Synopsis

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Thesis title: **Impact of Carbonation and Leaching on Lime Stabilized Clayey Soils**

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Use of lime as an additive for stabilizing subgrade soils with poor engineering properties is a common practice in highway industry. These stabilized layers are exposed to both traffic loading and environmental factors during their service life, both of which can inversely affect the long-term performance of these layers. Among the two, the impact of adverse climatic conditions is a major concern as they cannot be predicted or accounted for in the design of pavement sections. The efficacy of lime stabilization is therefore heavily reliant on the durability properties of these layers. The impact of long-term exposure to weathering factors are typically evaluated by monitoring mass and strength loss incurred in samples subjected to wet-dry cycles or freeze-thaw cycles which simulates the effect of changes in climatic conditions on stabilized layers. Even though these engineering techniques are widely used in pavement applications, they fail to explain the fundamental reasons behind durability loss in stabilized matrices. Hence, the focus of recent studies has shifted more towards micro morphological changes incurred during environmental exposure and on the impact of such micro-scale changes on the long-term behavior of cementitious materials. The current study explores the micro-scale as well as the long-term macro-scale behavior of lime-stabilized clayey soils subjected to long-term carbon dioxide exposure and moisture infiltration.

This thesis is divided into three experimental sections: (a) the first section, chapter 2, explains the mechanisms leading to microstructural changes in pure calcium silicate hydrate

(C-S-H, the primary contributor of strength in stabilized layers) phases when subjected to CO_2 exposure (b) the second section, chapter 3, extends the observations made in part one to stabilized soil matrices and also looks into the impact of micro-structural changes on engineering properties of lime-stabilized layers (c) the third experimental section of this thesis, chapter 4, focuses on how leaching with and without carbonation influences the long term performance of lime-stabilized subgrade soils.

Second chapter of thesis investigates the role of CO_2 and their concentrations on changes in micromorphological properties of pure C-S-H phases. Pure C-S-H (Type I and Type II) phases synthesized in the laboratory were exposed to different CO_2 concentrations (0.04 percent corresponding to atmospheric CO_2 levels, 1.0 percent and 3.0 percent) under controlled relative humidity conditions to facilitate CO_2 diffusion into the matrix. This study introduces a novel approach to estimate concentrations of metastable bicarbonate phases and stable carbonate phases precipitated in C-S-H during carbonation by combining stoichiometric principles and thermogravimetric techniques. Impact of CO_2 diffusion was identified based on changes in Ca/Si ratio, pH value changes, morphology variations and changes in concentrations of calcium carbonate ($CaCO_3$) in the samples. CO_2 diffusion was observed to cause Ca^{2+} ion extraction from crystalline C-S-H phases which transforms the cementitious matrix to an amorphous silicate gel. pH of the matrix was also found to decrease to near 8.4 which corresponds to the stable pH ranges of calcite mineral, the most stable polymorph of calcium carbonate. Observations suggest that carbonation of C-S-H phases is a multistep process where metastable calcium bicarbonate phases form initially. Decalcification of precipitated C-S-H phases and slow dissolution of precipitated $CaCO_3$ act as a consistent source for free Ca^{2+} ions needed for long term carbonation in cementitious matrices when subjected to extended CO_2 exposure. 30-day exposure to one percent CO_2 was observed to mimic 720 days of infield carbonation due to atmospheric exposure.

Third chapter of the thesis extends the observations in the previous (2nd) chapter and looks into the effect of carbonation on lime-stabilized soil matrix. Commercial grade bentonite and grade III standard sand were mixed in varying proportions to prepare the soil samples required for stabilization studies. Similar to the 2nd chapter, the compacted samples were exposed to varying CO_2 concentrations to evaluate the impact of long-term field carbonation on lime-stabilized soil samples. Gradual increase in $CaCO_3$ content along with a reduction in concentration of precipitated C-S-H phases was identified to be the damage mechanism in the matrix during extended CO_2 exposure. A multi-linear regression model to predict carbonation in lime stabilized soil mixtures was also developed as part of the study. Exposure of lime-stabilized layers to higher concentrations of CO_2 showed calcium carbonate contents to decrease with time suggesting polymorphic conversion of calcite to other carbonate phases like aragonite, vaterite etc. Concentrations of precipitated C-S-H phases in the matrix was also found to decrease with exposure time possibly due to decalcification which is causing a reduction in strength properties of the mixtures.

Fourth chapter of the thesis investigates the impact of water intrusion and leaching on carbonated stabilized soil matrices. Field leaching scenarios were simulated by modifying the moisture exposure protocols during wetting and drying cycles and by including intermediate curing cycles, drying cycles, saturated conditions etc. A differential scanning calorimeter along with an inductively coupled plasma mass spectrometer (ICP-MS) were used in the chemical analysis of samples used in the study. Reduction of Ca/Si ratio of C-S-H phases along with an increase in carbon intake was observed in majority of the samples. Leachate studies suggest progressive carbonation to enhance leaching of Ca^{2+} ions from the matrix which supports strength loss behavior observed in macro scale samples. C-S-H deterioration was further observed to decrease with depth suggesting lower accessibility of CO_2 at these depths. The observations support carbonation to be a diffusion-controlled process and/or dependent on pH levels of infiltrating water which defines CO_2 saturation levels in these waters.

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