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Comparison of clayey soil characteristics treated with lime and water base nano-polymer

Ata Aghaei Araei [a, *], Amirsaeid Salamat [a], Saeid Hashemi Tabatabaei [a], Hossein Hasani [a]

[a] *Geotechnics Department, Road, Housing & Urban Development Research Center (BHRC), Tehran, Iran.*

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ABSTRACT

This paper presents the results of laboratory tests to explicate the mechanism of the Poly Vinyl Acetate (PVA) and hydrated lime on the engineering properties of the treated soil. Soil improvement is a time and cost-saving method that enables unsatisfactory in-situ materials to obtain higher strength, obviating the need for costly excavation and replacement with suitable material. Laboratory tests, including consistency limits, compaction, unconfined compressive strength (UCS), and direct shear tests were carried out on treated soils. The results show that the addition of 4% PVA and 6% lime can improve soil properties, but lime had higher UCS for long period. Moreover, the optimum percentage of PVA has a small effect on the cohesion and UCS of treated soil, but its effect on friction angle is significant.

Keywords: *Curing, Direct shear, Lime, PVA, Unconfined compressive.*

1. Introduction

Soil improvement is especially important in weak soil conditions. Soil stabilization is a collective term for any physical, chemical, or biological method, or any combination of such methods, which is employed to improve certain properties of natural soil to make it adequately serve an intended engineering purpose over the service life of an engineering facility [1]. Soil stability, which every civil engineer is concerned with, is closely associated with the structures and mineralogy of the clay particles, clay-water interactions, clay particles' ionic exchange capacity, and the clay-organic or clay-inorganic interaction. The majority of road failures are associated with the action of water, or perhaps more precisely, the interaction between water and the clay particles in the road. The main objectives of chemical stabilization on soils are maintaining the characteristics of the soil, favorable to the aspects of the given engineering target, regardless of the moisture in its environment [2, 3, 4, 5, 6, and 7]. It is intended to modify the interactions between water and soil by surface reactions in such a manner as to make the behavior of the soil with respect to water effects most favorable for the given purpose.

Traditional stabilization methods include the application of various combinations of lime, cement, fly ash, and bituminous materials. Extensive research has been conducted on the use of traditional stabilizers [8, 9, 10, 11, 12, 13, 14, 15, 16, and 17]. The stabilization mechanisms for these traditional stabilizers are well documented, and the effectiveness of these traditional stabilizers has been demonstrated in many applications. Soil stabilization with lime occurs when lime is added to a reactive soil to generate long-term strength giant through a pozzolanic reaction. This reaction produces stable calcium silicate hydrates and calcium aluminates hydrate as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay. The full-term pozzolanic reaction can continue for a very long period, even decades as long as enough lime is present and the PH remains high (above 12). As a result, lime treatment can produce high and long-lasting strength gains. The key to pozzolanic reactivity and stabilization is reactive soil, a good mix of design protocol, and reliable construction practices. It should be noted that the clay percentage of the mix design should not be less than 20%.

Several researchers [18, 19, 20, and 21] have discussed aqueous polymer applications while others [22, 23, 24, 25, and 26] have provided useful data on polymer-soil interactions that determine the effectiveness of polymer solutions in various applications. Normally water-based polymers act to break or diminish the water membrane surrounding the soil particles. Upon compaction, it will enhance and improve the condition of the targeted soil with the significant load resistance. They act as a surface agent or surfactant where it transforms the hydrophilic nature of clayey material into hydrophobic nature through an ionization process and chemical reaction when it dissolves in water. Despite the potential advantage performances claimed by liquid polymer stabilizer providers, most agencies and engineers are resistant to accepting the use of these products. Polymers can cause a certain lack of confidence in the engineers to use them in actual construction because the liquid polymer's chemical composition is often not listed in full, which makes it difficult to understand the mechanism of stabilization. They also failed to demonstrate the benefits of their products with data from field performance and lack of long-term results.

The PVA has been prepared in the laboratory of Soil Mechanics in Iran's Polymer and Petrochemical Institute, according to the soil condition in Iran. Moreover, after CBR testing, which indicates the stabilization of clayed soil and its resistance, optimum water content is determined. The mineral clay particles are very small and look like the pages of a book surrounded by "surface absorption water". This nature of the clay book, which has a very high surface area, attracts metal ions. These ions also absorb large amounts of water. These water absorbers and exchangeable cations still absorb water and cause the clay to expand or swell more by forming the "double layer water". Double layer water reduces friction between soil particles, adhesion, cohesion, and strength of clay mass. Absorbent surface water is strongly bound to the clay surface and is not separated by solar heat, and only chemicals such as

* Corresponding author. Tel/Fax: +98-2188255942, *E-mail address:* aghaeiaraei@bhrc.ac.ir (A. Aghaei Araei).

nanopolymer polyvinyl acetate (PVA) can separate the adsorption water from the surface of the clay particles. PVA is a processing product of synthetic derivatives and complex molecules and consists of two components, the head, and the tail, which have a hydrophilic head and a hydrophobic tail (Fig. 1). These ions attach to the surface of the clay and replace water molecules in the clay structure.

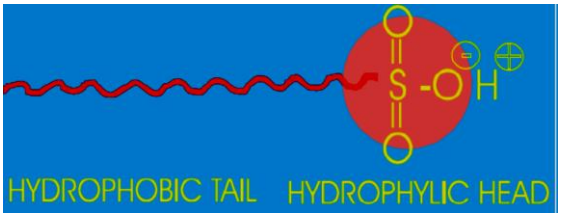

Figure 1. Molecule of polyvinyl acetate nano-polymer.

It either moves water or locks them in metal ions and removes its adsorbents and dehydrates the clay, creating a protective layer with an oily effect on the soil surface and clay particles and finally absorbing soil water, which makes clay hydrophobic. Therefore, this product can be used to stabilize and strengthen clay.

Joining clay particles (Figure 2) by PVA means more internal friction and improved capacity and increased bearing strength. As a result, soil material is less sensitive to moisture and causes more efficiency and compaction power and better bonding of particles by passing equipment and machinery. The efficiency and success of PVA in stabilizing and improving soil performance depends on the type of clay, the percentage of fine particles, replaceable ions, and the amount of clay. PVA affects materials ranging from clay to windy sand with some gravel. Non-cohesion materials such as sand can only be affected if they are mixed with clay with suitable materials. The process of transferring PVA nanopolymer to all soils in the soil requires a certain time as the green period or the period of evolution. The effects of PVA are not immediate and little change is seen in the soil. But at the end of the evolutionary period of 2 to 4 weeks, the soil becomes firm and tough. It should be noted that the presence of water up to the optimum moisture to deliver PVA (mobile product) is required to migrate to all clays. Water scarcity delays the process and thus delays evolution.

In this study, water base polymer soil stabilizers namely Poly Vinyl Acetate (PVA) and hydrated lime are introduced for soil treatment. These chemical stabilizers are suitable for all types of soil-based construction. Therefore, this research aims to study the behavior of PVA- treated soil in comparison with lime-treated soil on long-term performance.

2. Material and testing program

In this study, the soil was sampled from Ijroud town, Zanjan province, Iran. The soil was collected from the bottom (1.5m) of the test pit through excavation by hand shovels. Soil classification tests were being performed based on a combined sieving analysis with wet sieving and followed by the determination of fine particles by the hydrometer procedure in accordance with ASTM D 422[27]. Figure 3 shows the grain size distribution of the studied soil. Based on particle size results, the soil is classified as clayey sand (SC). More details about grain size of the soil are as follows: Passing 4.75 mm=96.5%, Passing 0.075=45.5%, D_{10}=0.003, D_{30}=0.017 and D_{60}=0.58. Dry soils that passed through a 4.75 mm sieve were used in this study.

The used Nano polymer additive (PVA) and hydrated lime were procured from the local market. The properties of PVA and lime are presented in Tables 1 and 2, respectively.

The results of the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI)(ASTM D 4318[28]) of the Original soil and lime and PVA treated samples are shown in Table 3. Results presented in Table 3 indicated that the presence of additives in defined percentages in the samples caused the changes in the liquid limits and plastic limits.

Figure 2. Clay particles after PVA adsorption.

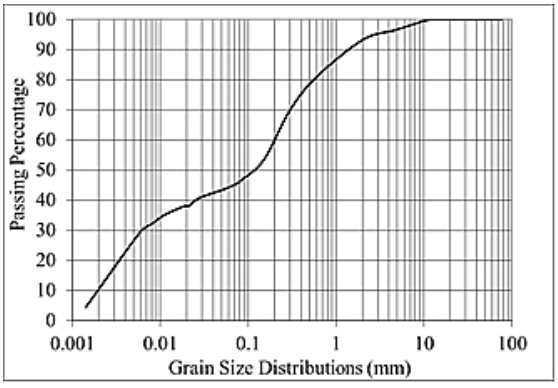

Figure 3. Grain size distribution of the studied soil.

The result reveals the plasticity index of 2% lime-soil admixture decrease with curing time. Moreover, for a higher percentage of lime-soil admixtures (4, 6, and 8% lime), non PI behavior is observed. The same behavior has been reported for lime-modified soil by Tabatabaei and Aghaei Araei [29]. The result indicates that for PVA-treated samples, the plasticity index is increased with curing time.

A standard compaction test (ASTM D 698[29]) is used in order to determination of maximum dry density (MDD) and optimum water content (OWC). To ensure a viable result from the testing, replication of the tests was done. Figure 4 presents the maximum dry density and optimum water content for soil and treated soil with various percentages of the lime and PVA. Figure 4 indicates lower MDD for lime admixture and higher MDD for PVA treated samples. The decrease in dry unit weight is attributed to the fact that lime reacts quickly with clay minerals, resulting in ion exchange, granularity, and flocculation which leads to an increase in the void ratio of the mixture. The liquid stabilizer chemically is neutralized the clay platelets and dismisses the water molecules that bonded to the clay platelets. Hence, neutral clay platelets can be compacted in a more ordered arrangement to achieve higher density.

3. Specimen Preparation

Obtained results from the compaction tests play an important role in the preparation of the treated specimen. All the treated specimens were prepared to their maximum dry densities (MDD) and optimum moisture contents (OMC) according to ASTM D 698[30]. Required dry mass of the soil samples had been calculated with the reference to the mold volume and the MDD. Predetermined quantities of PVA and hydrated lime were then measured based on the dry mass of the soil sample (MDD) and mixed with the required OMC. The percentages of the lime added to the soil were 2 %, 4 %, 6 %, and 8 % by total weight.

They mixed to become a homogenous admixture. The soil specimen was then mixed with the OMC. The mixing process was carried out within a reasonable time, approximately five minutes to ensure that the lime was not exposed to the air for a long time [3]. In order to the preparation of a PVA solution, initially, the amount of 2cc of the Nano polymer of PVA in 1000 cc water was mixed and 0.2% PVA solution was prepared. Then given solution was added to the test specimen with 2, 4, and 6% PVA, proportional to the OMC from the compaction test. The specimens were mixed thoroughly and compacted into the 100 mm x 200 mm cylindrical mold for unconfined compressive strength (UCS) or 100 × 100× 50 mm cubic mold for the direct shear test. In the next step, the Nano-mixed soil was placed in a plastic bag for 24 hours, then removes the specimens from the bag and put in a humidity tank for treatment periods of 7, 28, and 56 days.

Table 1. Chemical composition of the used PVA.

MW	Viscosity (C.P)	PH	Density (g/cm³)	Glass Transition (⁰k)	Color	Reinforcement Mechanism
83000	470	3.1	1.05	335	White	Physical (like glue)

Table 2. Chemical composition of the used hydrated lime.

SiO_2	$Al_2O_3 + Fe_2O_3$	CaO	MgO	SO_3	L.O.I
0.68	1.26	67.75	0.48	1.23	27.38

Table 3. Atterberg results for original soil and soil treated with different percentages of lime and PVA.

Original soil		Admixture Soils									
		Type of Additives	Additive Percentage	Curing Periods(day)							
				7			28			56		
				LL	PL	PI	LL	PL	PI	LL	PL	PI
11	36	Hydrated Lime	2	-	-	NP	34	25	9	37	22	15
			4	-	-	NP	-	NP	-	-	-	NP
PL	16		6	-	-	NP	-	NP	-	-	-	NP
			8	-	-	NP	-	NP	-	-	-	NP
PI	20	PVA	2	46	18	29	50	20	30	48	20	28
			4	46	16	29	43	19	24	48	20	28.5
			6	44	17	28	40	19	21	47	19	26.5

a site is extremely high, a wet-test procedure was developed. Replicate specimens of each mixture were stored over brick, about 10 cm above bath water level. The samples were cured under normal lab temperature and evaporate conditions, until testing times.

The results of experiments such as dry densities of different mixtures, UCS for all mixtures, and direct shear tests have been repeated at least twice and the average test results are presented.

4. Unconfined Compressive Strength

The UCS test was conducted in accordance with the ASTM D 2166[31]. After reaching the specified curing time, samples were taken out from the water bath. The specimen was carefully placed in the compression device. The test was carried out until the sample failed. At the end of each test, the failed specimen sample was taken to determine the plasticity index and moisture content. Figure 5 shows the UCS of soil treated with various lime & PVA percentages and different curing periods. Two samples for each soil mix design were prepared and tested [21]. The UCS was determined by taking the average of two test results. Obtained results revealed that the UCS of natural soil is 5kg/cm2, whereas UCS is increased for soil-lime specimens by increasing the curing period. The maximum unconfined compressive strength was achieved in the soil mixed with 4% lime and a 28-day curing period. Based on the results, soil-PVA mixture in a 7-day curing period has maximum UCS value, whereas strength growth has an almost decreasing trend with increasing curing periods. This can be best elucidated that during that period (longer curing times, i.e. 28 and 56 days), the chemical components of the PVA liquid were actively reacted with the clay platelets and increased liquid limit and well-led plasticity limits, which leads to slow strength growth.

Figure 6 shows the laboratory tests for measuring water content (ASTM 2216 [32]) on the tested UCS specimens. The result presented in Figure 6 is indicated that samples with higher lime content have higher OMC compared to PVA-treated samples up to 28 days, whereas after 56-day curing, the OMC of lime-treated soil is decreased, and almost constant for whole limes percentages. Considering the required UCS for treated subbase with lime (i.e. 14 kg/cm², [33]), periods of 28 and 56 days are appropriate for a mixture with 4% and 6% lime, respectively.

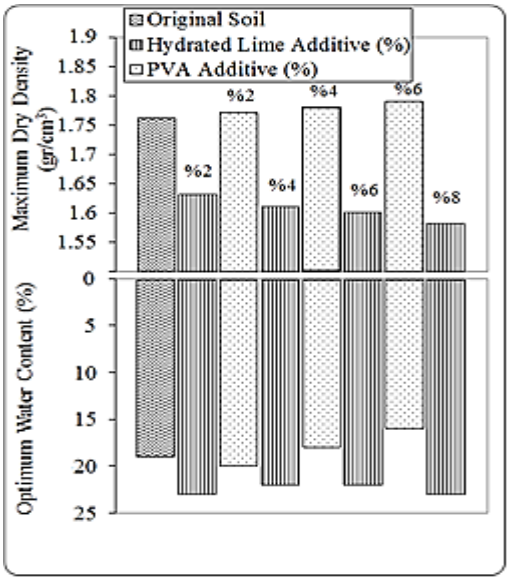

Figure 4. Maximum dry density and optimum water content for soil and treated soil with different percentages of lime and PVA

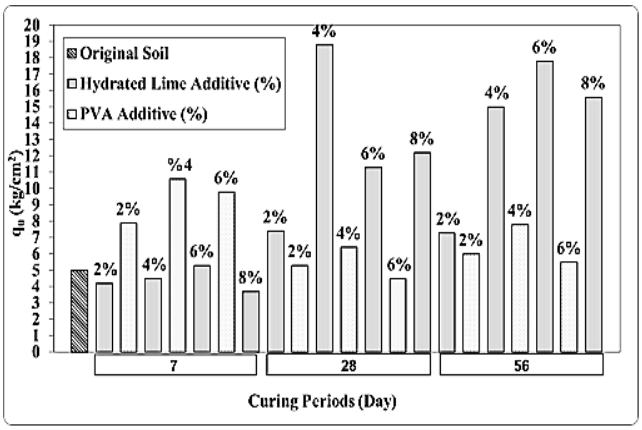

Figure 5. UCS of soil treated with various lime & PVA percentages and different curing periods.

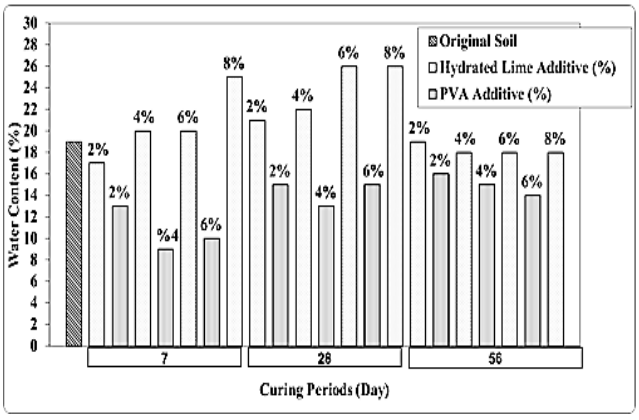

Figure 6. Variation of water content in different curing periods for different percentages of lime and PVA (the number above each bar is the percentage of the lime or PVA).

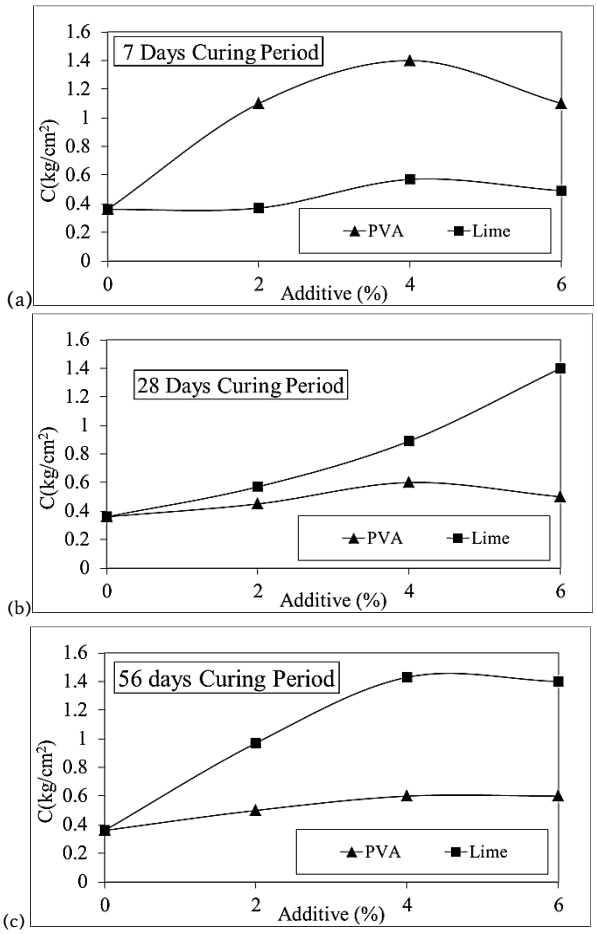

Figure 7. Variations of cohesive in treated soil specimens having 2, 4, and 6% lime or PVA in different curing times, a) 7 days, b) 28 days, c) 56 days.

5. Direct Shear Test

To determine the strength parameters of the studied soil, a direct shear test, using 10× 10 cm mold, was used (ASTM D3080 [34]). Surcharge pressures of 0.5, 1, and 2 kg/cm2 were selected. This test was performed on original soil samples as well as soil mixed with 2, 4, and 6% PVA and lime for curing periods of 7, 28, and 56 days. Based on obtained results, the cohesion of soil increases for both additive substances (Figure 7. a, b and c). Furthermore, a comparison of the results shows that lime additive has a greater effect on soil cohesion than PVA over time, but the PVA has considerable effects in increasing cohesion in early time (i.e. 7 days of curing). According to Figure 7 (b), the cohesion of samples with 6% lime reached a maximum value of 1.4 kg/cm3 after 28 days of curing. This value of cohesion is equal to the maximum cohesion of soil after 56 days of curing. Moreover, the cohesion for a mixture containing 4% lime in a 56-day curing period does not have much difference from those of 6% lime.

Variations of the internal friction angle of soil samples having 2, 4, and 6 lime or PVA in different curing times are presented in Figure 8. Based on the results, by increasing curing periods, the soil mixture with PVA material has a gently greater effect on the internal friction angle than that of the lime (Fig.8. a, b and c), especially for soil samples having 4% PVA at curing period of 56 days. Results presented in Figures 7 and 8 indicated that considering cohesion and friction angle, treatment of the soil with two additives (6% lime or 4% PVA) is similar in 56 days curing periods

6. Conclusions

An experimental study is carried out to investigate the clayey soil characteristics treated with lime and water base polymer, PVA. The following conclusions can be made on the performances of the additives stabilizer that had been used:

- Lime reduces plasticity indices whereas, a reverse trend is observed with PVA treated samples.
- PVA reduces optimum moisture content by ionizing and exchanging the water molecules on the surface of the clay platelets. Lime increases optimum water content by increasing the void ratio.
- PVA increases maximum dry density by neutralizing and orderly re-arranging the clay platelets. Lime shows a descending trend due to an increase in void ratio with an increment of lime proportion.
- Both additives increase the compressive strength by increasing the inter particles' bonding but, lime shows much better performance on a long curing period.
- Adding lime to the soil in the long term has a greater impact on the compressive strength and shear strength than the PVA.
- The best amounts of lime and PVA additives for the treatment of given soil, are 6% and 4% under a curing period of 28 and 56 days, respectively.

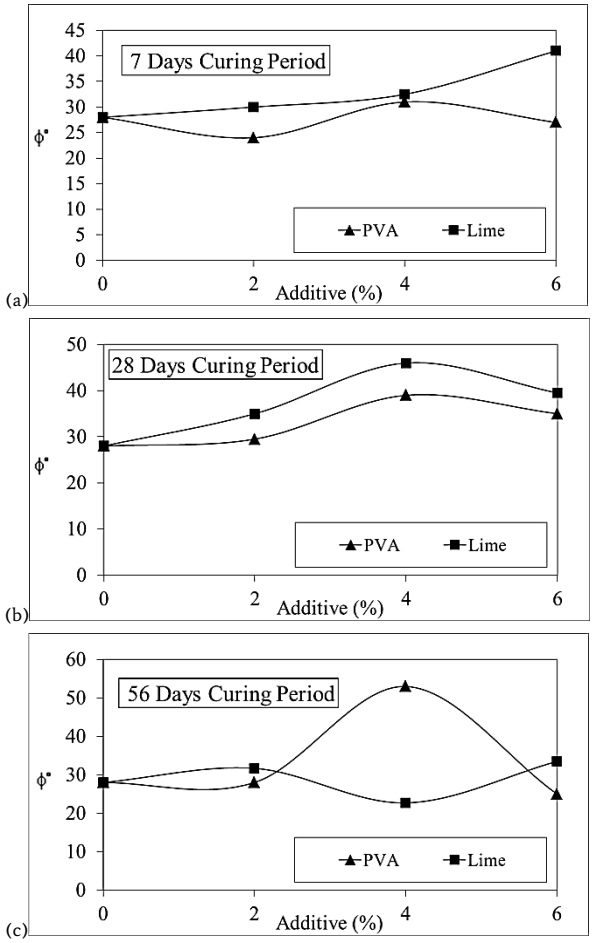

Figure 8. Variations of internal friction angle of soil sample having 2, 4, and 6% lime or PVA in different curing times, a) 7 days, b) 28 days, c) 56 days

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REFERENCES

[1] Fang, H. Y.,(1991). Foundation engineering handbook. Chapman &Hall, New York, NY10119.

[2] Kedzi, A., (1979). Stabilized earth roads, The Publishing House of the Hungarian Academy of Sciences.

[3] Wong, L.S., & Hashim, R.&Ali, F.H (2008). Engineering Behavior of Stabilized Peat Soil, European Journal of Scientific Research, pp581-591.

[4] Wong, L.S., Hashim, R. & Ali, F.H.(2008). Compression Rates of Untreated and stabilized Peat Soils. Electronic Journal of Geotechnical Engineering, 13 (Bundle F): Engineering (EJGE), World Wide Web of Geotechnical Engineers.

[5] Wong, L.S. Hashim, R. & Ali, F.H. (2009). Unconfined compressive strength of cemented pea", Australian Journal of Basic and Applied Sciences, 3(4), pp3850-3856.

[6] Wong, L.S., Hashim, R. & Ali, F.H., (2009). A review on experimental peat stabilization. Australian Journal of Basic and Applied Sciences, 3 (4). Pp 3537 -3552.

[7] Ali, F.H. Wong, L.S. & Hashim, R., (2010). Engineering properties of improved fibrous peat, Scientific Research, and Essay, 5 (2), pp154-169.

[8] Alexander, M.L. Smith, R E & Sherman, G. B., (1972). Relative stabilizing effect of various limes on clayey soils, Bulletin 381, Highway Research Board.

[9] Eades, J. L. & Grim, R. E., (1960). Reaction of hydrated lime with pure clay minerals in soil stabilization, Bulletin 262, Highway Research Board. Washington, D.C.

[10] Kumar, S., & Dutta, R.K., (2014).Unconfined Compressive Strength of Bentonite –Lime-Phosphogypsum Mixture Reinforced with Sisal Fibers. Journal of Civil Engineering, Vol8, No. 3.

[11] Singh Negi, A., Faizan, M., Siddharth, D, P., & Singh, R., (2013). Soil Stabilization Using Lime, International Journal of Innovative Research in Science, Engineering and Technology, Vol.2, Issue 2.

[12] Ferguson, G. & Levorson, S. M., (1999). Soil and pavement base Stabilization with self-cementing coal fly ash", American Coal Ash Association, Alexandria, Virginia.

[13] Ferguson, G., (1989). Stabilizing with fly ash Replacement for Portland cement or lime. Transportation Research Record 1219, TRB, National Research Council, Washington, D.C., pp. 68-81.

[14] Little, D. N., Males, E. H., Prusinski, J. R., & Stewart, B., (2000). Cementations stabilization. Transportation in the new millennium: Perspectives from TRB standing committees, Committee A2J01, Committee on Cementations Stabilization, National Research Council. Washington, D.C.

[15] Nikookar,M, Nikookar, H. Arabani,M.," (2013). Unconfined Compressive Strength of Lime-Stabilized Peat. Conference Paper, Bandar Abbas, Iran.

[16] Prusinski, J. R. & Bhattacharya, S., (1999). Effectiveness of Portland cement and lime in stabilizing clay soils." Transportation Research Record 1652, TRB, National Research Council, Washington, D.C pp. 215-227.

[17] Vidya Tilak, B., Kumar,R, & Mohanty, B. (2015). Effect of Coir Fibers on the Compaction and Unconfined Compressive Strength of Bentonite- Gypsum Mixture. Vol 23, No. 2, pp1-8

[18] Green, V. S., Stott, D. E., Norton, L. D., & Graveel, J. G., (2000). Polyacrylamide molecular weight and charge effects on infiltration under simulated rainfall Soil Sci". Am. J., Vol. 64, pp.1786-1791.

[19] Moustafa, A. B., Bazara, A. R., & Nour El-Din, A. R., (2003). Soil Stabilization by olymeric materials". Angenandte MaKromoleKular Chemie., Vol. 97, No. 1, pp. 1-12.

[20] Santoni, R. L., Tingle, J. S., & Webster, S. L., (2003).Stabilization of silty sand with non-traditional additives. Transportation Research Record 1787, TRB, National Research Council, Washington, D.C pp. 33-41

[21] Naeini, S. A. and Mahdavi, A., (2009). Effect of polymer on shear strength of silty sand, Master Thesis, Civil Engineering Department, Imam Khomeini International University.

[22] Daniels, J. L., Inyang, H. I, & Iskandar, I. K., (2003). Durability of Boston blue clay in waste containment applications". Journal of Material and Civil Engineering, Vol. 15, No. 2, pp. 144-155.

[23] Daniels, J. L. & Inyang, H. L.(2004). Contaminant barrier material Textural response to interaction with aqueous polymers, Journal of Material and Civil Engineering, Vol. 16, No. 3, p. 265-275.

[24] Khanbashi, A.A.L. & Abdalla,S.H.W., (2006). Evaluation of three waterborne polymers as stabilizer for sandy soil. Geotechnical & Geological Engineering, Vol. 24, No. 6. pp. 1603-1625

[25] Khanbashi, A.A. & El-Gamal, M., (2003). Modification of sandy soil using waterborne polymer. Journal of Applied Polymer Science, Vol. 88, Issue 10, pp. 2484-2491

[26] Marto,A., Boss,S., Makhtar, A.M., & Latifi, N., (2015). Strength Characteristic of Brown Kaolin Treated with Liquid Polymer Additives.

[27] ASTM D 422-63(2007). Standard Test Method for Particle-Size Analysis of Soils.

[28] ASTM D 4318(2010). Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of soils.

[29] Tabatabaei, S.H, Aghaei Araei, A., (2008). Comparison of hydrated and quick lime effects on geotechnical properties of improved soil. Geosciences, vol. 17, no. 67, spring 2008, p.14-2229-

[30] ASTM D 698(2012). Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3)).

[31] ASTM D 2166/D 2166M (2016). Standard Test Method for Unconfined Compressive Strength of Cohesive Soil.

[32] ASTM D 2216(2010). Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.

[33] Aghaei Araei, A., Rahmani, I., Attarchian, N., Lashani Zand, F., Salamat, A.S., Hasani, H., Rezaei, M., Niaki, M., Assessment and presentation technical characteristics of base soil Stabilized with lime and cement, BHRC, Research Project, 2021.

[34] ASTM D 3080/ D 3080M (2011). Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions.