Quarterly Progress and Performance Indicators Report:
Project Number and Title: 2.9: Carbonating Subgrade Materials for In-Situ Soil Stabilization
Research Area: New Materials for Longevity and constructability
PI: Aaron Gallant, Ph.D., P.E., University of Maine
Co-PI(s): Warda Ashraf, Ph.D., University of Texas at Arlington
Reporting Period: 1/1/2022-3/31/2022
Submission Date: 3.31.2022

Overview:

*Provide **BRIEF** highlights of activities performed during the reporting period.*

- Based on our first large-scale soil box (2 m in length, 1 m in width and 0.75 m in depth) experiment, we improved the testing methodology to better understand the carbonation progress in real-time, and to perform the freeze-thaw (i.e. durability) testing on the carbonated soils. The detailed instrumentation for the second carbonation experiment is presented in Figure 1. It is noted that similar instrumentation and testing plan were adopted for both Zones (zone A and B represent initial degree of saturation, S_r, of 30% and 40%, respectively for the 10% lime mixed soils or soils only). This enhanced instrumentation incorporates thermocouples, *T*, (total 20 nos.) and additional bender element, *BE*, pairs (total 4 pairs) for Zone A and B to monitor the soil cementation process via CO_2 gas consumption. These thermocouples will also be used to monitor the temperatures during freeze-thaw (F-T) cycles in a controlled environmental chamber. Additionally, the LVDTs that mounted on the on the wooden settlement plate (SP) would capture the heave and settlement associated with the freezing and thawing processes, respectively.
- We performed a total of 30 nos. of California Bearing Ratio (CBR) testing on the untreated soils (i.e. before introducing CO_2 gas) and carbonated soils at various locations and depths of the soil box to evaluate the strength improvement via carbonation. The overall soil box carbonation experiment and CBR testing set up are shown in Figure 2.

Meeting the Overarching Goals of the Project:

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

- The above activities helped to develop a carbonation technique to stabilize shallow roadway subgrade soils as well as to evaluate the durability of the carbonated soils due to freezing and thawing. It would also help to understand what influences the spatial uniformity and rate of binder formation and the efficiency of CO_2 storage/consumption due to carbonation (i.e. sustainability).
- To determine the strength improvement of carbonated soils as compared to untreated soils. The CBR of the untreated and carbonated soils is presented in Figure 3. The preliminary results revealed that the soil strength has improved significantly especially in layer 1 (between 0-150 mm) after carbonating for 15 hours at low CO_2 pressure. Further investigation and interpretation of results are in progress and the findings will be included in our final report.

Accomplishments:

List any accomplishments achieved under the project goals in bullet point form…

- One peer-reviewed conference paper has been published in ASCE Geotechnical Special Publication No. 315 which was presented at Geo-Congress 2020 in Minneapolis, MN. An update on project progress was recently presented at the TIDC Showcase Presentation on April 21, 2021, and 2021 TIDC student Poster Competition on December 1, 2021.

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 1.1: Literature review, scope of the research, and experimental planning	September 2018	Ongoing	100% to date
Task 2.1: Elemental testing on lime mixed soils	December 2018	December 2020	100%
Task 2.2: Laboratory trial of aqueous-phased carbonation	February 2021	April 2021	100%
Task 2.3: Bench scale trial (gaseous carbonation at elevated pressure)	April 2021	May 2021	100%
Task 3.1: Planning, design and site establishment of carbonation testing in a large soil box	May 2021	September 2021	100%
Task 3.2: Performing the field carbonation testing	October 2021	February 2022	90%
Task 3.3: Data processing, interpretation and, final reporting	December 2021	May 2022	50%
Phase 1 Overall	September 2018	Ongoing	100% to date
Phase 2 Overall	December 2018	April 2021	100%
Phase 3 Overall	May 2021	August 2022	80%

Table 2: Milestone Progress			
Milestone #: Description	**Corresponding Deliverable**	**Start Date**	**End Date**
Milestone 1: N/A			
Milestone 2: N/A			
Milestone 3: N/A			

Table 3: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date (include the date)**
$323,748.00	$315,408.00	97.42%

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):

1. 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?

   N/A

2. 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?

   N/A

3. 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?

   N/A

Technology Transfer:

Complete all of the tables below and provide additional information where requested.

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)**
Student poster competition	Implementation of Soil Carbonation for Subgrade Stabilization		2021 TIDC Student Poster Contest	Virtual	10/28/2021

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**
Peer-reviewed conference paper	Elemental testing of carbonated silty sand treated with lime	Hossen, S. B., Gallant, A. P., & Ashraf, W. (2020). Elemental Testing of Carbonated Silty Sand Treated with Lime. *Geo-Congress 2020*, ASCE GSP 315, Minneapolis MN, pp. 562-571.	February 21, 2020	Published
Peer-reviewed Journal	Influence of initial soil state parameters on strength improvement of granular soils under low CO_2 pressure conditions	Hossen, S. B., Gallant, A. P., & Ashraf, W. (2021). Influence of initial soil state on calcium carbonate binder precipitation and strength improvement of lime mixed granular soils via accelerated carbonation. *J. Geotech. Geoenviron. Eng.*, ASCE (In preparation).	-	Under in- house review for final submission

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

1. 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?

   N/A

2. 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

3. 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?

   N/A

4. 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

5. 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

6. 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).

   N/A

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.

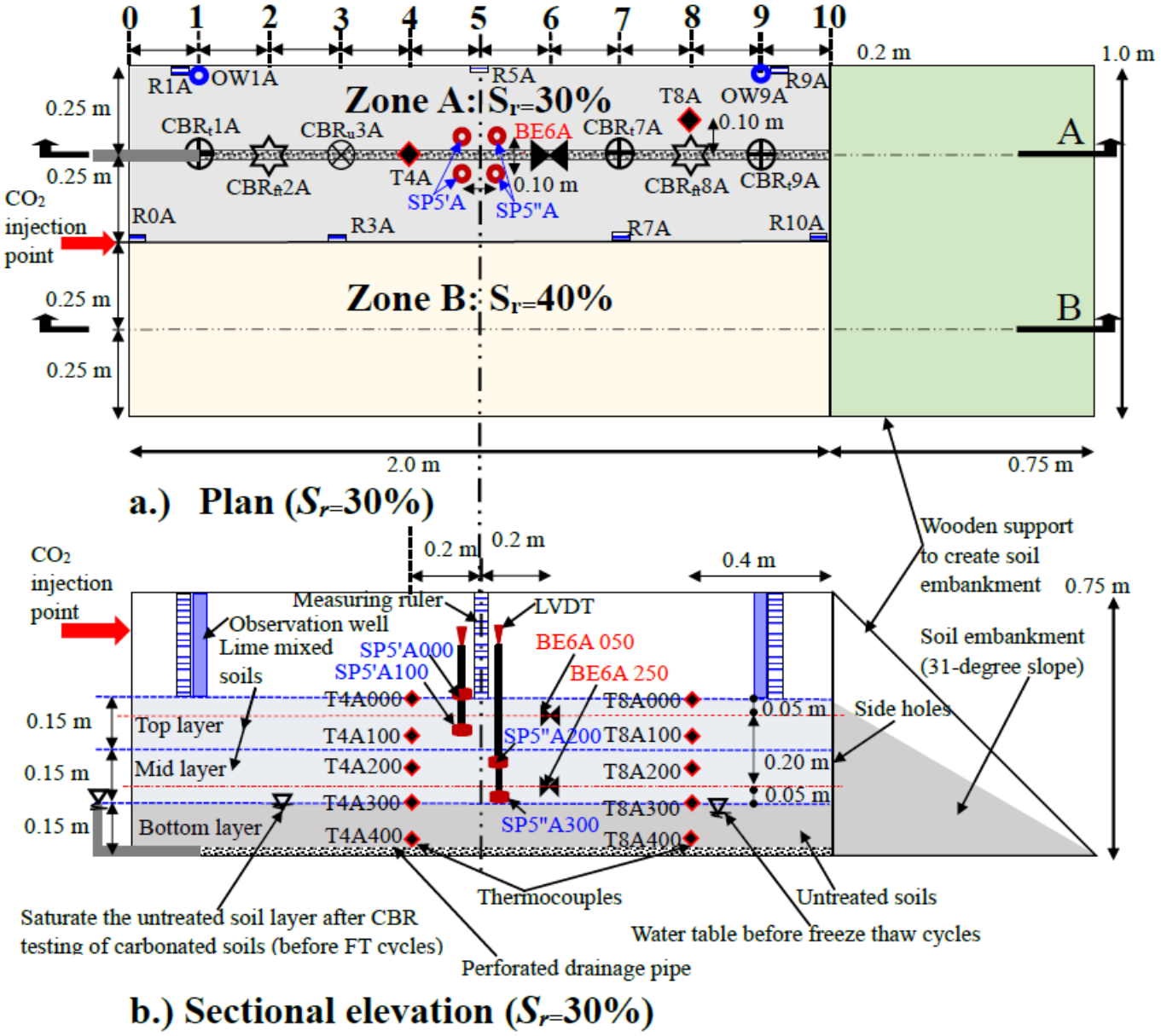

Figure 1. Detail instrumentation of the soil box carbonation experiment.

Figure 2. A large-scale soil box carbonation experiment. a.) Overall test set-up. b.) CBR testing in the soil box

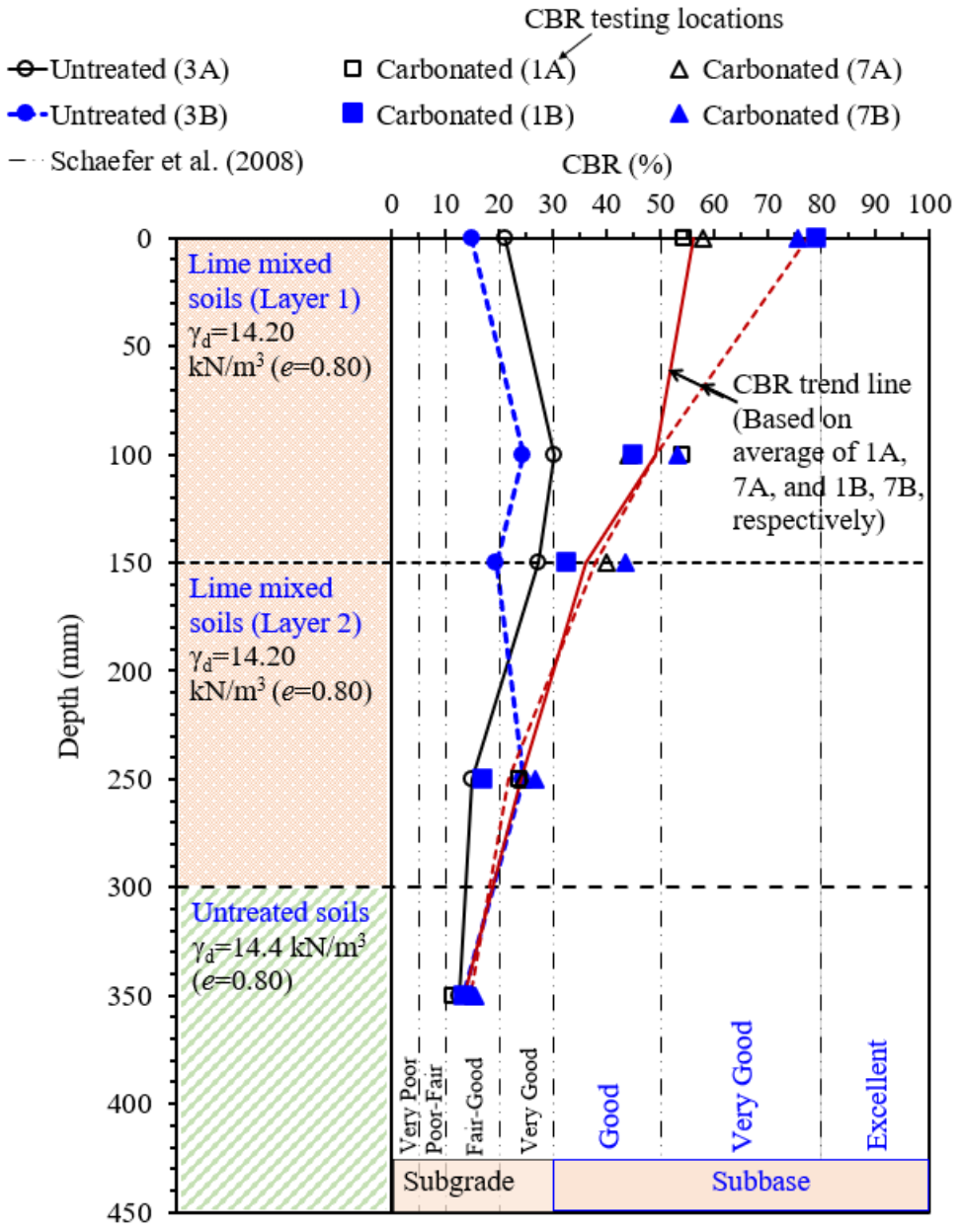

Figure 3. CBR profile of carbonated and untreated soils.

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:

The development of an innovative ground improvement technique (i.e. soil carbonation) to sequester gaseous CO_2 via shallow subgrade soils stabilization is in progress with potential field implementation.

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:

N/A

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:

N/A

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
Aaron Gallant, PhD, PE Assistant professor of geotechnical engineering	09/2018-09/2021	aaron.gallant@maine.edu	Civil Engineering, University of Maine	PI
Warda Ashraf, PhD	09/2018-09/2021	warda.ashraf@uta.edu	Civil Engineering, UT Arlington	Co-PI

*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**
SK Belal Hossen, EI	09/2018	-	Aaron Gallant, PhD, PE Warda Ashraf, PhD		PhD	Civil and geotechnical engineering	TIDC & UMaine	Graduate Research Assistant

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?**
N/A	N/A	N/A	N/A

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?**
N/A	N/A	N/A	N/A

*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		
N/A	N/A	N/A	N/A	N/A	N/A	N/A

*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.)*

Table 11: Other Collaborators				
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Date(s) Involved**	**Contribution to Research**
	For internal use only			(i.e. technical champion, technical advisory board, test samples, on-site equipment, data, etc.)
N/A	N/A	N/A	N/A	N/A

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**
N/A	N/A	N/A	N/A	N/A	N/A	N/A

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.

- To evaluate the durability of the carbonated materials via freeze-thaw testing in a temperature and humidity controlled environmental chamber (i.e. HASTEST chamber at the Advanced Structures and Composites Center, ASCC UMaine).
- Data processing and interpretation to evaluate the field performance of the proposed soil carbonation technique.
- Preparation of the final report.