Quarterly Progress 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: 1/1/2020-3/31/2020
Submission Date: 3/31/2020

Overview: (Please answer each question individually)

*Provide **BRIEF** overview and summary of activities performed during the reporting period. This summary should be written in lay terms for a general audience to understand. This should not be an extensive write up of findings (those are to be included in the final report), but a high-level overview of the activities conducted during the last three months **no more than 3 bullet points no more than 1 sentence each** ….*

The unconfined compressive strength (UCS) of carbonated and ambient cured (28-days) lime-mixed granular soils was previously reported. In case of carbonated soils, the strength is mainly attributed to the amount of calcium carbonate (i.e. binder) formation in the soil matrix through chemical reaction between alkali (i.e. lime) and carbon dioxide (CO_2) gas in water. Therefore, we previously discussed the importance of quantifying the binder to fully understand its influence on strength and stiffness in carbonated soils. We performed a total of 18 thermogravimetric analyses (TGA) tests on small (~35 mg) powder samples of carbonated granular soils after UCS testing.

Figure 1 shows the amount of calcium carbonate that precipitated at the center of the reconstituted soil specimens, which were carbonated for 3 or 24-hours at different lime contents (i.e. 1% and 10% of dry soil weight) and the same initial water content (~15%). For reference, the hypothetical binder content for "full carbonation" at 1% and 10% lime content is shown. Figure 1 also shows (i.e. secondary vertical axis) the corresponding initial degree of saturation, S_r, for each soil specimens prior to carbonation. Interestingly, these experiments revealed that the amount of calcium carbonate (binder) appears to increase with the alkali content and changes for different soil types, but the carbonation period (i.e. 3 and 24-hours) appears to have a negligible influence on binder formation at the center of the sample. Soils with higher fine contents achieved nearly full carbonation, and had a significantly higher amount of binder than soils with a lower fine content. The corresponding S_r shows a strong correlation with binder formation for each sample. Those samples with lower S_r (i.e. also higher fine content) exhibit higher binder contents. At lower initial S_r, for instance 40% for higher fine contents, a continuous air phase may be expected in the specimen, facilitating flow of CO_2 gas and subsequent formation of $CaCO_3$ throughout the sample. For coarser grained samples S_r was closer to 70%, where a discontinuous air phase would be expected throughout the sample. Therefore, CO_2 would have needed to dissolve and subsequently diffuse through water in the sample for $CaCO_3$ to form, which is a much slower process. This observation is attributed to the lower strengths observed at lower fine contents. Initially, it was thought that fines facilitated greater binding of the sediment—which may still be the case to some degree—but could be less influential than originally thought. This is important, as carbonation may be effective in coarser grained sediments as well, thus increasing the soil types where carbonation may be beneficial. In a preliminary trial we carbonated sand with no fines for 72 hours and the same initial S_r of 70%, and achieved UCS = 850 kPa. These strengths are closer to that achieved for samples with higher fine contents. However, we have not yet had the opportunity to verify the amount of binder formed in this test—though we speculate that similar strengths will be achieved for much shorter carbonation periods if the initial S_r is lower (e.g. similar to that for specimens with higher fine content). This finding has motivated our subsequent set of experiments, which are currently delayed due to COVID-19. Our future tests will be carried out to investigate the relative influence of initial state, and in addition to S_r, we will investigate initial density (void ratio) and a range of water contents to define the optimum initial states to practically achieve rapid soil improvement in the field.

Provide context as to how these activities are helping achieve the overarching goal(s) of the project…

Elemental testing as part of Phase I of this project is being performed to characterize the factors contributing to soil carbonation and associated strength for different soil types to gain rapid strength. It also provided a framework on designing future testing that would provide the optimum conditions for soil stabilization via carbonation.

Describe any accomplishments achieved under the project goals…

One peer-reviewed conference paper has been published in Geo-Congress 2020: Foundations, Soil Improvement, and Erosion under Geotechnical Special Publication No. 315, Geo-Institute (G-I) of the American Society of Civil Engineers (ASCE). Additionally, a poster presentation, titled *Rapid Stabilization of Non-plastic Granular Soils via Carbonation* has been made in Geo-Congress 2020 in Minneapolis, MN on February 26. It is worth to mention that the proposed novel soil stabilization technique has been appreciated by both industry and academia.

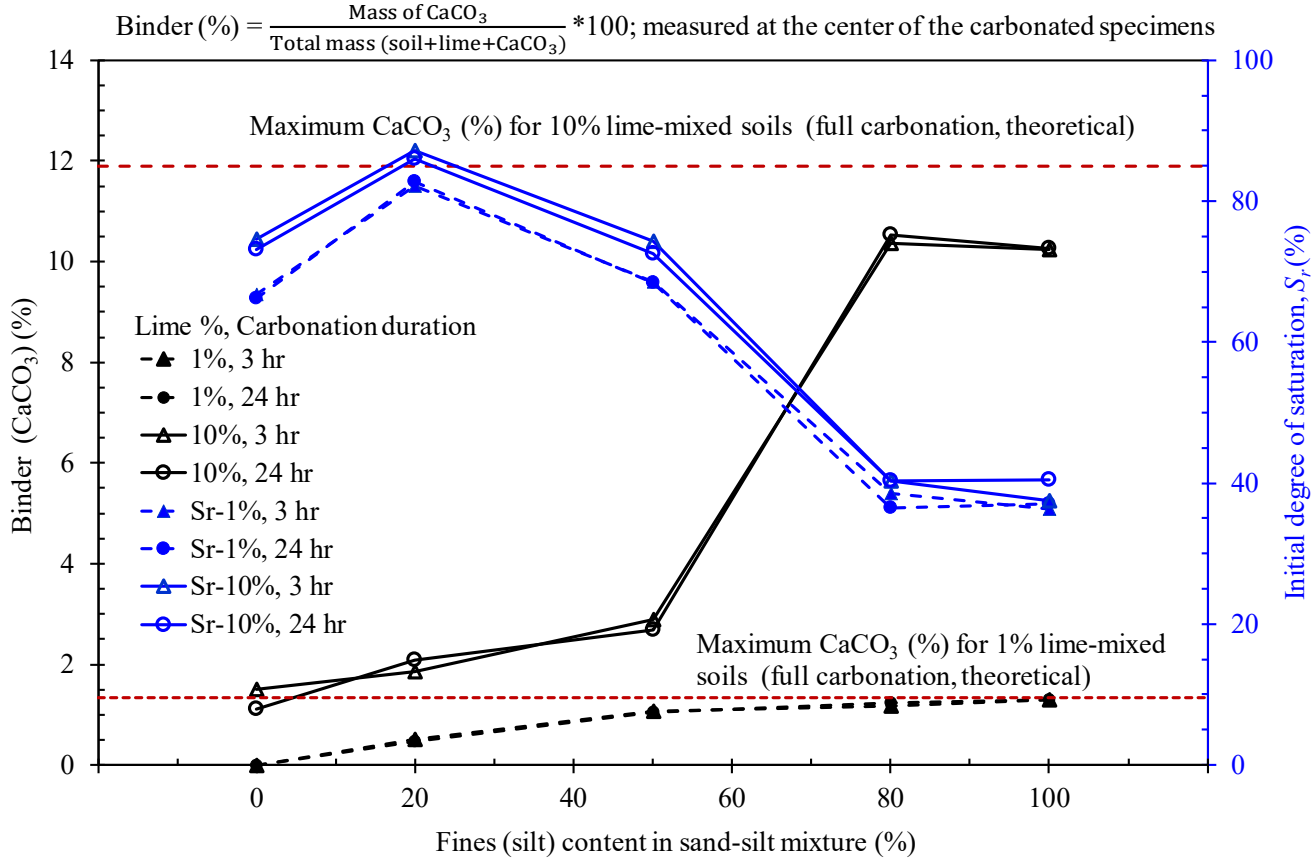

Figure 1. *Effects of initial degree of saturation on formation of calcium carbonate precipitation for different granular soils*

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	**Start Date**	**End Date**	**% Complete**
Task 1: Literature Review	September, 2018	Ongoing	100% to date
Task 2: Elemental testing	December 2018	May 2020	80%
Task 3: Pseudo Field-Scale Trial (Laboratory soil box)	June 2020	February 2021	0%
Overall Project:	September 2018	August 2021	40%

Table 2: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date***
$323,748	$157,035	50% (3/31/2020)

Include the date the budget is current to.
Describe any opportunities for training/professional development that have been provided…

The graduate student was sponsored to attend the Geo-Congress 2020, held in February 25-28 in Minneapolis, Minnesota. This was a unique opportunity to meet the peers and present his research work in the conference. The student also attended different technical sessions on recent advances in ground improvement techniques and latest geotechnical practices. It would help him to develop knowledge and skills for further improvement in his research and future career in the field.

Describe any activities involving the dissemination of research results (be sure to include outputs, outcomes, and the ways in which the outcomes/outputs have had an impact during the reporting period. Please use the tables below for any Publications and Presentations in addition to the description of any other technology transfer efforts that took place during the reporting period.)… Use the tables below to complete information about conferences, workshops, publications, etc. ***List all other outputs, outcomes, and impacts after the tables*** *(i.e. patent applications, technologies, techniques, licenses issued, and/or website addresses used to disseminate research findings).*

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events

Title	Event	Type	Location	Date(s)
Rapid Stabilization of Non-plastic Granular Soils via Carbonation	Geo-Congress 2020	Annual Geotechnical Conference of ASCE	Minneapolis, Minnesota	February 25-28, 2020

Table 4: Publications and Submitted 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-review Journal	Influence of initial state on rapid carbonation of non-plastic granular soils under low-CO_2 pressure conditions	Hossen, S. B., Gallant, A. P., & Ashraf, W. (2020). Influence of initial state on rapid carbonation of non-plastic granular soils under low CO_2 pressure conditions. *Can. Geotech. J.*, (in preparation).		In preparation

Participants and Collaborators:

Table 5: Active Principal Investigators, faculty, administrators, and Management Team Members

Individual Name	Email Address	Department	Role in Research
Aaron Gallant, PhD, PE	aaron.gallant@maine.edu	Civil Engineering, University of Maine	PI
Warda Ashraf, PhD	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. (This includes all paid, unpaid, intern, independent study, or any other student that participated in this project.)

Table 6: Student Participants during the reporting period

Student Name	Email Address	Class	Major	Role in research
SK Belal Hossen		PhD	Civil and geotechnical engineering	Graduate Research Assistant

Use the table below to list any students who worked on this project and graduated during this reporting period. N/A

Table 7: Student Graduates			
Student Name	**Role in Research**	**Degree**	**Graduation Date**
N/A			

Use the table below to list organizations have been involved as partners on this project and their contribution to the project. N/A

Table 8: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
N/A						

List all other outputs, outcomes, and impacts here (i.e. patent applications, technologies, techniques, licenses issued, and/or website addresses used to disseminate research findings). Please be sure to provide detailed information about each item as with the tables above. N/A

Have other collaborators or contacts been involved? If so, who and how? (This would include collaborations with others within the lead or partner universities; especially interdepartmental or interdisciplinary collaborations.) N/A

Table 9: Other Collaborators			
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Contribution to Research**
N/A			

Who is the Technical Champion for this project?
Name: Dale Peabody
Title: Director of Transportation Research
Organization: MaineDOT
Location (City & State): Augusta, ME
Email Address: dale.peabody@maine.gov

Changes:

Discuss any actual or anticipated problems or delays and actions or plans to resolve them…
Discuss any changes in approach and the reasons for the change…

COVID-19 has delayed our final testing program for the elemental portion of this research.

Planned Activities:

Description of future activities over the coming months.

We plan to conduct two series of tests that will include mechanical and TGA testing to verify our hypothesis that rapid gains in strength may be achieved under low CO_2 pressure conditions, and for a wider range of soil types than initially thought based on preliminary testing. We intend to focus on the influence of initial state (water content, degree of saturation, void ratio) and will investigate three soil types that cover a wide range of soil types encountered in the field (sand, silty sand and silt). This will inform our understanding of requisite conditions necessary for carbonation to be successful in the field.