Semi-Annual 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 Maine
Reporting Period: *03/2018-08/2019*
Date: *9/30/2019*

Overview: (Please answer each question individually)
Provide overview and summary of activities performed during previous six months.

Soil carbonation is a potentially sustainable soil stabilization alternative to strengthen the subgrade when challenging soils exist. This ground improvement method precipitates carbonate minerals (i.e. binding agent) in the soil matrix to cement the grains, increasing strength and stiffness. The process occurs when alkali minerals, water, and CO_2 gas are combined in soil. Most native subgrades (including Maine soils) are alkali deficient, requiring addition of an alkali source to the soil. The method has the potential to use waste by-products or readily available materials (e.g. CO_2 gas, lime, cement slag) to rapidly gain strength.

Task 1: Elemental Testing

During the previous research time-period elemental testing was performed to investigate the use of lime (contains 99.4% $Ca(OH)_2$) and ground granulated blast furnace slag, or GGBS (GGBS, contains ~42% CaO), as potential alkali sources. Elemental testing was conducted on reconstituted soil specimens with two alkali percentages (1 and 10%) and carbonation periods (3 and 24 hours). Different soil types were also investigated, specifically non-plastic granular materials with different fine contents (0, 20, and 50%) to investigate the intergranular bonding and applicability of soil carbonation for different subgrade materials (see Figure 1). Unconfined compressive strength (UCS) tests and thermogravimetric analyses were conducted to verify gains in strength and formations of stable carbonate minerals in the soil. Three specimens were considered for each alkali mineral (lime or GGBS), carbonation period, and soil type. A total of 73 and 52 UCS tests were carried out for lime- and GGBS-treated soil specimens, respectively. Select specimens were considered for TGA testing. A summary of elemental UCS testing results are presented in Figure 2.

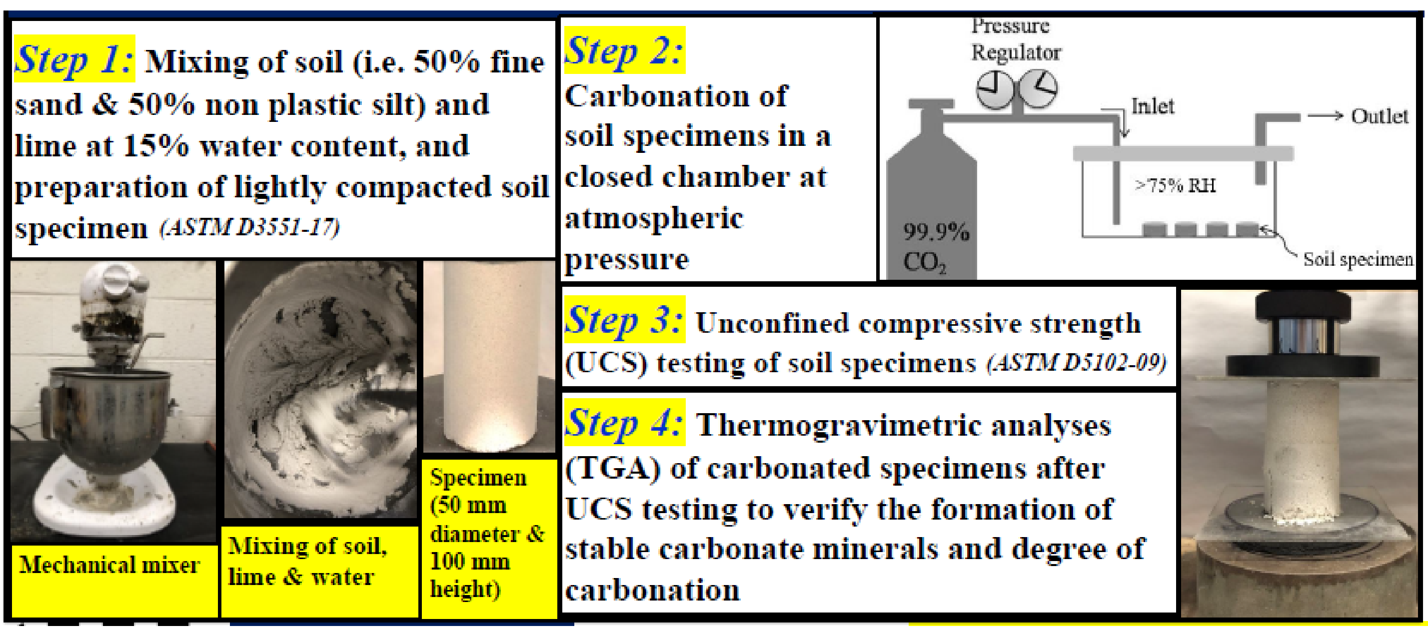

Figure 1. *Soil specimen preparation and elemental testing sequence for carbonated soil specimens*

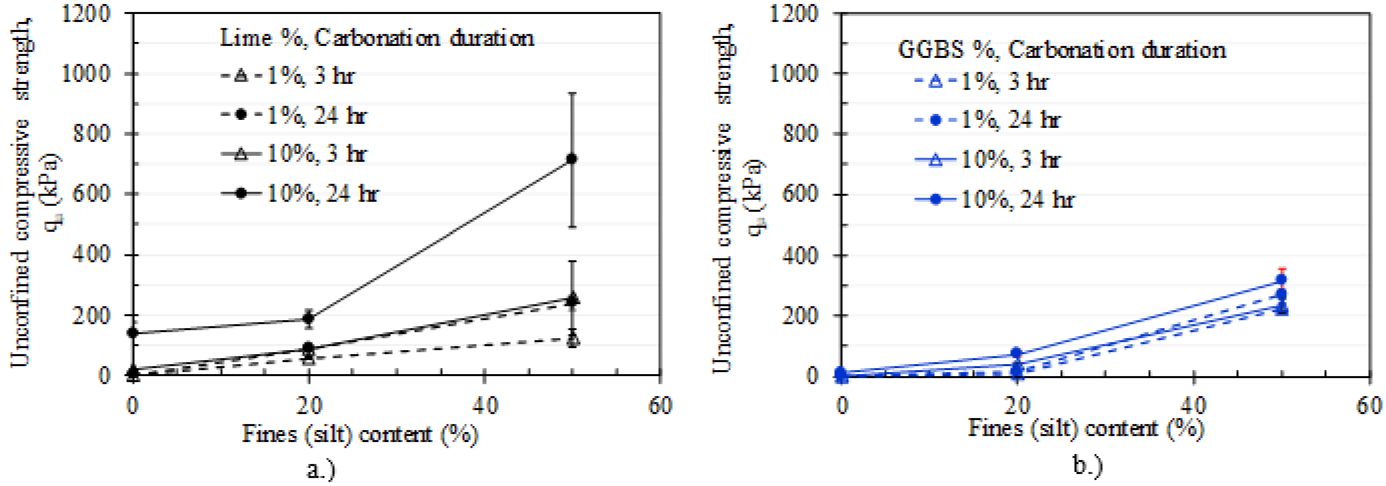

Figure 2. *Effects of fine content, carbonation period, and alkali content on peak strength of carbonated soil specimens treated with: a.). lime and b.) GGBS*

Provide context as to how these activities are helping achieve the overarching goal of the project.

Elemental testing during the project period has verified there is potential for soil carbonation to cement subgrade materials for potential application as a subgrade stabilization method. This phase of the project is intended to investigate the applicability of a.) the mineral type and b.) soil type to soil carbonation.

Describe any accomplishments achieved under the project goals.

Soils range from coarse grained (e.g. sands and gravels) to fine grain materials (e.g. silts/clays). This initial effort has provided a better understanding of how the selection of alkali minerals and soil type influence strength with regards to the carbonation process. Two main conclusions have come out of this initial testing phase. The first being that lime generates greater strengths (i.e. reacts more) during the carbonation periods considered. The second main conclusion is that for alkali contents considered (max 10% of dry weight of soil), the fine content in soil is an important consideration in applicability—i.e. higher fine contents generate more intergranular bonding and greater increases in strength achieved during carbonation. Thus far we have tested only non-plastic materials (i.e. sands and sand with silt), though we believe greater strengths may be achieved with the introduction of finer grained materials (e.g. clays). We are currently completing our elemental study of non-plastic fines by testing materials with fine contents of 80 and 100%.

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

The graduate student has not been involved with any professional development (outside the university).

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). Encouraged to add figures that may be useful (especially for semi-annual reporting by the project manager and management team).

One paper titled "Elemental Testing of Carbonated Silty Sand Treated with Lime" was submitted and accepted for inclusion in ASCE Geo-Institute's Geotechnical Special Publication as part of Geo-Congress 2020. This work will also be presented in February 2020 at Minneapolis, Minnesota. The student also plans to present this project to academics and geo-professionals at the Geo-Congress 2020 conference under the professional development goal of the project. Specifically, these results will be disseminated during a "ground improvement" session at GeoCongress 2020, readily attended by engineering professionals, academics, and students. Another manuscript is under preparation, focusing on comparison of the performance of GGBS compared with lime. We anticipate submitting this article to Geotechnique Letters. The project was highlighted with a poster presentation at the University of Maine Graduate Student Symposium.

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Participants and Collaborators:

List all individuals who have worked on the project.
Faculty Members: Aaron Gallant, PhD, PE (PI), Warda Ashraf, PhD (co-PI)

Graduate Students: SK Belal Hossen (Ph.D Student)

List all students who have participated in the project. (Include name, email address, class standing, major, and role in the research)

SK Belal Hossen; Class standing: Full time graduate student; Major: Civil and geotechnical engineering; Role: Graduate Research Assistant.

What organizations have been involved as partners on this project? What was their role?

University of Maine has been involved with the project.

Have other collaborators or contacts been involved? If so, who and how?

External collaborators have not been involved at this time.

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.

Based on the results of our preliminary study, and alkali contents investigated, this soil stabilization approach is likely to be more applicable to fine grained soils. An initial implementation concept was to introduce alkali minerals in a slurry through either surface percolation or permeation grouting with a slurry. However, permeation methods are highly dependent on soil pore size distribution, and typically more applicable in coarser soils—e.g. fine sands or even fine sand with silt. Though lime and GGBS are finer than cement used in these slurries, which have proven successful in fine sand, we believe these methods will not be applicable to fine grained soils (where higher strengths are achieved), especially at shallow depths. Therefore, applications where soil mixing is used must be considered (e.g. dry soil mixing, wet soil mixing, jet grouting).

Planned Activities:

Description of future activities over the coming months.

Thus far sands with fine contents of 0, 20 and 50% fines were investigated. To obtain the complete picture on the influence of fine content, we will finish preliminary tests mechanical and TGA considering silty sand with 80% fines and silt (100% fines). The current graduate student and another M.S. student (supported elsewhere) are also performing more advanced mechanical tests to better understand the influence of confining stress on strength and stiffness degradation for consideration of mixing methods, including mass mixing or deep mixing methods to create columns (e.g. applicable to ground improvement concepts such as column-supported embankments).