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: *10/1/2019-12/31/2019*
Submission Date: *12/31/2019*

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….*

We have previously reported on the formation of an alternative binder (calcium carbonate) via carbonation to increase the strength and stiffness of subgrade materials. Our initial hypothesis—that carbonation would precipitate calcium carbonate on the soil grains and bind the material together—was verified during year one of this study. We explored the use of two potential alkali sources, lime and cement slag. Potential advantages of carbonating subgrade materials include rapid gains in strength relative to other chemical stabilization methods (e.g. conventional lime or cement mixing). Lime was a more favorable alkali mineral with regards to rapid strength gain. Preliminary results also highlight that soil type and fine content (i.e. non-plastic silt) play an important role in the mechanical benefits and associate inter-particle bonding achieved during carbonation—which were assessed with unconfined compressive strength (UCS) tests. Given the wide ranging subsurface conditions and materials encountered during civil infrastructure projects, an essential component of advancing any ground improvement methods requires demonstration of the soil types where stabilization methods—in this case carbonation—may be applied. This motivated us to further investigate the effects of fines content (i.e. 0, 20, 50, 80 and 100%, by weight of dry Ottawa sand) on carbonated soil mixed with lime at different lime dosages (i.e. 1 and 10%, by weight of dry soil mass). Reconstituted specimens were carbonated for 3 and 24 hours to assess temporal differences in strength gains. Reconstituted specimens with 10% lime were also cured for 28-days (i.e. not carbonated) to compare differences in improvement achieved through "long-term" pozzolanic reaction (i.e. conventional lime stabilization). Three specimens were considered for each soil type, lime content, and carbonation/curing period considered.

Figure 1 shows the effects of fines content on the UCS of carbonated silty sand mixed with 1% and 10% The UCS of 28-days cured strength is also compared with the carbonated soils. Generally, UCS increases with lime content, carbonation time and fine content. . However, one unexpected exception in this trend was observed when the fine content was increased from 50 to 80% (i.e. decrease in UCS). The initial void ratio for fine contents for fine contents of 80 and 100% were appreciably greater (~1-1.15), whereas soils with lower fine contents varied between ~0.42-0.6. The void ratio of reconstituted specimens is largely influenced by fine content and water content (initial water content of 15% was maintained here). This observation elucidates the importance of initial state parameters— especially for soils with higher fine contents—on the performance of carbonated soils. To fully characterize the relative influence of other state parameters contributing to gains in strength, future tests will be carried out on specimens with different void ratios that may be practically achieved in the field (e.g. via compaction). One limitation in our current findings is a lack of understanding in the actual *amount* of binder of binder formed in all cases. Though it is apparent that higher carbonation times resulted in greater strengths, and undoubtedly more binder, the amount of calcium carbonate and calcium-silicate-hydrate need to be measured directly to assess heterogeneity in formation of these binders and the amount to fully characterize their influence on strength. Our studies initially quantified the amount of binder formed via thermogravimetric analyses on samples taken from carbonated and uncarbonated specimens. However, this instrument was damaged during the reporting period and has been inoperable. The device is currently being repaired and we hope to resume testing and complete our characterization of carbonation for different materials in the following reporting period to complete this initial phase of the project.

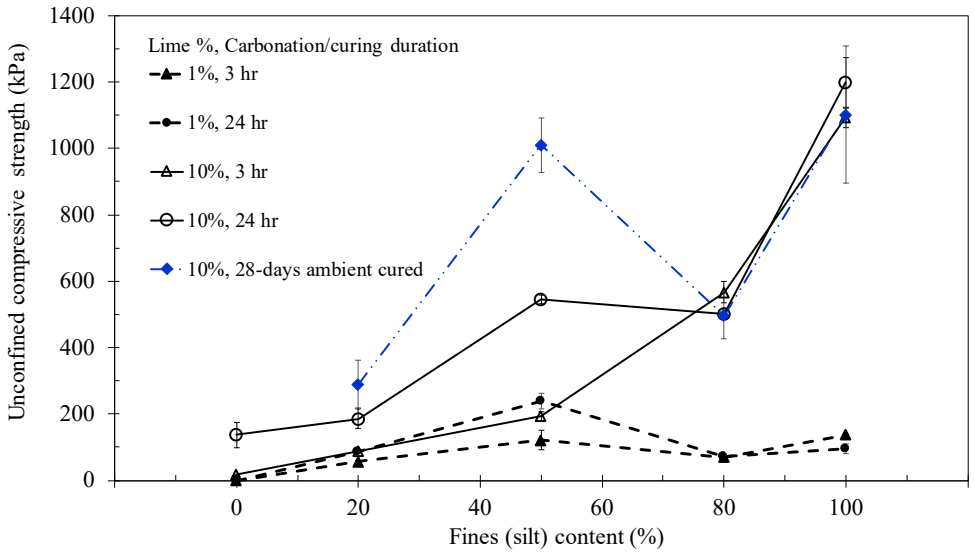

Figure 1. Effects of fine content on peak strength of carbonated and 28-days ambient cured (uncarbonated) lime mixed granular soil

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 soil types where carbonation may be applied and the alkali sources that most effective for rapid strength gain. Testing is also being compared with conventional lime stabilization to demonstrate adequacy of the binder formed during carbonation (calcium carbonate) with that formed with other existing (slower) chemical stabilization methods.

Describe any accomplishments achieved under the project goals…

One peer-reviewed conference paper was accepted and will be presented at GeoCongress, 2020 in Minneapolis, MN in February. The paper, "Elemental Testing of Carbonated Silty Sand Treated with Lime," will be included in an ASCE Geotechnical Special Publication (GSP). Another manuscript is under preparation based on year one and ongoing elemental testing focused on performance of Ground Granulated Blast-Furnace Slag (GGBS) compared to lime as an alkali source for carbonation of granular soils.

Complete the following tables to document the work toward each task and budget (add rows/remove rows as needed)…

Table 1: Task Progress

Task Number	Start Date	End Date	Percent Complete
Task 1: Literature Review	9/2018	Ongoing	
Task 2: Elemental Testing	12/2018	May 2020	
Task 3: Pseudo Field-Scale Trial (Laboratory soil box)	6/2020	2/2021	
Overall project:	9/2018	8/2021	

Table 2: Budget Progress

Entire Project Budget	Spend Amount	Spend Percentage to Date
$323,748	$138,602	42.8% (12/31/2019)

Describe any opportunities for training/professional development that have been provided…

The graduate student was trained on advanced mechanical (i.e. triaxial) testing of carbonated soils in the laboratory, which is planned for future work.

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). Encouraged to add figures that may be useful (especially for the website)*

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

Title	Event	Type	Location	Date(s)
Elemental testing of carbonated silty sand treated with lime	GeoCongress 2020	Conference	Minneapolis, MN	February, 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., and Ashraf, W. (2020). "Elemental testing of carbonated silty sand treated with lime." Geotechnical Special Publication, Geo-Congress 2020, American Society of Civil Engineers.	10/8/2019	Accepted

Participants and Collaborators:

Use the table below to list all individuals who have worked on the project.

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, UMaine	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.

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.

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.

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

Changes:

Discuss any actual or anticipated problems or delays and actions or plans to resolve them…

Our studies initially quantified the amount of binder formed via thermogravimetric analyses on samples taken from carbonated and uncarbonated specimens. However, this instrument was damaged during the reporting period and has been inoperable. The device is currently being repaired and we hope to resume testing and complete our characterization of carbonation for different materials in the following reporting period to complete this initial phase of the project. The internal hang down wire, which we believe is needed to repair the device, has been ordered.

Planned Activities:

Description of future activities over the coming months.

Based on the results presented in Figure 1, the influence of state parameters (i.e. water content and void ratio) need to be considered explicitly. Therefore, a series of mechanical and TGA tests are planned to investigate the effects of initial water content and void ratio (or dry density) in carbonation of lime mixed soils considering sand with higher fines content (i.e. 50, 80 and 100%), where carbonation has thus far proved to a potential method to stabilize subgrade materials.