The enhancement of the properties of clay soils by the addition of cement or lime

L'amélioration des propriétés des sols argileux par l'addition de ciment et de chaux

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SYNOPSIS: Clay soils, especially clay soils of high or very high plasticity, often present difficulties in construction operations. Fortunately, however, the engineering properties of clay soils can be enhanced by the addition of small percentages, by weight, of either cement or lime, thereby producing an improved construction material.

The properties of the soil-cement or soil-lime mixtures are affected by the type of minerals present, as well as the length of the curing period. As the range of mineralogy of clay deposits varies enormously, three of the most important components in clay soils, namely, kaolinite, montmorillonite and quartz, were combined to stimulate clay soils of high or very high plasticity. The engineering properties of such 'soils' were assessed and compared with the same properties when the 'soils' were treated with small amounts of cement or lime.

1 INTRODUCTION

Clay soil is a variable and complex material but because of its availability and low cost it frequently is used for construction purposes. At a particular location, however, a clay soil may not be wholly suitable for the desired purpose. In such a case its properties may be altered by the addition of a small amount, by weight, of cement or lime. The amenability of clay soil to such treatment depends not only on the type and amount of cementitious material added but also on the chemical and mineralogical composition of the soil. Consequently the success of this form of soil stabilization depends on determining the character of the clay soil and those of its properties which require upgrading.

Clay deposits generally contain some species of clay mineral(s) and fine quartz as the dominant minerals, together with other minerals, generally in accessory amounts, which may include feldspar, limonite, pyrite, calcite and organic matter. The three principal groups of caly minerals are the kandites, the illites and the smectites. The commonest type of clay minerals belonging to each of these groups is kaolinite, illite and montmorillonite respectively. Those clay minerals belonging to the vermiculite and palygorskite groups are not common. In order to study the influence of mineralogy on the ability to stabilize clay soil with cement or lime, three of the major constituents of such soils, namely, kaolinite, montmorillonite and fine quartz (less than 5 microns) were blended to form 'standard' clay soils. Illite was not chosen since it has properties intermediate between those of kaolinite and montmorillonite. Three standard soils A, B and C, were formed in which one of the minerals dominated in amount (ie A = 70% kaolinite, 20% quartz, 10% montmorillonite; B = 20% kaolinite, 70% quartz, 10% montmorillonite; C = 20% kaolinite, 10% quartz, 70% montmorillonite).

These soils all possessed a high or very high plasticity and therefore presented soils which would be likely to be more suspect as far as construction were concerned.

As stabilization of clay soils is used most frequently in relation to the formation of sub-grades and sub-bases in road construction, the soils underwent appropriate tests, namely, plastic and liquid limit tests, unconfined compressive strength tests, compaction tests and California Bearing Ratio tests. The values of the modulus of elasticity also were determined. The soils were tested with and without additions of cement or lime, and the additions were in 2 per cent increments up to a maximum of 8 per cent.

2 PLASTICITY

Soil A underwent notable increases in platicity indices with the additions of cement and of lime, the increases being greater in the case of the latter stabilizer. The reason for this is that the plastic limits of soil treated with cement or lime are very similar whereas the liquid limits of lime treated soil are some 10 per cent or so higher than those of cement stabilized soil. The greatest increases in plasticity index both occurred with the addition of 2 per cent of cement and of lime. After this amount of addition the index declined gradually but in both instances remained appreciably above the untreated soil (Figure 1).

When Soil B was treated with either cement or lime the plastic and liquid limits rose in all cases, the largest rises being obtained with the addition of 2 per cent in both series of tests. Hence the most significant rise in plasticity index also was at 2 per cent additive, after which there was a very slight decline in plasticity in both instances. The rise in plasticity index was somewhat higher with the addition of lime than cement (Figure 1).

The opposite trend is found in the case of Soil C in that the addition of both cement and of lime leads to a reduction in plasticity index. When cement is added the largest decrease occured at 6 per cent, whilst the largest decrease with the addition of lime took place at 4 per cent. The reduction in plasticity index was slightly larger when lime rather than when cement was added (Figure 1).

3 STRENGTH AND ELASTICITY

All three soils underwent increases in strength and modulus of elasticity when treated either with cement or with lime (Figure 2). In particular, striking increases took place when cement or lime was added to Soil B, the largest proportional increases taking place with the addition of 2 per cent cementitious material in each case. The increases in strength and elasticity of Soil B nonetheless continued, again with both types of additive.

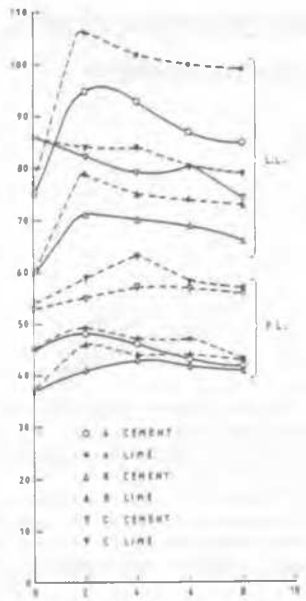

FIG. 1 PLASTICITY OF TREATED SOILS

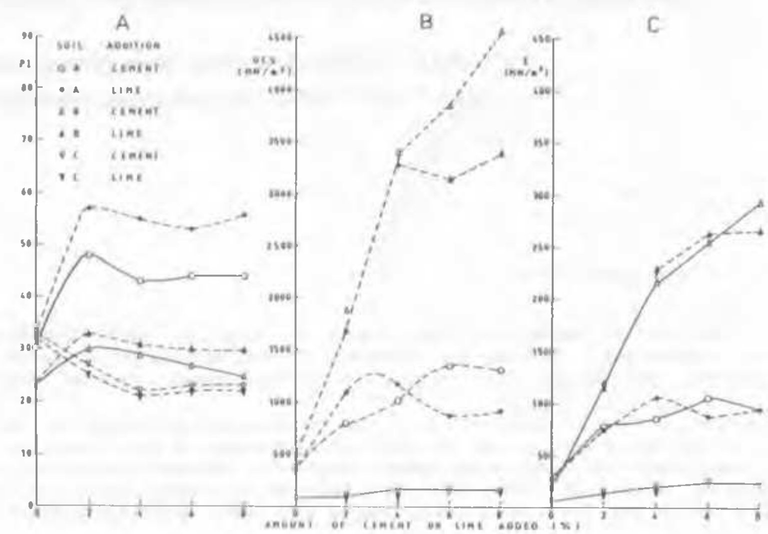

FIG 2 PROPERTIES OF TREATED SOILS

up to 8 per cent (there was a sixfold increase in strength with the addition of lime and a ninefold increase with the addition of cement: with cement the value of Young's modulus increased 15 times whilst with lime it increased over 13 times). By contrast, the increases in strength and modulus of elasticity developed by Soil C when treated with these two materials were modest. The highest values of strength and elasticity were obtained with the addition of 6 per cent cement and of 6 per cent lime. However, the gain in strength and elasticity was somewhat greater when lime rather than cement was used. Significant rises in the values of strength and Young's modulus also were obtained when Soil A was treated with cement and with lime. The greatest increases in these two properties were achieved when 6 per cent cement was used but only 4 per cent of lime needed to be used to produce the highest gains in both strength and elasticity of Soil A.

In every series of tests, the strength increased with increasing length of curing time. In the case of Soil A all 28 day strengths were higher than the 1 day strengths. However, the gain with age was greater with increasing amount of cement (eg with 2 per cent the strength at 28 days was 50 kN/m^2 higher than at 1 day, but with 8 per cent the gain was around 300 kN/m^2). With the addition of lime the increases developed in strength with curing time from 1 to 28 days for 2, 4, 6 and 8 per cent amounts were remarkably similar, averaging about 100 kN/m^2 gain for this period. When cement was added to Soil B the increase in strength with curing time tended to be gradual. Again, however, the greatest proportional increase in strength with curing time was developed with 8 per cent added. The addition of lime to Soil B saw the gain in strength with curing time increase with increasing amounts. With each 2 per cent addition the increase in strength was more or less linear. Turning to Soil C the increases in strength of treated specimens with curing time obviously were not so significant. However, when lime was added the rises in strength with curing time were not necessarily regular.

4 COMPACTION AND CALIFORNIA BEARING RATIO

Compaction and California Bearing Ratio tests were carried out on untreated and treated specimens of the three soils, the treated specimens being compacted with optimum strength additions of cement and lime (Table I). All three soils showed slight increases in optimum moisture content and decreases in maximum dry density when mixed with these two cementitious materials. The greatest changes in optimum moisture content and least in maximum dry density were recorded when Soil C was tested. The changes occurred in these two properties when the other two soils were treated with cement and with lime were similar.

Table I Results of Compaction and California Bearing Ratio (CBR) Tests on Clay Soils Treated with Optimum Amounts of Cement and Lime

Soil	Amount Added (%)		Compaction: Optimum Moisture content (%)	Compaction: Maximum dry density Mg/m3	CBR (%)
A	Cement	0	29	1.41	8
		6	33	1.345	46
	Lime	0	29	1.41	8
		4	31	1.353	17
B	Cement	0	31	1.4	19
		8	33	1.37	84
	Lime	0	31	1.4	19
		8	35	1.34	24
C	Cement	0	22	1.22	17
		6	29	1.205	18
	Lime	0	22	1.22	17
		6	33	1.2	18

Each soil showed an increase in California Bearing Ratio when cement or lime was added to it (Table I). However, in Soil A, the increases with both additives was negligible. In the other two soils more notable increases were obtained with the addition of cement than with lime.

5 CONCLUSIONS

In each of the three soils one particular mineral was dominant and this factor generally exerted a significant influence on the change in character of a given soil property when specimens were treated with cement or lime. Mineralogy would appear to have the most notable influence on strength and modulus of elasticity. Highly significant changes occur in these properties when either cement or lime is added to a quartz rich soil (Soil B). Conversely the effects of such additions on montmorillonitic soil (Soil C) are much less striking, for example, the strength only more or less doubles. Significant increases also are obtained in strength and modulus of elasticity when kaolinitic soil (Soil A) is treated with either cement or lime. The reason for the differences in strength increase between montmorillonitic and kaolinitic soils when cementitious materials are added may be due to the fact that the former mineral does have an effect on the hydration and hardening process whereas the latter has little effect.

The kaolinitic soil was the most plastic. The reason for this is probably that the kaolinite used was of finer grain size than the Ca montmorillonite. Initially this soil had a very high plasticity which when treated with cement or lime became and extremely high plasticity. Its plasticity indices were the highest of all three soils. It has been suggested that the liquid limit of kaolinitic soil rises when treated with these cementitious materials because hydroxyl atoms from $Ca(OH)_2$ increase the affinity of the surfaces of the kaolinite particles of water.

The quartz rich soil had a plasicity which increased to a very high plasicity when either cement or lime was added. All the specimens of montmorillonitic soil, whether untreated or treated with either cement or lime, fell within the very high plasticity range. However, this soil, unlike the other two, underwent a reduction in plasticity range. However, this soil, unlike the other two, underwent a reduction in plasticity index when treated with cementitious material. The decrease in liquid limit experienced by montmorillonitic clay soils when treated with cement or lime may be attributable to the effects of flocculation on montmorillonite which cause it to behave as a silty material.

Mineralogy, no doubt, also accounts for the differences noted in the compaction characteristics and California Bearing Ratio between the three soils, especially between montmorillonitic soil and the other two types. The decrease in maximum dry density and corresponding increase in optimum moisture content in clay soils treated with either cement or lime may be caused by flocculation so that when compacted the soils each have an increased volume of voids compared with the untreated soils. In addition the increase in hydroxyl ions which are liberated, especially by lime, increase the affinity of the surfaces of clay particles for water.

Finally, in the case of Soils B and C the changes brought about by the addition of cement or of lime are similar. Also the optimum amount of additive for bringing about the most significant change is frequently 4 per cent or less.