

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

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Overview:

Design, construction, location, and maintenance/durability of transportation facilities are impacted by existing subsurface conditions, and unlike many construction materials the soil cannot be specified but is instead discerned via subsurface explorations. Even in filling scenarios, where “borrow” materials may be specified, designers are limited by local geology and the availability of desired soil. Challenging subsurface conditions often leave transportation assets vulnerable to excessive deformations, or even a complete loss of subgrade support in more extreme cases (e.g. Figure 1). In New England, shallow subgrade sediments are also susceptible to cold-weather conditions that result in significant frost penetration, causing the ground to swell and subsequently collapse during thaw periods. Seasonal fluctuations of groundwater levels also cause wetting and collapse of voids that can contribute to creep deformations that affect transportation infrastructure. These issues are pervasive throughout New England and the United States, affecting millions of miles of roadway and costing billions of dollars in maintenance and repairs. Excavation and replacement with more suitable material is sometimes a viable option (e.g. new roadway), but is typically time-intensive, requires the use of heavy construction equipment, and in these times of economic austerity is often too expensive. Current methods of ground improvement/stabilization, the alteration of material properties in situ to benefit engineering design, construction, and performance, utilize specialized equipment and contractors, often introduce cement-based materials with a relatively high carbon footprint, and typically require considerable time and expense. The *objective* of this research is to develop a cost-effective and more sustainable approach to carbonate subgrade materials in situ, and alter the mechanical (i.e. strength and stiffness) and drainage (permeability) properties of soil supporting new and existing transportation assets. The carbonation process requires introduction of carbon dioxide (CO_2) gas, which reacts with alkali minerals naturally occurring and/or added to the soil. In the presence of moisture, stable carbonate minerals increase strength and stiffness and lower permeability of soil with formation of a binder.

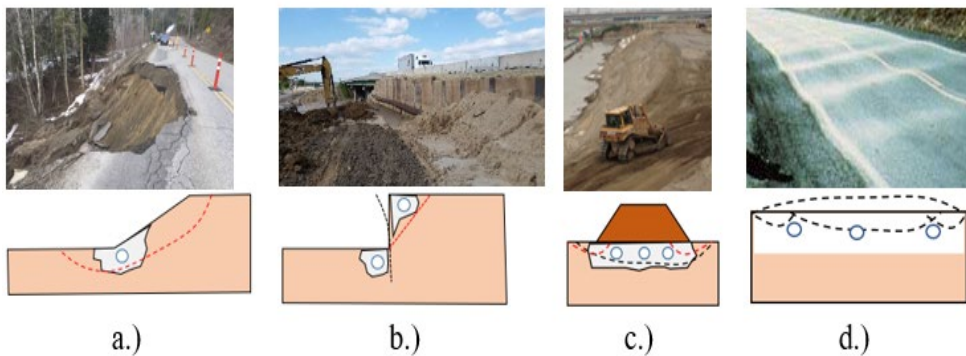


Figure 1. Potential needs for ground stabilization and envisioned method of implementation: a.) toe/slope instability, b.) excessive deformations with earth retention system, c.) embankment construction, d.) frost action

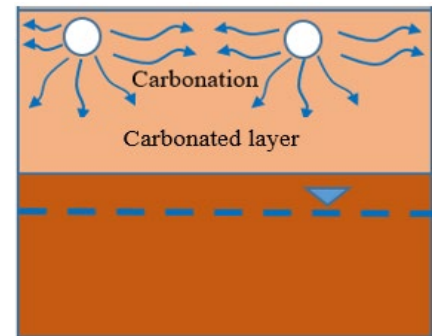


Figure 2. A conceptual method for field implementation of soil with perforated pipes and existing drilling technology

The results of elemental testing being conducted in year 1 are presented to illustrate the potential of this method, and how they contribute to the longer-term vision for implementation. Tasks carried out in the first six months of this project include: a.) collection of native soils; b.) index tests (i.e. sieve analyses); c.) mineralogical assessment via X-ray diffraction (XRD); d.) mechanical testing (i.e. unconfined compressive strength) of carbonated soils (mixture of sand and non-plastic silts) treated with lime (as a alkali source) at different percentages (i.e. 1% and 10%) and carbonation periods (i.e. 3 and 24 hours); and e.) thermogravimetric analyses (TGA) of carbonated soils to verify the formation of stable carbonate minerals and degree of carbonation. Based on XRD analyses, soils in Maine are alkali-deficient, and therefore require introduction of an

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alkali mineral. As currently envisioned, we aim to introduce alkali minerals by dissolving them in water and permeating this solution through the ground either via i.) surface penetration or ii.) through a perforated pipe installed via cost-effective means and with a low footprint, such as directional drilling (Figure 2). Afterwards, CO₂ gas will be injected through the perforated pipes to permeate and carbonate the soil.

In our experiments we have added lime as the alkali source (Ca(OH)₂). The chemical mechanism facilitating formation of carbonate minerals (CaCO₃) is divided into three steps. Step 1: when solid lime (Ca(OH)₂) is added to soils (primarily SiO₂ bearing minerals) in presence of water (H₂O), it dissolves in water and provides Ca²⁺ (aq) ion in the solution: Ca(OH)₂ [s]+H₂O [l]→ Ca²⁺ (aq)+2OH⁻ (aq). The disassociation of cations in solution is necessary for the method of implementation currently envisioned. Step 2: Once lime dissolves into solution, CO₂ gas is introduced and also dissolves in water to produce a weak carbonic acid (H₂CO₃), which dissociates to H⁺ and bicarbonate (i.e. HCO₃⁻) ions: CO₂[g] + H₂O ↔ H⁺(aq) + HCO₃⁻ (aq), and step 3 is subsequent formation of carbonate mineral: Ca²⁺ (aq)+2OH⁻ (aq)+ H⁺(aq) + HCO₃⁻→ CaCO₃ [s] (↓) (Calcium Carbonate) + 2H₂O [l]. Note: s=solid, l=liquid, aq=aqueous=dissolved in water, g=gas, ↓=deposited. Representative TGA results presented in Figure 3 show the weight loss curve (i.e. green solid line) and derivative of weight loss curve (i.e. blue solid line) of a sample taken from the center of the specimen (50% sand+50% silt+10% lime+24-hour carbonation) under a constant rate of temperature increment (10°C/min). Generally, they indicate Ca(OH)₂ and CaCO₃ are present in the sample based on decomposition of the material (weight loss) at different temperatures, and the percentage of Ca(OH)₂ and CaCO₃ is measured. Figure 4 shows the percentage of CaCO₃ and unreacted Ca(OH)₂ across the specimen after 24 hours of carbonation.

Figure 5 illustrates the increased strength and stiffness of the material with unconfined compressive strength (UCS) tests performed on reconstituted soil specimens (i.e. mixture of fine sand and non-plastic silt) at different lime contents (1% and 10% of soil weight), carbonated for 3 or 24 hours, with untreated specimens. All specimens were prepared at a target water content of 15% and dry density of 16.5 kN/m³ except one specimen (i.e. 50% sand and 50% silt without lime) which was prepared at 7.5% water content to facilitate the laboratory testing. The results of UCS and chemical testing are encouraging, and support the potential of soil carbonation as a new method of ground improvement/stabilization.

Planned Activities:

Moving forward, we plan to experiment with waste materials, such as blast furnace slag or cement-kiln-dust, which can be dissolved in water and potentially decrease the cost soil carbonation for field-scale applications. Subsequent activities will include development of a soil box with perforated pipes to demonstrate the envisioned field implementation process. We intend to measure changes in shear wave velocity that correlate to changes in strength and stiffness with bender elements. We also plan to install electrodes to measure electrical resistivity that will confirm changes in water content and the occurrence of the intended chemical reaction.

Sample: 50%Sand+50%Silt+10%Lime_24 hour carbonation (Center)

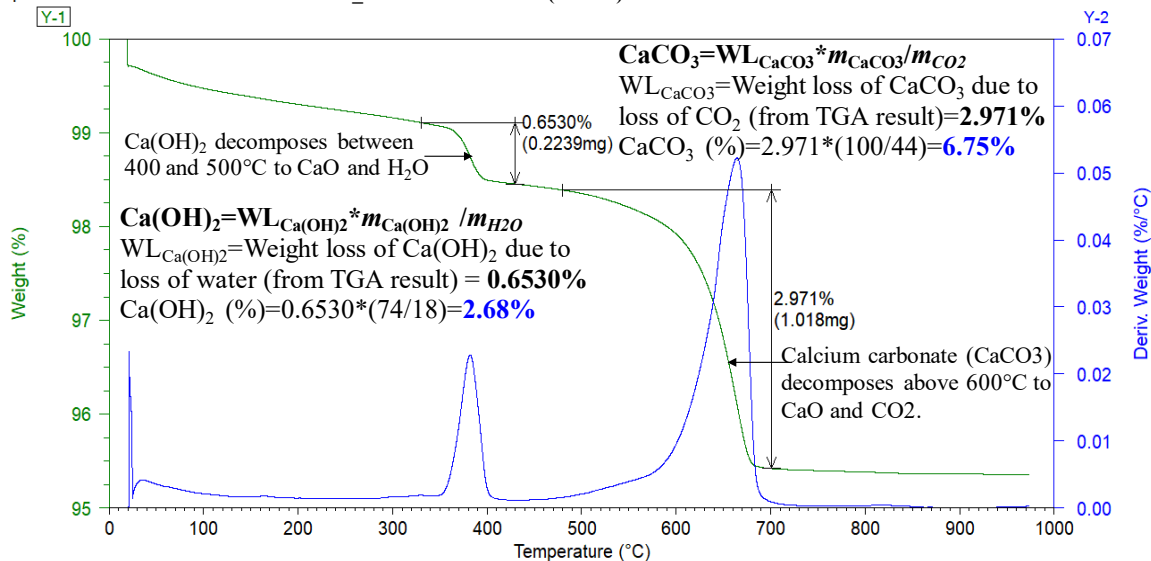


Figure 3. Representative thermogravimetric analysis (TGA) to verify the formation of calcium carbonate

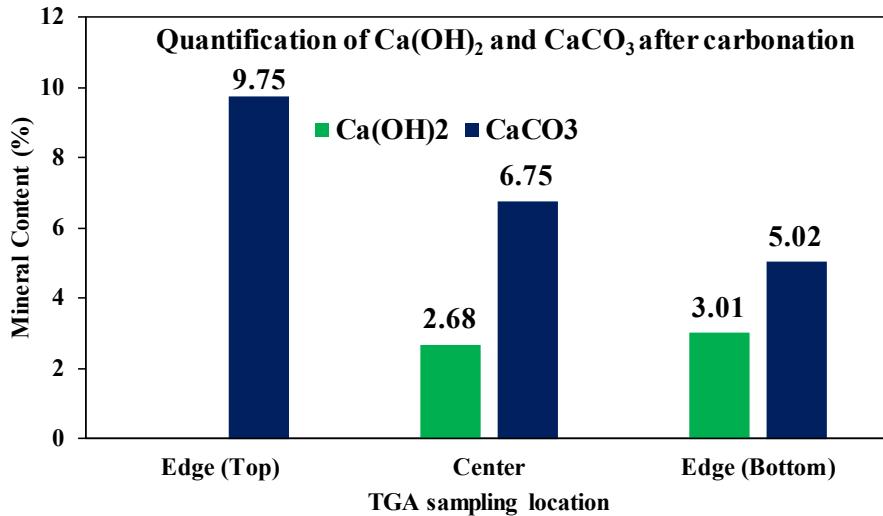


Figure 4. Representative degree of carbonation across the specimen (50% sand+50% silt+10% lime) for one test after 24 hours of carbonation

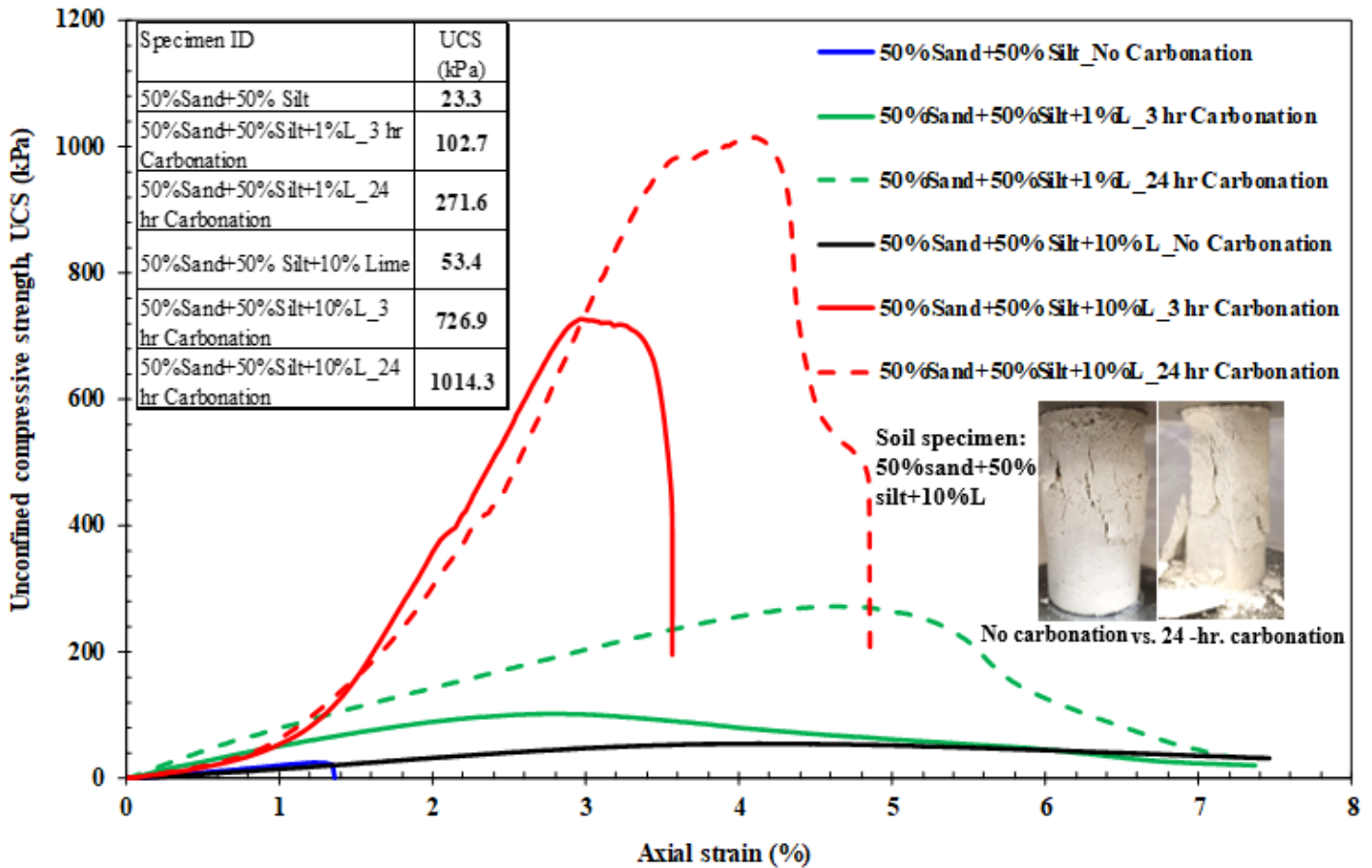


Figure 5. Unconfined compressive strength of different soil specimens with different percentages of lime content and carbonation periods

Participants and Collaborators:

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