Technical Note

Optimal Strength of Lime Stabilized Soil

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Introduction

Lime soil is often used in building and road projects situated in or passing through clay soils. However many soil technicians are not aware of the reactions taking place between lime and clay soil. If lime and water are mixed with improper type and amount of soil for making lime soil, strength may even decrease with respect to the strength of the natural soil strata. Hence the effect of factors, such as type and amount of fine grained soil, amount of coarse grained soil and amount of lime to be used, on unconfined compressive strength have been studied in an effort to optimise the use of lime and coarse grained soil for maximizing the strength of locally available soils by the conventional method prevalent in Iran.

Lime-Soil Reactions

Upon mixing of hydrated lime $Ca(OH)_2$, and water with clay soil a new material is formed called lime soil having entirely different properties compared to original soil. With the passage of time lime soil hardens and becomes capable of sustaining loads.

Lime soil reactions are divided into two groups (1) immediate reactions and (2) pozzolanic reactions. For a detailed discussion on lime, water and soil reactions, reference may be made to Mazindrani and Ghane (1990).

Immediate Reactions

When lime and water are added to clay soil, due to exchange of cations

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between lime and clay, the character of the clay soil is altered immediately. The clay particles flock around one another and form bigger particles of soil of the size of silt, the soil becoming less plastic with reduced plasticity index (PI), more friable and workable. The amount of lime required for immediate reactions is about 3% (TRC 180, 1976) depending upon the clay mineral. This amount of lime is known as 'lime fixation' (Bell, 1988).

Pozzolanic Reactions

When lime in excess of lime fixation is added to soil and water, silicious and aluminous materials in clays enter into pozzolanic reactions with lime resulting in gel like calcium alumino silicate complexes having binding property that precipitate on the soil grains and hold the grains together. With passage of time, the lime soil transforms into a hardened mass having strength to sustain loads (Bell, 1988). Impurities such as sulphates of calcium and sodium induce considerable heave in lime soil (Dal Hunter, 1988). Hence it is desirable that the hydrated lime should be free of such impurities.

Experimental Work

A brief description of the experimental work carried out to study the effects of various parameters mentioned earlier on compressive strength of lime soil is given. For more details the reader may refer to the research report by Mazindrani and Ghane (1990). Four different fine-grained soils were collected from four different parts of the North Eastern city of Mashhad, Iran having Atterberg limits as indicated in Table 1. From geological and soil formation point of view, considering the small stretch of the city of Mashhad, by plotting the Atterberg limits of the four soils on Casagrande's plasticity chart (1948) it was concluded that excepting the soil OL_4, all of the other three soils are glacial inorganic clays, the differences in the Atterberg limits being due to the differences in the quantity of clay rather than the type of clay mineral. Clay mineralogy aspects were not studied. Three types of coarse-grained soils were prepared, they being well graded gravel (GW), well graded sand (SW) and well graded gravel-sand mixture (GW-SW) for use in the investigation.

TABLE 1 : Different Soils used in Investigation

S.No.	Type of Soil	LL	PL	PI
1.	CL_1 Low plastic clay	28	20	08
2.	ML_2 Low plastic silt	16	12	04
3.	CL_3 Moderately plastic clay	39	22	17
4.	OL_4 Organic soil with very low plasticity	22	21	01

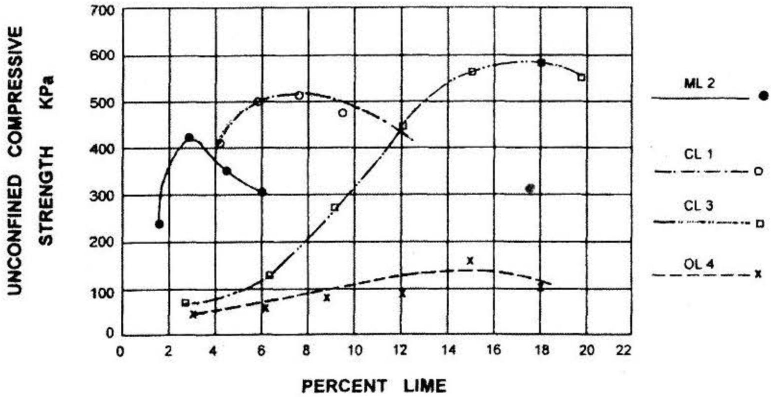

FIGURE 1 : Variations in Unconfined Compressive Strength with Percent Lime for Various Soils

Different percentages by weight of lime with respect to dry weight of soil, and enough water (w ≈ LL) as per the practice called conventional method in Iran were added to the four types of fine grained soils and mixed thoroughly well, the initial water content of the soil having been taken into account while adding additional water. The lime-soil-water mixture was poured in metallic cylindrical moulds 12 cm (height) × 5.4 cm (dia.) and vibrated thoroughly well on table vibrator. The samples were air dried for 24 hours and later were transferred to humidity chamber for 96 hours at 80% RH to simulate the natural air climatic conditions in Mashhad over a considerable period of the year and 49 °C being nearly two and half times the room temperature to speed up drying. The samples were then kept immersed in water at 20 °C for 24 hours for complete saturation to simulate worst site conditions. Samples were then extracted from the metallic moulds and their unconfined compressive strength was determined. The average values of unconfined compressive strength of a large number of samples prepared under similar conditions over a period of two years are plotted in Fig.1.

Optimum Lime Content

For pozzolanic reactions to occur lime in excess of lime fixation needs to be added. If enough lime is not added to soil, pozzolanic reactions do not take place completely as part of soil remains unreacted and maximum possible strength is not developed. On the other hand if lime content is added in excess of what is required for maximum possible strength to develop, the excess lime remains unreacted in the soil. The unreacted lime cannot by itself harden without clay material and thus resulting in reduced strength. Thus it can be observed from Fig.1, that there is an optimum lime content for any given soil to attain maximum possible compressive strength. Lesser or more

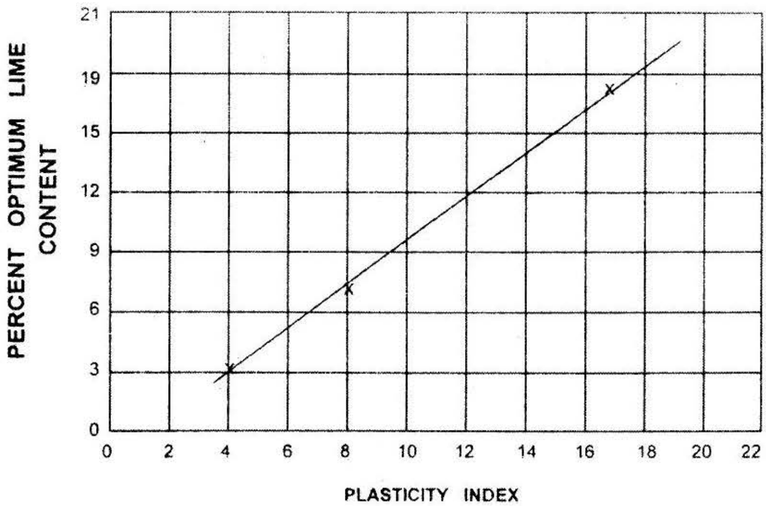

FIGURE 2 : Variations of Optimum Lime Content with Plasticity Index of Soil

lime than the optimum results in reduced strength. Similar phenomenon was observed in case of combinations of soils.

Optimum lime required depends on the amount and type of clay in the soil characterized by PI. Even for a particular type of clay as is believed to be in the present case in the absence of detailed mineralogical studies, PI of a soil is more if the amount of clay in the soil is more, which means more pozzolanic reactions would occur, requiring more lime, producing more cement, and imparting greater strength to the soil. Fig.2 shows the percent optimum lime requirement for the different soils in Table 1. It is seen from Fig.2 that with increase in plasticity index (PI), due to more amount of clay in soil, optimum lime content increases (organic soil OL_4 is not considered in the study). Based on these experimental results the optimum percentage of lime can be calculated from the following equation,

$$\% \, \text{Lime}_{\text{opt}} = 3 + 1.07(\text{PI} - 4) \tag{1}$$

where $4 \leq \text{PI} \leq 20$. Similar relations may be established for clay soils of other regions.

Effect of Coarse Grained Soil in Lime-Soil

Large quantities of water ($w \approx LL$) are used for facility in producing and working with lime soil in the conventional method in Iran. Lime soils so

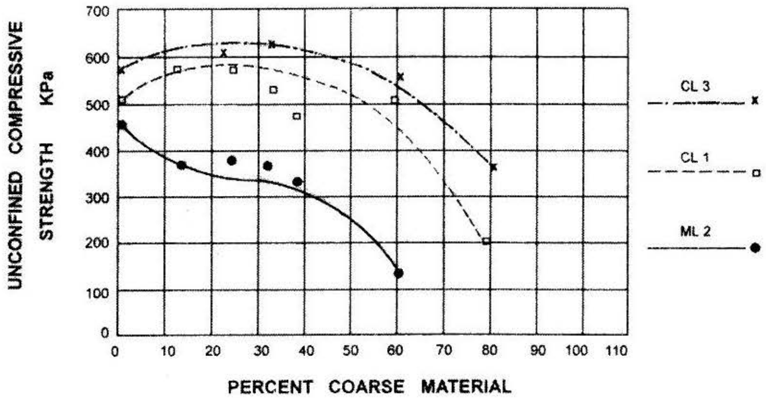

FIGURE 3 : Unconfined Compressive Strength vs. Percent Coarse Material in Lime Soil

produced have low densities of the order of 11 kN/m^3 to 14 kN/m^3 indicating large porosities and consequent low strength and possibly large settlements on loading (settlement aspects are not studied). For countering the low density problem in Iran, boulders, cobbles and gravel are added to lime soil to improve the density of soil. Considering lime soil as a mass of weak cement, different percentages of coarse grained soil (well graded mixture of gravel and sand were added to lime soil as the other two types of coarse soils namely well graded gravel and well graded sand were found to be less effective) were added to lime soil made from different fine grained soils listed in Table 1 using optimum lime. As coarse grained soils are devoid of clay material, lime does not react with coarse soils and hence the optimum lime content is based on fine grained clay soil only.

Samples of size 12 cm (height) and 5.4 cm (dia.) were made as explained in the earlier paragraphs. The unconfined compressive strength of samples was determined. Several samples prepared under similar conditions and cured as described earlier were tested for unconfined compressive strength over a period of two years. The averaged results are shown plotted in Fig.3. The percent coarse grained soil mixed with lime soil is calculated as follows,

$$\% \text{ Coarse grained soil} = \frac{\text{wt. of coarse grained soil}}{\begin{pmatrix}\text{wt. of coarse grained soil} \\ + \text{wt. of fine grained soil (dry)}\end{pmatrix}} \times 100 \quad (2)$$

It can be seen from Fig.3 that in the case of inorganic silt of low plasticity, there is no benefit of adding coarse soil. However in the case of inorganic clay with low to moderate plasticity maximum compressive strength occurs if an optimum of 30% of coarse soil is added. Further adding upto 60% of coarse soil does not in any way result in substantial reduction in compressive strength while having the benefit of reducing the porosity and increasing the density.

Example

60% of soil at a particular site passes through sieve no. 40 and has PI = 8. Calculate the amount of hydrated lime and coarse grained soil to be added to the soil per 10 kN (1000 kg) of natural soil to obtain the maximum strength.

From Fig.2, for PI = 8, the optimum percentage of lime required = 7.5%.

i.e. $7.5/100 \times 6 = 0.45$ kN (45 kg).

To calculate the amount of coarse soil material m, we have,

$$\frac{4 + m}{m + 1} \leq \frac{60}{100}$$

i.e. m = 5 kN (500 kg)

Hence 45 kg of hydrated lime and 500 kg of coarse soil material are to be added to the natural soil to get the best strength results of lime soil

Conclusions

1. Coarse grained soil such as gravel, sand and even non-plastic silt do not show any chemical reaction with lime and hence do not produce hardened mass of lime soil.

2. It is not desirable to make lime soil with organic soils as can be concluded from Fig.1.

3. For soils of inorganic clays, optimum lime required for making lime soil depends on the plasticity index (PI). Percentage of optimum lime required increases with increase in plasticity index, which may be calculated from equation such as Eqn.1 for any given region for which such equations are established.

4. Use of coarse material in lime soil has the effect of increasing the unit weight and strength of lime soil. Adding 30% of coarse material in

lime soil made from low plastic clays and 60% coarse material in lime soil made from low to moderate plastic clays is recommended.

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