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ORIGINAL PAPER

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The behaviour of organic matter in the process of soft soil stabilization using cement

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Abstract In some projects where cement is used to stabilize soft soil foundations, it is found that the organic matter influences the stabilization effect. As a consequence, extra admixtures are added to accelerate the reactions of cement and improve the stabilization effect. In this study, different kinds of extra admixtures were used with cement to stabilize a soft soil with a high organic content. Direct shear and unconfined compression tests were undertaken and the mechanical indices in different conditions obtained. The total amount and components of the organic matter in every sample were also determined. The results show that the addition of extra admixtures improves the properties of cement-stabilized soils and that different extra admixtures play a different role.

Keywords Cement · Soft soil · Organic matter · Extra admixture · Behaviour

Résumé La matière organique a une forte influence sur l'efficacité des traitements au ciment visant à augmenter la résistance des sols. En conséquence, des ajouts de substances particulières sont souvent réalisés pour accélérer/améliorer les processus en cause. Dans cette étude, différents produits ont été ajoutés au ciment pour stabiliser des sols mous contenant une forte teneur en matière organique. Des essais de cisaillement direct et de compression simple ont été réalisés. Les résultats montrent que ces ajouts améliorent les propriétés des mélanges sol-ciment et que leurs effets dépendent du type de sol et de la nature de la matière organique présente. Des suggestions sont faites pour adapter au mieux le type d'ajout en fonction de la nature de la matière organique et de la minéralogie du sol, avec l'objectif d'améliorer la résistance de sols mous.

Mots clés Sols mous · Matière organique · Stabilisation au ciment · Ajouts

Introduction

The technique of using cement to improve soft soil properties has been widely applied to the treatment of soft soil foundations; however, it is difficult to achieve the expected consolidation effect when the organic content of the soft soil is high, due to the organic matter impeding the hydration of the cement. For example, Xun (2000) reports a foundation reinforcing project undertaken in the winter of 1985, when the strength of the peaty soil did not reach 300 kPa even with deep admixing with a cement ratio up to 30%. Only when a clearer understanding of the behaviour of the organic matter in the process of cement stabilization of a soft soil has been obtained will it be possible to determine whether this method of reinforcement can be appropriate.

Humic substances are the main body of soil organic matter or humus, most of which combines with the inorganic constituents in the soil (Dai 2004). Lu (2000) refers to three kinds of humus, i.e. loosely combined humus, stably combined humus and tightly combined humus. Loosely combined humus is the most active and inclined to combine with other substances (Kovda 1981). On the other hand, the most representative components of organic matter in soil are humic acid, fulvic acid and humin. Humin is the main composition of tightly combined humus, while humic acid and fulvic acid exist not only in loosely combined humus but also in stably combined humus.

The study reported here involved a number of experiments using different admixtures with cement to stabilize a soft soil with a high organic content, in order to better understand the behaviour of organic matter during the stabilization process.

Selection of admixtures

The strength increase of cement-stabilized soil is attributed to the physico-chemical reactions which take place, including hydration and hardening of the cement and the interaction between the substances in the soil and the products of cement hydration (Pan 2001). However, organic matter has a high retention of liquids because of its special structural features which cause the organic particles to be absorbed on the surface of cement and soil particles, which in turn impedes both the formation of cement hydration products and the interaction between soil particles and the hydration products. As a consequence, the process results in only a limited improvement of the cement soil strength.

The study considered the possibility of enhancing the early improvement of the strength of the cement soil. On the one hand extra admixtures may react with minerals on the surface of cement particles and water-immiscible hydration products may result while on the other, the addition of extra admixtures could accelerate cement hydroxylation and hydration in which calcium hydroxide, calcium silicate hydrate, sodium silicate hydrate and calcium aluminate hydrate may form. In this case, iron exchange, granulation and hardening reactions take place between the hydration products and clay particles, resulting in an improvement of the cement soil strength (Zeng et al. 2002).

There are three main kinds of accelerator admixtures in common use, chloride, sulphate and organic amine based. For this study, mixtures of sodium sulphate, sodium chloride and triethanolamine were used as accelerator admixtures in proportions of 2, 0.5 and 0.05%, respectively.

Black humic acid in organic matter has a strong chemical affinity to calcium; hence where calcium is present in solution, humic acid may react with the calcium and form insoluble calcium humic acid (Bonomaluwa and Palutnicowa 1987). The combination of humic acid with calcium ions produced in hydration makes it difficult for the calcium crystallization which is responsible for the increase of cement soil strength to take place. Crystal calcium sulphate was therefore chosen as the second kind of admixture and used in the proportion of 2.55% to the cement.

Fulvic acid in organic matter tends to combine with mineral particles containing aluminium, which may induce the decomposition of a layered crystal lattice. Initially fulvic acid exists in its water-soluble form and cement hydration begins as soon as the cement comes into contact with the fulvic acid solution. However, the absorbed layer caused by the reaction of the fulvic acid and the cement minerals impedes the process of cement hydration. In addition, fulvic acid may decompose existing crystals such as calcium aluminate hydrate, calcium sulphate–aluminate hydrate and calcium ferrite–aluminate hydrate, thus preventing the formation of a cement soil structure (Xun 2000). The third admixture was therefore aluminium sulphate, in the proportion of 2.55% to the cement.

Preparation of test samples

The soil used in the tests is a "mucky" soil from an island in GunagZhou, China. The soil was air dried, disintegrated and sieved through a 2.5 mm sieve so as to ensure its uniformity. The samples were first weighed and then mixed with the cement and admixture in the designed ratios. Water was then added to the powders to provide a soil with a 60% moisture content which was mixed with cement in a proportion by weight of 85% soil and water to 15% cement/admixture (Table 1). After sufficient agitation the material was pressed into cutting rings by hand to provide samples for direct shear and unconfined compression testing. Each sample was moisture sealed in plastic wrapping and cured for 28 days.

Sample properties and analysis of the results

Direct shear and unconfined compression tests were performed on the cured samples. In addition, the total amount and composition of the organic matter were determined following the method described in Lu (2000).

Table 1 Description of samples

Sample	1	2	3	4
Description	Soil + cement	Soil + cement + accelerator admixtures	Soil + cement + crystal calcium sulphate	Soil + cement + aluminium sulphate

Table 2 Unconfined compression strength for samples

Sample	1	2	3	4
Unconfined compression strength q_u (kPa)	63.7	99.5	103.4	92.6

Mechanical properties

Table 2 provides the results of the unconfined compression tests and shows that higher strengths were achieved for the samples with admixtures, i.e. >90 kPa compared with the soil and cement alone of 64 kPa. The different admixtures play a different role in the improvement of the cement soil properties with the soil cement intermixed with crystal calcium sulphate providing the highest value (103 kPa). It is considered that the addition of crystal calcium sulphate offsets the precipitation of calcium due to the humic acid and the calcium produced in the cement hydration hardens and crystallizes, thus accelerating the increase in strength of the cement soil. Similarly, the addition of accelerator admixtures and aluminium sulphate also plays a role in promoting early hydration of the cement and compensating for the loss of aluminium minerals.

The results of the direct shear strength tests (Table 3) indicate a consistency in the derived cohesion of the treated samples (42–45 kPa) while the internal friction angle varies from 16.2° for soil and cement to 17.7° for soil, cement and calcium sulphate. According to Coulomb's law, the internal friction becomes the main decisive factor of shear strength while cohesion becomes less importance when there is a large confining load (Tang et al. 2000). The uniformity between the shear strength and unconfined compression strength suggests that the crystal calcium sulphate limits the influence of the organic matter and allows a better effect of the cement compared with the other admixtures.

Table 3 Indices of shear strength for samples

Sample	1	2	3	4
Cohesion (kPa)	41.7	44.6	42.7	41.7
Angle of internal friction (degree)	16.2	17.4	17.7	17.2

Determination of organic matter

Table 4 gives the total organic content of the original soil sample and the four treated samples. The organic content of the treated samples is lower than that of the original soil due to the interactions between the organic matter and the hydration products leading to the decomposition of the organic matter, formation of new minerals and the transformation of the organic carbon to inorganic carbon.

The organic matter determined for the different soil mixtures is given in Table 5. This indicates that the amount of loosely combined humus changes significantly, decreasing to less than 10% of that in the original sample. In the case of the stably combined humus, there is a 400% increase relative to the original sample while the tightly combined humus is increased only slightly. It is considered that the loosely combined humus interacts with the cement hydration products and the admixtures.

The humic and fulvic acid contents of the loosely combined humus of the original soil were determined to be 8.07 and 0.66%, respectively. This explains why there is a better stabilizing effect when the admixture is crystal calcium sulphate (which reacts with humic acid) compared with aluminium sulphate (which reacts with fulvic acid).

Conclusions and suggestions

On the basis of the analysis discussed above, the following conclusions and suggestions are put forward:

Table 4 Total content of organic matter in samples (%)

Sample	1	2	3	4	Original sample
Organic content	12.14	12.90	13.47	12.71	17.42

Table 5 Content of organic matter in different combinations

Form	Sample				
	1	2	3	4	Original sample
Loosely combined humus	0.51	0.39	0.39	0.3	8.37
Stably combined humus	4.35	4.13	4.41	4.30	1.00
Tightly combined humus	7.28	8.38	8.67	8.11	7.69

It is difficult to stabilize soft soil with high organic contents using only cement. However, appropriate extra admixtures can be used to enhance the soil strength. It has been shown that different kinds of admixture play a different role in cement soil stabilization.

The main substance which reacts with cement hydration products and the admixtures is the loosely combined humus in the organic matter, hence the composition of the loosely combined humus plays an important role in the stabilization of soft soil foundations.

Better stabilization effects can be achieved using crystal calcium sulphate as the admixture when the loosely combined humus contains more humic acid.

It is suggested that both the amount and composition of the loosely combined humus and the clay mineralogy should be determined before attempting to stabilize a soft soil with a high organic content using cement, in order to decide the most appropriate admixture and the proportions required.

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