Field Verification of Stabilized Soil Strength

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ABSTRACT

In marginal soils, it is common to use chemical stabilizers to improve the strength properties of those soils for roadway construction. Many departments of transportation have a standard or design guide that is used to determine the stabilizer type (i.e. Lime, Fly Ash, Cement Kiln Dust, etc.) and the amount of stabilizer to use based on soil classification. These design guides do not always provide an ideal stabilization design since only a few index soil properties like Atterberg Limits and grain size distribution are used for soil classification. The testing in this study involves five roadway construction sites where the use of Class C Fly Ash (CFA) as a stabilizer and quicklime as a modifier to reduce Plasticity Index (PI) and increase workability was performed. The roadway sites were tested with the Dynamic Cone Penetrometer (DCP) and unconfined compression strength (UCS) specimens were prepared to match the cure times of the field testing. The results of this research show that the DCP can be effectively utilized to verify strength gains of stabilized roadway subgrades and that the change in Average Dynamic Cone Index (DCI) could possibly be correlated to strength increase results from laboratory UCS testing.

INTRODUCTION

It has been a common practice in roadway construction to use chemical stabilizers to modify and strengthen marginal soils in the subgrade. Some of the chemical additives used include Portland Cement, Lime, Class C Fly Ash (CFA), and Cement Kiln Dust (CKD). The use of these additives and methods to determine proper soil stabilization designs has been well established in the literature. Different laboratory testing procedures, including stabilizer mix design and unconfined compressive strength (UCS) determination are used to establish optimum designs. The results in this paper discuss the possible correlation of in-situ testing methods of the stabilized subgrades to the laboratory determined strengths.

In order determine a correlation between strength increases in laboratory samples and the strength gains developed in the field, five actual roadway construction stabilization sites were tested using the Dynamic Cone Penetrometer

(DCP). The five sites include Site #1 stabilized with CFA, Site #2 stabilized with CFA, Site #3 modified with quicklime, Site #4 modified with quicklime and then stabilized with CFA, and Site #5 stabilized with CFA.

LITERATURE REVIEW

Fine-grained soils that fall into the AASHTO Group Classifications A-4 through A-7 are often chemically stabilized when they are present in roadway subgrades. In Oklahoma, these fine-grained soils are prevalent and can make pavement design difficult. These stabilizers are widely used and allow for cost effective designs when subgrades are not naturally suitable for roadway construction. Lime stabilization of clay soils has been in use for more than sixty years and the basis of ideas for which stabilization processes have been built upon were published mostly before 1960 (Petry 2002). The use of CKD in cohesive and cohesionless soils improves the UCS and has been used in Oklahoma on county roads and has begun to be used on state highway projects (Miller 2000). The results of Miller (2000) show CKD provided strength gains in a short period of time within the first 7 to 14 days and that the DCP could be used effectively to measure the relative improvement in stabilized subgrades. CFA also has been proven to provide stabilization benefits and works similarly to lime in creating calcium exchange and pozzolanic reactions to stabilize the soil (Petry 2002).

TESTING PROCEDURE

Dynamic Cone Penetration (DCP) Field Testing

For this study, five roadway construction sites were chosen to be tested for in-situ strength after chemical stabilization by use of the DCP, performed in accordance with ASTM D6951/D6951M (ASTM 2009). At each construction site a flat graded location was picked for testing at all cure times. Three testing points were designated as Test Point #1, #2, #3 at each location, usually station number markings, and were consistently tested as such for subsequent cure time testing. Average DCI reported in this paper is the average penetration rate (mm/blow) in the stabilized layer, usually a depth of 15.24 cm (6 in.) to 20.32 cm (8 in.) depending on construction specifications, of the three test points at each site.

Laboratory Specimen Preparation

Each soil collected from the field sites was taken to the laboratory for drying and processing in order to prepare strength testing specimens. For the UCS testing, compacted samples were prepared as compacted Harvard Miniature samples with material passing the #10 sieve. The specimens were compacted according to ASTM D698 (ASTM 2005) with one difference in the compaction method. The compaction method used a repeatable mechanical compaction device that had been calibrated to the Standard Proctor compaction energy and produced the same Optimum Moisture Content (OMC) and Maximum Dry Density (γ_{dmax}) with the use of less material (Khoury and Khoury 2008). This calibrated compaction device requires the sample be compacted in 5 equal layers at 10 blows per layer. Each specimen was prepared at their respective OMCs and densities and then wrapped and preserved in a relatively constant humidity and room temperature (68°F) condition for the duration of the designated cure time.

Unconfined Compression Testing (UCT)

The UCT was performed on an axial-strain controlled testing frame. Specimens were tested for UCS at curing times that matched the field testing timeline for each site as well as at a typical 1, 3, 7, 14, & 28 day curing schedule used to monitor strength gains over time. The specimens were axially loaded with this device and these loads were recorded from a digital readout connected to a calibrated load cell. The axial strain rate used for all UCT specimens was 0.071 mm per minute (0.0281 inches per minute) or a 2% axial strain rate. Specimens were tested until failure and the peak loading recorded used to determine the maximum unconfined compressive strength (UCS). From each maximum UCS (kPa) an average UCS strength for each testing group (cure time) was determined.

RESULTS

Site #1

As seen in Figure 1, the DCI goes down after stabilization and with increasing curing of the stabilized subgrade. This is an indication of the strengthening and stiffening of the subgrade as the CFA additive creates cementitious bonds in the soil.

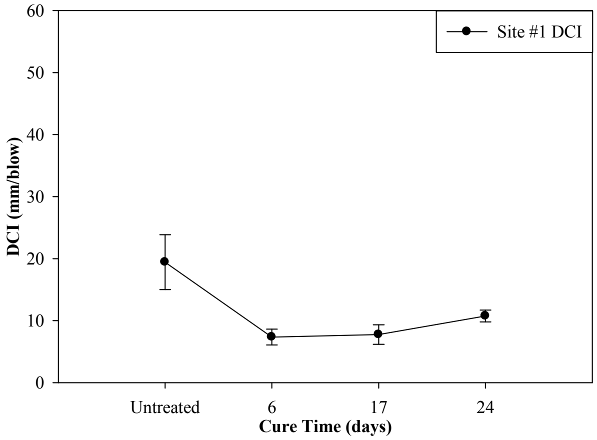

Figure 1: Site #1 DCI

The increase in DCI for the last testing is a result of a substantial amount of rain at the roadway construction site, approximately 5.26 cm (2.07 in.) in the time between the 6 day and 24 day cure times. Figure 2 shows the results of the UCS testing for the Site #1 samples. This soil shows immediate strengthening from the CFA stabilization. This is due to the cementation that occurs with CFA stabilization which occurs after mixing since CFA contains the elemental content required, alumina, silica, and calcium, to produce a cementitious reaction. After the initial large increase in strength there is only moderate strength increase with time, due to the fact that the pozzolanic reaction associated with CFA stabilization are not as significant as the initial cementation.

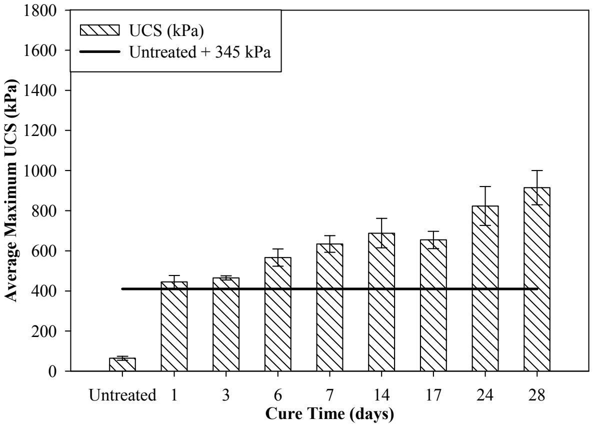

Figure 2: Site #1 UCS

Site #2

As seen in Figure 3, the CFA stabilization results in an eventual decrease in DCI over time. The initial increase in the DCI from the natural state to the 1 day cured is most likely due to mechanically working of the site elevation for preparation of the roadway. Also, the increase in DCI from 1-day testing to 3-day testing was due to rain at the roadway site on the 3-day testing of approximately 2.69 cm (1.06 in.) and the soil becoming more saturated in the treated layer.

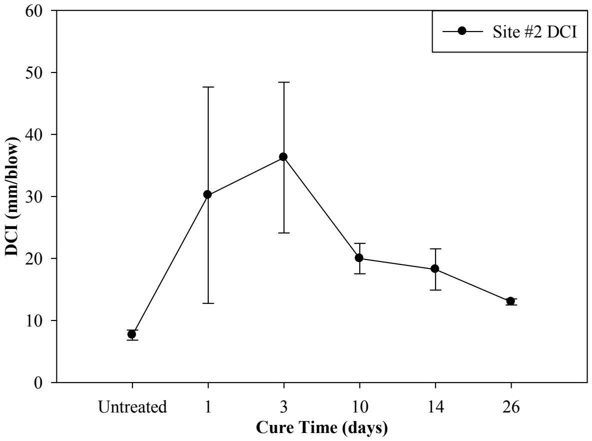

Figure 3: Site #2 DCI

Figure 4 shows the results of the UCS testing for Site #2. Again, Site #2 exhibits a large amount of initial strength increase due to the cementation from the CFA stabilization and some strength gain over additional time due to some pozzolanic reactions. There is an anomaly in the results at the 14 day testing which resulted in lower strength than the previous curing time. The sample preparation data (density and water content) was looked at for an explanation; however these parameters are similar to the rest of the specimens prepared for this site. So, this anomaly may be due to testing variability that resulted in lower strength.

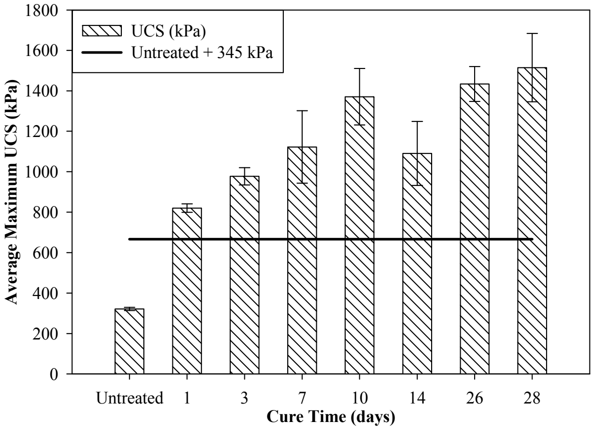

Figure 4: Site #2 UCS

Site #3

Figure 5 shows a similar trend of decreasing DCI after modification with lime. Again, a rain event of approximately 1.42 cm (0.56 in.) in the time before the last testing took place resulted in an increase in DCI.

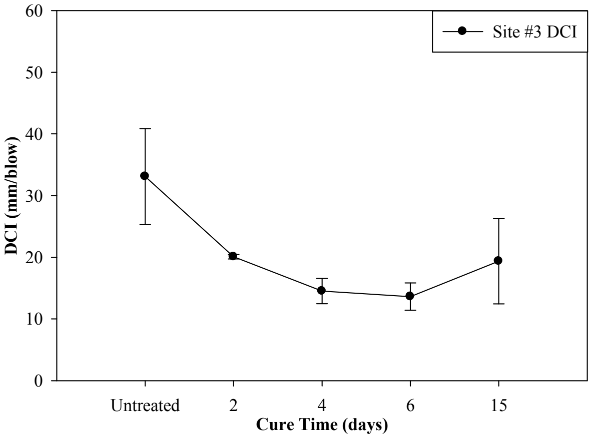

Figure 5: Site #3 DCI

Figure 6 shows the results of the UCS testing for Site #3. This site was treated with granulated quicklime in order to reduce the PI and improve workability. This soil does not show as high of immediate strength gains as the CFA stabilized soils. This is expected since the main mechanism of strength gain of lime stabilization is due to the slower pozzolanic reactions that result from the increased pH of the soil from the lime and the subsequent reaction that makes silica and alumina from the soil soluble. This allows these minerals to react with the calcium in the lime to create cementious bonds within the soil. There are overall strength gains with added curing time with two exceptions at 7 and 15 day testing. These lower strength results are most likely due to the type of chemical stabilizer used for this site. The lime used was collected on site as large granulated quicklime and then processed similarly to the soil in the lab for sample preparation. However, the granulated nature of the lime resulted in larger particles of lime that would have a lower surface area resulting in less chemical reactivity and thus lower strength gains. This highlights a potential problem with using a granulated lime with larger particles which could result in lower strength gains than expected if heterogeneous reactions occur.

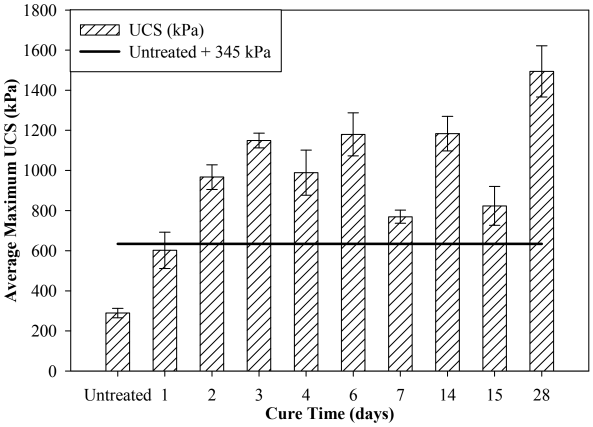

Figure 6: Site #3 UCS

Site #4

Figure 7 shows a good example of the behavior of stabilized soils over time. This site received no rain events during testing and the results show a trend expected when conditions allow for proper curing.

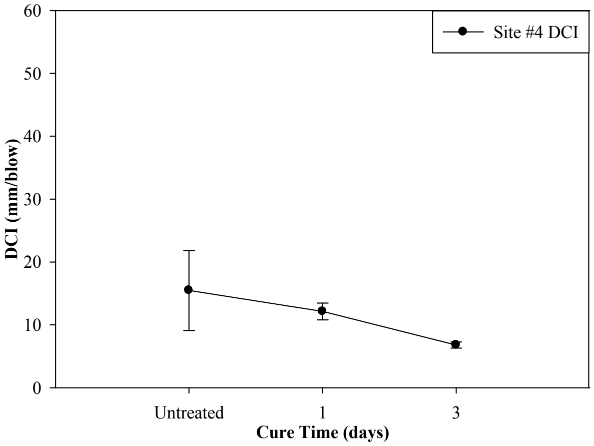

Figure 7: Site #4 DCI

Figure 8 shows the results of the UCS testing for Site #4. This soil shows some significant initial strength gain resulting from the cementation due to the CFA and also shows good strength gain over time as a result on the lime and the pozzolanic reactions. The lower strength results seen for the 28 day cured specimens were due to some slight density variations in these samples (0.3 kN/m^3 lower) from the average of the whole testing set for this site.

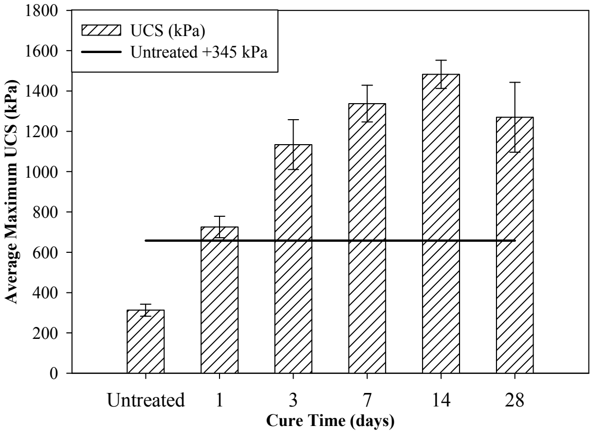

Figure 8: Site #4 UCS

Site #5

Figure 9 shows that the DCI decreased steadily with curing after the initial working of the grade of the site from the natural state to the 2 day cured state.

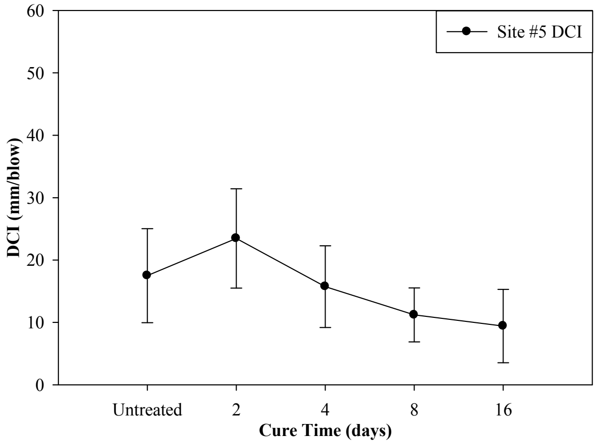

Figure 9: Site #5 DCI

Figure 10 shows that there was significant increase in strength from the natural state to the treated 1 day cured specimens due to immediate cementation from the CFA stabilization; however there was very little increase in strength with additional curing time. This suggests that there were very little pozzolanic reactions, if any at all, from the CFA used at this site.

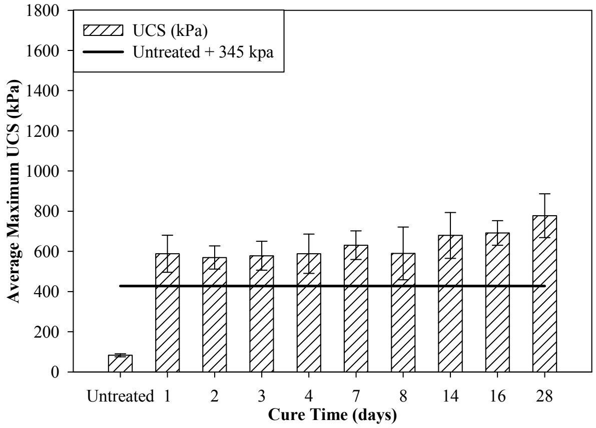

Figure 10: Site #5 UCS

Developed Correlations

A multiple linear regression analysis was run on the results of this study to develop correlations that could be used to predict UCS values from the field testing method results of this study and laboratory measured parameters that could increase the accuracy of the predictions. The correlation developed that accurately predicted UCS for all the CFA stabilized soils in this study is seen in Figure 11, where: **UCS** is the unconfined compression strength, **DCI** is the dynamic cone index (mm/blow) from the DCP testing, **t** is curing time (days), **S.C.** is the chemical stabilizer content (%), and **SSA** is the total specific surface area (g/m^2) obtained from the EGME desiccation testing method. These CFA stabilized soils included two A-4 soils (Site #1 and #5) and one A-6 soil (Site #2). Also, seen in Figure 12 and Figure 13 are more accurate predictions of UCS for soils within one classification, A-4. These figures show that even more accurate predictions can be made when a correlation is developed concerning soils within the same classification. Also, Figure 12 shows that the result of the field testing, DCI, can be used to provide reasonable predictions of UCS gains without requiring the Total SSA parameter.

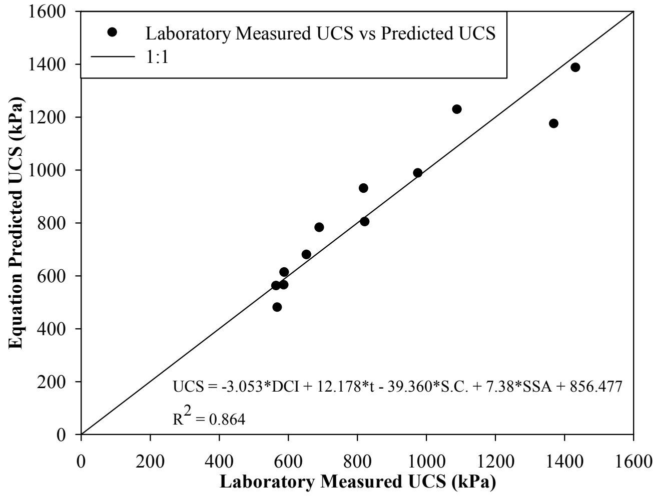

Figure 11: UCS Predictions for CFA Stabilized Soils using DCI and SSA

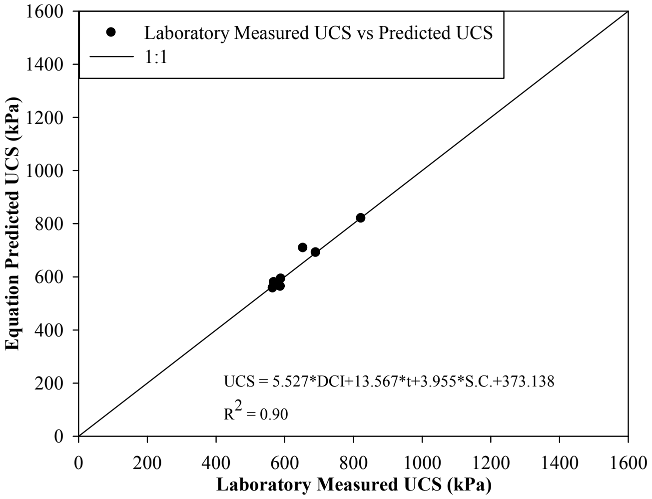

Figure 12: UCS Predictions for A-4 Soils using DCI

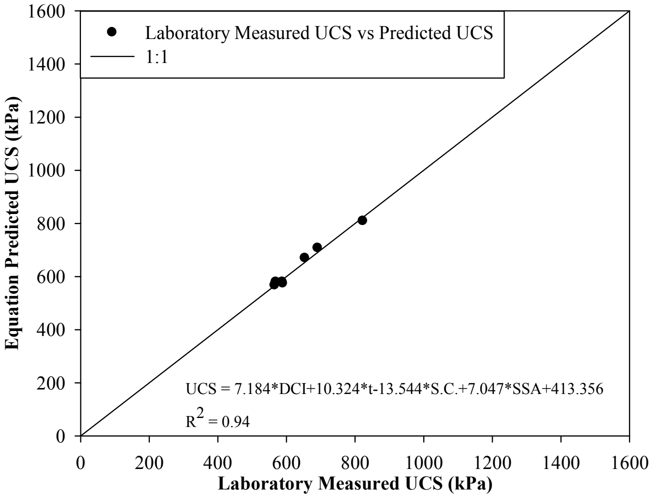

Figure 13: UCS Predictions for A-4 Soils using DCI and SSA

CONCLUSIONS

The DCP test can be used effectively to monitor strengthening and stiffening of the stabilized subgrades in real world field applications. Also, along with the total SSA parameter, the results from these field tests show that the correlations developed provide reasonable predictions of UCS values similar to those obtained in laboratory prepared and tested samples for CFA stabilized soils of A-4 and A-6 classification. More accurate correlations were developed for the A-4 soils using only the DCI field testing result as well as with the SSA parameter. The correlations developed allow the field testing methods to be used as practical ways to verify that the strength gains needed for a subgrade stabilization design are achieved.

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