

**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:** 4/1/2022-6/30/2022

**Submission Date:** 6/30/2022

**\*\*\*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 rows 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.*

**Overview:**

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

- Previously we have reported the successful demonstration of a novel soil carbonation technology to stabilize subgrade soils supporting transportation infrastructure mimicking a half embankment in a large box (i.e. 1-m in length and 2-m in width with a 0.45 m thick compacted subgrade layer). The soil strength, determined via field California Bearing Ratio (CBR) testing, got improved significantly after carbonation through top of the lime-mixed (10% by weight) soil layer (refer to Figure 2). During this reporting period, a large-scale freeze-thaw (F-T) experiment, first of its kind, was developed to evaluate the F-T (durability) performance of that stabilized soils in the box.
- An overview of the F-T experiment inside an environmental chamber at the Advanced Structures and Composites Center (ASCC UMaine) is presented in Figure 1. The experiment was equipped to monitor the effects of temperature changes in real-time during each F-T cycle via measurement of shear wave velocity and vertical movement of the subgrade soils at various depths using bender elements (BE) and linear variable displacement transducer (LVDT), respectively in addition to temperature measurement using temperature sensors (thermocouples). After each F-T cycle, the strength degradation of stabilized soil was measured via field CBR testing using a unique test setup developed in this project. A total of 22 CBR tests were performed at different depths on side *A* and side *B* of the soil box during F-T experiment. The CBR results are presented 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 evaluate the freeze-thaw performance (durability) of frost susceptible subgrade soils (silt with sand, ML) that stabilized via carbonation.
- The direct quantification of strength degradation of carbonated soils via CBR testing provided frost susceptibility rating (refer to Figure 2) which would be helpful to make recommendations on the applicability of this novel soil cementation method (i.e. carbonation) in cold regions of the USA, for example in Maine, for pavement subgrade soil stabilization.

The effects of freeze-thaw cycle on CBR of the carbonated soils is presented in Figure 2. The results revealed that the soil strength was improved significantly especially in layer 1 (between 0-150 mm) after carbonating. The surface CBR was as high as 80% which reduced with depth and the CBR at a depth of 150 mm was about 40%. This CBR value, a commonly used pavement design parameter adopted by transportation agencies, represents excellent to good subbase materials for pavement construction. On the other hand, the saturation followed by freezing and thawing reduced the strength of stabilized soils in terms of CBR after two subsequent F-T cycles. The CBR after two F-T cycles varied between 15-20 within the top 100 mm which still represents very low frost susceptibility as compared to natural soil which showed very high frost susceptibility. It is worth to mention that this study simulated the most severe field condition providing continuous water supply from the bottom of the box with 1-D freezing front from the top. The obtained results are highly encouraging for further field application to stabilize frost susceptible soils in Maine.

**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)...

<b>Table 1: Task Progress</b>			
<b>Task Number: Title</b>	<b>Start Date</b>	<b>End Date</b>	<b>% Complete</b>
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 for carbonation testing in a large soil box	May 2021	September 2021	100%
Task 3.2: Performing the pseudo-field carbonation and freeze-thaw (durability) testing	October 2021	August 2022	95%
Task 3.3: Data processing, interpretation and, report preparation	December 2021	Ongoing	60%
Phase 1 Overall	September 2018	Ongoing	100% to date
Phase 2 Overall	December 2018	April 2021	100%
Phase 3 Overall	May 2021	December 2022	80%

**Table 2: Milestone Progress**

Milestone #: Description	Corresponding Deliverable	Start Date	End Date
Milestone 1:			
Milestone 2:			
Milestone 3:			
Milestone 4:			
Milestone 5:			
Milestone 6:			
Milestone 7:			
Milestone 8:			
etc.			

**Table 3: Budget Progress**

Project Budget	Spend – Project to Date	% Project to Date (include the date)
Enter Phase 1 Full Budget	Enter Phase 1 Full Spend Amount (Federal + Cost Share)	Enter Phase 1 % Spent
Enter Phase 2 Full Budget	Enter Phase 2 Full Spend Amount (Federal + Cost Share)	Enter Phase 2 % Spent
Enter Phase 3 Full Budget	Enter Phase 3 Full Spend Amount (Federal + Cost Share)	Enter Phase 3 % Spent

**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? (i.e. The research team provided an in the field training for the SAR technology for 3 maintenance crew members of the MassDOT on 3/31/2021. The members learned how to use the technology and interrupt the data.)

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? (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
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? (i.e. 25 8<sup>th</sup> 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.)  
N/A

**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:*

<b>Table 4: Presentations at Conferences, Workshops, Seminars, and Other Events</b>					
<b>Type</b>	<b>Title</b>	<b>Citation</b>	<b>Event &amp; Intended Audience</b>	<b>Location</b>	<b>Date(s)</b>
Conference organized by Geo-Institute Chapter of the ASCE Illinois Section	Gas mobility and its role in emerging ground improvement methods	Gallant, A. (2022). Gas mobility and its role in emerging ground improvement methods. 2022 Chicago Geotechnical Lecture Series, May 5, Chicago, IL.	2022 Chicago Geotechnical Lecture Series (geotechnical and geoenvironmental engineering community)	Harborside International Golf Center, Chicago, IL	May 5, 2022

*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.*

<b>Table 5: Submitted/Accepted Publications, Technical Reports, Theses, Dissertations, Papers, and Reports</b>				
<b>Type</b>	<b>Title</b>	<b>Citation</b>	<b>Date</b>	<b>Status</b>
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. <i>Geo-Congress 2020</i> , 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 <sub>2</sub> 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. <i>J. Geotech. Geoenviron. Eng.</i> , ASCE (In preparation).	-	Under in- house review for final submission
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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 it 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.*



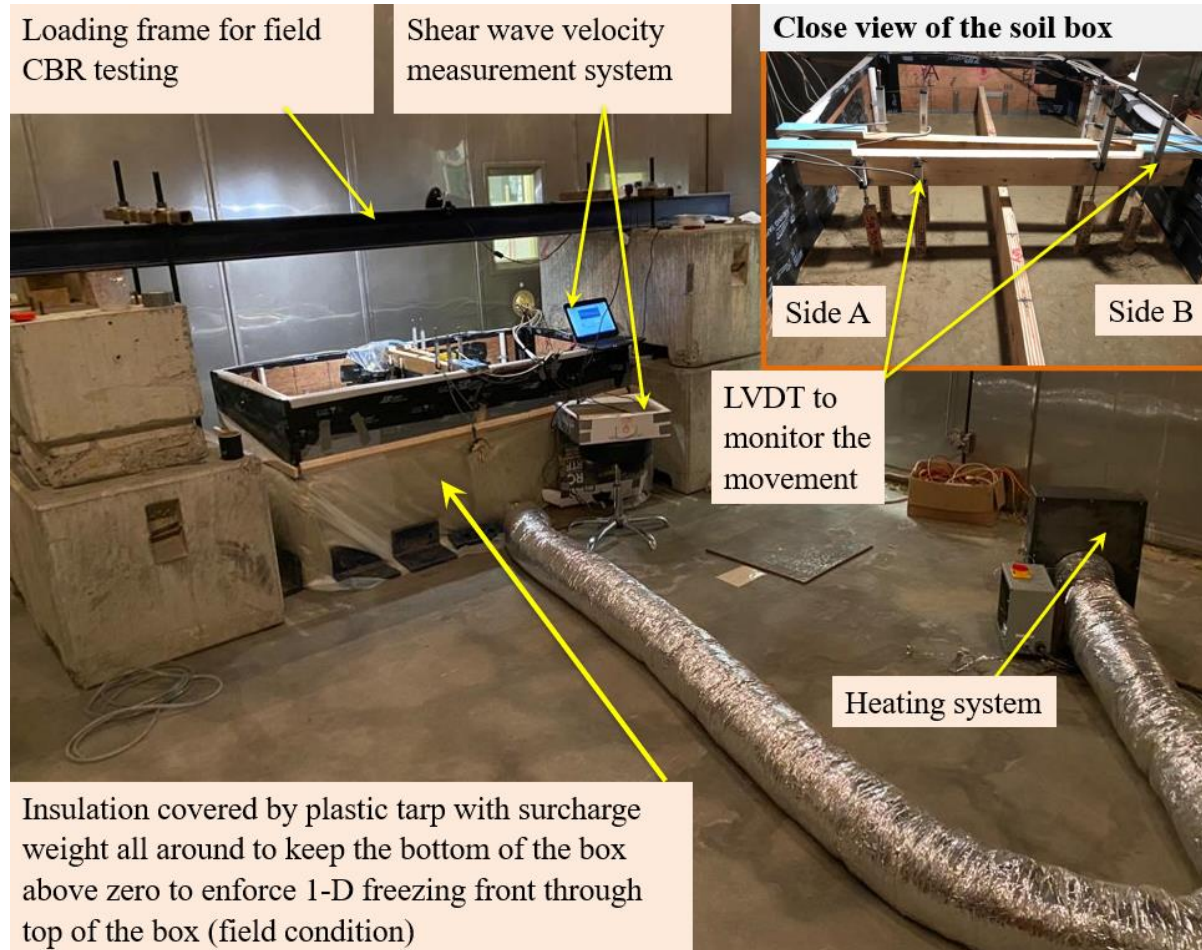


Figure 1. An overview of large-scale freeze-thaw experiment inside a temperature and humidity controlled environmental chamber (HASTEST chamber) at the Advanced Structures and Composites Center, ASCC UMaine.

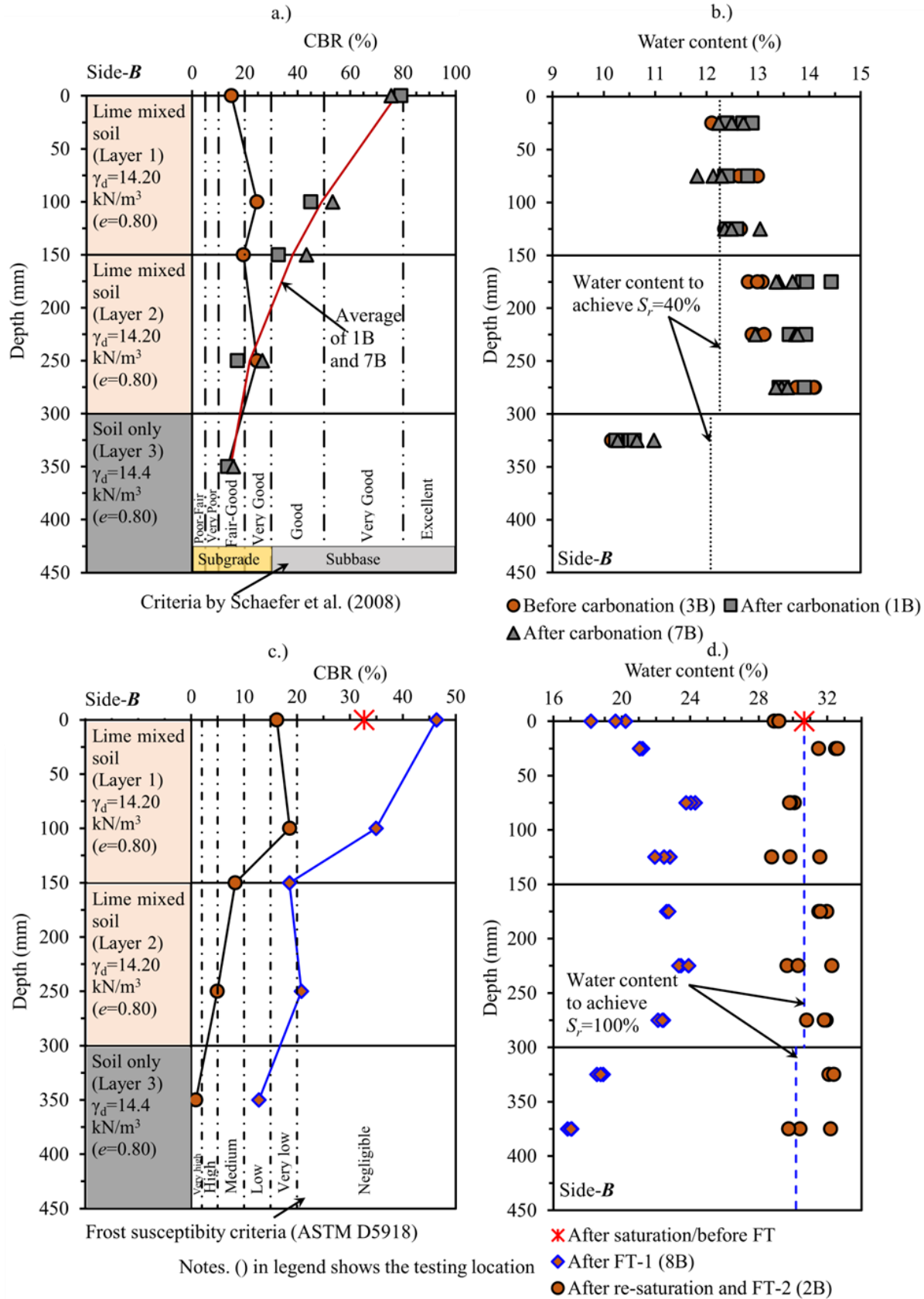


Figure 2. California Bearing Ratio (CBR) and water content profile for Side B of the soil box. a.) strength improvement, and b.) associated water content after carbonation; c.) strength degradation, and d.) water content of carbonated soils after saturation and freeze-thaw (FT) cycle.

*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:*

- Examples: New sensing technology was developed. This technology will... A UAV was created to hold new monitoring technology. This will allow maintenance crews to... A new college course was created based on the research findings. This will train future transportation professionals to...

The development of an innovative ground improvement technique (i.e. soil carbonation) to sequester gaseous CO<sub>2</sub> 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:*

- 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.

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:*

- Example: The developed sensing technology's successful deployment resulted in the adoption of the technology by the StateDOT. The technology will be installed in all new bridge installments of this type. This adoption will... The new UAV monitoring technology was adopted by \_\_\_ organization to be used for \_\_\_ bridges inspections. This will allow inspectors to... The college course has been adopted by another member university...

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	09/2018-09/2022	aaron.gallant@maine.edu	Civil Engineering, University of Maine	PI
Warda Ashraf, PhD	09/2018-09/2022	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?
			Please list the organization or degree
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?
			Please list the organization or degree
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						

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				

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?
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 long-term strength of carbonated soils via CBR testing after subjected to saturation and freeze-thaw cycles (summer field condition).
- To quantify the carbonate binder content via thermogravimetric analyses on samples subjected to freezing and thawing.
- Data processing and interpretation to evaluate the freeze-thaw performance of frost susceptible soils stabilized via carbonation.
- Drafting two technical manuscripts on novel carbonation technique to stabilize the subgrade soils and its freeze-thaw performance.
- Preparation of the final report.