Engineering Properties of Cement and Lime Stabilized Silty Sand in Pavement Sub Bases

W.K. Mampearachchi
Senior Lecturer, Department of Civil Engineering, University of Moratuwa, Katubedda, Sri Lanka

H.M.S.M. Herath
Chief Engineer, Executive Engineers Office, Road Development Authority, Sri Lanka

ABSTRACT: Chemical stabilization of soils is a widely used practice for improving engineering properties of soil. This technology is used very effectively in developed countries with standard and appropriate machinery specific to them. This study is focused on sensitivity analysis of important parameters of soil stabilization and the effect of nonstandard machinery on improving of medium plastic silty sand soil which is abundantly available in Sri Lanka. Three soil samples of silty sand with medium plasticity which do not meet the specified requirements for subbases were studied. Laboratory test results indicate that both stabilizers improve soil properties up to a considerable degree. Comparison of Unconfined compressive strength (UCS), degree of pulverization (DOP) and mixing time for drum mixing and rotary mixing were made and it was found that the rotary mixing provides higher UCS and DOP with a minimum number of mixing cycles. It was observed that the DOP and UCS reduce with extended mixing time in drum mixing and values slightly increase after achieving the maximum in rotary mixer. Two possible compaction scenarios (under prevailing moisture content and optimum moisture content relevant to the compaction time) were evaluated for both cement and lime stabilization. Furthermore, variation of the optimum moisture content (OMC) with the time was studied for cement stabilized and lime stabilized soil. Test results show that compaction time (delayed compaction), moisture content at the mixing time and moisture content at the compaction time are crucial factors that must be considered in soil stabilization with cement and lime.

1 INTRODUCTION

Soil stabilization can be defined as any treatment applied to in-situ soil to improve its strength and reduce its compressibility and especially its vulnerability to water (O'Flaherty, 2006).This technique was used nearly 2000 years ago by Romans in road construction (Emilijan and Mladen, 1990; Mallawarachchi and Silva, 1995). Mainly, there are two types of stabilization; mechanical stabilization (granular stabilization) and chemical or admixture stabilization.

This paper addresses the issues of chemical stabilization of silty sand in Sri Lankan road subbases. The most important factors that should be considered in soil stabilization using admixtures are; (1) type of stabilizer, (2) amount of stabilizer, (3) degree of pulverization, (4) mixing time and (5) mixing method. In addition to the above factors, compaction time (the time difference between mixing and compaction) is an important factor to achieve target strength in the stabilized samples. Further, it is very important to refine this technology in the developing world for local construction industry to manage it effectively with limited funds. It is also more economical to adopt locally available equipment for stabilization.

2 STABILIZATION OF SILTY SAND

<u>Soil- Cement mixing</u>
The gradation and plasticity of a soil are the most important factors affecting its suitability for cement stabilization. Cement contents of up to 5% can be considered as an economically feasible amount for stabilization of selected silty sand soil in the Sri Lankan context.

<u>Soil – Lime mixing</u>
Standard test method of ASTM 6276 was used to determine the minimum lime percentage for stabilization.

<u>Degree of Pulverization</u>
DOP of soil is one of the most important factors that affect the mixing quality with stabilizer. The standard test method to determine the DOP is given in British Standard (BS) 1924 -2.

3 BEHAVIOR OF STABILIZED SOIL

3.1 *Relationship between Pulverization and Mixing Time for Mixing in a Drum Mixer*

Pulverization is one of the important parameters in soil stabilization. Illukner and Brozbey (2009) performed a few studies to investigate the effects of pulverization on unconfined compressive strength of 24 hours mellowed expansive clay – lime mixture.

Pulverization has been divided in to 3 categories (poor, medium and high) based on the time spent for the pulverization.

To study the effect of mixing method on pulverization, two type of mixers have been used; a drum mixer and a rotary mixture. In this study, a concrete mixer with rotational speed of 24 rpm which is used for cement concrete production was selected as a drum mixer. On the other hand, a rotary tiller of 2 feet width, 18 blades and 90 rpm that is typically used for agricultural purposes in Sri Lanka was selected as the rotary mixer. Mixing time was varied from 1 min to 9 minutes.
The differences in the formation of soil lumps with the time of mixing were observed It was also observed that the degree of pulverization reduces as the mixing time increases in drum mixing.

The selected optimum stabilizer amount was mixed with the relevant soil in preparation of soil samples. DOP and UCS of the soil were measured at different mixing times for both stabilizers; cement and lime for the three selected soils. Results shows that DOP and UCS increase as the mixing time increases and DOP and UCS decreases with extended mixing. The optimum UCS is achieved after 3 min. of mixing in the drum mixture and the optimum DOP is achieved at the optimum UCS. Mixing of the soil in a drum mixture in a longer duration tends to form soil lumps thus reducing the DOP. The maximum DOP in the drum mixture with cement stabilization was 85% while that with lime was 78%.

3.2 *Relationship between Pulverization and Mixing Time for Mixing in a Rotary Mixer*

Laboratory tests were conducted at the test sections constructed in the university premises to check the behavior of UCS, DOP with mixing time. Field test sections were constructed and mixing of stabilizer was carried out using a rotary mixture. The rotary mixture used in the field test was 600mm (2 feet) wide and had 18 blades. Its rotating speed was 90 rpm. It was found in a previous study that During soil pulverization, chip dimensions can be affected by the operational speeds, soil strength, blade geometry, and number of pulverizer blades in rotary mixture (Petry and Wohlegemuth, 1988).

It was observed that DOP increases as the mixing time increases. Soil lumps are not built up as observed in the drum mixture because the soil lumps break down in the field due to the rotary action. However, more than 90 percent of the ultimate strength for both lime and cement stabilization was achieved after one mixing cycle and the increase in strength with further mixing was minimal. Fig. 1 shows the percentage increase of UCS of lime and cement stabilization against mixing time. The minimum DOP of the rotary Mixture was 85% and 80% for cement and lime respectively and it was observed after one mixing cycle.

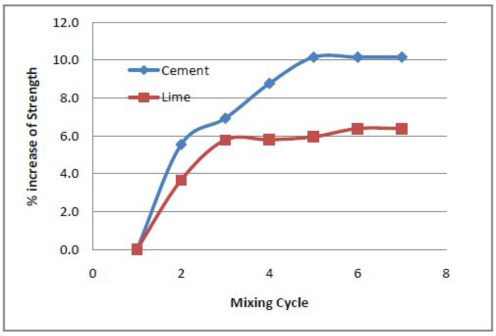

Fig. 1 Effect of mixing cycle on 28 days strength

3.3 *Effect of Compaction Delay*

In order to obtain the best results compaction should commence as soon as mixing is completed. Delays of the order of two hours typically occur in practice and changes taking place within the mixed material result in changes in their compaction characteristics. To determine the sensitivity of the stabilized materials to delays in compaction, another set of tests were conducted. Delayed compaction is one of the main reasons for the non-achievement of the target strength in stabilized soil. It was observed that there is a considerable reduction of the UCS of the samples which were delayed for compaction. However, reduction of UCS could be minimized by compacting the soil at the relevant OMC of the stabilized soil. Soil and stabilizer mixing was done under two scenarios to evaluate the effect of the mixing method and delayed compaction.

Scenario 1 – Mixing of Natural Soil + Stabilizer (with the stabilizer added and mixed at the prevailing moisture content of the soil). At the time of compaction, water was added to obtain the relevant OMC condition. This paper will refer it as the “Air dried soil”

Scenario 2 – Mixing of Natural Soil + Stabilizer + Water (with a pre-calculated amount of water added to the mixture to obtain the OMC condition). This mixture was subjected to air drying during the delayed compaction. At the time of compaction, water was not added. The paper will refer to it as the “Wetted dry mixture”

Densities and UCS values (at 7 days and 28 days) of stabilized soil compacted several hours after mixing under scenario 1 were determined. The samples were compacted at the optimum moisture requirements of the air dried sample at the time of compaction. OMC of the samples delayed for compaction were determined for both cement and lime stabilized samples.

In this study OMC was seen to decrease as much as 5.5% after a 6 hour delay in compaction of cement stabilized soil and 4% in lime stabilized soil for silty-sand soil. This behavior can be explained by the fact that clay particles are bonded around cement particles and reduce the water affinity of the clay. The hydration of cement in clay-cement interface act as a barrier for further hydration of cement particles. There is a significant difference of particle sizes of cement and clay. The majority (90%) of cement particles in Portland cement is in the range of 0.002mm - 0.09 mm while clay particles are less than 0.002 mm in equivalent diameter. Therefore, there is a possibility to have un-hydrated cement particles in delayed compaction samples which will tend to decrease the strength of delayed compacted samples

Fig. 2 present the variation of UCS with delayed compaction for cement stabilized soil. It can be seen that air dried soil mixed with stabilizer compacted at the OMC provides the highest UCS (scenario 1)

Strength deduction of stabilized soil due to compaction delay is a function of the moisture content at the compaction time and initial reactions with stabilizer. Reduction of UCS in soil mixed at OMC and compacted under the prevailing moisture content (scenario 2) after 6 hours of delay are 37 % and 35 % respectively for cement and lime stabilized soil. When mixing is carried under dry conditions and compacted after 6 hours at the relevant OMC at the time of compaction as per scenario 1, the corresponding reduction can be reduced up to 22 % and 17 % for cement and lime stabilized soil respectively.

Furthermore, it can be observed that there is a relationship with strength achieved and water content at the stabilizer mixing time. Therefore, commencement of hydration process of stabilizer at stabilizer mixing time could be identified as the main reason for the strength reduction.

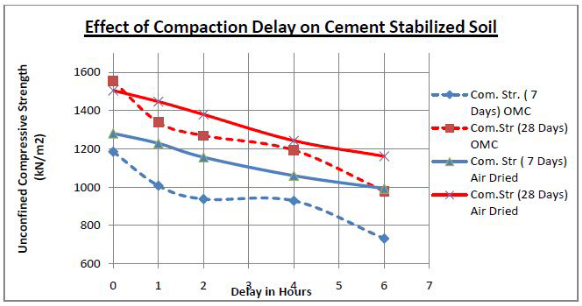

Fig. 2 Relationship of UCS of Soil Cement mix with compaction delay

To achieve the optimum UCS value, the stabilized soil should be compacted immediately after mixing of stabilizer. Soil mixed at dry condition and compacted at OMC of the time of compaction gives higher UCS values than that of soil mixed at OMC and delayed for compaction as per scenario 2.

Reduction of bulk density of samples mixed at OMC and compacted at the prevailing moisture condition (scenario 2) are about 10% for 6 hours delay for both cement and lime stabilized soil. But the reduction of density is generally low for samples mixed at the dry condition and compacted at OMC at the time of compaction (scenario 1). Reductions of density are 4.7 % and 3.5% for cement and lime stabilized soil respectively for 6 hours delay. All the densities were measured after 28 days.

Furthermore, the reduction of density can be minimized by performing compaction under the relevant optimum moisture content. It can be seen that there is a similar behavior in both bulk density and UCS with compaction delay. Variation of gradation with the time could be identified as the main reason for the density variation. It is realized that reactions start in the presence of stabilizer and water and the gradation varies due to formation of soil lumps resulting from the reaction.

3.4 *Factors to be considered in Laboratory Mix design*

Very often it is common to perform mixing of soil stabilizers in the field using a rotary mixer. In most situations, there are industrial drum plants in centralized locations for mixing the stabilizer with soil from where the mixed soil is transported to the road sections for placement. However, the selection of the optimum stabilizer amount and the target strength are determined in drum mixers available in laboratories. Therefore, because of the differences in the compaction equipment, it is very important to consider the effect of mixing on the target strength in designing the laboratory procedures to simulate the corresponding field practices. The graph of DOP vs. mixing cycles needs to be plotted and the number of optimum cycles for mixing needs to be determined prior to making samples for the UCS test.

Compaction delay is another key factor to be considered in laboratory mix design. Mixing of the stabilizer with soil under several moisture conditions; (1) prevailing moisture condition (below OMC), (2) OMC, and, (3) above OMC, needs to be considered in mix design. Although this study was not focused on mixing of the stabilizer above the OMC, lime stabilization is usually conducted at high moisture conditions. This is because for lime stabilized soil, a "mellowing" period (a purposeful delay between mixing and compaction) is often used to allow for flocculation and agglomeration of the clay portion of a soil. One of the important findings of this study is that allowing of mellowing period for medium to low plasticity soil mixed below OMC (soil type considered in this study) is not required and it will lead to a decrease in the strength of the stabilized soil. However, mixing of soil at OMC and allowing for a period of "mellowing" has not shown any improvement of strength in this study since the stabilizer mixed soil may not be compacted at OMC. It must also be noticed that the moisture condition at the time of compaction can be different from OMC at the time of compaction and it is unable to verify this since no recording is generally made during compaction. It is realized that a moisture condition different from OMC can lead to a lower dry density of the stabilized soil. It has been proven that compaction of the stabilized soil at OMC is much more important than allowing mellowing of the stabilized soil and compacting at a moisture content different from OMC.

Usually there is a delay in mixing of the stabilizer and the compaction in construction of a stabilized layer due to unavoidable delays in workmanship and machinery. Therefore it is paramount that those circumstances are considered in the mix design process. Two possible scenarios (1 and 2 documented above) have been considered in this study. It was observed that a larger reduction of UCS occurs in soil mixed with the stabilizer at OMC and delayed for compaction than that of the dry mixing of the soil with the stabilizer and delayed for compaction.

4 CONCLUSIONS

Degree of Pulverization is one of the important parameters in soil stabilization. It directly affects the UCS of the stabilized material. In this study, it was observed that the mixing action affected the DOP and facilitated the soil lump formation as the mixing time extended in the drum mixer. It was also found that the optimum UCS was achieved after 3 min. of mixing in the drum mixture and the optimum DOP was achieved at the optimum UCS. Extended mixing of the soil in the drum mixture tends to aid the formation of soil lumps thus reducing the DOP. The maximum DOP in the drum mixture for silty sand soil with cement was 85% while that with lime was 78%.

It was observed that DOP increases as the mixing time increases in the rotary mixer. It is evident that DOP of the soil increases with mixing cycles as the soil lumps are subjected to constant breaking in rotary mixers. However, more than 90 percent of the ultimate strength for both lime and cement stabilization was achieved after one mixing cycle and the increase of strength with further mixing was minimal.

In order to obtain higher UCS values, compaction should commence as soon as mixing is completed. Therefore, mixing at the job site is better than central plant mixing. The moisture content of the soil should be maintained lower at the mixing time and at the relevant optimum moisture content during compaction.

Behavior of the stabilized soil for delayed compaction was studied and it was found that there is a significant drop of UCS with delayed compaction. UCS of delay compaction can be improved with mixing the stabilizer at air dried condition and compacting at the OMC of the stabilized soil. Effects of compaction delay and field mixing method (rotary or drum) should be considered in setting up the appropriate laboratory mix design procedures.

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