Optimum Mix Design for the Wet Method of Deep Mixing

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Project Background

The deep mixing method is a widely used in-situ ground improvement technique that mixes cementitious binder with soil to improve the engineering properties of soil. There are two types of deep mixing methods. The dry method involves adding binder the in dry powder form, and the wet method involves mixing the binder with the soil in the form of a binder-water slurry.

For the wet method of deep mixing, the amount of binder and water mixed with soil influences not only the cured strength of the binder-treated soil, but also the consistency of the mixture during mixing. Adding more binder increases the cured strength of mixture, but more binder increases material costs and can produce a stiff mixture that is hard to mix thoroughly. On the other hand, adding more water makes the mixture easier to mix, but more water decreases the cured strength. Therefore, deep mixing contractors are interested in determining the amount of added binder and water for an economical and efficient project. The mix design can be optimized by minimizing the amount of binder while achieving the target cured strength and the target consistency during mixing. In addition, deep mixing contractors can estimate how much mixing energy will be needed to thoroughly mix the binder slurry with the soil. This way, contractors can select an appropriate mixing machine and process parameters for their project. Optimum mix design depends on the amount of soil, water, and binder, the plasticity of the base soil, and the water content of the base soil ($w_{base\ soil}$).

Project Objectives

The principal objectives of this research and the corresponding benefits are listed below:

1. Develop an optimum mix design selection process for both lean and fat clay (CL and CH)
2. Investigate the influence of plasticity and water content of base soil ($w_{base\ soil}$) on optimum mix design

Materials and Methods

The fabricated base soil for this study was fat clay (CH), and the water content (w) of the base soil was 65%. Portland cement was used as a binder. To cover practical ranges of mix design parameters, values of cement factor in-place ($\alpha_{in\text{-}place}$) equal to 125, 200, 275, and 350 kg/m^3 and water-to-cement ratio of the slurry (w:c) equal to 0.6, 1.0, and 1.4 were selected. To obtain the strength of the mixture after curing, the specimens were cured in plastic tubs containing water, and the tubs were stored in a humidity-controlled room with a temperature of 21.1 °C. After 3, 7, 14, and 28 days of curing, unconfined compressive strength (UCS) tests were conducted on the specimens. For the consistency of the mixture during mixing, laboratory miniature vane shear tests were conducted at 30, 40, 50, and 60 minutes after mixing. The undrained shear strengths ($s_{u,mix}$) obtained from the vane shear tests were used to represent the consistency of the mixture during mixing. Strength (UCS) and consistency ($s_{u,mix}$) data for the lean clay (CL) mixture were obtained from Nevarez-Garibaldi et al. (2018).

Important Findings

1. Two equations were developed for the cured strength of the cement-treated soil mixture and the consistency of the mixture during mixing. These are applicable to both CL and CH.
   - Strength equation: $\frac{UCS_{pred}}{p_a} = \left[d_1 + d_2 \ln\left(\frac{t}{1\,day}\right)\right] * [w_t : c]^{d_3} * \left[\gamma_{d,mix} : \gamma_w\right]^{d_4}$

   where UCS_{pred} is predicted UCS, p_a is the atmospheric pressure, d_1, d_2, d_3, and d_4 are dimensionless coefficients, t is the curing time in days, w_t:c is the total-water-to-cement ratio, and $\gamma_{d,mix}$:γ_w is the dry unit weight of the mixture normalized by the unit weight of water.
   - Consistency equation: $\frac{s_{u,pred}}{p_a} = \left[e_1 + e_2\left(\frac{t}{60\,min}\right)\right] * [w_t : s]^{e_3} * [e_4]^{w_t:c}$

   where $s_{u,pred}$ is predicted s_u, e_1, e_2, e_3 and e_4 are dimensionless coefficients, t is the time right after mixing in minutes, w_t:s is the total-water-to-soil-solids ratio, which is defined as the weight of the water in the mixture divided by the weight of soil solids. The coefficient values for the both equations vary depending on the base soil type.

2. By using the strength and consistency equations above, the optimum mix design can be selected that uses the smallest amount of cement to achieve the target cured strength and the target uncured consistency. As an example, the contours in Figure 1 produce a UCS_{28days} of 400 psi and a consistency of 50 psf. Any point above the strength and consistency contours has UCS_{28days} greater than 400 psi and $s_{u,60min}$ smaller than 50 psf. The intersection of the contours represents the most cost-effective mix design in terms of minimum cement usage.

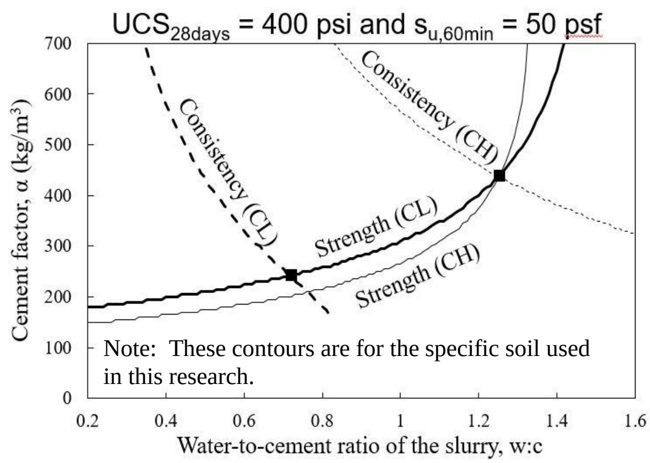

Figure 1. Strength and consistency curves ($w_{base\ soil}$=40%)

3. Although the $w_{base\ soil}$ of CL and CH are the same for the contour lines shown in Figure 1, the locations of the optimum mix design are not the same. But the strength curves for CL and CH are similar, while the consistency curves are far apart. This indicates that the plasticity of the base soil does not significantly affect the cured strength of mixture but has a significant influence on the consistency of mixture during mixing. As shown in Figure 2, when the $w_{base\ soil}$ is low, the α and the w:c for the optimum mix design (α_{opt} and w:c_{opt}, respectively) are high, so the mixture requires more cement and water to achieve the target strength and consistency, thereby increasing the material cost. However, the value of $\alpha_{in\text{-}place}$, which is defined as the weight of the cement divided by the volume of the mixture, for the optimum mix design ($\alpha_{in\text{-}place,opt}$) is constant regardless of the $w_{base\ soil}$. This is because only one set of mixture proportions (with one set of ratios of soil solids, water, and cement) will simultaneously achieve both the target strength and the target consistency.

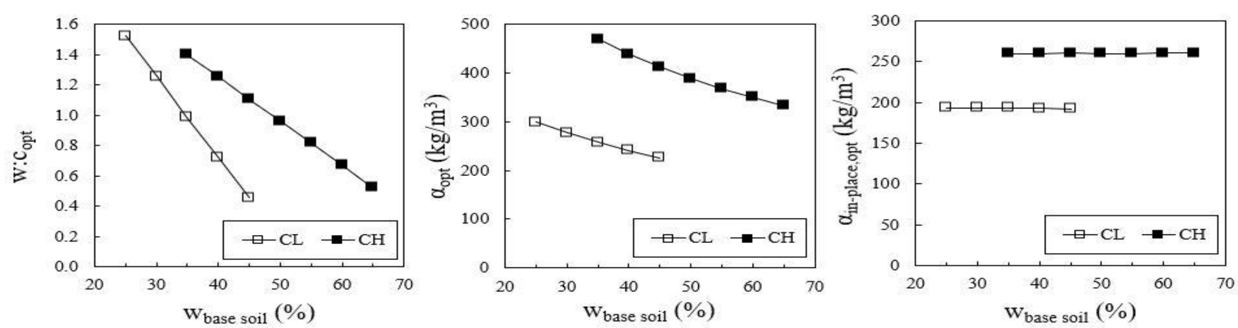

Figure 2. Influence of $w_{base\ soil}$ on optimum mix design