation issues

At UCD, Dr. Kim's group aims to understand the core of durability issue of transportation infrastructure and to provide cost-effective solutions. Dr. Marshall's team is helping researchers and municipalities in their collection of sidewalk metrics so that they can improve their asset management capability and better prioritize investments in sidewalk and bicycling infrastructure. Dr. Farnoush Banaei-Kashani increased the awareness of CDOT bridge engineers about computation solutions that can help them perform their daily tasks.

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

Nothing to report.

4.3 Increases in the body of knowledge

Dr. Jimmy Kim's projects used the agent-based modeling approach, which is recognized in computational sociology, to advance the success of using modeling methods to solve the durability problem of constructed bridge columns. Dr. Wesley Marshall's work increases the usefulness of remote sensing technologies for measuring and understanding the provision of sidewalk and bicycling infrastructure. Dr. Farnoush Banaei-Kashani generated and evaluated promising computation and data-driven solutions for bridge anomaly detection.

Dr. Chris Pantelide's research improved the understanding of time to corrosion and what it takes to achieve slight corrosion versus severe corrosion.

The concrete-shotcrete interface study conducted by Dr. Haifang Wen's team specifically focuses on the interface bond performance than the individual material performance with respect to short term tensile and shear strength and long-term frost resistance for varying substrate surface preparation techniques. Such a detailed analysis on the bond has not been conducted before for shotcrete-concrete bi-material interfaces.

Results indicate that the fracture energy is a more sensitive parameter to the variations in the surface preparation technique than bond strength (shear or tension).

4.4 Improvement of existing techniques, practices, technologies

Technical findings from Dr. Jimmy Kim's research suggest novel solutions that can enhance existing techniques with an emphasis on evaluation and repair. Dr. Wesley Marshall's research finds that remote sensing and planimetric data enables sufficient data collection from sidewalk and bicycling infrastructure, which will provide cities with improved aptitude for asset management, prioritizing investments, and improving upon disparities. Dr. Farmoush Banaei-Kashani's research not only adapted several existing methods to deploy for anomaly detection in bridge performance, but also introduced an ensemble method that outperforms these methods.

Dr. Christian Carloni's team is developing a new approach to determine the crack opening in RC structures reinforced with FRP bars and we are proposing a new test method for the bond of the FRP bars.

Dr. Mostafa Tazarv's team developed the autonomous damage detection software for RC bridge columns using AI-based computer vision, which will significantly expedite and facilitate the post-earthquake response. 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. Novel repairable details for RC bridge columns have been developed and the performance was evaluated through large-scale RC bridge column testing. Digital Image Correlation (DIC) to extract structural responses was implemented using opensource software and low-cost cameras. Computer vision and other technologies such as lidar will be used to facilitate bridge inspections.

Dr. Chris Pantelides' research improved the understanding numerical modeling techniques for incorporating slight and severe corrosion.

4.5 Enlargement of the pool of trained transportation professionals

TriDurLE has implemented several initiatives to assist in and help fund students to work in TriDurLE laboratories, as stated previously. Several TriDurLE universities are graduating doctoral and master's degree students who have been conducting research and receiving training by TriDurLE faculty (see earlier sections). Undergraduate students are also hired as research assistants to have professional training for lab tests and field inspections. These graduates will help enlarge the pool of trained transportation professionals.

4.6 Incorporation of new techniques, practices, technologies

Dr. Farmoush Banaei-Kashani and his team plan to integrate the methods they have developed into a software tool for bridge asset management, which will be used by Colorado Department of Transportation Bridge Engineering Team.

A mode-II fracture-mechanics based test method was designed and developed by Dr. Haifang Wen and Dr. Pizhong Qiao at WSU. This test has the potential to analyze other types of bi-material interfaces in addition to concrete-shotcrete interface bonds. The investigators expect to develop the proposed mode-II fracture test as a standard test method in the future.

5. IMPACTS

The National UTC TriDurLE conducts a variety of research, education and outreach, workforce development, technology transfer, and diversity activities.

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

The results of Dr. Haifang Wen's project can help industry practitioners decide between the most effective substrate surface preparation technique. Note that most common techniques in the industry have been evaluated here, and hence are directly applicable to the practitioners. Furthermore, the new mode-II fracture

based test method can be developed into a more robust testing technique for analyzing cementitious bi-material interfaces, especially in concrete repairs.

5.2 What is the impact on other disciplines?

Dr. Farnoush Banaei-Kashani has introduced a new ensemble learning method that extends the computer science literature on anomaly detection, and can be used with other applications.

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

The undergraduate students trained under Dr. Farnoush Banaei-Kashani's project are graduating soon and considering transportation agencies (among others) as potential alternatives for a career. They have also incorporated results of their project in course materials, which will in turn encourage a larger body of students to engage with the transportation sector.

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

Dr. Farnoush Banaei-Kashani's project has inspired the building of a large multi-disciplinary team of researchers at the university focusing on the extended topic of Infrastructure Informatics. This project has recently received considerable funding from the university to pursue joint research in this area.

5.5 What is the impact on technology transfer?

Dr. Farnoush Banaei-Kashani started a new collaboration with Colorado Department of Transportation to tech transfer their findings to practice.

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

Anomaly detection in Dr. Farnoush Banaei-Kashani's research can identify bridge failures, which are frequent and catastrophic with considerable fatalities. Moreover, it enables optimization of bridge maintenance, which in turn can save significant cost for the taxpayers.

The AI-based computer vision bridge serviceability assessment tool developed by Dr. Mostafa Tazarv is expected to help the 16 seismic-prone states of the nation to evaluate affected bridges quickly and safely after earthquakes, which will save time, costs, and lives. The repairable RC bridge column detailing developed at SDSU allows quick (e.g., a few hours) and low cost (e.g., use of a few bars or tendons) repair of RC bridge columns. The detailing, which was found feasible and robust, has combined the benefits of accelerated bridge construction (ABC) with low-damage and repairable detailing. Structural displacement measurement at sub-millimeter accuracy using drones is novel and can revolutionize bridge field testing by eliminating conventional sensors. Most inspection-related field measurements are done manually. Computer vision and other technologies such as lidar can significantly automate the field measurements and reduce the inspection effort, time, and cost.

6. CHANGES/PROBLEMS

6.1 Changes in approach and reasons for change

In Dr. Haifang Wen's project, the tensile bond test was conducted using a laboratory-based tensile test apparatus, as opposed to the proposed pull-off test because the team was unable to rent/acquire a pull-off testing machine due to the cost and unavailability. The cylindrical samples were extracted from the panels using water-jetting as opposed to coring to avoid saw-cutting. Instead of a peridynamic model, a non-linear cohesive zone model was used to numerically simulate the mode-II fracture test of the concrete-to-shotcrete interface bond.

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

Nothing to report.

6.3 Changes that have a significant impact on expenditure

The cost of materials (wood and steel) has reduced the ability to perform additional tests in Dr. Christian Carloni's project.

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

1. **Website:** https://tridurle.wsu.edu/
2. **Directory of Advisory Board:** Available on the program website: https://tridurle.wsu.edu/advisory-board/
3. **Directory of Key Personnel:** Available on the program website: https://tridurle.wsu.edu/staff/
4. **Financial and Annual Recipient Share Reports:** The Federal Financial Report (SF-425) requirements will be met by separate reports.
5. **Research Project Descriptions:** Available on the program website https://tridurle.wsu.edu/research/

APPENDIX

Table B1. summarizes the 2021 and 2022 Research Projects at TriDurLE. Please visit https://tridurle.wsu.edu/research/ for more information and to view 2020 projects.

2021 Research Projects	PIs and Co-PIs	University
Using Deep Learning for Accurate Detection of Bridge Performance Anomalies	Farnoush Banaei-Kashani Chris Pantelides	University of Colorado Denver University of Utah
Design of Fly Ash-based Geopolymer Concrete-filled FRP Tube Composite for Highly Durable and Environmentally Friendly Infrastructure	Xianming Shi	Washington State University
Developing High-performance Nanocomposite Coating for Steel Reinforcement Protection in Chloride-rich Concrete	Xianming Shi	Washington State University
Development of Microcapsule-based Self-healing, High-strength Engineered Cementitious Composites (SHHS-EE)	Xianming Shi Liang Fan	Washington State University
Sustainable nHPC Mixtures for Durable Overlay of Concrete Bridge Decks in Cold Regions: Proof of Concept	Xianming Shi Jialuo He	Washington State University
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
Preparation of Pavement Infrastructure for Connected and Autonomous Vehicle Deployment – Phase I	Xianbiao Hu Jenny Liu	Missouri University of Science & Technology
Drone-based Measurements for Bridge Field Testing	Mostafa Tazarv Marco Ciarcia Kwanghee Won	South Dakota State University
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
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
Seismic Performance and Fragility of Retrofitted Reinforced Concrete Bridge Columns to Long-duration Earthquakes	Adam Phillips Chris Motter	Washington State University
Assessment and Evaluation of Post-liquefaction Lateral Spread Impact on Bridge Deep Foundations	Mohamad Ashour Sudip Bhattacharjee	Alabama A&M University
Use of Recycled Plastics in Asphalt Pavement (Yr 2)	Jenny Liu Xinhua Liang	Missouri University of Science & Technology
AI-based Prediction Models for Transportation Infrastructure Asset Management Data Hub – Phase I	Xianbiao Hu Jenny Liu	Missouri University of Science & Technology
Effects of Combined Carbonate and Biofilm on Shrinkage Cracking in Unsaturated Cementitiously Stabilized Soils Using Microcapsules	Xianming Shi	Washington State University
Repairable Precast Bridge Bents for Extreme Events	Mostafa Tazarv	South Dakota State University
UAV-enabled Structure-From-Motion Photogrammetry for Bridge Crack Detection and Characterization	Xiong Zhang Jenny Liu Genda Chen	Missouri University of Science & Technology
A Multiple-camera System to Determine the Absolute Volume of Soil Specimen During Dynamic Triaxial Testing (Yr 1)	Xiong Zhang Jenny Liu	Missouri University of Science & Technology
The (In)Equitable Distribution of Quality Bicycling Infrastructure	Wesley Marshall Nicholas Ferenchak	University of Colorado Denver University of New Mexico

Durability of Transverse Sawcut Joints in Midwestern Jointed Concrete Pavements	Dan Zollinger Jenny Liu	Texas A&M University Missouri S&T
Development of Infrastructure Research Weekly APP	Xianming Shi Kakan Dey	Washington State University West Virginia University
Developing Enhanced Performance Curves of ITD Asphalt Pavements by Mining the Historical Data	Xianming Shi Yong Deng	Washington State University
Comparing the Performances of Different Wicking Fibers for Water Removal for Transportation Applications	Xiong Zhang Xinhua Liang	Missouri University of Science & Technology
Corrosion Propagation Monitoring Legacy Samples and Forensic Analysis on Selected Sample	Francisco Moreno-Presuel	Florida Atlantic University
Poro-Elastic Modeling and Measurement of Rebar Corrosion and Crack Formation Using High Frequency Ultrasonics	Pierre-Phillipe Beaujean	Florida Atlantic University
Upcycling agro wastes as additions for sustainable roadway anti-icing operations	Xianming Shi	Washington State University
2022 Research Projects	**Pls and Co-Pls**	**University**
Computer Vision Tools for Bridge Inspections and Reporting	Mostafa Tazarv Kwanghee Won	South Dakota State University
Current state of simulated deck samples cast with corrosion resistant alloys (>16 years)	Francisco Moreno-Presuel	Florida Atlantic University
Protective Performance of Externally-Bonded, Nano-Modified FRP for Concrete	Xianming Shi	Washington State University
Nanomodified Cementitious Composites Incorporating Waste Polymer Microfibers for Durable and Environmentally Friendly Infrastructure	Xianming Shi	Washington State University