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Experimental Study on Cemented Soil in Sulfate Radical Corrosive solution

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Abstract: The cemented soil is a widely used method to stabilize the weak soil. It would be working in polluted environment, and be influenced by environmental pollution such as acid rain, seawater invasion or industrial pollution, which may lead to deterioration of the structure. In order to simulate and study the erosion effect process including as the changes of corrosive degree of surface, compression strength of cemented soil samples and SO_4^{2-} concentration of corrosive solutions, a series of tests are conducted on the cemented soil blocks cured in different concentrations of $MgSO_4$, H_2SO_4 and Na_2SO_4 solutions. The test results show that the corrosive degree of the sample surface increases while the compression strength decreases with the increase of the corrosive solution concentration at the same erosion time, and that the corrosive degree increases with the corrosive time. The influence of inorganic compound solutions on the cemented soil follows the order of Na_2SO_4 > $MgSO_4$> H_2SO_4. By analyzing the mechanism, the corrosive type of H_2SO_4 and $MgSO_4$ solutions to cemented soil is a composite type of resolving and crystallizing combination, and Na_2SO_4 solution to cemented soil is a composite type of dissolving and crystallizing combination.

Key words: Cemented soil, compressive strength, corrosion, sulfate.

1. Introduction

The cement stabilized soil in natural condition, as well as stabilization in corrosive site, will be influenced by environmental pollution such as acid rain, seawater invasion or industrial pollution, which will lead to deterioration of the structure. Especially in the corrosive site, the strength of soil stabilized by cement will increase, but at the same time, it will decrease due to the deterioration at the beginning of stabilization [1-3]. Cemented soil, sometimes, has to be worked in SO_4^{2-} corrosive environment, when the groundwater is polluted or worked under the seawater such a corrosive environment inevitably erodes the cemented soil affect its mechanical property [4]. In turn, the reduction of mechanical property of cemented soil can cause some serious damage to the structure supported by it, which should be considered in the practical project. Many researchers have paid much affection to the influences study of the corrosive environment the cemented soil property. Jiao et al. analyzed the influencing factors of cement-soil strength in acid environment [5]. Pei's study shows that the influence of Na_2SO_4 on the cemented soil mainly presents the diffusions of Na^+ and SO_4^{2-} and their chemical reaction to $Ca(OH)_2$ existed in cemented soil, the chemical reaction causes the cemented soil decomposed and broken, so makes its strength decrease [6]. Ning et al. investigated the behaviors of cemented soil under various environmental conditions and made the conclusion that the environmental erosion had little effects on fracturing process in contrast to evident influence on mechanical strength [7, 8]. Rolling and Dong tested mechanical property and electrical resistance of cement-soil polluted by H_2SO_4 [9][10]. In order to further simulate and study the erosion effect process in sulfate corrosive environment, a series of tests including unconfined compressive tests were conducted on the cemented soil blocks which were cured in the $MgSO_4$, H_2SO_4 and Na_2SO_4 solutions with different

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concentrations, meanwhile, the appearance change of the block were taken photos, the corrosion mechanism of sulfate solutions to cemented soil were studied.

2. Materials and Experimental

2.1 Preparations of Test Blocks

The air dried silt soil was used in the tests with 8.1 plasticity index (I_P), taken from a building site in Taiyuan, China. The cement used was ordinary Portland cement (OPC), brand 32.5#, produced in Taiyuan SHITOU Cement Co. LTD. Soil, cement and water were mixed an HJW-30 blender, rotating speed 48 round/min with certain proportion shown in table 1. After well mixing, the mixture was put into a steel mold to form a cemented soil block. After molding 24 hours, the blocks were taken out from the molds, cured in a standard conservative box to cure for 7 days. Then the cemented soil blocks were cured in the solutions with various concentrations prepared in advance.

2.2 Preparations of Solution

The $MgSO_4$, H_2SO_4 and Na_2SO_4 concentrations of the solution used in this experiment were 1.5g/L, 4.5g/L, 9.0g/L and 18.0g/L respectively. The selection of this based on *Code for investigation of geotechnical engineering* [11] and *Code for anticorrosion design of industrial constructions* [12]. The sulfate solutions and cemented soil samples are given figure 1.

Table 1 The Formula of Cemented Soil.

Air dried soil(g)	Cement (g)	Water (g)
100	15	50

Fig. 1 Cemented soil samples and $MgSO_4$ solutions.

2.3 Testing Procedure

In order to simulate the erosion process and study the erosion mechanism, following test procedures were adopted:

Step 1: make cemented-soil blocks, described in above section.

Step 2: cure the blocks in $MgSO_4$, H_2SO_4 and Na_2SO_4 solutions with 4 concentrations, such as 1.5, 4.5, 9.0 and 18.0 g/L respectively.

Step 3: take photos for every block at certain curing time, like 28 days, respectively, in order to observe the appearance changing during the erosion process.

Step 4: take the unconfined compress tests for the blocks at same curing times as step 3 at 28 day, 3 blocks were tested in parallel for one concentration of the solution. The average value of the three testing results is used as the block strength.

3. Results and Discussion

3.1 Block Appearance Change

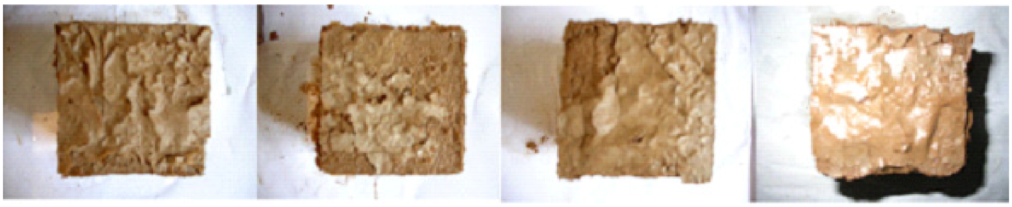
Fig.2 gives the photos of the appearance of the blocks curing in the solutions for 28 days, respectively. Comparing the photos, it can be clearly seen that sulfate solution does make the cement-soil block change, mainly representing as the block appearance peeling off, the block size reducing, even the block cracking. The influence of sulfate solutions to the blocks is increasing with the concentration of solutions and curing time increasing. Inorganic compound solutions can be arranged in a series for the influence as follows: Na_2SO_4 > $MgSO_4$> H_2SO_4.

3.2 Unconfined Compressive Test Results

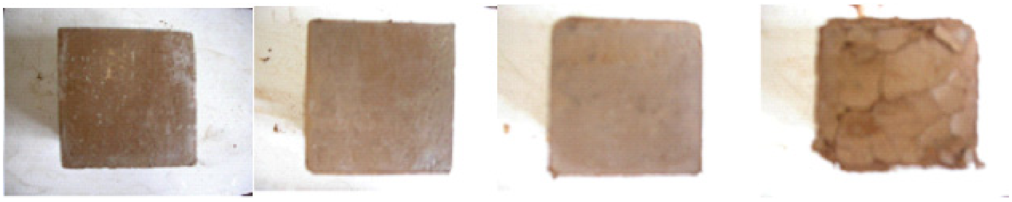
The unconfined compression strength of the cemented soil blocks was tested at the 28th day, and from tested results equation 1 can be put forward:

$$f'_{cu} = \alpha f_{cu} \tag{1}$$

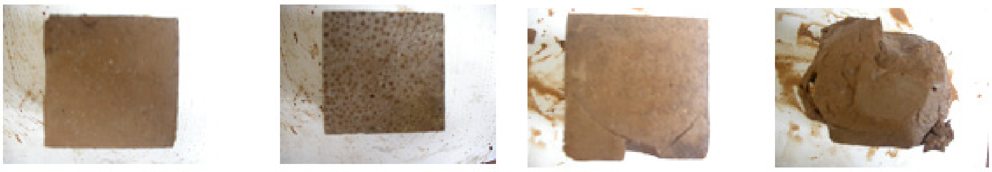
where f'_{cu} is compression strength of the block which cured in sulfate corrosive solutions,



Samples' surface in $MgSO_4$ solutions



Samples' surface in H_2SO_4 solutions



Samples' surface in Na_2SO_4 solutions

Fig. 2 Photos of cemented soil samples' surface at the 28th day.

Table 2 Compressive strengths modified coefficient

concentration	$MgSO_4$	H_2SO_4	Na_2SO_4
1.5 g/L	1.131	0.98	0.9
4.5 g/L	0.869	0.70	0.85
9.0 g/L	0.629	0.55	0.44
18.0 g/L	0.560	0.49	--

α is modified coefficient (table 2), expressing blocks corrosive degree,

f_{cu} is compression strength of the block which cured in pure water.

The unconfined compressive strength testing results show that the compression strength decreases with the increase of the corrosive solution concentration at the same erosion time, and that the corrosive degree increases with the corrosive time. From table 2, in $MgSO_4$ solutions, all the cemented soil strength modified coefficients are great than 1 for the 1.5 g/L solution environments, from which it may be drawn out that these environments are beneficial to the strength increasing of cemented soil. On the other hand, other solutions, all of strength modified coefficients for the other solutions are less than 1, which may be indicated out that these environments are proposing the corrosion to the cemented soil, and cause the strength reduce. Therefore, the working environmental condition of the cemented soil should be taken into account when designing and calculating the foundation bearing capacity and settlement in order to optimize design, reduce the cost, adopt suitable measures, and assure the safety.

3.3 Discussion of Corrosion Mechanism

The main chemical reaction of cemented soil with SO_4^{2-} in sulfate solution is as follows:

$$Ca(OH)_2 + Na_2SO_4{\cdot}10H_2O = CaSO_4{\cdot}2H_2O + 2NaOH + 8H_2O \quad (2)$$

It is well known that the resultant volumes of $CaSO_4{\cdot}2H_2O$ is 2 times of $Ca(OH)_2$'s, so the new product $CaSO_4{\cdot}2H_2O$ may fill into the void in the cemented soil and be good for unconfined compressive strength of cemented soil, when the mass of Na_2SO_4 is suitable and the new reactant $CaSO_4{\cdot}2H_2O$ is small. But, the mass of $CaSO_4{\cdot}2H_2O$ will be great and may make the cemented soil block inflate in turn, block strength decreases when the mass of Na_2SO_4 is large enough. Therefore, this explain why the unconfined compressive strength of the cemented soil blocks cured in the low concentration $MgSO_4$ solutions (1.5 g/L) are greater than those cured in either pure water (0 g/L concentration) or higher concentration solutions.

Meanwhile, the $CaSO_4$ takes chemical reaction with the cemented soil, as equations 3 and 4, products the $3CaO·Al_2O_3·3CaSO_4·32H_2O$ and $CaCO_3·CaSO_4·CaSiO_3·15H_2O$ crystallizing resultants. When such crystallizing resultants are large enough, the inflating force would be greater than the sticking force within the cemented soil, so cracks may bring about in the cemented soil block and the strength would be reduced. Therefore, the SO_4^{2-} corrosion to cemented soil is a sort of crystallizing corrosion.

$$2CaSO_4+3CaO·Al_2O_3·CaSO_4·18H_2O+14H_2O$$
$$=3CaO·Al_2O_3·3CaSO_4·32H_2O \quad (3)$$
$$CaCO_3 + Ca(OH)_2 + SiO_2 + CaSO_4·2H_2O + 12H_2O$$
$$= CaCO_3·CaSO_4·CaSiO_3··15H_2O \quad (4)$$

The main chemical reaction of cemented soil with Mg^{2+} in $MgSO_4$ solution is as follows:

$$MgCl_2 + Ca(OH)_2 + 6H_2O$$
$$= CaCl_2·6H_2O + Mg(OH)_2 \quad (5)$$
$$2Mg(OH)_2 +3CaO·2SiO_2·3H_2O$$
$$= 2(MgO·SiO_2·H_2O) +3Ca(OH)_2 \quad (6)$$

As mentioned above, the new product $Mg(OH)_2$ may take chemical reaction with $3CaO·2SiO_2·3H_2O$, when the $Mg(OH)_2$ is enough in the cemented soil. For cemented soil, the $3CaO·2SiO_2·3H_2O$ is acted as sticking materials, which make the soil particles stick together and are main providers of the strength of cemented soil. But, $Mg(OH)_2$ takes chemical reactions with $3CaO·2SiO_2·3H_2O$ and forms new reactants such as $MgO·SiO_2·H_2O$, which are poor coagulation and easy to produce an unsteady structure, in turn, making the strength of cemented soil reduce.

The main chemical reaction of cemented soil with H^+ in H_2SO_4 solution is as follows:

$$Ca(OH)_2 + H_2SO_4 = CaSO_4·2H_2O \quad (7)$$
$$3CaO·2SiO_2·3H_2O + 3H_2SO_4$$
$$=3CaSO_4·2H_2O + 2(SiO_2·H_2O)+ 2H_2O \quad (8)$$

From the equations 10 and 11, the H^+ cations reactions the $3CaO·2SiO_2·3H_2O$, make the cement soil produce an unsteady structure as well as Mg^{2+} cations action. Therefore, the Mg^{2+} corrosion to cemented soil is a sort of resolving corrosion.

The main chemical reaction of cemented soil with Na^+ in Na_2SO_4 solution, may take chemical reaction with $3CaO·2SiO_2·3H_2O$ and $3CaO·Al_2O_3·6H_2O$, the chemical equations are given below:

$$3CaO·2SiO_2·3H_2O+4NaOH$$
$$=3Ca(OH)_2 + 2Na_2SiO_3 + 2H_2O \quad (9)$$
$$3CaO·Al_2O_3·6H_2O+2NaOH$$
$$=3Ca(OH)_2 + Na_2O·Al_2O_3 + 4H_2O \quad (10)$$

For cemented soil, the $3CaO·2SiO_2·3H_2O$ and $3CaO·Al_2O_3·6H_2O$ are acted as sticking materials, which make the soil particles stick together and are main providers of the strength of cemented soil. But, the new reactants such as $2Na_2SiO_3$ and $Na_2O·Al_2O_3$, which are poor coagulation and easy to produce an unsteady structure, in turn, making the strength of cemented soil reduce. Therefore, the Na^+ corrosion to cemented soil is a sort of dissolving corrosion.

As mentioned above, the mechanism of the corrosive type of H_2SO_4 and $MgSO_4$ solutions to cemented soil is a composite type of resolving and crystallizing combination, and Na_2SO_4 solution to cemented soil is a composite type of dissolving and crystallizing combination.

4. Conclusions

The sulfate solution does make the cement-soil block change, mainly representing as the block appearance peeling off, the block size reducing, even the block cracking. The unconfined compressive strength of cemented soil block is decreased with the increasing of sulfate solution concentration. The corrosive type of H_2SO_4 and $MgSO_4$ solutions to cemented soil is a composite type of resolving and crystallizing combination, and Na_2SO_4 solution to cemented soil is a composite type of dissolving and crystallizing combination.

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