Use of lime and cement treated soils with rigid inclusions

Umur Salih OKYAY
Dr. Research director, Entreprise PINTO, 48, rue Jules Verne, 35300 Fougères, France

Daniel DIAS
Prof. Dr. Joseph Fourier University, LTHE, UMR 5564 BP 53, 38041 Grenoble cedex 9, France

KEYWORDS: Soil treatment, lime, cement, rigid inclusion, pile

ABSTRACT: In recent years, the interest in soil treatment for foundations has significantly increased. The use of soils on place avoids the transportation and consumption of natural materials such as sand, gravel or rock. The principal materials used for the soil stabilization are lime and cement. The sustained pozzolanic reaction between lime and soil improves the characteristics of soil and provides resistance. In this context, treated soils are used under structure foundations in order to homogenize settlements and establish a resistant base layer called earth platform. An application of this technique is the use of treated soils between foundations of structures and vertical piles. Load transfer mechanisms occur in the earth platform and loads are transferred to the pile heads. The mechanical characteristics of the treated soils are then important due to the fact that it is the place where load transfer mechanisms occur. The technique has been widely used in construction of roads and railways.

An experimental study was performed in order to obtain the mechanical properties of lime/ cement treated soils. Firstly, physical properties of the Goderville silt were examined. Then different quantities of lime/cement were added to the silt and compacted at the optimum water content. Stabilized specimens were tested at 7, 28, 90, and 350 days after the treatment in order to observe the evolution of mechanical resistance in time.

1 INTRODUCTION

Soil improvement with rigid inclusions aims to increase the bearing capacity of the soil and decrease the settlements of the surface structure. The most remarkable difference of this technique from the deep foundation systems is the constitution of an artificial soil layer between inclusions and structure (Briançon et al., 2004). Generally this soil layer, called earth platform (EP), can be made of lime and cement treated soils. This platform participates to the load transfer mechanisms by arching and shear mechanisms. Figure 1 shows the execution of rigid inclusions on Goderville site where silts are treated and used as earth-platform over rigid inclusions.

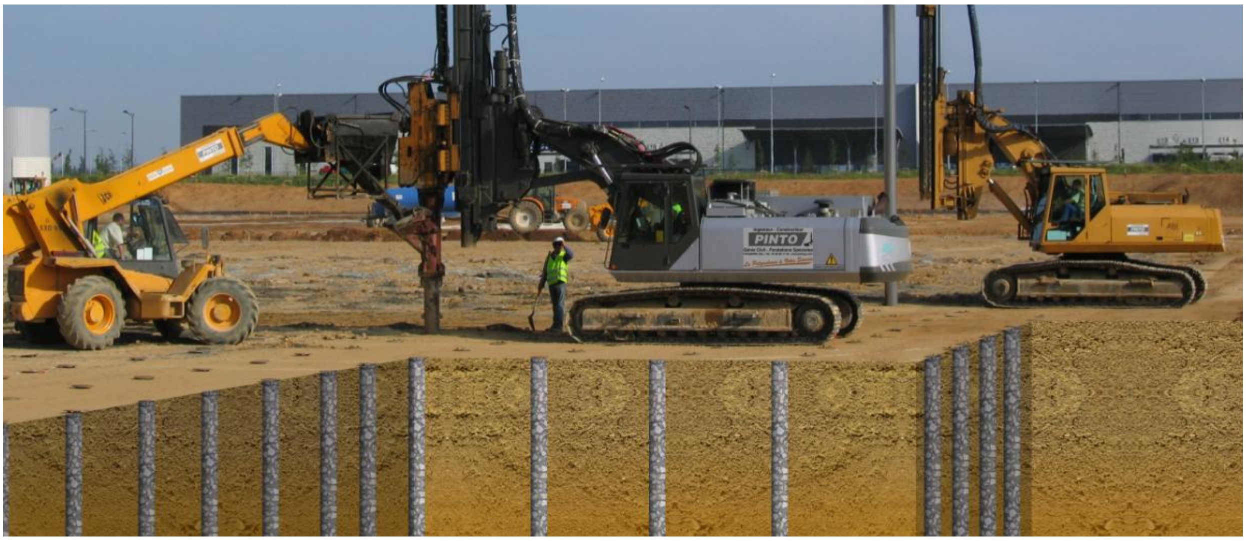

Figure 1. Rigid inclusion execution

The principal materials used for the soil stabilization are lime and cement. The sustained pozzolanic reaction between lime and soil improves the characteristics of soil and provides resistance. The engineering properties of clayey soils can be improved by the addition of small percentages of lime. These soils can be used as construction material (Bell, 1996). The treated soils by lime and/or cement are used to establish a resistant base layer called earth platform.

2 EXPERIMENTAL STUDY

2.1 Soil and Sample Preparation

In the experimental program, the Goderville soil was characterized by laboratory tests and appropriate treatment formulations were chosen. Mechanical soil tests were conducted to deduce the strength characteristics of soils at 7, 28, 90 and 350 days after treatment (Okyay & Dias, 2010).

The first part of the experimental program concerns the homogenisation and characterization tests of the Goderville soil. The initial water content of the soil was between 16 and 20%. The material was dried in a climatic room at 35°C of temperature and 25% of humidity respecting the natural weather conditions (Figure 2). This step is necessary to facilitate the grinding and sieving of the material. The soil was grinded, sieved and homogenized by the cone and quarter technique (Carver, 1981).

Figure 2. Climatic room of IFSTTAR - Nantes (Okyay, 2010)

The particle size distribution is one of the important characteristics of soils. The results of particle size analyses of Goderville soil show that 95% of the particles are fine grained (Figure 3). Particles smaller than 0.063 mm and larger than 0.002 mm constitute 70% of the soil. 25% of the particles are smaller than 0.002 mm. These silty soils are quite common in occurrence. They frequently have an affinity for water. If the compaction is not sufficient, they may swell and lose much of their stability. The characterization soil is important to evaluate the appropriateness of the chosen treatment formulation and the batching. The characteristic properties of the Goderville soil are summarized in Table 1.

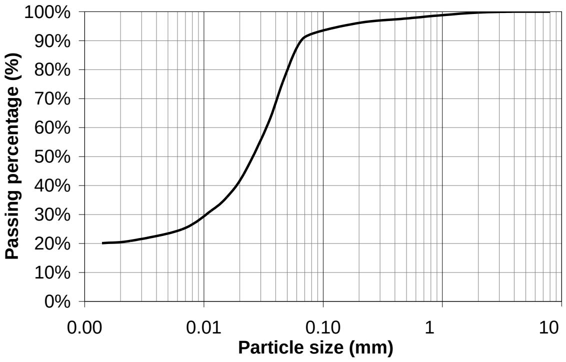

Figure 3. Particle size distribution of Goderville soil

Table 1. Properties of Goderville silt

Liquid limit	LL (%)	30
Plastic limit	PL (%)	20.4
Plasticity index	PI (%)	9.6
Specific gravity	Gs	2.65
Clay fraction	(%)	20
Organic content	(%)	2
CaCO3 content	(%)	2.12
Maximum dry density	(g/cm^3)	1.80

Cylindrical samples were prepared for unconfined compressive strength, Brazilian indirect tensile strength, and direct shear tests. Prismatic 4x4x16 cm specimens were prepared for bending tests.

The soil treated with cement materials requires a prompt preparation of the samples after treatment. For only cement and only lime treatment, they were immediately prepared after the mixing. For the treatment with 2 agents, firstly the soil was treated with lime then the cement treatment was applied 1 hour later (NF 94093). This procedure is used on construction sites, facilitates the flocculation of soil particles by lime attack and provides a good treatment.

The specimens were kept in aluminium covered plastic bags for curing. The temperature of the room was fixed at 20°. The samples were taken out from their protective bags after the curing period, and the tests were then conducted in accordance with French testing standards. The tests were repeated on at least three identical specimens in order to minimize possible errors due to the material and testing conditions.

The treated soil specimens were tested to establish their suitability for treatment using the accelerated swelling tests and indirect tensile strength tests. The capacity of each treatment formula was verified. Standard Proctor compaction test was used to determine the maximum achievable density of natural and treated soils. Table 2 presents the studied formulations for natural and treated soils.

Table 2. Notation of the tested materials and optimum Proctor values

	Notation	Lime	Cement	wopt	γd (g/cm^3)
Soil	S	-	-	15.2	1.80
Soil + Lime	SL	3%	-	19.0	1.70
Soil + Cement	SC	-	6%	17.5	1.75
Soil + Lime + Cement	SLC1	2%	3%	18.5	1.73
Soil + Lime + Cement	SLC2	2%	5%	18.5	1.73

2.2 Determination of Mechanical Properties

The mechanical resistance tests were conducted at 7, 28, 90 and 350 days after the preparation of specimens. Direct shear, unconfined compressive strength and tensile strength, and bending tests were performed in order to obtain mechanical properties of treated soils.

The strength parameters of soil materials such as the internal friction angle and cohesion were identified by undrained direct shear tests. The tests were performed with 50 mm height and 60 mm diameter cylindrical specimens at constant shearing speed (0.1 mm/min) in accordance with the appropriate French standard NF P 94-071. The shearing tests were carried on normal stress range 50 to 100 kPa. This range corresponds to the vertical stress exerted by most of engineering structures founded on this kind of treated soils. Initial tests on natural compacted soil show that the effective cohesion of untreated soil is 12.5 kPa and its effective angle of internal friction is 10.8°.

Unconfined compressive strength tests were conducted on the natural and treated specimens in accordance with the appropriate French standard NF P 94-077. The tests were carried out with 100 mm height and 50 mm diameter cylindrical specimens at a constant loading speed of 0.1 mm/min.

Cylindrical specimens were loaded diametrically across the circular cross section. By using the record of the ultimate load and the specimen dimensions, the indirect tensile strengths of the materials were calculated. Tests were conducted in accordance with the French standard NF P 94-422. The specimens obtained were 50 mm in height and 50 mm in diameter.

Three-point bending test is a classical mechanical test which is generally used for concrete specimens. It represents the case of a plane beam placed on two simple supports and subjected to a vertical load at the middle. The use of this kind of tests for treated soils is recent and in the geotechnical domain, there is no standard to describe this test. The test is interesting due to the fact that the Young's modulus obtained from three-point-bending tests may represent the behaviour of the earth platform under surface loads. The French standard NF EN 196-1 was used as reference in order to determine a testing procedure. Prismatic specimens (4 x 4 x 16 cm) were prepared and compacted at optimum water content and tested.

3 EXPERIMENTAL RESULTS

The laboratory based investigation explores the effects of the treatment formulation and curing period on the strength parameters of treated soils. Results of the tests confirm that the strength of the treated soils is dependent on treatment formulation and curing period. Almost 85% of the total resistance is achieved after 90 days of curing (Figure 4).

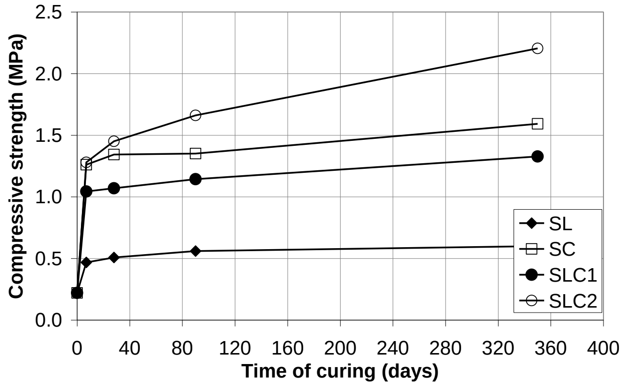

Figure 4. Evolution of compressive strength (Okyay & Dias, 2010)

For each of the tests, the highest strength values are obtained with SLC2 treatment. The treatment SL has the weakest strength values. The presence of cement in the treatment formulation increases rapidly the strength of the material at the first 28 days after the curing (Okyay & Dias, 2010).

The lime has a long term effect that the strength of the material increases till 350 days after the treatment. The cohesion and internal friction of the treated soil follow the same evolution. The cohesion increases when the quantity of the cement increases. Figure 5 and Figure 6 show the evolution of effective cohesion and internal friction angle values for each treatment formulation. The treated soil shows a significant apparent cohesion. The value of the cohesion reaches at least 25 kPa at the first week treatment. These values are above 60 kPa at 28 days after the treatment in presence of cement. The evolution of cohesion for the soil treated with lime is quite slow and the cohesion does not exceed 45 kPa in long term. The internal friction angle also increases with time. The experiences showed that the internal friction angle of treated silt reaches 21°. The cement increases rapidly the internal friction angle.

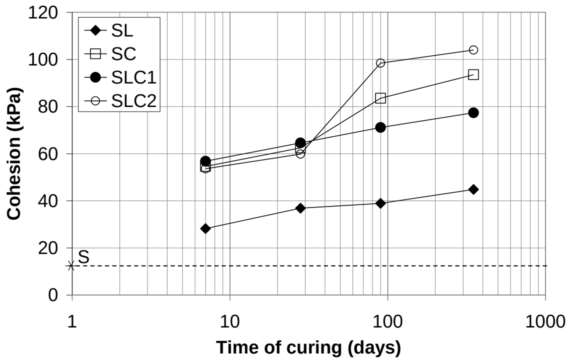

Figure 5. Evolution of cohesion

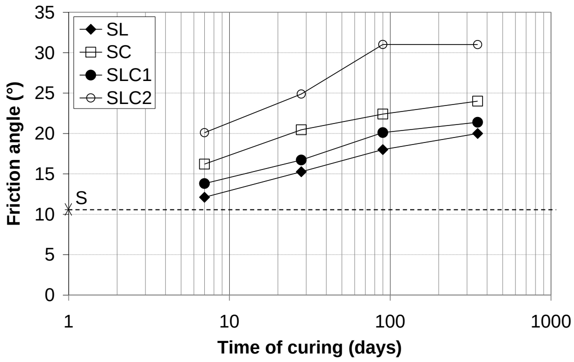

Figure 6. Evolution of internal friction angle (Okyay & Dias, 2010)

In addition, relations between tensile strength, compressive strength and cohesion are presented at Table 3. The ratio of the tensile to the compressive strength of the specimens indicates that soils which are treated by cement have brittle behaviour. The ratio of tensile strength to the effective cohesion of treated soils is between 1.54 and 2.44. The best tensile strength (0.24 MPa) was obtained for the treated soil SLC2. The best effective cohesion value (98.4 kPa) was obtained with the same treatment formulation. The other treatment formulations have the same tendency. When the cohesion of the soil increases its tensile strength increases too. Addition of lime in the treatment formulation rapidly increases the cohesion but the tensile strength does not increase rapidly. Cement treatment increases the tensile strength of the soil. Especially the comparison between SLC1 and SLC2 shows that the tensile strength of the treated soils is mostly depends on the cement quantity in the treatment formulation.

Table 3. Summary of the results at 90 days after the treatment and comparisons (Okyay & Dias, 2010)

		S	SL	SC	SLC1	SLC2	Test type
Rc	MPa	0.39	0.56	1.35	1.14	1.66	Unconfined compression
Rt	MPa	0.028	0.06	0.18	0.15	0.24	Tensile strength
Rb	MPa	0.25	0.39	1.02	0.74	1.06	Bending
Es	MPa	9	53	106	100	145	Unconfined compression
Et	MPa	10	64	114	99	170	Unconfined compression
E	MPa	9	51	101	92	135	Bending
c′	kPa	12.5	38.9	83.5	71.1	98.4	Direct shear
ϕ′	°	10.8	18.0	22.4	20.1	31.0	Direct shear
ν	-	0.303	0.310	0.296	0.307	0.300	Tensile strength
Comparisons							
Rt/Rc	-	0.07	0.11	0.13	0.13	0.14	Comparison 1
Rt/c′	-	2.24	1.54	2.16	2.11	2.44	Comparison 2

4 CONCLUSIONS

The soil stabilization by use of treated soils between foundations of structures and vertical inclusions is studied. The mechanical characteristics of the treated soils become then important due to the fact that it is the place where load transfer mechanisms occur.

The mechanical properties of treated soils were investigated by laboratory tests. The strength of the soil increases in time by lime treatment. The lime treatment has a long term influence on soil strength. The cement treatment quickly increases the strength of the soil. For all treatments where the cement is present almost 85% of the total strength is achieved after 90 days of curing. Young's modulus, cohesion and internal friction of the treated soil evolve in time. These parameters are highly dependent on the quantity of lime/cement present in the treatment formulation. Especially the treatment with cement is an appropriate solution if high strength values are envisaged after treatment. The results provide a wide database on different types of treatment formulations which can be used easily in most projects.

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