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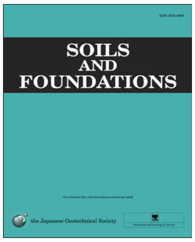

Laboratory characterization of cementitiously treated/stabilized very weak subgrade soil under cyclic loading

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Abstract

This research study was performed to examine the appropriate treatment/stabilization schemes for very weak subgrade soils at high water contents, and to evaluate the corresponding performance-related properties [e.g., resilient modulus and permanent deformation] for use in the design and analysis of pavement structures. Five different soil types, that represent the typical range in subgrade soils in Louisiana, were collected and considered in this study. Three different moisture contents (at the wet side of optimum), producing a raw soil strength of 172 kPa (25 psi) or less, were selected for treatment/stabilization. The percentage of cementitious stabilizer (lime or cement) was determined to achieve a target 7-day strength value of 345 kPa (50 psi), as treatment for working table applications, and 1034 kPa (150 psi), as stabilization for subbase applications. Repeated load triaxial (RLT) tests were performed on the laboratory-molded treated/stabilized specimens in order to evaluate their resilient modulus and to study their deformation behavior under cyclic loading. A good correlation was observed between the water/cement ratio and both the resilient modulus and the permanent deformation of the specimens. The soil specimens were compacted at low water/cement ratios and showed better performances than those compacted at high water/cement ratios. The test results also showed that the use of a direct correlation between the unconfined compressive strength (UCS) and the resilient modulus for cementitiously stabilized soil can be misleading. In the case of heavily treated/stabilized subgrade soils for subbase applications, the permanent deformation of this layer can be ignored in pavement design.

Keywords: Cementitiously treated/stabilized soil; Weak subgrade; Repeated load triaxial test; Resilient modulus; Permanent deformation

1. Introduction

Subgrade is the lowest supporting layer in the pavement structure underlying the base layer. Generally, the subgrade consists of locally available soil deposits that sometimes might be very soft and/or very wet and do not have enough strength/stiffness to support the pavement's traffic loading. The replacement of such soil with better quality borrow soil fill is not always a good option, especially in pavement construction, due to the associated extra costs of the excavation and the hauling of the materials. The use of cementitious materials to treat/stabilize poor subgrade is a widely accepted practice by many state highway agencies. A well-engineered and constructed cementitiously treated/stabilized subgrade layer usually requires achieving a threshold compressive strength that is capable of providing strong and durable support to construction loading and pavement structures. This treated/stabilized layer can be incorporated into the structural design of pavements by increasing the modulus of the composite subgrade layer and considering it as a separate subbase layer.

The soil stabilization mechanism depends on the type of applied stabilizer; it may vary from the formation of new compounds,

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binding the finer soil particles, to a coating particle surface by the stabilizer to limit the moisture sensitivity (Little and Nair, 2009). The overall stabilization/treated process in the presence of water can be summarized into four different processes: cation exchange, flocculation and agglomeration, cementitious hydration, and pozzolanic reaction (Prusinski and Bhattacharja, 1999; Mallela et al., 2004). Portland cement and lime are both calcium-based products; however, their differences may include important properties such as strength, time-dependency on the strength development, curing, and the durability and performance of the treatment (Prusinski and Bhattacharja, 1999). In the case of cement-treated/stabilized soils, all four aforementioned processes will occur, whereas in the case of lime-treated/stabilized soils, cementitious hydration will be absent.

For soil–lime mixtures, cation exchange and flocculation–agglomeration are the primary reactions which take place immediately after mixing. During these reactions, the divalent calcium ions, supplied by the lime, replace the monovalent cations that are generally associated with clay minerals. These reactions bring about immediate changes in texture, plasticity, and workability because the exchange of cations causes a reduction in the size of the diffused double water layer, thereby allowing clay particles to clump together into large-sized aggregates. The pozzolanic reaction process is a long and slow process. It occurs between the lime and the silica and alumina of the clay mineral and produces cementitious materials such as calcium–silicate–hydrates and calcium–alumina–hydrates. Studies have shown that when the pH of the soil increases to 12.4, which is the pH of saturated lime water, the solubility of the silica and the alumina increase significantly (Muhunthan and Sariosseiri, 2008). Therefore, as long as enough calcium from the lime remains in the mixture and the pH remains at least at 12.4, the pozzolanic reaction will continue to occur. The basic pozzolanic reactions are described in the following equations:

$$Ca(OH)_2 + SiO_2 \rightarrow CaO \cdot SiO_2 \cdot H_2O \text{ (C–S–H)} \quad (1)$$

$$Ca(OH)_2 + Al_2O_3 \rightarrow CaO \cdot Al_2O_3 \cdot H_2O \text{ (C–A–H)} \quad (2)$$

Portland cement is comprised of calcium–silicates and calcium–aluminates that hydrate to produce cementitious materials, which bind the soil particles together. For soil–cement mixtures, the hydration of cement is the most important contributor to the improvement of the engineering properties of soil (Pendola et al., 1969). Cement hydration is relatively fast and causes an immediate gain in the strength of the soil. The hydration behavior of calcium–silicates in cement can be described by the following equations, while the hydration of calcium–aluminates is somewhat more complex:

$$2Ca_3SiO_5 + 7H_2O \rightarrow 3\ CaO \cdot 2SiO_2 \cdot 4H_2O \text{ (C–S–H)} + 3\ Ca(OH)_2 \quad (3)$$

$$2Ca_2SiO_4 + 5H_2O \rightarrow 3\ CaO \cdot 2SiO_2 \cdot 4H_2O \text{ (C–S–H)} + Ca(OH)_2 \quad (4)$$

Much of the tricalcium silicate (Ca_3SiO_5) hydration occurs during the first few days, leading to substantial gains in strength. The dicalcium silicate (Ca_2SiO_4) hydration contributes little to the early strength of cement soil, but makes substantial contributions to the strength of mature cement paste. Similar to soil–lime mixtures, the cation exchange and flocculation–agglomeration also take place immediately after the soil and the cement are mixed, resulting in a reduction in soil plasticity. The lime generated during the hydration of the cement helps increase the binding between the soil particles through the pozzolanic reactions.

A lot of factors have been identified in the literature as having an effect on the stiffness (or resilient modulus) of cementitiously stabilized soils. These factors include the curing time, the deviatoric stress, the moisture content, the porosity-cement ratio, the curing temperature, the percentage and type of stabilizer, the soil properties, the density, and the delay time in compaction (e.g., Puppala et al., 1996; Achampong et al., 1997; Solanki et al., 2009; Consoli et al., 2011; Taheri and Tatsuoka, 2012). In general, the resilient modulus of the treated/stabilized subgrade soils increases with an increase in stabilizer content under an identical moisture content, while the permanent deformation of the treated/stabilized subgrade soils decreases with an increase in stabilizer content (Puppala et al., 1996; Achampong et al., 1997; Mohammad and Saadeh, 2008; Ling et al., 2008; Solanki et al., 2010). Several studies in the literature have shown a strong double logarithmic linear relationship between the resilient modulus and the curing time for lime/cement-stabilized soils (e.g., Ling et al., 2008; Chen and Abu-Farsakh, 2010). Generally, lime- and lime/fly ash-stabilized soils cure much more slowly than cement-stabilized soils (Little, 1999). The stress state (deviatoric stress and confining pressure) at which the resilient modulus should be estimated can be determined, in general, from a structural analysis of the trial design (after properly accounting for overburden pressure) (ARA, 2004). The correlations between the resilient modulus and the unconfined compressive strength (UCS) for stabilized layers have also been studied and proposed by several researchers (Thompson, 1966, 1986; Little et al., 1994). Some of these correlations are recommended by the Mechanistic-Empirical Pavement Design Guide (MEPDG) for determining the resilient modulus of stabilized soil for Level 2 designs (ARA, 2004).

In many cases, the subgrade soils in Louisiana have in-situ moisture contents that are much higher than the optimum value. Therefore, the predictions of the subgrade behavior, based on the soil properties determined at or near the optimum moisture content, are not rationale. Since most of the available studies on the evaluation of treated/stabilized subgrade soils are focused on evaluating the performance of subgrades compacted at or near optimum moisture contents, this research will focus on evaluating the behavior of treating/stabilizing very weak subgrade soils having moisture contents way beyond the soils' optimum moisture contents, even sometimes reaching up to the liquid limit of the soil, in order to cope with the in-situ worst scenario of pavement/foundation construction in Louisiana. Two levels of target UCS values will be selected: (a) to represent the construction of a working table [minimum 7-day strength of 345 kPa (50 psi)] and (b) to represent the construction of a subbase layer [minimum 7-day strength of 1034 kPa (150 psi], as recommended in a previous study conducted on Louisiana soils (Gautreau et al., 2010). The behavior of the laboratory-molded specimens will be