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Effect mechanism of admixture on the strength of cement consolidated soil

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ABSTRACT

Cement and all kinds of admixture have been used in the treatment engineering of soft soil foundation in coastal cities to improve soil strength and sustain the demands of engineering construction. In engineering practice, soil composition varies because of different origins and formation environments. Thus, cement consolidated soil likely exhibits different strength characteristics when different admixtures are added. In this study, soft soil obtained from Fuzhou, Zhuhai, and Yingkou was used as test samples. Physical properties, soluble salt content, organic matter content, and other basic parameters of the soil were analyzed. Indoor tests were also performed to simulate the consolidating process of soft soil with different admixture. Uniaxial compressive test was also performed to measure mechanical index. The combined effects of cement hydration reaction with different organic matter composition, granularmetric and water characteristics were considered to determine the effect mechanism of cement consolidated soil with different admixtures. Results showed that the soft soil of the three areas contained high amounts of organic matter and soluble salt. The uniaxial compressive strength increased when early-strength agent and water-reducing agent were used. However, the increased amplitude varied with different early-strength agents. The optimum effect was obtained when $CaSO_4$ was added, and the sample was inseparable with high amounts of fulvic acid and humic acid. The same additive agent resulted in uniaxial compressive strength with low moisture content and high clay content. Thus, the basic properties of soft soil and its organic matter content should be considered in selecting the optimum admixture during cement consolidation in engineering.

KEYWORDS

Soft soil; Cement; Organic matter; Admixture; Granularmetric.

INTRODUCTION

With the increasing demands of social construction, soft soil has been developed as foundation materials in coastal cities. Reinforcement technology is an inevitable problem because soft soil contains high moisture and short diachronic sediments and exhibits compressibility, low strength, and other characteristics[1-3]. In current reinforcement methods, cement is one of the most common curing agents; this curing agent can increase the bearing capacity of foundation, thereby decreasing settlement for its use[4-6]. Previous studies indicated that the material composition of soil affects cement hydration; thus, the effects of reinforcement vary[7-9]. Cement can achieve an optimum effect when this material is used to reinforce soil with high organic content; however, strength decreases as organic matter content increases[3-5]. The reasons for this phenomenon are mainly: under the effect of organic matter, the soft soil showed higher water capacity, plasticity, swelling, with permeability reducing, organic matter block and disrupt the structure formation of cement consolidated soil, and it brings out the characteristic of chemical weathering[6]. According to experience, when using general cement to strengthen soft soil foundation, studies have shown that 2% should be the maximum in other countries, whereas 6% is the maximum value allowed locally[7]. Studies have also been conducted involving ground improvement programs in which soft soil is consolidated with cement. Xun obtained a good reinforcement effect when the industrial waste gypsum, cement, and a small amount of fly ash are used as curing agents. Pan 9 formulated a composite additive from the active mechanism of fulvic acid to enhance the effect of reinforcement. Zeng et al. also proposed different curing agent solutions to reinforce soft soil[10-15].

Many existing types of admixture can be used in consolidating cement. However, improvement effects vary when soft soil is consolidated with different agents and formation environments. The influence of admixture on the consolidation effect was elucidated in this study. Different soft soil samples from different coastal cities were selected. An amount of cement and admixture was used to consolidate the samples. The effect of the different admixtures on soil strength was analyzed, and the mechanism was discussed on the basis of the basic properties of the soil samples.

CEMENT SOLIDIFICATION MECHANISM

In the cement consolidation process of soft soil, the cement dosage is very small, and the hydrolysis and hydration reaction of cement is done in soil with a certain activity, so the strength growth process of the cement consolidated soil relatively slows.

Hydrolysis reaction and hydration reaction of cement

Ordinary Portland cement is mainly composed by CaO, SiO2, Al2O3, Fe2O3 and SO3, etc, and these different oxides form different cement minerals: 3CaO·SiO2, 2CaO·SiO2, 3CaO·Al2O3, 4CaO·Al2O3·Fe2O3 and CaSO4, etc. When using cement reinforce the soft soil, the minerals on the surface of cement particles and the water in the soft soil quickly happen hydrolysis reaction and hydration reaction, and generate Ca(OH)2, 3CaO·2SiO2·H2O, 3CaO·Al2O3·6H2O, 3CaO·Fe2O3·6H2O and others 18. The reaction processes are as follows:

(1) 3CaO·SiO2: The content is highest in the cement (about 50% of total weight), and it is main factor that determines the strength.

$$2(3CaO\cdot SiO_2)+6H_2O\rightarrow 3CaO\cdot 2SiO_2\cdot H_2O+3Ca(OH)_2$$

(2) 2CaO·SiO2: The content is higher in the cement (about 25% of total weight), and it mainly produces later strength.

$$2(3CaO\cdot SiO_2)+4H_2O\rightarrow 3CaO\cdot 2SiO_2\cdot H_2O+Ca(OH)_2$$

(3) 3CaO·Al2O3: The content is about 10% of total weight, hydration speed is fastest, and it can promote the early coagulation.

$$3CaO \cdot Al_2O_3 + 6H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 6H_2O$$

(4) 4CaO·Al2O3·Fe2O3: The content is about 10% of total weight, and it can promote the early strength.

$$4CaO \cdot Al_2O_3 \cdot Fe_2O_3 + Ca(OH)_2 + 10H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 6H_2O + 3CaO \cdot Fe_2O_3 \cdot 6H_2O$$

(5) CaSO4: Although the content is only about 3% in the cement, 3CaO·Al2O3 and it react with water, generate a kind of chemical compound named "cement coli".

$$3CaSO_4 + 3CaO \cdot Al_2O_3 + 32H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4$$

The role of clay particles and cement hydrates

After the cement of all kinds of natural gas hydrates generation, have their own continue to hardening, the formation of cement skeleton; others react around it has a certain active clay particles.

(1) Ion exchange and aggregate role: When clay and water combine, it shows a colloid characteristic, such as: after SiO2 with highest content in the soil meet with water, colloidal silicate particles form, sodium ions or potassium ions which are on the surface, can equivalent exchange adsorption with calcium ions generated by hydration of cement, that makes small soil particles to form larger soil aggregate, so that increasing the soil strength.

(2) Hard condensation reaction: with the deepening of the cement hydration reaction, a large number of calcium ions in the solution precipitate, when the quantity is over ion exchange requirements, in alkaline environment, it can make SiO2, part or most of Al2O3 react with calcium ions, gradually produce crystalline compound insoluble in water, increase the strength of cement-soil, and the reactions are as follows

$$SiO_2 + Ca(OH)_2 + nH_2O \rightarrow CaO \cdot 2SiO_2 \cdot (n+1)H_2O$$
$$Al_2O_3 + Ca(OH)_2 + nH_2O \rightarrow CaO \cdot Al_2O_3 \cdot (n+1)H_2O$$

BASIC PROPERTY ANALYSIS OF SOIL SAMPLES

Soft soil samples were obtained from Fuzhou, Zhuhai, and Yingkou. The basic properties of the soil samples were initially tested.

Analysis of granularmetric and plasticity

The physical properties of the soil samples are shown in TABLE 1. All of the soil samples exhibit a grain size of <0.075 mm and >90% silt fraction and clay fraction content. Fuzhou and Zhuhai samples contain high amounts of clay; Yingkou samples contain high silt fraction. In particle content analysis, the clay content of the soil samples increases and the silt content decreases after a dispersing agent was added; thus, dispersing agents significantly affect soft soil from three locations. This finding is due to the flocculation of the soil samples, in which large amounts aggregate to form water-resistant “false silt” 13. After dispersant agents are added, the “false silt” disperses into clay; thus, clay content increases. The “false silt” content decreases and eventually dissipates. Plasticity strength depends on the clay content and the hydrophilic degree of clay minerals. High clay content and plasticity index strengthen soil plasticity. Differences in plasticity are due to the inference among the particle contents of the samples from the three sites. In TABLE 1, Fuzhou and Zhuhai soil samples have relatively high plasticity indexes that correspond to the measured value of the clay content.

TABLE 1 : Physical property of the original samples

Soil samples	Dispersing agent	The percentage of fraction (%) Sand fraction 2~0.075	Silt fraction 0.075~0.005	Clay fraction <0.005	Liquid limit (%)	Plastic limit (%)	Plasticity index
Fuzhou	without	2.73	69.14	28.13	45	25	20
	within	2.73	56.85	40.42			
Zhuhai	without	3.88	63.86	32.26	50	25	25
	within	3.88	61.14	34.98			
Yingkou	without	0.36	90.14	9.50	27.4	14.2	13.2
	within	0.36	86.99	12.65			

Mineral composition

Mineral composition is another important factor that affects the geological properties of soil engineering. It can further determine the soil composition by analyzing mineral composition and granulometric composition. Mineral composition mainly includes primary and secondary minerals. X-ray diffraction is conducted for semi-quantitative analysis and sample evaluation. TABLE 2 shows that the primary mineral in the soil is quartz and that the secondary mineral content is very high at approximately 50%. The clay minerals are mainly illite, a mixed layer of illite–smectite, and minimal kaolinite and chlorite, but no montmorillonite. The high clay content allows the soil to have stronger hydrophilicity and increases the difficulty for consolidation.

TABLE 2 : Results of mineral c

Soil samples	Mineral relative amount (B)/10-2 Q	Fs	Pl	Cc	Mu	I/S	I	K	Ch	Am
Fuzhou	21	5	4	6	3	15	33	7	5	1
Zhuhai	22	7	11	5	4	11	32	2	5	1
Yingkou	20	5	9	6	5	10	34	4	4	3

Q--Quartz Fs--Feldspar Pl--Plagioclase Cc--Calcite Mu--Muscovite Am--Amphibole I/S--illite –smectite mixed layer K--Kaolinite I--Illite Ch--Chlorite

Analysis of soluble salt composition

Chloride, soluble sulfates, carbonates, and other soluble salts are collectively referred to as soluble salts. The existing form of soluble salts interchanges between solid and liquid 13. Previous studies found that the changes in content, composition, and status of soluble salts significantly influence the structural and soil particle surface-linked double-layer characteristics; as such, the physical and mechanical properties of soil are affected.

The soluble salt composition of the soil samples is shown in TABLE 3. The results show that the total soluble salts of the samples from the three regions mainly comprise mainly Cl–. Solid soluble salts affect the cementation of the particles in dry soil, whereas ionic soluble salts interact with charged particles in the soil with high amounts of water; thus, engineering geological soil properties are affected. Soluble salts can cause changes in the chemical properties of the soil and decrease its physical properties, particularly water flow. Contrast soluble salt composition is observed in different locations. The Yingkou sample contains the is highest soluble salt, whereas the Fuzhou sample contains the lowest salt but exhibits more Ca2+ and SO42–. SO42– reacts with Ca2+ and Al3+ produced from cement hydration and then forms ettringite. The volume of ettringite can expand and partially fill in the cement-soil porosity. Ettringite decreases porosity and generates large needle-like crystals. Crystals and calcium silicate hydrate form spatial structure in the pores, inducing a refined pore size distribution of cement consolidated soil; thus, soil strength is improved.

In TABLE 2, the pH of the soil samples is weakly alkaline. The clay minerals of the samples from the three areas are substantially illite, smectite, and soluble salts. The solution pH and the isoelectric pH values of these minerals, particularly soluble salts, significantly differ and form a thick diffusion layer. The presence of Na+ in soluble salts thickens this diffusion layer; as such, the engineering geological characteristics of the soil are weakened.

Cation exchange capacity (CEC) differs in the samples from the three locations. The Fuzhou sample yields the highest CEC. The clay content of the soil and CEC are positively correlated. Thus, more clay contents result in higher CEC, which is also consistent with the granularmetric composition results. Numerous Na+ in the Fuzhou samples form a thicker diffusion layer of the particle surface. Thus, the engineering geological properties of the soil in Fuzhou are poorer than those of the two other regions.

TABLE 3 : Chemical composition

Soil samples	Soluble salt (g/100g)								pH	CEC (mmol/100g)
	Amounts	cl-	HCO-3	Ca2+	Mg2+	SO42-	K+	Na+		
Fuzhou	0.944	0.692	0.011	0.037	0.053	0.338	0.001	0.051	7.15	11.31
Zhuhai	1.101	0.884	0.014	0.023	0.043	0.252	0.001	0.005	7.13	4.11
Yingkou	1.466	1.168	0.006	0.031	0.088	0.327	0.046	0.017	7.12	2.22

Organic ingredients

Most of the organic matter in soft soil is constituted by yellow or brown, comp and uneven acidic polymer known as humus. Humus is classified as soluble humus (mainly humic acid and fulvic acid) and insoluble humic (mainly humin); humic acid and fulvic acid greatly influence the reclamation effects of cement consolidated soil 14. Fulvic acid can be dissolved by acid and alkali, and the formed salts are soluble in water. The monovalent salts formed by humic acids only are also soluble in water. The contents of humic acid and fulvic acid in the soil samples were extracted and analyzed. The results are shown in TABLE 4. The total amount of organic matter in the soil samples is approximately 11% to 13%, and the Yingkou sample yields the lowest total organic matter. The concentrations of humic acid, fulvic acid, and humin are 4% to 5%, approximately 5%, and approximately 2%, respectively.

Fulvic acid is easily absorbed by minerals containing more aluminum when cement is used as a curing agent to consolidate soft soil with high organic content. Fulvic acid eventually forms an adsorption film layer on the surface, thereby preventing cement hydration. Fulvic acid decomposes the generated hydrated calcium aluminate, hydrated sulfoaluminate, and hydrated calcium aluminoferrite; fulvic acid also disrupts the formation of cement consolidated soil structures 15. Humic acid is more sensitive to calcium in cement consolidated soils. Humic acid can interact with calcium ions and can produce insoluble substances when cement hydration produces a high amount of calcium ions; as a result, the formation of crystalline substances 16 and the growth of cement-soil strength are impeded.

TABLE 4 : Composition of organic matter and each component

Soil samples	Amounts (%)	Humic acid (%)	Fulvic acid (%)	Humin (%)
Fuzhou	12.129	4.578	4.907	2.032
Zhuhai	12.906	4.436	5.183	2.131
Yingkou	11.293	4.548	4.937	2.032

Preparation of samples

Many factors, such as granularmetric, mineral, and chemical compositions, affect cement reinforcement. The soil samples from each region were treated with the same admixture solution to ensure comparative results. The effect mechanism of the admixture to cement consolidated soil was analyzed using the reinforcing effect of the same areas with different admixture. The effect mechanism in combination with the basic physical properties, soluble salt composition, organic matter content, and other test results were used to determine the possible effects of these factors on the admixture.

The samples for uniaxial compression test were prepared. The soil samples were soaked in a specified amount of water for a day to ensure that soil and water form a system. Under the general conditions of soft soil and mucky soil, the moisture content of each sample was 60%. The moisture content of the Yingkou sample is 60%, as observed during the preparation process. However, its consistency in the actual condition is different from the two other regions because of high silt content and low clay content. Therefore, the moisture content of the Yingkou sample was adjusted to 40%. Soil, cement (mixing ratio is 15%), and admixture were stirred uniformly, and the sample density was approximately the same in each group. The mixture was placed by hand into a saturator and then subjected to uniaxial compression tests. The samples were sealed and cured for 28 d.

Admixture design

Various cement admixtures are commercially available; the commonly used mixtures are early-strength agent, water-reducing agent, retarder, and air-entraining agents 17. In this research, early-strength agent and water-reducing agent were used. Early-strength agents accelerate the development of the early strength of cement-consolidated soil. These agents include chlorine salts, sulfates, organic amine, and the mixture of these three types. Water-reducing agents decrease water consumption to maintain the same slump condition. Commonly used water-reducing agents include lignin and water-soluble resin. Excessive chloride can cause corrosion that affects reinforcement. Thus, early-strength agents selected in this experiment are calcium sulfate, aluminum sulfate, and sodium sulfate; water-reducing agent is UNF. UNF is commonly used in engineering and mainly consists of β-naphthalene sulfonate. The test solutions are listed as follows: (1) soil + cement; (2) soil + cement + UNF (mixing ratio, 0.7%); and (3) soil + cement + UNF + early strength (mixing ratio, 1%).

Analysis of test results

The soil samples from the three regions were prepared for uniaxial compression test according to the admixture program and sample preparation requirements. Mechanical index was evaluated among the samples. The results are shown in TABLE 5, as presented below.

TABLE 5 : Uniaxial compressive test results

Soil samples	The uniaxial compressive strength (KPa)				
	Cement	Cement+UNF	Cement+UNF+CaSO4	Cement+UNF+Al2(SO4)3	Cement+UNF+Na2SO4
Fuzhou	112.6	120.8	154.5	140.6	130.6
Zhuhai	96.9	99.4	122.8	112.8	103.9
Yingkou	187.7	191.5	211.8	205.9	200.7

(1) The three sites show similar patterns of uniaxial compressive strength in the samples within the same area with different admixture solutions. The strength is lowest when only cement was added but improves when an appropriate amount of admixture was provided. Different admixtures also elicit varying effects. The samples with water-reducing agent and early-strength agent exhibit higher uniaxial compressive strength than the samples with water-reducing agent only. The type of early-strength agent significantly affects the uniaxial compressive strength, as observed in the samples with early-strength agent and water-reducing agent. The sample added with calcium sulfate as early-strength agent exhibited the highest uniaxial compressive strength.

These results could be attributed to the origins of the soil samples, which are obtained from coastal areas in China. Moreover, organic matter and soluble salts in the soil significantly affects the reinforcement of cement. Aluminum sulfate and calcium sulfate used as early-strength agent can promote early strength and provide a particular amount of aluminum ions and calcium ions that can enhance the consumption of humic acid and fulvic acid. Thus, the generated calcium ions and aluminum ions during cement hydration can participate in various hydration and hardening reactions, thereby increasing the cement-soil strength. Sodium used as an early-strength agent in the samples improves early strength but does not participate in the hydration reaction of cement because of insufficient calcium and aluminum ions. Fulvic acid and humic acid also consume calcium ions and aluminum ions produced by cement hydration; thus, the strength of the samples added with calcium sulfate or aluminum sulfate is poor.

The uniaxial compressive strength of the samples added with calcium sulfate and aluminum sulfate as early strength agent was compared. The uniaxial compressive strength is slightly higher in the sample added with calcium sulfate as early-strength agent. This finding confirms that the effect of fulvic acid, which can easily combine with calcium ions, on cement hydration is significantly higher than that of humic acid. Fulvic acid and humic acid contain aromatic nuclei, amino acids, and other groups and exhibit almost the same chemical structure. Fulvic acid shows a relatively simple molecular structure and higher carboxyl content than humic acid. However, these two acids significantly differ in nature. Fulvic acid exhibits higher dispersion and fluidity than humic acid. Fulvic acid can also stabilize the coacervation of electrolytes and the acidity of its hydroxy acids is stronger than that of humic acid; therefore, fulvic acid elicits a strong destructive effect on soil minerals 18.

(2) The experimental results of Fuzhou and Zhuhai samples with the same admixture program were compared. The uniaxial compressive strength of the Fuzhou sample is higher because of lower organic matter and soluble salt content in other samples. Fulvic acid content, which significantly affects the destruction, is also lower. Small amounts of fulvic acid and humic acid can react with aluminum ions and calcium ions produced in cement hydration. The delay degree of cement hydration is low and slightly affects the formation of cement-soil structure and strength; therefore, the strength is slightly higher.

The results of the samples in different locations and sample programs, but the same admixture program were also compared. The uniaxial compressive strength of the Yingkou sample is the highest followed by Fuzhou and Zhuhai. This finding could be attributed to the preparation of the test samples and lower the moisture content of the Yingkou sample (40%) than the two other samples. The link between solid particles is strong and mechanical strength is high when water content is low, but these links weaken when water content is high. The Yingkou sample contains more silt but less clay than the other samples; thus, the soil exhibits strong permeability is strong, low compression and hydrophilicity, and decreased void ratio; as a result, strength is increased.

CONCLUSIONS

On the basis of the experimental results, we present the following conclusions:

(1) The soft soil of the three areas mainly contains silt and clay. Fuzhou and Zhuhai soil samples contain high clay, whereas the Yingkou sample contains high silt. All of the soil samples contain high amounts of soluble salts. The soil sample solutions are weakly alkaline. Moreover, the Fuzhou sample yields the highest CEC among the three areas.

(2) The samples from the three regions contain high organic matter. The experimental results of the samples in one site were compared. The uniaxial compressive strength increases in the samples added with water-reducing agent and different early-strength agents as admixture. Strength increases in the samples added with calcium sulfate as early-strength agent. The strength also increases in the samples with sodium as early-strength agent but lower than the improvement effect in the samples added with aluminum sulfate and calcium sulfate as early-strength agents. This result shows that the sample contains high amounts of fulvic acid and humic acid; this result also shows that the effect of fulvic acid on cement-consolidated soil is greater than that of humic acid.

(3) The test results of the samples with the same admixture program in different locations were compared. The universal compressive strength is high when the moisture content or clay content of the soil samples is low. This finding explains that many factors, including organic matter content,

granularmetric, soluble salt, and moisture content, could affect cement consolidated soil. Therefore, cement could be used as a curing agent to consolidate the soft soil of coastal cities that contain high organic matter and exhibit cohesion. However, granularmetric, soluble salt, and organic matter contents should be considered in selecting the optimum admixture.

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REFERENCES

[1] Yan Shu-wang, Liu Ke-jin, Li Wei et al.; Study of creep properties of soft clay in Tianjin Binhai New Area and no-yield-surface constitutive model [J]. Rock and Soil Mechanics, **31(5)**, 1431-1436 **(2010)**.

[2] Li Fang, Chen Jian; Soil and stratum factors influencing the quality of dry-jet-mixing pile in soft soil foundation [J]. Journal of Highway and Transportation Research and Development, **13(1)**, 6–21 **(1996)**.

[3] Chen Huie, Wang Qing; The behavior of organic matter in the process of soft soil stabilization using cement [J]. Bull Eng Geol Environ, **65**, 445–448 **(2006)**.

[4] Chen Huie, Wang Qing; Influences of organic matter on the effects of consolidating soft soil with cement [J]. Chinese Journal of Rock Mechanics and Engineering, **24**, 5816–5820 **(2005)**.

[5] Chen Huie, Zhang Jun, Yan Huan; Quantitative evaluation of microstructure characteristics of cement consolidated soil [J]. Bull Eng Geol Environ, **72**, 233-236 **(2013)**.

[6] Wang Guangyue, Wang Shenggui, Fu Zhiqian; Foundation and Ground Engineering [M]. Beijing: China Water Power Press, **(2001)**.

[7] John Bensted; Early hydration behavior of rortland cement containing trataro and titamo gypsum, cem.conc.bes., **2(11)**, **(1982)**.

[8] Xun Yong, Li Yushou; Room experiment research on strengthening soil of cement, fly-ash and phosphogypsom [J]. Journal of Jilin Insttute of Chemical Technology, **16(4)**, 29-33 **(1999)**.

[9] Pan Linyou; Soft soil cement stirring pile reinforcement search in special muck quality range [J]. Building Science Research of Sichuan, **27(4)**, 58–59 **(2001)**.

[10] Zeng Weidong, Tang Xueyun, He Mizhou; Application of cement deep-mixing method in treatment of peat soil [J]. Journal of Geological Hazards and Environment Preservation, **13(2)**, 67-69 **(2002)**.

[11] S.Valls, E.Vajzquez; Stabilization and solidification of sewage sledges with Portland cement. Cement and Concrete Research, **30**, 1671-1678 **(2000)**.

[12] Liu Pinhui, Xiao Shufang, Wang Qing; Mechanism of improvement of dredger fill serous fluid with additive [J]. Journal of Engineering Geology, **2**, 285-288 **(2005)**.