Final Report:
Project Number and Title: 3.19 Detection and Monitoring of Material Aging and Structural Deterioration using Electromagnetic and Mechanical Sensors with Virtual Reality and Machine Learning Modeling
Research Area: Thrust 1: Transportation infrastructure monitoring and assessment for enhanced life
PI: Tzuyang Yu (UMass Lowell)
Co-PI(s): Jianqiang Wei (UMass Lowell)
Reporting Period: 01/01/2022 ~ 09/30/2025
Submission Date: 09/30/2025

****IMPORTANT: Please fill out each section fully and reply with N/A for questions/sections with nothing to report. For ease of reporting to the USDOT, please do not remove, or change the order of, any sections/text. You may remove/add each row in tables as needed. Thank you! ****
The report is due on the last day of the reporting period in .doc format to tidc@maine.edu.

Summary of the project:

The research problem we are trying to solve is the detection and monitoring of aging civil infrastructure components and systems in New England by using visual information and subsurface images in a virtual reality (VR) environment for data visualization and machine learning (ML) for data interpretation. The overall research objective is to study the detection and monitoring problem of aging civil infrastructure components and systems in New England by using visual information and subsurface images in a virtual reality (VR) environment for data visualization and machine learning (ML) for data interpretation.

- New GPR B-scan image datasets have been created for the nondestructive inspection and structural health monitoring of a highway bridge in Massachusetts.
- New XRD data have been developed for material aging study.
- We monitored a RC highway bridge (I-495, Chelmsford, MA) by collecting high-frequency GPR B-scan images for about two year on 186 days.
- We analyzed the material samples collected from the RC highway bridge for material aging characterization.
- We developed a VR chamber for training transportation professionals.
- We proposed and applied a new Deep Learning model (Power2Net) to predict steel rebar corrosion in GPR B-scab images without using any environmental data.

Overview:

- We have collected more GPR B-scan images of intact and corroded concrete bridge piers from I-495 bridge in Chelmsford, MA since last quarter to continue studying the detectability (signal-to-noise ratio) of corroded reinforced concrete.
- For field GPR B-scan images of **corroded** concrete bridge piers, we have been developing pattern recognition algorithms to study the pattern in GPR images and correlate it with the level of steel rebar corrosion.
- For field GPR B-scan images of **intact** concrete bridge piers, we have been studying the backscattering pattern of different concretes to understand the impact of background variation on corrosion detectability on concrete structures.

Meeting the Overarching Goals of the Project:

How did the previous items help you achieve the project goals and objectives? Please give one bullet point for each bullet point listed above.

- We analyzed the noisy ground-penetrating radar (GPR) images of a corroded RC bridge piers by using the ML model.

Accomplishments:

- We have designed and manufactured laboratory concrete specimens for material aging study.
- We developed an ML model for data interpretation.

Task, Milestone, and Budget Progress:

Complete the following tables to document the work toward each task and budget (add rows/remove rows as needed, make sure you complete the Overall Project progress row and include all tasks even if they have ended or have not been started)…

Table 1: Task Progress

Task Number: Title	Start Date	End Date	% Complete
Task 1: Selection of candidate transportation infrastructure systems for high-frequency NDT inspection	6/1/22	6/31/22	100%
Task 2: Collection of high inspection frequency NDT sensor data from transportation infrastructure systems	6/15/22	7/31/25	100%
Task 3: Laboratory and field investigation of material aging with sensor data	7/1/22	7/31/24	100%
Task 4: Manufacturing of concrete specimens with simulated material aging problems	7/1/22	7/31/24	100%
Task 5: Training and development of ML/AI models with NDT sensor data	11/1/22	7/31/25	100%
Task 6: Development of predictive models for material aging and structural deterioration	6/1/22	7/31/25	100%
Task 7: Meetings, Documentation, dissemination, and reporting	6/1/22	7/31/25	100%

Table 2: Milestone Progress

Milestone #: Description	Corresponding Deliverable	Start Date	End Date
Milestone 1: Selection of candidate structures for high inspection frequency NDT inspection	Selection of candidate highway bridges in Massachusetts; Quarterly report (9/31/22)	6/1/22	6/31/22
Milestone 2: Development of preliminary NDT sensor data for ML/AI modeling	Collection of NDT sensor data using GPR; Quarterly report (12/31/22)	6/1/22	12/31/22
Milestone 3: Development of baseline model for each new bridge	Development of data processing algorithms for baseline calculation; Quarterly report (12/31/22)	6/1/22	11/1/22
Milestone 4: Development of graphic user interface tool for each bridge	Development of data interpretation model in a VR environment; Quarterly report (12/31/22)	11/1/22	12/31/22
Milestone 5: Development of annual monitoring dataset	Development of annual dataset comprising of visual and NDT inspection information in a VR environment; Quarterly report (3/31/23)	1/1/23	7/31/25

Milestone 6: Development of structural performance curve for each bridge	Development of ML models for processing NDT data to generate structural performance curve of the monitored bridge; Quarterly report (3/31/23)	4/1/23	7/31/25
Task 7: Meetings, Documentation, dissemination, and reporting	Submission of quarterly reports	6/1/22	7/31/25

Include the date the budget is current to.

Match part expenditure:

Table 3: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date (include the date)**
$199,256 (federal)	$199,256 (federal)	100% (federal)

Is your Research Project Applied or Advanced?

☒ **Applied** (*The systematic study to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met.)*

☐ **Advanced** *(An intermediate research effort between basic research and applied research. This study bridges basic (study to understand fundamental aspects of phenomena without specific applications in mind) and applied research and includes transformative change rather than incremental advances. The investigation into the use of basic research results to an area of application without a specific problem to resolve.)*

Education and Workforce Development:

Answer the following questions (N/A if there is nothing to report):

- Did you provide any workforce development or training opportunities to transportation professionals (already in the field)? If so, what was the training? When was it offered? How many people attended? (i.e. The research team provided an in the field training for the SAR technology for 3 maintenance crew members of the , on 3/31/2021. The members learned how to use the technology and interrupt the data.)

Yes, we applied an EM sensor (ground penetrating radar or GPR) on intact and corroded concrete bridge piers in the field on February 20, 2022.

- Did you hold meetings with any transportation industry organizations or DOTs? If so, what was the meeting's purpose? When was it offered? How many people attended? (i.e. The research team held a meeting with MaineDOT to update them on the progress of the research findings and how the findings can be implemented on 3/31/2021. 15 DOT maintenance members were present at the meeting.)
    - N/A
- Did you host/participant in any K-12 education outreach activities? If so, what was the activity? What was the target age/grade level of the participants? How many students/teachers attended? When was the activity held? (i.e. 25 8th graders and 2 teachers visited the concrete lab and created small concrete trinkets like Legos on 3/31/2021. They learned about the different types of fibers that can be used in the concrete.)

- Yes. On three different dates (11/12/24, 11/16/24, and 11/19/24) for the visits of Chelmsford High School students at the senior year at UML. There were nine students and one teacher on 11/12, twenty-six students and three teachers on 11/16, and eight students and one teacher on 11/19. In total, there were 43 students and 5 teachers in these visits. These visits were held in the NDT/SHM Lab in Southwick Hall Room 130.

Technology Transfer:

Complete all of the tables below and provide additional information where requested. Please provide ALL requested information as this is one of the most important sections for reporting to the USDOT. ***ONLY provide information relevant to this reporting period.***

Use the table below to complete information about conference sessions, workshops, webinars, seminars, or other events you led/attended where you shared findings as a result of the work you conducted on this project:

Table 4: Presentations at Conferences, Workshops, Seminars, and Other Events

Type	Title	Citation	Event & Intended Audience	Location	Date(s)
i.e Conference, Symposium, DOT/AOT presentation, Seminar, etc.	Presentation Title	Full Citation	Name of event (i.e. TIDC 1st Annual Conference) or who was the presentation given to?		
Conference presentation	Interpretation of synthetic aperture radar images of concrete by combined uses of image parameters	Tzuyang Yu, Ahmed Alzeyadi, SPIE SS/NDE Symposium, Conference 12047 *Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace, Civil Infrastructure, and Transportation XVI*	International conference & Academics, practitioners, government officials	Long Beach, CA	March 8, 2022
Conference presentation	Application of dual-frequency GPR for subsurface void detection in culverts	Koosha Raisi, Nimun Nak Khun, Tzuyang Yu, SPIE SS/NDE Symposium, Conference 12047 *Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace, Civil Infrastructure, and Transportation XVI*	International conference & Academics, practitioners, government officials	Long Beach, CA	March 8, 2022
Conference paper	Damage Detection of Surface Cracks on Reinforced Concrete	Maryam Abazarsa, TzuYang Yu, Scott Becher, Burak Boyaci, SPIE Smart Structures/NDE Symposium, Proceedings Volume 13436, Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace,	Conference paper	Vancouver, Canada	6/20/25

	Bridge Piers using Virtual Reality	Civil Infrastructure, and Transportation XIX; 134360H (2025) https://doi.org/10.1117/12.3051530			
Conference paper	Leveraging AI and remote sensor technology in transportation infrastructure management	Scott Becher, SPIE Smart Structures/NDE Symposium, Proceedings Volume 13436, Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace, Civil Infrastructure, and Transportation XIX; 134360Z (2025) https://doi.org/10.1117/12.3051510 Event: SPIE Smart Structures + Nondestructive Evaluation, 2025, Vancouver, B.C., Canada	Conference paper	Vancouver, Canada	6/20/25
Conference paper	Hydration of sustainable cementitious composite with internal conditioning by functionalized montmorillonite	Dayou Luo, Jianqiang Wei, Hydration of sustainable cementitious composite with internal conditioning by functionalized montmorillonite, Engineering Mechanics Institute Conference, Baltimore, MD	Engineering Mechanics Institute Conference 2022	Baltimore, MD	June 01, 2022
Conference paper	Exploring the Role of Magnesium Nitrate in Modifying Properties of Alkali-Silica Reaction Gels	Arkabrata Sinha, Jianqiang Wei, Exploring the Role of Magnesium Nitrate in Modifying Properties of Alkali-Silica Reaction Gels, Engineering Mechanics Institute Conference, Baltimore, MD	Engineering Mechanics Institute Conference 2022	Baltimore, MD	June 01, 2022
Conference paper	Multi-Scale Characterization of Alkali-Silica Reaction Gels Modified with Magnesium Nitrate	Jianqiang Wei, Arkabrata Sinha, Dayou Luo, Multi-Scale Characterization of Alkali-Silica Reaction Gels Modified with Magnesium Nitrate, 16th International Symposium on Functionally Graded Materials, Hartford, CT	16th International Symposium on Functionally Graded Materials	Hartford, CT	August 07, 2022
Invited talk	Nondestructive Evaluation of Reinforced Concrete Structures	N/A	Jenike & Johanson Inc.	Tyngsboro, MA	February 9, 2023

Invited talk	Noncontact Quantification of Chloride Ion Content in Concrete Specimens using Radar Images	N/A	Department of Mechanical and Materials Engineering, Worcester Polytechnic Institute (WPI)	Worcester, MA	March 30, 2023
Conference paper	Structural Health Monitoring (SHM) of a Train Model under Traffic Loading	Ritham Batchu, Koosha Raisi, Tzuyang Yu, Structural Health Monitoring (SHM) of a Train Model under Traffic Loading, In: Proceeding of SPIE Smart Structures/NDE Symposium, March 12-15, Long Beach, CA.	SPIE Smart Structures/NDE Symposium	Long Beach, CA	March 15, 2023
Conference paper	Phase Evolution and Property Development of Alkali-Silica Reaction Gel in Carbonation	Arkabrata Sinha, Jianqiang Wei, Phase Evolution and Property Development of Alkali-Silica Reaction Gel in Carbonation, The 16th International Congress on the Chemistry of Cement 2023 (ICCC2023), September 18–22, 2023, Bangkok, Thailand.	The 16th International Congress on the Chemistry of Cement 2023 (ICCC2023)	Bangkok, Thailand	March 16, 2023
Conference paper	Functionalization of Metakaolin with Non-Ionic Surfactants: Swelling and Pozzolanic Reactivity	Dayou Luo, Jianqiang Wei, Functionalization of Metakaolin with Non-Ionic Surfactants: Swelling and Pozzolanic Reactivity, The 16th International Congress on the Chemistry of Cement 2023 (ICCC2023), September 18–22, 2023, Bangkok, Thailand.	The 16th International Congress on the Chemistry of Cement 2023 (ICCC2023)	Bangkok, Thailand	March 16, 2023
Presentation	Enhanced Alkali-Silica Reaction Mitigation by Functionalized Montmorillonite	Dayou, Luo, Jianqiang Wei*, Enhanced Alkali-Silica Reaction Mitigation by Functionalized Montmorillonite, 2023 MassDOT Transportation Innovation Conference, Worcester, MA, May 2-3, 2023	2023 MassDOT Transportation Innovation Conference	Worcester, MA	May 2. 2023
Presentation	Influence of Carbonation on Alkali-Silica Reaction	Dayou Luo, Jianqiang Wei*, Influence of Carbonation on Alkali-Silica Reaction, ASCE Engineering Mechanics Institute 2023 Conference, Atlanta, GA, June 6 – 9, 2023	ASCE Engineering Mechanics Institute 2023 Conference	Atlanta, GA	June 7, 2023
Presentation	Phase and Property Evolutions of Alkali-silica Reaction Gels Under Carbonation	Arkabrata Sinha, Jianqiang Wei*, Phase and Property Evolutions of Alkali-silica Reaction Gels Under Carbonation, ASCE Engineering Mechanics Institute 2023 Conference, Atlanta, GA, June 6 – 9, 2023	ASCE Engineering Mechanics Institute 2023 Conference	Atlanta, GA	June 7, 2023

Presentation (poster)	Phase Evolution and Property Development of Alkali-Silica Reaction Gel in Carbonation	Arkabrata Sinha, Jianqiang Wei*, Phase Evolution and Property Development of Alkali-Silica Reaction Gel in Carbonation. 16th International Congress on the Chemistry of Cement (ICCC 2023), Bangkok, Thailand, Sep. 18–22, 2023.	16th International Congress on the Chemistry of Cement (ICCC 2023)	Bangkok, Thailand	September 18-22, 2023
Presentation (poster)	Functionalization of Metakaolin with Non-Ionic Surfactants: Swelling and Pozzolanic Reactivity	Dayou Luo, Jianqiang Wei*, Functionalization of Metakaolin with Non-Ionic Surfactants: Swelling and Pozzolanic Reactivity. 16th International Congress on the Chemistry of Cement (ICCC 2023), Bangkok, Thailand, Sep. 18–22, 2023.	16th International Congress on the Chemistry of Cement (ICCC 2023)	Bangkok, Thailand	September 18-22, 2023
Presentation (poster)	Electromagnetic Detection and Identification of Concrete Cracking in Highway Bridges	Amirhossein Madadi, Ritham Batchu, Koosha Raisi, Tzuyang Yu*, Jianqiang Wei, Electromagnetic Detection and Identification of Concrete Cracking in Highway Bridges, 2023 Transportation Infrastructure Durability Conference, Orono, ME, Aug. 8-10, 2023.	2023 Transportation Infrastructure Durability Conference	Orono, ME,	August 8-10, 2023
Presentation/ Invited talk	Structural Engineering Research for Sustainable Civil Infrastructure	Tzuyang Yu	Simpson, Gumpertz & Heger / Structural engineers, bridge engineers, material scientists	Waltham, MA	June 29, 2023
Conference presentation	Leveraging AI and remote sensor technology in transportation infrastructure management	Scott Becher, SPIE Smart Structures/Nondestructive Evaluation (SS/NDE) Symposium	International conference / academia (faculty and students), government industry	Vancouver, Canada	March 19, 2025
Conference paper	Damage Detection of Surface Cracks on Reinforced Concrete Bridge Piers using Virtual Reality	Maryam Abazarsa, TzuYang Yu, Scott Becher, Burak Boyaci, SPIE Smart Structures/NDE Symposium, Proceedings Volume 13436, Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace, Civil Infrastructure, and Transportation XIX; 134360H (2025) https://doi.org/10.1117/12.3051530	SPIE SS/NDE Symposium	Vancouver, Canada	May 12, 2025

Conference paper	Leveraging AI and remote sensor technology in transportation infrastructure management	Scott Becher, SPIE Smart Structures/NDE Symposium, Proceedings Volume 13436, Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace, Civil Infrastructure, and Transportation XIX; 134360Z (2025) https://doi.org/10.1117/12.3051510 Event: SPIE Smart Structures + Nondestructive Evaluation, 2025, Vancouver, B.C., Canada	SPIE SS/NDE Symposium	Vancouver, Canada	May 12, 2025

Use the table below to report any publications, technical reports, peer-reviewed articles, newspaper articles referencing your work, graduate papers, dissertations, etc. written as a result of the work you conducted on this project. Please list only completed items and exclude work in progress.

Table 5: Submitted/Accepted Publications, Technical Reports, Theses, Dissertations, Papers, and Reports

Type	Title	Citation	Date	Status
i.e. Peer-reviewed journal, conference paper, book, policy paper, magazine/newspaper article	Publication title	Full citation		**i.e. Submitted, accepted, under review (by org. submitted to)**
Conference paper	Long-Term Monitoring on a New Composite Bridge Girder Based on a Fiber Optic Sensing Textile	Wu, R., Biondi, A., Cao, L., Cui, G., Abedin, S., Wang, X., HarshNareshkumar, G. and Yu, T., 2025, July. Long-Term Monitoring on a New Composite Bridge Girder Based on a Fiber Optic Sensing Textile. In International Conference on Experimental Vibration Analysis for Civil Engineering Structures (pp. 590-597). Cham: Springer Nature Switzerland.	2-4 July 2025	Published
Journal paper	A Deep Learning Model Power2Net for Predicting Steel Rebar Corrosion in Concrete by using Two-Year GPR B-scan Images	Maryam Abazarsa, Tzuyang Yu, *Maryam Abazarsa, Tzuyang Yu, Case Studies in Construction Materials, 2025, e05671, ISSN 2214-5095, https://doi.org/10.1016/j.cscm.2025.e05671.*	12/2025	Published
Journal paper	Mitigating alkali-silica reaction through metakaolin-based internal conditioning: New insights into property evolution and mitigation mechanism	Dayou Luo, Arkabrata Sinha, Madhab Adhikari, Jianqiang Wei*, Mitigating alkali-silica reaction through metakaolin-based internal conditioning: New insights into property evolution and mitigation mechanism, Cement and Concrete Research, 2022,	09/2022	Published

		159, 106888, https://doi.org/10.1016/j.cemconres.2022.106888		
Journal paper	Exploring the role of magnesium nitrate in alkali-silica reaction suppression	Dayou Luo, Jianqiang Wei, Exploring the role of magnesium nitrate in alkali-silica reaction suppression, Cement and Concrete Composites.	12/2022	Published
Journal paper	Understanding the role of a novel internal conditioning technique with functionalized montmorillonite in cement hydration kinetics	Dayou Luo, Jianqiang Wei, Understanding the role of a novel internal conditioning technique with functionalized montmorillonite in cement hydration kinetics, Construction and Building Materials.	12/2022	Published
Journal paper	Long-Term Monitoring on a New Composite Bridge Girder Based on a Fiber Optic Sensing Textile	Wu, R., Biondi, A., Cao, L., Cui, G., Abedin, S., Wang, X., HarshNareshkumar, G. and Yu, T., 2025, July. Long-Term Monitoring on a New Composite Bridge Girder Based on a Fiber Optic Sensing Textile. In International Conference on Experimental Vibration Analysis for Civil Engineering Structures (pp. 590-597). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-96110-6_57	07/2025	Published
Conference paper	Structural Health Monitoring (SHM) of a Train Model under Traffic Loading	Ritham Batchu, Koosha Raisi, Tzuyang Yu, Structural Health Monitoring (SHM) of a Train Model under Traffic Loading, In: Proceeding of SPIE Smart Structures/NDE Symposium, March 12-15, Long Beach, CA.	05/022023	Published
Journal paper	Phase Evolution and Mechanical-Hydroscopic Properties of Alkali-Silica Reaction Gels Modified by Magnesium Nitrate	Arkabrata Sinha, Jianqiang Wei*, Phase Evolution and Mechanical-Hydroscopic Properties of Alkali-Silica Reaction Gels Modified by Magnesium Nitrate (submitted to Cement and Concrete Composites)	05/172023	Published
Journal paper	Hydration and Phase Evolution of Blended Cement Composites Containing Lithium and Saturated Metakaolin	Dayou Luo, Jianqiang Wei*, Hydration and Phase Evolution of Blended Cement Composites Containing Lithium and Saturated Metakaolin, (submitted to Cement and Concrete Composites)	06/02/2023	Published
Journal paper	The Efficacy of Functionalized Sodium-Montmorillonite in Mitigating Alkali-Silica Reaction	Dayou Luo, Jianqiang Wei*, The Efficacy of Functionalized Sodium-Montmorillonite in Mitigating Alkali-Silica Reaction (submitted to Applied Clay Science)	06/24/2023	Published

Conference paper	Functionalization of Metakaolin with Non-Ionic Surfactants: Swelling and Pozzolanic Reactivity	Dayou Luo, Jianqiang Wei*, Functionalization of Metakaolin with Non-Ionic Surfactants: Swelling and Pozzolanic Reactivity, 16th International Congress on the Chemistry of Cement 2023 (ICCC2023), "Further Reduction of CO2-Emissions and Circularity in the Cement and Concrete Industry", Bangkok, Thailand, Sep. 18–22, 2023.	September 18-22, 2023	Published
Conference paper	Phase Evolution and Property Development of Alkali-Silica Reaction Gel in Carbonation	Arkabrata Sinha, Jianqiang Wei*, Phase Evolution and Property Development of Alkali-Silica Reaction Gel in Carbonation, 16th International Congress on the Chemistry of Cement 2023 (ICCC2023), "Further Reduction of CO2-Emissions and Circularity in the Cement and Concrete Industry", Bangkok, Thailand, Sep. 18–22, 2023.	September 18-22, 2023	Published
Journal paper	Phase Evolution and Mechanical-Hydroscopic Properties of Alkali-Silica Reaction Gels Modified by Magnesium Nitrate	Arkabrata Sinha, Jianqiang Wei*, Phase Evolution and Mechanical-Hydroscopic Properties of Alkali-Silica Reaction Gels Modified by Magnesium Nitrate, Cement and Concrete Composites, 2023, 144: 105283	September 04, 2023	Published
Journal paper	Hydration and Phase Evolution of Blended Cement Composites Containing Lithium and Saturated Metakaolin	Dayou Luo, Jianqiang Wei*, Hydration and Phase Evolution of Blended Cement Composites Containing Lithium and Saturated Metakaolin, Cement and Concrete Composites, 2023, 144: 105268.	August 22, 2023	Published
Journal paper	The Efficacy of Functionalized Sodium-Montmorillonite in Mitigating Alkali-Silica Reaction	Dayou Luo, Jianqiang Wei*, The Efficacy of Functionalized Sodium-Montmorillonite in Mitigating Alkali-Silica Reaction, Applied Clay Science, 2023, 245: 107-139.	September 09, 2023	Published
Journal paper	Elucidating the role of magnesium nitrate in alkali-silica reaction: performance and multiscale mechanisms	Dayou Luo, Jianqiang Wei*, Elucidating the role of magnesium nitrate in alkali-silica reaction: performance and multiscale mechanisms	September 25, 2023	Published
Conference paper	Damage detection of a bridge model under traffic loading using short time Fourier transform and wavelet transform	Ritham Batchu, Koosha Raisi, TzuYang Yu, Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace, Civil Infrastructure, and Transportation XVIII	December 15, 2023	Published`

Answer the following questions (N/A if there is nothing to report):

- Did you deploy any technology during the reporting period through pilot or demonstration studies as a result of this work? If so, what was the technology? When was it deployed?
  - Yes, we applied an EM sensor (ground penetrating radar or GPR) on a RC highway bridge for high frequency NDT data collection.

- Was any technology adopted by industry or transportation agencies as a result of this work? If so, what was the technology? When was is adopted? Who adopted the technology?
  - N/A

- Did findings from this research project result in changing industry or transportation agency practices, decision making, or policies? If so, what was the change? When was the change implemented? Who adopted the change?
  - Yes, we shared our findings with engineers at SGH in a visit. We shared various projects undertaken by UML and SGH researchers and decided to continue exploring how we can apply research findings to the projects at SGH.

- Were any licenses granted to industry as a result of findings from this work? If so, when? To whom was the license granted?
  - N/A

- Were any patent applications submitted as a result of findings from this research? If so, please provide a copy of the patent application with your report.
  - N/A

- Did industry organizations or DOTs provide cost-share (cash or in-kind) to your research during the reporting period? Who was the organization? Please provide an in-kind support invoice from the organization with your report (this is kept confidential and used for record keeping purposes only).
  - Yes, Bentely Systems provided their software license for cost share that was submitted in the past.

Please add figures/images that can be included on the website and/or in marketing/social media materials to further clarify your research to the general public. This is very important to our Technology Transfer initiatives.

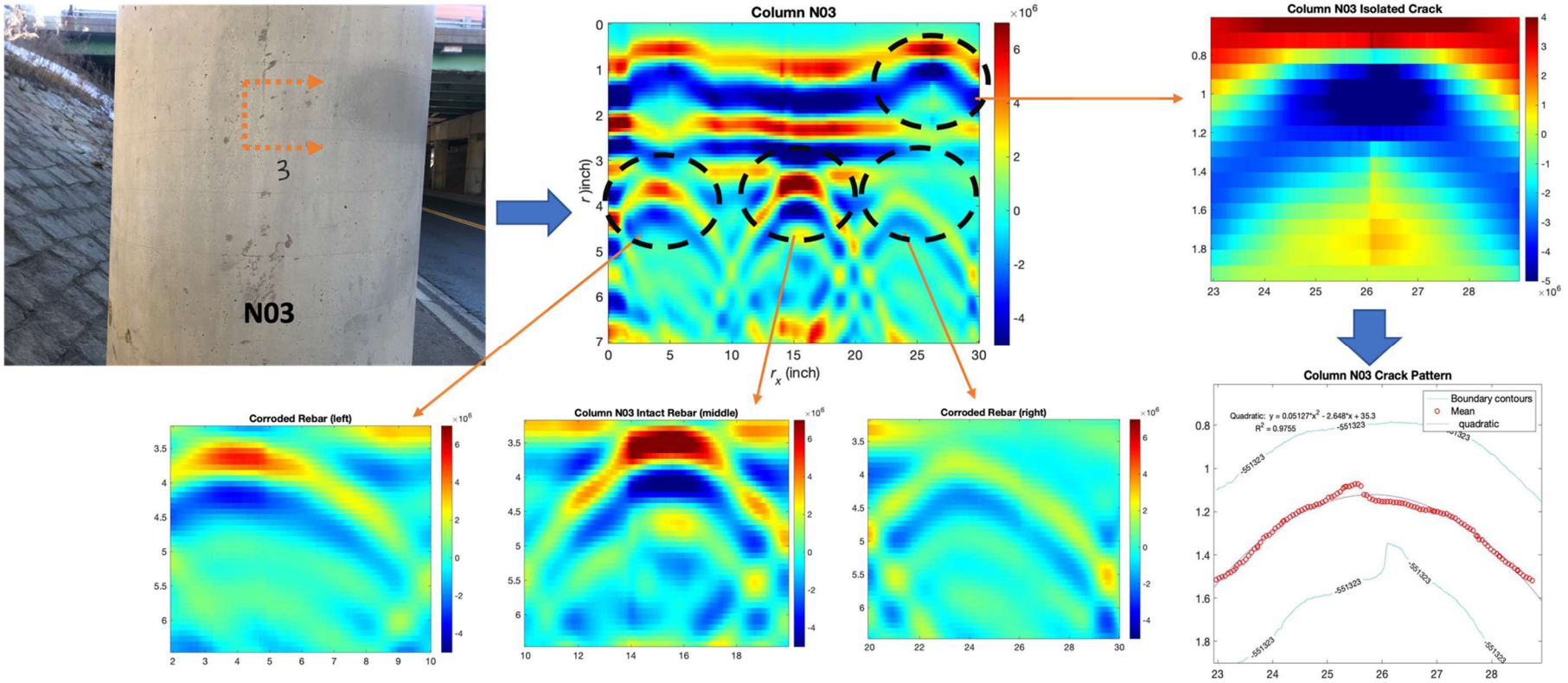

Figure 1. I-495 Bridge pier N03 (Chelmsford, MA) and its GPR B-scan images with extracted pattern

Figure 2. (a) GPR inspection of corroded RC bridge pier column (Koosha and Nak); (b) Visual inspection of RC bridge pier column (PI Yu)

Figure 3. (a) cubes for compressive strength test, (b) beams for flexural strength test, and (c) mortar bars for ASR expansion test.

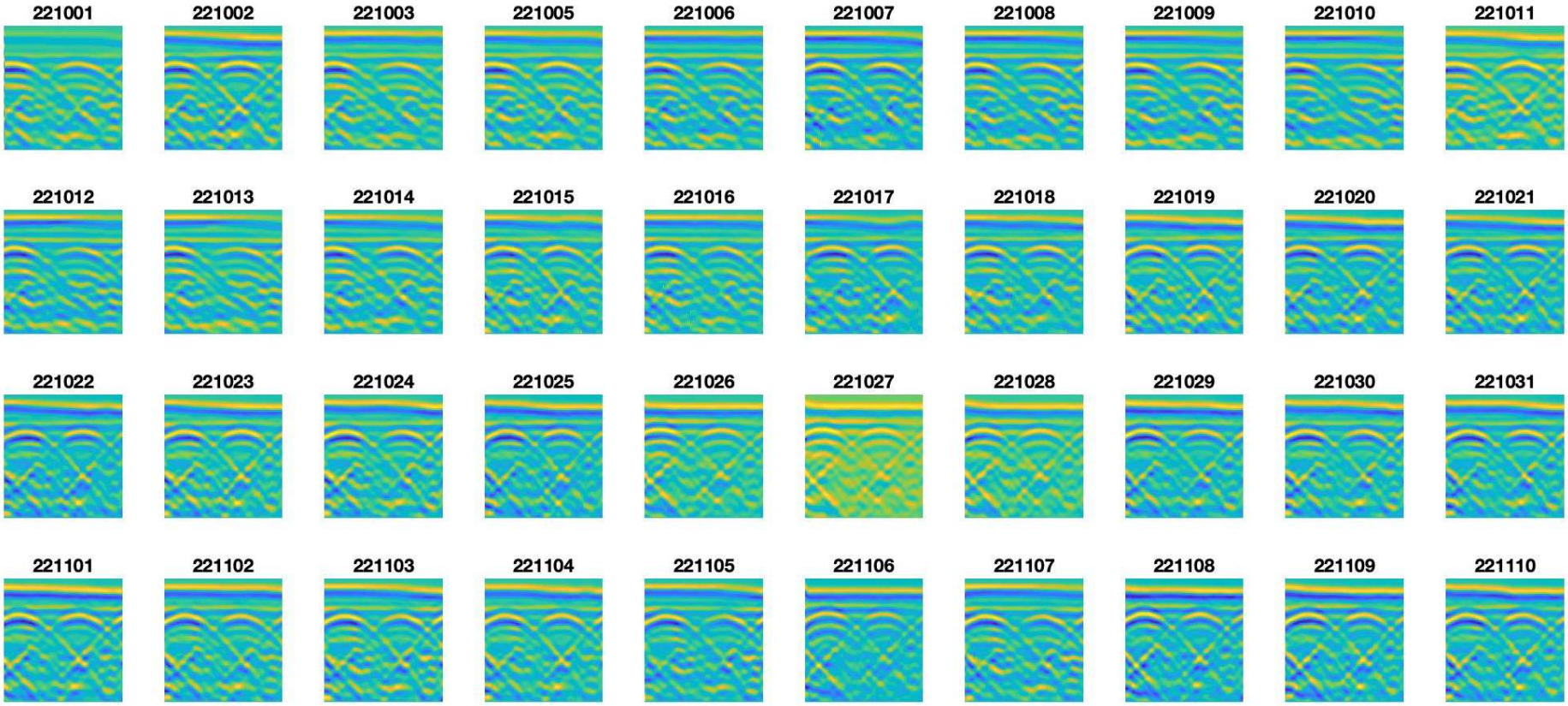

Figure 4. GPR B-scan images of bridge pier W8A – Part 1

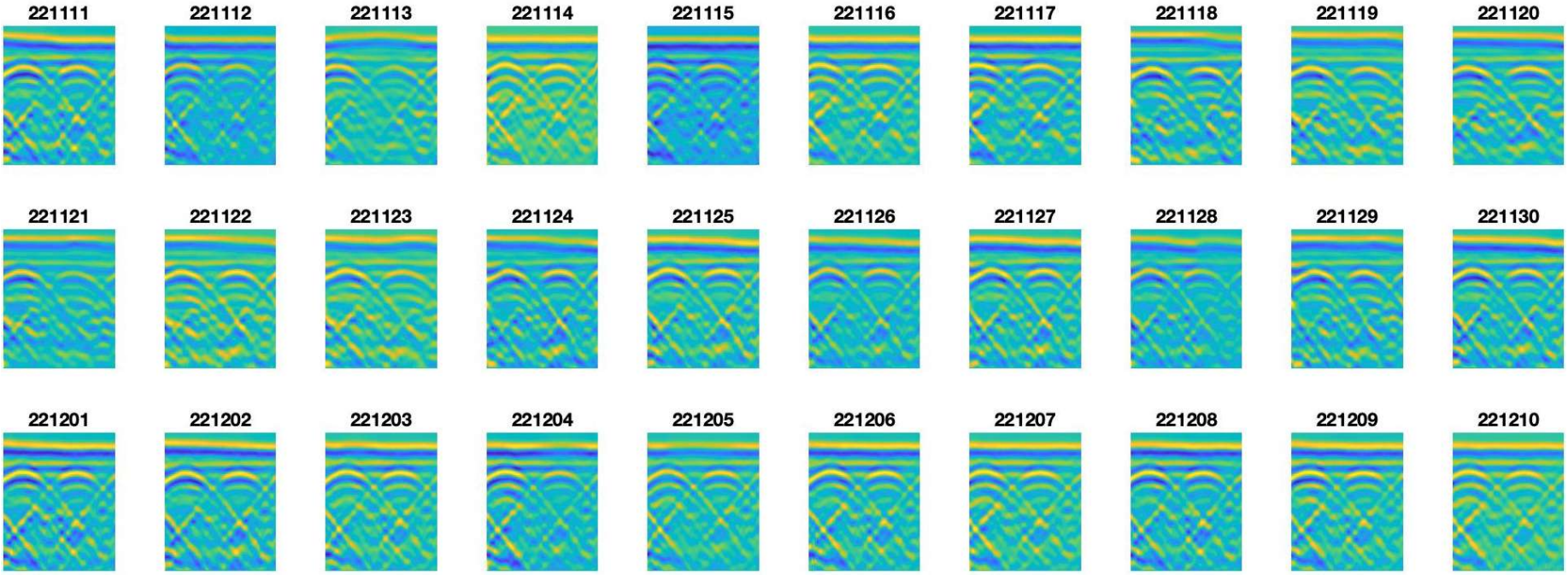

Figure 5. GPR B-scan images of bridge pier W8A – Part 2

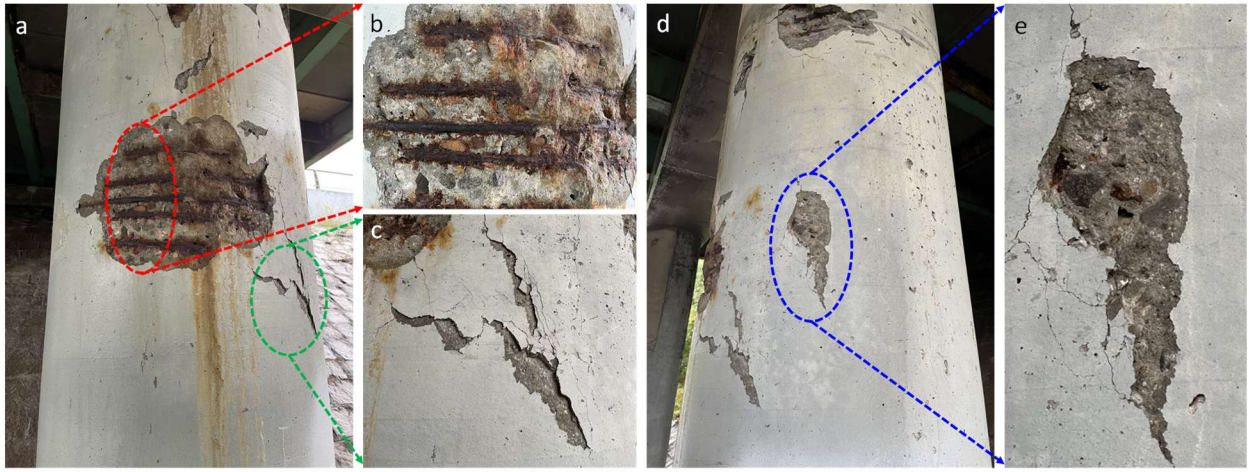

Figure 6.(a) E3 column of the bridge, (b) Sample 1 collected from the corroded rebar area, (c) Sample 2 collected from pier surface, (d, e) Sample 3 collected under surface.

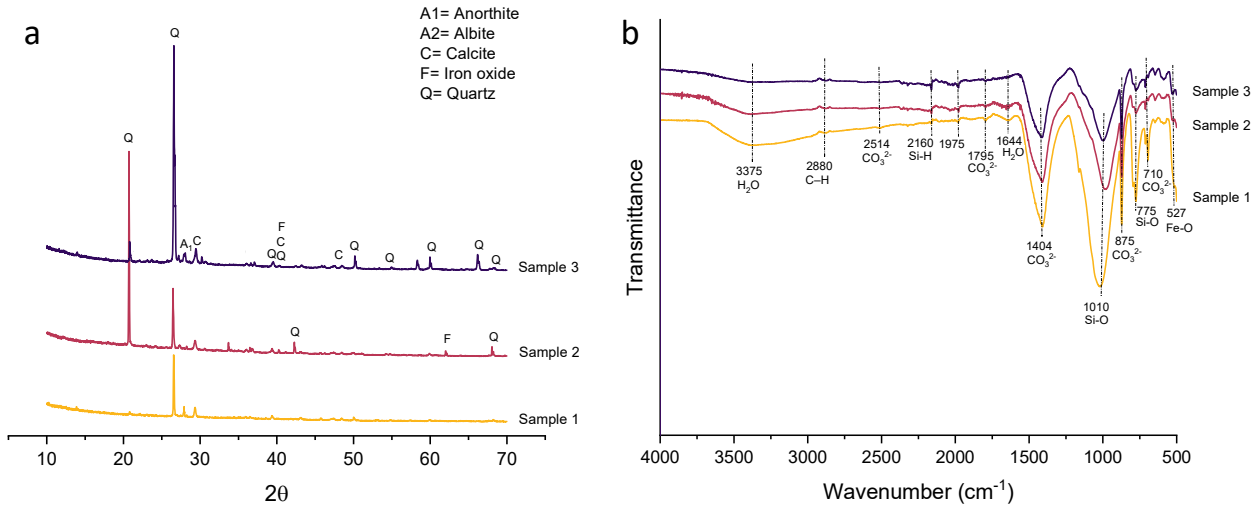

Figure 7. (a) XRD and (b) FTIR analyses of the collected concrete samples from the aged bridge.

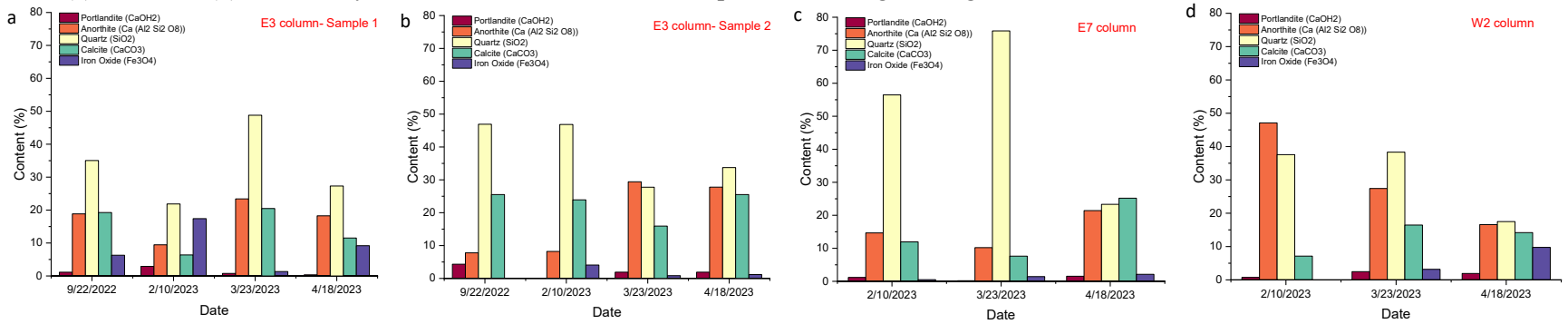

Figure 8. Quantification of reaction products in the concrete samples collected from bridge piers: (a) sample 1 (concrete sample collected from the corroded rebar in pier E3) and sample 2 (concrete sample collected from the surface of pier E3), and (b) sample 3 (concrete sample collected from a crack in pier E7) and sample 4 (concrete sample collected from the corroded rebar in pier W2, which a mix of rust and adjacent cement paste).

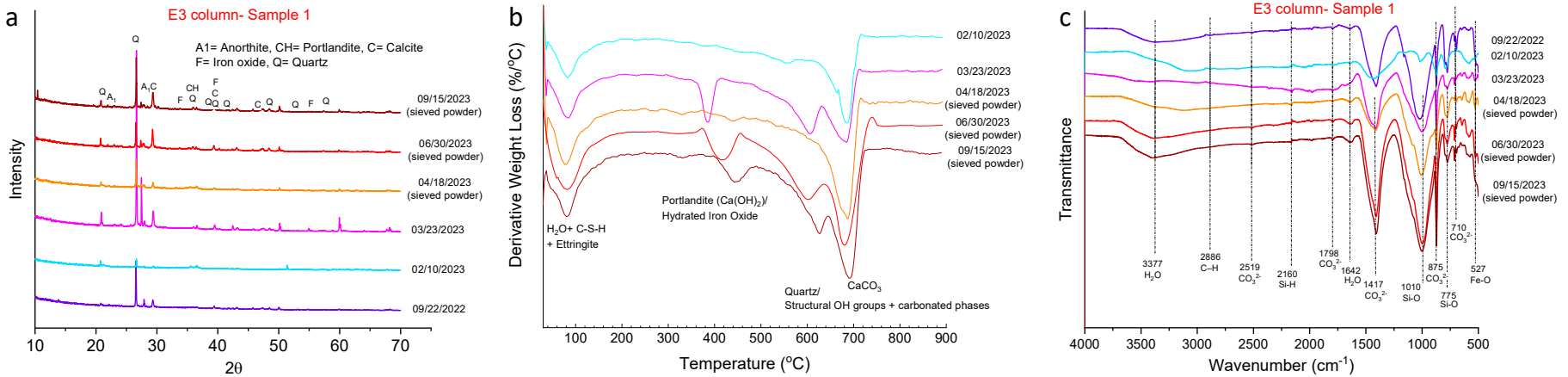

Figure 9. Selected characterizations of reaction products in the concrete samples collected from bridge pier E3 (sample 1: concrete sample collected from the corroded rebar; sample 2: concrete sample collected from the surface of the pier) at different ages: (a) XRD, (b) TGA, and (c) FTIR.

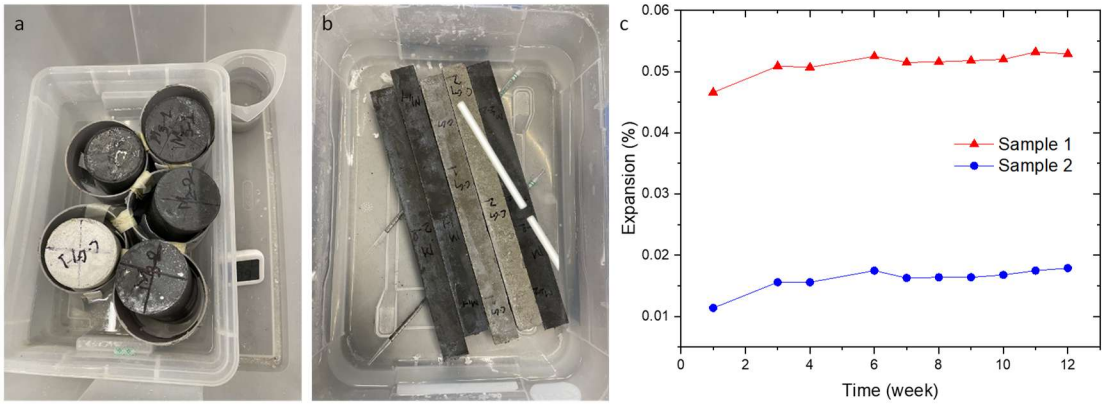

Figure 10. (a) Cylinder samples (NIST) and (b) mortar bar samples (ASTM C1012) for accelerated sulfate attack tests, and (c) the length change of the mortar bars induced by sulfate attack.

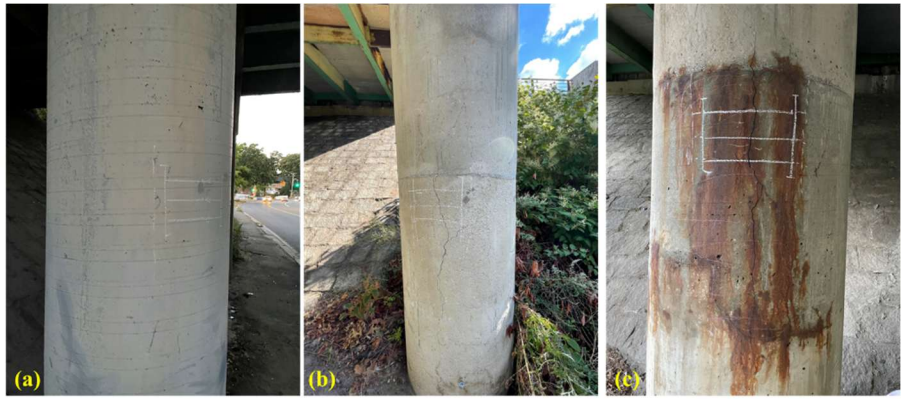

Figure 11. (a) The column without any cracks or rust is labeled as intact (I), (b) the column with surface cracks is labeled as having a moderate corrosion level (MC), (c) the column with both cracks and rust on the surface is labeled as having a severe corrosion level (SC).

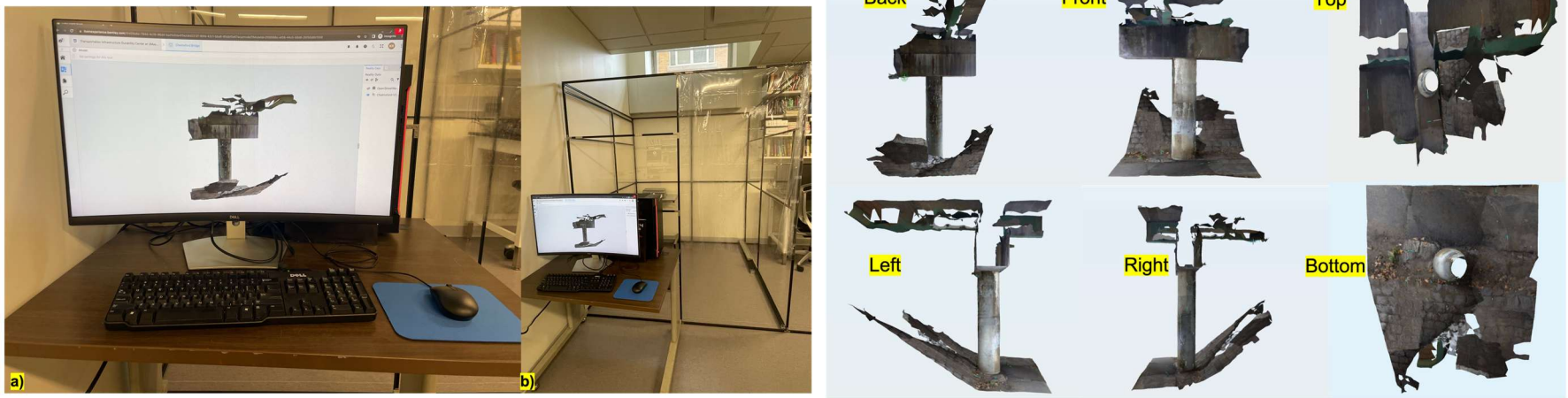

Figure 12. (a) VR desktop (b) VR chamber at UML (c) VR model of a bridge pier

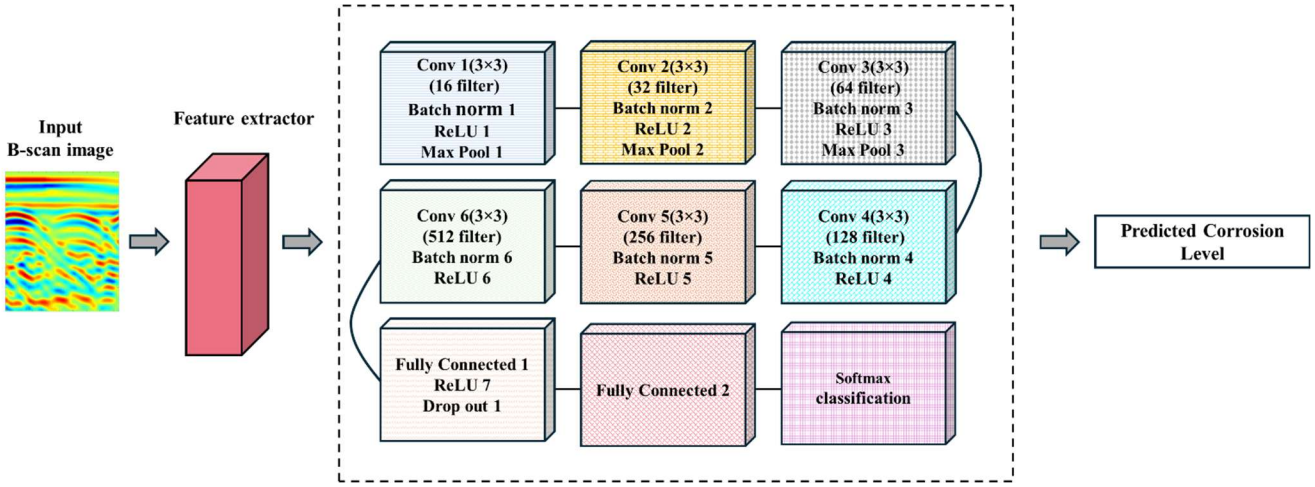

Figure 13. Model framework for corrosion detection in GPR B-scan images.

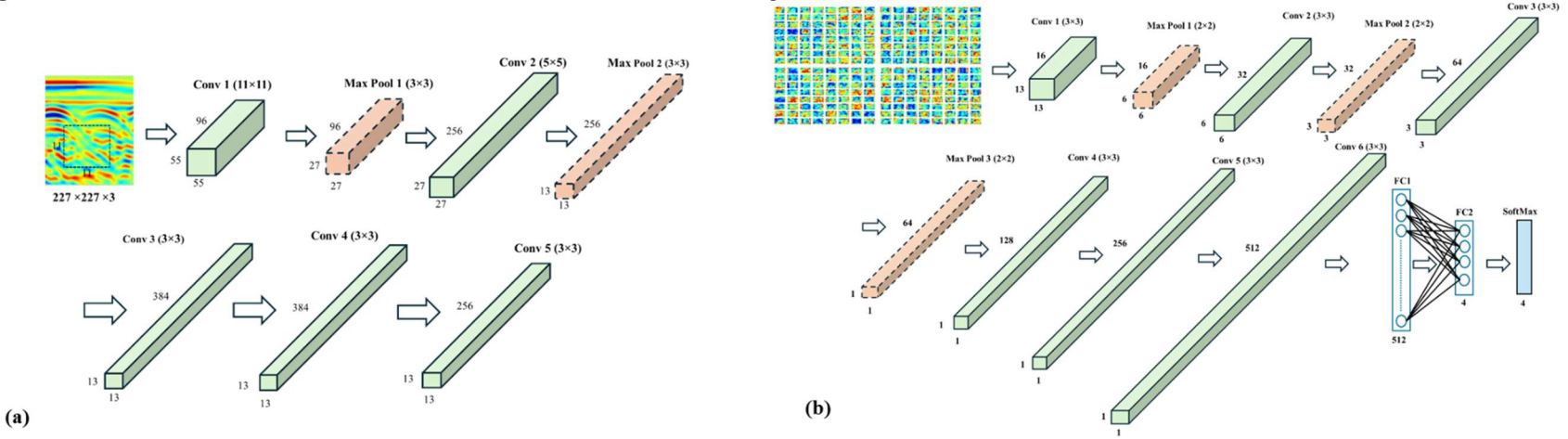

Figure 14. Architecture of the developed ML model for GPR images.

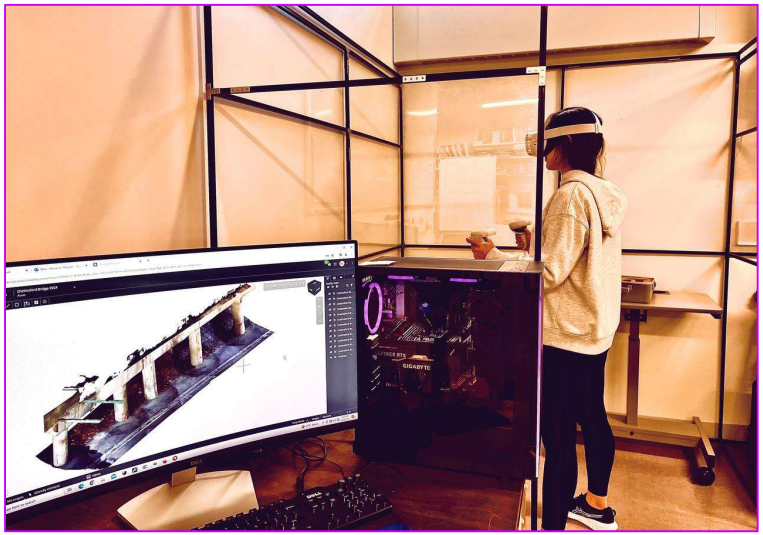

Figure 15. VR chamber at UML.

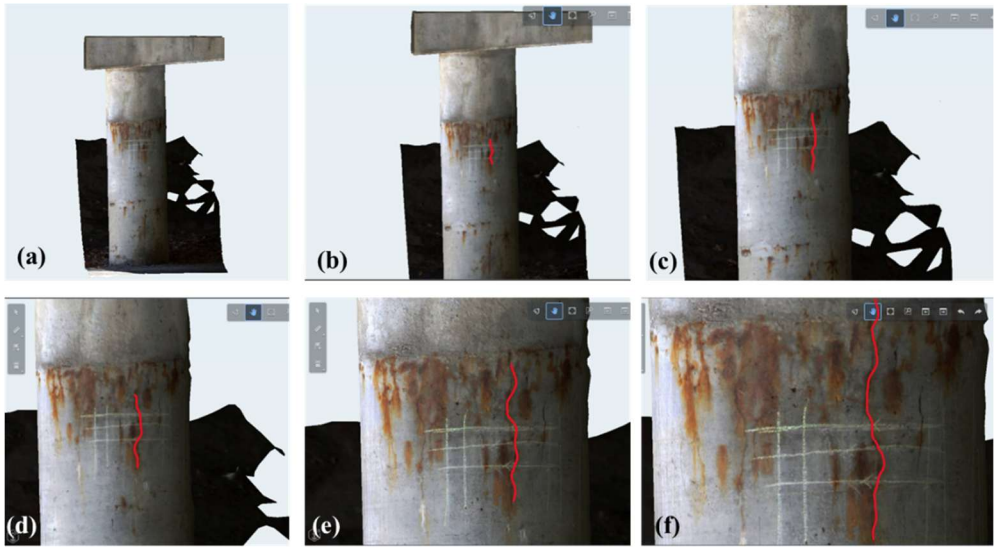

Figure 16. (a) 0% zoom, (b) 10% zoom, (c) 20% zoom, (d) 30% zoom (e) 40% zoom (f) 50% zoom.

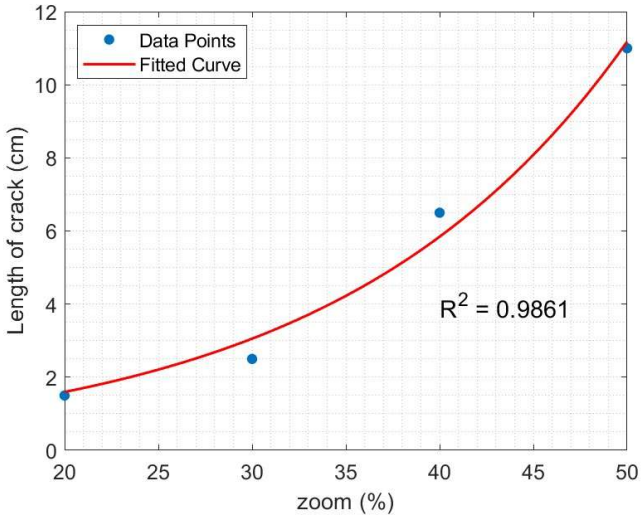

Figure 17. Crack length vs. zoom level.

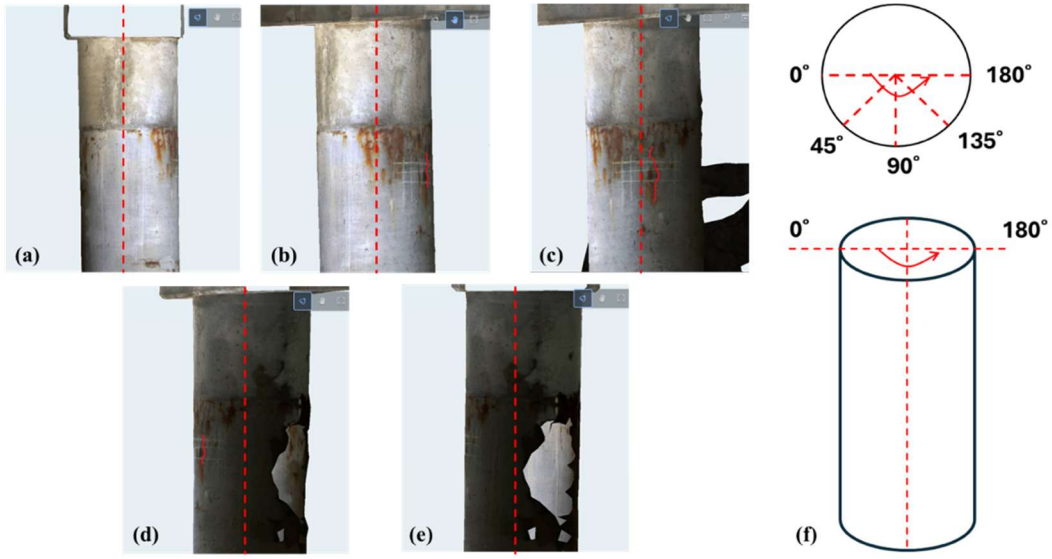

Figure 18. (a) 0˚, (b) 45˚, (c) 90˚, (d) 135˚, (e) 180˚, (f) schematic pattern of angle rotation.

Describe any additional activities involving the dissemination of research results not listed above under the following headings:

Outputs:

Definition: Any new or improved process, practice, technology, software, training aid, or other tangible product resulting from research and development activities. They are used to improve the efficiency, effectiveness, and safety of transportation systems. List any outputs accomplished during this reporting period:

- New GPR B-scan image datasets have been included to our EM database for the nondestructive inspection and structural health monitoring of a highway bridge in Massachusetts.
- New image processing algorithm (written in Matlab) has been developed (and will be further improved) with the GPR B-scan images collected during this period of the project.
- We presented our radar imaging study at the 2022 SPIE Smart Structure/NDE Symposium (Long Beach, CA, March 6~10, 2022) to in-person and online attendees from around the world, through two conference presentations. We have received many questions regarding the use of GPR for concrete characterization.
- Experimental and thermodynamic modeling data of ASR gels under carbonation have been developed.
- Experiments of sulfate attack on concrete has been developed.
- Experimental data for the phase evolution of the reaction products in concrete of bridge piers have been developed.
- Laboratory data for the swelling of ASR gels under different conditions have been developed.
- Expansion data for concrete under sulfate attack have been collected.

Outcomes:

Definition: The application of outputs; any changes made to the transportation system, or its regulatory, legislative, or policy framework resulting from research and development activities. List any outcomes accomplished during this reporting period:

- Example: The developed sensing technology was installed in Bridge A in town, state on 1/1/2021. This installation will… The UAV was successfully used by ___ Organization to inspect ___ Bridge in in town, state on 1/1/2021… The newly created college course was taken/completed by __ students in the 2021 fall semester.

- We presented our ASR study at the 2023 MassDOT Transportation Innovation Conference (May 2-3, 2023, Worcester, MA) to the attendees from FHWA, state DOTs and industry.
- We also presented our ASR study at the ASCE Engineering Mechanics Institute 2023 Conference (Atlanta, GA, June 6-9, 2023) to the attendees from around the world.
- We have submitted two ASR-related papers to Cement and Concrete Composites and one ASR-related paper to Applied Clay Science.
- Our material research papers to the 16th International Congress on the Chemistry of Cement 2023 (ICCC2023) (September 18–22, 2023, Bangkok, Thailand) was presented.

Impacts:

Definition: The effects of the outcomes on the transportation system such as reduced fatalities, decreased capital or operating costs, community impacts, or environmental benefits. The reported impacts from UTCs are used for the assessment of each UTC and to make a case for Federal funding of research and education by demonstrating the impacts that UTC funding has had on technology and education. NOTE: The U.S. DOT uses this information to assess how the research and education programs (a) improve the operation and safety of the transportation system; (b) increase the body of knowledge and

technologies; (c) enlarge the pool of people trained to develop knowledge and utilize technologies; and (d) improves the physical, institutional, and information resources that enable people to have access to training and new technologies. List any outcomes accomplished during this reporting period:

- **Improved Transportation Safety and Monitoring**
  The development of a new modality by using Virtual Reality (VR) for bridge inspection allows bridge engineers from different locations to jointly assess the condition of bridge models (digital twins) represents a next-generation capability to improve transportation safety and monitoring. Our R&D effort in AI/ML also leads to the development of a novel Deep Learning model (Power2Net) that can predict unseen, subsurface steel rebar corrosion in reinforced concrete bridges without the use of environmental data.
- **Contribution to Knowledge and Technology Development**
  The developed VR chamber and a procedure to conduct bridge condition assessment in a VR environment has contributed to the area of virtual bridge inspection. Our prototype VR chamber and the associated computer system also serves as an example for state DOTs to apply virtual bridge inspection technology. Our proposed Power2Net model is a breakthrough in the development of Deep Learning models for radar image processing.
- **Education and Workforce Development**
  We have trained undergraduate and graduate students in our project activities for education and workforce development. We also have hosted many high school students in our laboratories and disseminated our technology through field demonstrations.
- **Enhanced Research Infrastructure**
  Through this project, we established a collaborative research infrastructure with participants from academia and industry (Bentley Systems) to work on the problem and explore the full potential of virtual bridge inspection technology.

Participants and Collaborators:

Use the table below to list individuals (compensated or not) who have worked on the project other than students.

Table 6: Active Principal Investigators, faculty, administrators, and Management Team Members				
Individual Name & Title	**Dates involved**	**Email Address**	**Department**	**Role in Research**
Tzuyang Yu, Professor	1/1/2022 ~ 9/30/2025	Tzuyang_Yu@UML.EDU	Civil and Environmental Engineering	Project principal investigator and Institutional Lead at UML; overseeing all projects and working on radar imaging and interpretation
Jianqiang Wei, Associate Professor	1/1/2022 ~ 8/30/2025	Jianqiang_Wei@UML.EDU	Civil and Environmental Engineering	Project co-principal investigator; materials expert

*Use the table below to list **all** students who have participated in the project during the reporting period. (This includes all paid, unpaid, intern, independent study, or any other student that participated in this project.) **ALL FIELDS ARE REQUIRED.***

Table 7: Student Participants during the reporting period								
Student Name	**Start Date**	**End Date**	**Advisor**	**Email Address**	**Level**	**Major**	**Funding Source**	**Role in research**
Maryam Abazarsa	1/1/23	9/30/25	Prof. Yu	Maryam_Abazarsa@student.uml.edu	Ph.D.	Civil and Environmental Engineering	TIDC	Data processing and analysis
Mohammad Mustafa	1/1/23	8/30/25	Prof. Wei	Mohammad_Mustafa@student.uml.edu	Ph.D.	Civil and Environmental Engineering	NSF/TIDC	Concrete specimen testing, bridge sample collection and laboratory material characterization
Koosha Raisi	1/1/22	3/31/22	Prof. Yu	Koosha_Raisi@ student.uml.edu	Ph.D.	Civil and Environmental Engineering	TIDC	Data processing and analysis
Aiyad Alshimaysawee	1/1/22	3/11/22	Prof. Yu	Aiyad_Alshimaysawee@ student.uml.edu	Ph.D.	Civil and Environmental Engineering	TIDC	Laboratory radar imaging and data processing
Nimun Nak Khun	1/1/22	3/31/22	Prof. Yu	NimunNak_Khun@ student.uml.edu	M.S.	Civil and Environmental Engineering		Laboratory radar imaging and data processing
Yaneliz Garcis Ruiz	1/1/22	3/31/22	Prof. Yu	Yaneliz_Garciaruiz@ @student.uml.edu	B.S.	Civil and Environmental Engineering		Assistance in the preparation for bridge field tests
Farel Adelson	1/1/22	3/31/22	Prof. Yu	Farel_Adelson@ student.uml.edu	B.S.	Civil and Environmental Engineering		Assistance in the preparation for bridge field tests
Amirhossein Madadi	10/1/22	12/31/22	Prof. Wei	Amirhossein_Madadi@student.uml.edu	Ph.D.	Civil and Environmental Engineering	NSF	Concrete specimen casting, bridge

								sample collection and laboratory material characterization
Maryam Abazarsa	7/1/23	9/30/23	Prof. Yu	Maryam_Abazarsa@student.uml.edu	Ph.D.	Civil and Environmental Engineering	TIDC	Data processing and analysis

Use the table below to list any students who worked on this project and graduated or received a certificate during this reporting period. Include information about the student's accepted employment during the reporting period (i.e. the student is now working at MaineDOT) or if they are continuing their students through an advanced degree (list the degree and where they are attending).

Table 8: Students who Graduated During the Reporting Period

Student Name	Degree/Certificate Earned	Graduation/Certification Date	Did the student enter the transportation field or continue another degree at your university?
Nimun Nak Khun	Master's in Civil Engineering	8/31/2022	Yes

Use the table below to list any students that participated in Industrial Internships during the reporting period:

Table 9: Industrial Internships

Student Name	Degree/Certificate Earned	Graduation/Certification Date	Did the student enter the transportation field or continue another degree at your university?
NA			Please list the organization or degree

*Use the table below to list **organizations** that have been involved as partners on this project and their contribution to the project during the reporting period.*

Table 10: Research Project Collaborators during the reporting period

Organization	Location	Contribution to the Project				
		Financial Support	In-Kind Support	Facilities	Collaborative Research	Personnel Exchanges

		List the amount	List the amount	Mark with an "x" where appropriate		
MassDOT	Boston, MA				X	X
City of Lowell	Lowell, MA	X			X	X
Geophysical Survey Systems, Inc. (GSSI)	Nashua, NH				X	X
Urban Mining Industries, LLC	New Rochelle, NY		X		X	
Eco Material Technologies	Oxford, MA		X		X	X

*Use the table below to list **individuals** that have been involved as partners on this project and their contribution to the project during the reporting period. (**List your technical champion(s) in this table.** This also includes collaborations within the lead or partner universities who are not already listed as PIs; especially interdepartmental or interdisciplinary collaborations.)*

Collaborator Name and Title	Contact Information	Organization and Department	Date(s) Involved	Contribution to Research
NA	For internal use only			(i.e. technical champion, technical advisory board, test samples, on-site equipment, data, etc.)
Gregory Krikoris	Gregory.Krikoris@state.ma.us	MassDOT	07/16/24	Technical champion
Mark Jen	Mark.Jen@kiewit.com	Kiewit Corporation	05/21/24	Technical champion
David Cist	David_C@Geophysical.com	GSSI	3/16/22	Technical champion

Number of active industrial partners involved in this research project
One

Number of technical Champions actively involved in this project:
Two

Use the following table to list any transportation related course that were taught or led by researchers associated with this research project during the reporting period:

Table 12: Course List

Course Code	Course Title	Level	University	Professor	Semester	# of Students
i.e. CE 123		Grad or undergrad?	Where was the course taught?	Who taught the course?	Enter Spring, Fall, Summer, Winter and the year	How many students were enrolled in the class?
CIVE.3110-802	Engineering Materials Laboratory	Undergrad	UMass Lowell	Jianqiang Wei	Fall 2022	14
CIVE.3110-803	Engineering Materials Laboratory	Undergrad	UMass Lowell	Jianqiang Wei	Fall 2022	14
CIVE.3110-805	Engineering Materials Laboratory	Undergrad	UMass Lowell	Jianqiang Wei	Fall 2022	14
CIVE.5040	Advanced Strength of Materials	Grad	UMass Lowell	Jianqiang Wei	Fall 2022	26
CIVE.5150	Cementitious Materials for Sustainable Concrete	Grad	UMass Lowell	Jianqiang Wei	Spring 2023	25
CIVE.5120	Structural Stability	Grad	UMass Lowell	Tzuyang Yu	Spring 2023	16
CIVE.3110	Engineering Materials Laboratory	Undergraduate	UMass Lowell	Jianqiang Wei	Fall 2023	54
CIVE.5040	Advanced Strength of Materials	Graduate	UMass Lowell	Jianqiang Wei	Fall 2023	25
CIVE.3110	Engineering Materials Laboratory	Undergraduate	UMass Lowell	Jianqiang Wei	Fall 2024	52
ENGN.2070	Dynamics	Undergraduate	UMass Lowell	Tzuyang Yu	Spring 2025	21
CIVE 5110	Inspection and Monitoring of Civil Infrastructure	Grad	UMass Lowell	Tzuyang Yu	Fall 2025	35
ENGN.2070	Dynamics	Undergraduate	UMass Lowell	Tzuyang Yu	Fall 2025	50

Changes:

List any actual or anticipated problems or delays and actions or plans to resolve them (list no-cost extension requests here)…
N/A

List any changes in approach and the reasons for the change…
N/A

Planned Activities:

List the activities planned during the next quarter.
N/A