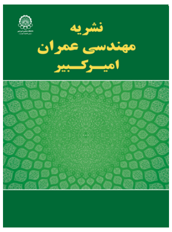

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Experimental Study of the Effect of Chemical and Biological Stabilization on Clay Subgrade Soil

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ABSTRACT: Chemical stabilization of weak subgrade soil is a viable and essential method of avoiding weak soil replacement problems with selected borrow pit from an economically and environmentally point of view. Although the use of new materials such as polymers instead of traditional materials such as lime accelerates operations and reduces resource pressure, the environmental impact and long-term resistance in these methods are concerns for experts. Recently, according to the "Kyoto Environmental Protocol" recommendation on soil stabilization with geotechnical purposes, research on new biological methods of soil stabilization including "soil microbial stabilization" has been developed. In this study, the effect of clay subgrade stabilization with chemical and biological methods was investigated and compared through different experiments. Cationic polyelectrolyte as a liquid polymer and microbial-induced calcium carbonate precipitation (MICP) was used to stabilize chemically and biologically respectively. In both methods, the specific dry weight of soil decreases, and its optimum moisture content increases. Chemical stabilization increases plastic index and microbial stabilization decreases it. Both materials at low concentrations raise the pH for up to three days. Both materials increase the uniaxial compressive strength and elasticity modulus of the soil almost equally. In terms of project economy (time and cost), chemical stabilization with cationic polyelectrolyte, and terms of environmental issues, the MICP method is suitable for the studied soil.

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1. INTRODUCTION

Weak subgrade soil replacement is a time and cost-consuming process. Soil stabilization is one of the methods which can be used to enhance subgrade conditions and has different types including chemical stabilization. Chemical stabilization using traditional materials (e.g. lime and cement) can have an adverse impact on the natural resources and environment. As such, non-traditional materials such as polymers are considered as a suitable alternative [1]. One of the polymers is cationic polyelectrolyte, which falls into the polyacrylamide (PAM) group and is generally used in water filtration systems. Due to its effectiveness in the flocculation of clay soils, it has been used in agricultural industries [2] and recently in geotechnical engineering fields such as minimizing clay soil erosion and depressiveness at temporary helicopter landing sites [3], sealing and stabilizing landfills [4] and improving CBR and UCS characteristics of clayey and silty soils [5]. Considering the importance of environmental aspects, 'biological' methods, such as microbial stabilization, have been developed in recent years. This process involves adding precipitator bacteria and nutrients to the soil, which results in calcium carbonate precipitation in soils and binds the particles together (MICP). Microbial stabilization is widely employed in geotechnical engineering fields, such as slope [6] and weak trench [7] stabilization and wind-blown sands [8]. NCHRP[1] has recently issued an implementation program for using this method in stabilizing problematic pavement subgrade sections [9]. Although this method has generally been employed in sandy soils, its implementation in clay soils has recently been considered.

In this research, stabilizing subgrade clay using non-traditional materials (chemical stabilization) and MICP method (microbial stabilization) has been discussed and the results have been compared.

2. METHODOLOGY

Table 1 provides a summary of soil properties. For chemical stabilization, cationic polyelectrolytes and for microbial stabilization, Bacillus pasteuri, urea, and calcium chloride nutrient were used. For chemical stabilization, polymer and water solution with 3, 7, and 10 gr/lit dosages is added to the soil up to the optimum moisture content percentage and then is mixed with the soil [8, 10]. For microbial stabilization, bacteria and nutrient solution are added to the soil to provide optimum moisture content. First, bacteria weighing equal to one-third of the weight of the nutrient solution is added to and

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1- National Cooperative Highway Research Program

Table 1. Engineering properties of collected clay soil

TYPE (ASTM)	CH		
LL (%)	53		
PL (%)	22		
PI (%)	31		
G_S	2.61		
γ_{dmax} (gr/cm^3)	1.61		
ω_{opt} (%)	19.6		
q_u (kg/cm^2)	5.7		
$E_{50\%}$[1] (kg/cm^2)	362.8		
pH	1 h	3 d	7 d
	7.43	8.1	7.61

[1] Secant Modulus of Elasticity as half of ultimate uniaxial strength of the soil

Table 2. The results of the compaction test

MICP (M)			Polyelectrolyte (gr/lit)			
1	0.75	0.5	10	7	3	
1.61	1.57	1.54	1.53	1.5	1.56	$\gamma_{d\,max}$ (g/cm^3)
22	21.5	22.5	22.4	24.4	21	W_{opt} (%)

Table 3. The results of the Atterberg limits test

MICP (M)			Polyelectrolite (gr/lit)			
1	0.75	0.5	10	7	3	
24	24	23	26	26	24	**PL (%)**
48	50	52	59	59	54	**LL (%)**
24	26	29	33	33	30	**PI (%)**

Table 4. The results of the pH determination test

MICP (M)			Polyelectrolyte (gr/lit)			
1	0.75	0.5	10	7	3	
7.54	7.54	7.77	7.54	7.56	7.68	**1 h**
7.74	7.92	8.05	7.97	8.27	8.14	**3 days**
7.08	7.23	7.44	7.58	7.75	7.73	**7 days**

Table 5. The results of the UCS test (kg/cm^2)

Curing (days)		Polyelectrolyte (gr/lit)			MICP (M)		
		3	7	10	0.5	0.75	1
3	q_u	25.2	33.9	27.3	22	24.2	29.9
	E	1463	1544	1402	932	902	1219
7	q_u	26	38.6	32.1	25.4	28	25.7
	E	1568	1623	1792	1451	683	1205
14	q_u	27.8	39.2	31	28	29.6	25.9
	E	1668	1899	1780	1555	915	1402
28	q_u	27.6	39.4	28.4	37	30.7	24.9
	E	1845	1892	1619	1913	1048	1611

mixed with the soil. Subsequently, a nutrient solution with 0.5, 0.75, and 1 Molar densities are added to and mixed with the soil [8, 11-12].

The laboratory tests included: Compaction testing (ASTM D698), Atterberg limits (ASTM D4318), pH (ASTM D4972) and UCS and Secant Modulus of Elasticity ($E_{50\%}$) (ASTM D2166).

3. RESULTS AND DISCUSSION

A summary of test results is presented in Tables 2 to 5.As Table 5 shows, in chemical stabilization, polymer solution with dosages up to 7gr/lit significantly increases the strength and stiffness of the soil. However, at dosages, more than 7gr/lit the increasing trend stops and long-term strength declines. In microbial stabilization, the peak strength and stiffness are achieved at 0.5 molar nutrient density. Soil strength and stiffness do not respond to higher density values up to 1.0 molar, at which point the declining trend commences.

4. CONCLUSION

Chemical and microbial stabilization of clay soils within weak pavement subgrade is proved to be possible using cationic polyelectrolytes and bacillus bacteria with urea and calcium chloride nutrients, respectively. A summary of findings and conclusions of this research is as follows:

Ø Both chemical and microbial stabilization results in a reduction in maximum dry density and an increase in optimum moisture content.

Ø The experimented increase in plastic limit is possibly due to hydrogen bond between the liquid polymer and water molecules in chemical stabilization, and cation exchange between clay soil particles and calcium chloride ions in microbial stabilization.

Ø At the beginning of microbial stabilization, pH value increases to a certain point and improves the precipitation in soil.

Ø The maximum strength and stiffness were achieved at 0.5 molar nutrient in microbial stabilization and 7gr/lit dosage of polymer in water in chemical stabilization, both with a 28-day curing time.

Ø This study revealed that both chemical and microbial stabilization have similar effects on the stabilization of the soil employed in this research. Therefore, chemical stabilization would be a better option when a more efficient economical, and the practical outcome is required while giving priority to environmental aspects would warrant using microbial stabilization.

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