Study of Enhancement of Strength of Clayey Soil Stabilized with Acrylic Polymer

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Abstract— The need for soil improvement is increasing due to pressures to build and rehabilitate infrastructure and other civil works on sites with marginal soils. If the infrastructure cannot be relocated or adapted to the soil conditions, then the soil must be stabilized. Soil stabilization methods are typically mechanically or chemically based. A laboratory test program was undertaken to evaluate a series of engineering properties for three types clayey soil with different range of plasticity to develop understanding of the engineering significance of polymer amendment. Three soils were prepared and tested with varying ranges of plasticity. Index properties of all the three soils were determined by Sieve analysis and Atterberg limits and classification done by plotting the fine grained soils on plasticity chart. Performance evaluation of the polymer addition was carried out by determining dry unit weight / moisture content relationships through compaction tests; shear strength through unconfined compression strength tests and CBR tests. The polymer addition rate required to achieve peak engineering performance ranged from 2% to 5%, based on soil type. Polymer modified the engineering properties of soil through physical bonding. It was determined that polymer amendment had an optimal addition percentage that resulted in the greatest increase in engineering parameters. Polymer amended soils displayed an improved performance of soils.

Key words: Clayey Soil, Polymer 0 to 5% Add, Strength

I. INTRODUCTION

Marginal soil usually may has little or no potential for infrastructure development i.e. they are not very suitable in-situ soils. If the infrastructure cannot be relocated or adapted to the soil conditions, then the soil must be stabilized. Soil stabilization methods are typically mechanically or chemically based. Historically, chemical amendments have been used to stabilize soils. The Appian Way, built during the Roman Empire was often considered the first lime stabilized road (ASCE 1978). Chemical soil stabilization has been extensively used worldwide.

Some of the most common non-traditional additives are: polymers, salts, acids, enzymes, lignosulfonates, petroleum emulsions, and tree resins. Two common polymer products used for soil stabilization are vinyl acetate and acrylic based copolymers. Both vinyl acetate and acrylic copolymers are hydrophobic and have had moderate success in bonding to a range of soils (Terratech 2012).

Polymer amendment for improvement of soils is a growing industry and has been of particular interest in recent field applications. Polymers improve the soil by providing physical stabilization through the use of binding agents. Polymers are easily modified; therefore, a range of polymer combinations can be prepared to modify soils.

II. POLYMER STABILIZATION

Polymers consist of long hydrocarbon chains. Polymers are present in many industries including food, cosmetics, paint, and road construction. The polymer industry is larger than the aluminum, copper, and steel industries combined (Chappat 1994).

Polymers are easily modified, resulting in potentially endless combinations of polymers used in different industries. Many different polymers have been proposed as soil stabilizers, including cationic, anionic, and non-ionic (Ingles and Metcalf 1973). Studies have determined that most chemical stabilizers react with soil in one of two ways: the additive relies on specific chemical reactions with soil particles, or the additive provides physical stabilization through the use of binding agents. Polymers fall into the latter category (Tingle et al. 2007).

In general, a polymer for soil stabilization should have excellent physical properties including high tensile, flexural, and compressive strengths, good adhesion to soil particles, and a high resistance to water, chemical, and ultraviolet effects (Newman and Tingle 2004, Tingle et al. 2007).

The most common polymers used in soil stabilization today are vinyl acetate or acrylic based copolymers. These polymer emulsions typically consist of 40-50% solid particles by weight of emulsion (Newman and Tingle 2004,Tingle et al. 2007).

Acrylic copolymers are designed to conglomerate soil particles into a solidified matrix with superior engineering properties (Terratech 2012). Acrylic copolymers are dispersed in an aqueous polymer emulsion by surfactants, or wetting agents when mixed with the soil. The polymer then cures by the evaporation of the water, and the remaining polymer particles coalesce to form a continuous film of polymer around the aggregate.

This cemented bond creates additional strength between the soil particles as displayed in Figure 1 (Feller 1966, Rushing and Tingle 2005). Because the primary stabilization mechanism of polymer is physical bonding, strength improvement depends on the ability of polymer to adequately coat the soil particles. The strength improvement also depends on the physical properties of the polymer. Therefore, polymers are typically less effective per unit of addition with fine grained soils due to the higher specific surface area, as compared to coarse grained soils (Tingle et al. 2007)

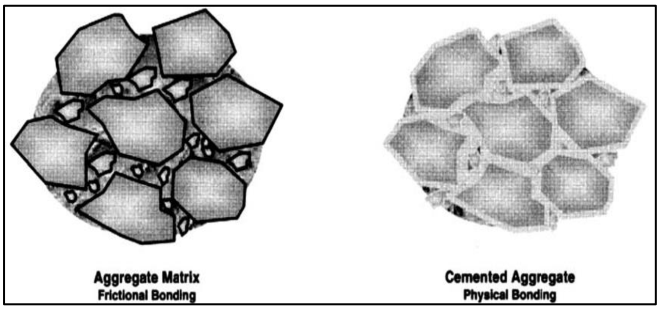

Fig. 1: Difference between Frictional & Physical Bonding (Feller 1966, Rushing And Tingle 2005)

Limited testing has been completed on polymer amended soils to date. Most laboratory and field experimentation with nontraditional additives, including polymers, have had a focus on performance evaluation rather than mechanism evaluation. Also, due to the proprietary nature of the commercial stabilization additives, exact chemical compositions are commonly not disclosed. Therefore, relatively little is published regarding the fundamental stabilization mechanisms between non-traditional stabilizers and geotechnical materials, and what was known tends to be subjective (Tingle et al. 2007, Muhunthan and Sariosseiri 2008). Some of the products are soil specific or environment sensitive. So some polymers may work well in specific soil types or a given environment, but perform poorly in another soil type or other environment.

Mixed results have been published regarding the success of polymer based soil stabilizers. Newman and Tingle (2004) determined that acrylic copolymer amendments improve the strength of soil at addition levels below those of typical cement stabilization. Newman and Tingle also noted that all acrylic copolymers tested had higher strengths than control strengths. Roosevelt (2005) completed a field test with an acrylic polymer (i.e., Soiltac) and concluded that soil stabilizers mixed with crusher run stone do not increase the stiffness or bearing capacity of the material. Rushing and Tingle (2005) determined that polymer emulsions provide excellent initial dust mitigation. The material physically adhered to soil particles and provided bonding. However, heavy wheeled and tracked vehicles were able to break the bonds at the road surface. They also noted that once the soil matrix was disturbed it could not be restored without the addition of additional polymer. Though each of these test programs tested the same type of polymer, each tested different parameters, and used a different proprietary product.

Santoni et al. (2002) conducted a test program with 6 polymers added to silty sand (SM) with an accelerated curing duration. Of the six polymers tested, only one had higher unconfined compressive strength than the control after 7 days. Increased strengths were demonstrated when cement was added as an accelerator. A test program was conducted on silty sand (SM) with 28-day curing periods, and unconfined compressive strength as the engineering parameter of comparison. Three polymers were tested at application rates of 0.1% to 5% by dry weight. The polymer additives gained significant strength with time over their 28-day curing duration. Polymer amended specimens had an average of 57% increase in strength in the dry test condition, and 221% in the wet test condition relative to control. An optimum polymer addition rate to obtain maximum unconfined compressive stress was identified. Finally, it was concluded that nontraditional stabilizers gained strength over a shorter time duration than traditional stabilizers. A summary of the test results is presented in Figure 2 (Santoni et al 2002).

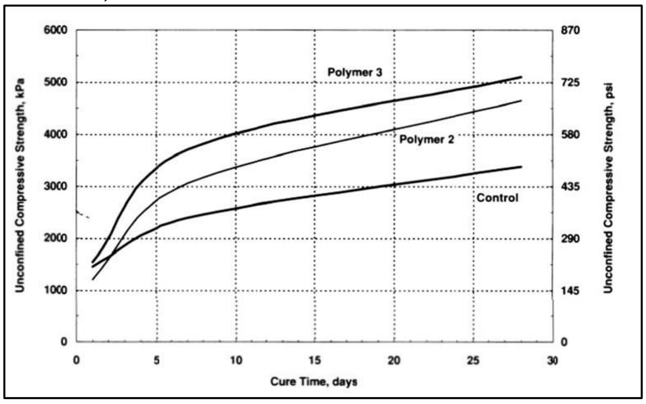

Fig. 2: Increase in Unconfined Compressive Strength as a Function of Polymer Addition Rate & Time (Santoni et al. 2002)

The addition of acrylic polymer to date has provided mixed results. This may be partially attributed to a lack of standard testing basis. Most case studies used varying soil types, curing periods, and addition rates.

A standard for preliminary evaluation of admixtures for improving engineering properties of fine grained soils is outlined in ASTM D 4609-08 (ASTM 2011). This test is used to evaluate moisture content, particle size, liquid limit, plastic limit, plasticity index, moisture density relations, volume change, and unconfined compressive strength to determine if the admixture possesses enough improvement to warrant further testing. No such evaluation procedure has been standardized in India.

In summary, the proprietary nature of polymer has limited the quantity of testing data published to date. A portion of the data published to date displays potential for improving the engineering properties of soil with the addition of acrylic copolymer, warranting further research. However, the lack of standardization for testing polymer amended soils has led to a variety of test arrangements and basis for comparison. Furthermore, the limited scope within each of these previous test programs does not provide sufficient data to distinguish between products that deliver enhanced performance and those that do not.

Therefore, a test program is needed that evaluates a single polymer product, and conducts a systematic and extensive series of engineering property tests to obtain comparable data on the performance of polymer amended soils across the range of conditions typically encountered in industry. An all-inclusive test program would provide a standard basis to compare the performance of polymer amended soil over typical field conditions. Furthermore, an all-inclusive test program would assist with drawing accurate conclusions, and gaining an understanding of the mechanisms facilitating change in the engineering properties with the addition of polymer. The study of mechanism of the change in engineering properties of soils has not even started in India. This study thus restricts the study of polymer in performance evaluation only.

III. Objective of Study & Methodology

The objective of this study is to see the effect of polymer addition on engineering properties of soil and to evaluate optimum percentage of polymer for performance evaluation based on unconfined compressive strength and CBR values. The methodology adopted is as follows.

In this work Acrylic Polymer has been used as additive. A series of tests were conducted by varying the amount of polymer in clayey soils with three different values of plasticity index. A laboratory test program was undertaken to evaluate a series of engineering properties for three types clayey soil with different range of plasticity to develop understanding of the engineering significance of polymer amendment. Three soils were manufactured and tested with varying ranges of plasticity. Engineering properties determined throughout the test program included dry unit weight / moisture content relationships through compaction tests; shear strength through unconfined compression strength tests and CBR tests. The polymer addition amount required to achieve peak engineering performance are determined.

Three test soils were designed and prepared to evaluate the effectiveness of polymer over a range of plasticity index. Soils included three clays with varying values of plasticity, i.e. low, medium and high having plasticity index as 11, 18 and 27 %. The experimental test program was also used to evaluate optimum percentage of polymer for performance evaluation based on unconfined compressive strength and CBR values

IV. Experimental Investigations

A laboratory test program was undertaken to evaluate the engineering properties of polymer amended soil viz. Unconfined compression Strength and CBR values. The objectives were to determine the influence of soil types, moisture content, and polymer addition rates on these engineering properties. The comparisons were made between polymer modified soil and in-situ soil without polymer addition. Three types of Clayey Soil are used for the investigation.

Testing was performed in accordance with all applicable Indian Standard Codes IS: 2720 (Part 16) 1979.The index properties tests are conducted first, then the soil optimum moisture content and dry density tests are conducted and at OMC, maximum dry density, the tests are performed. Soil index properties such as maximum dry unit weight, optimum moisture content, and specific gravity were used to classify soils. These tests were performed in accordance with their respective standards.

V. Results & Discussions

Various tests for engineering properties were conducted for each of the three types of soil taken in this study. These includes Specific gravity test, Sieve analysis, Liquid limit and Plastic limit test , standard Proctor test for determination of Optimum moisture content (OMC) and Maximum dry density(MDD). The performance evaluation of polymer content on each of these soils was carried out using unconfined compressive strength test (UCS) and California Bearing Ratio tests (CBR test).

Three clay specimens were collected: two from Gwalior and one from Morena. The soil samples were collected from sites where rural roads are proposed to be constructed in future. The Sieve analysis was first carried out on these soils were carried out to determine their index properties The results of Sieve analysis are tabulated in Table 1 to 3.

IS Sieve No.	Wt. Retained in gm	% Wt. Retained in gm	Cum. % Wt. Retained in gm	% Wt passing
4.75 mm	0	0	0	100
2.00 mm	0	0	0	100
850 µm	2	0.4	0.4	99.6
600 µm	1	0.2	0.6	99.4
425 µm	2	0.4	1	99
150 µm	4	0.8	1.8	98.2
75 µm	110	22	23.8	76.2
Pan	381	76.2	100	0

Table 1: Grain Size Distribution of soil A

IS Sieve No.	Wt. Retained in gm	% Wt. Retained in gm	Cum. % Wt. Retained in gm	% Wt passing
4.75 mm	9	1.8	1.8	98.2
2.00 mm	8	1.6	3.4	96.6
850 µm	7	1.4	4.8	95.2
600 µm	6	1.2	6	94
425 µm	2	0.4	6.4	93.6
150 µm	11	2.2	8.6	91.4
75 µm	23	4.6	13.2	86.8
Pan	434	86.8	100	0

Table 2: Grain Size Distribution of soil B

IS Seive No.	Wt. Retained in gm	% Wt. Retained in gm	Cum. % Wt. Retained in gm	% Wt passing
4.75 mm	18	3.6	3.6	96.4
2.36 mm	17	3.4	7	93
1.18 mm	15	3	10	90
425 µm	12	2.4	12.4	87.6
300 µm	3	0.6	13	87
150 µm	22	4.4	17.4	82.6
75 µm	42	8.4	25.8	74.2
Pan	371	74.2	100	0

Table 3: Grain size distribution of soil C

Based on above all the three soil samples come under broad categories of fine grained soils. Next the liquid limit and plastic limit tests were carried out. The results are tabulated in Table 4.

Soil type	Soil A	Soil B	Soil C
Liquid limits, (%)	31	40	52
Plastic limits, (%)	20	22	25
Plasticity index, (%)	11	18	27
Soil classification, (USCS)	CL-CI	CI	CH

Table 4: Liquid Limit and Plastic Limit of Collected Soils

After finding the plastic limit, liquid limit test for all the three type of soils the plasticity index was calculated and the three soils were plotted on plasticity chart as shown in Figure 3.

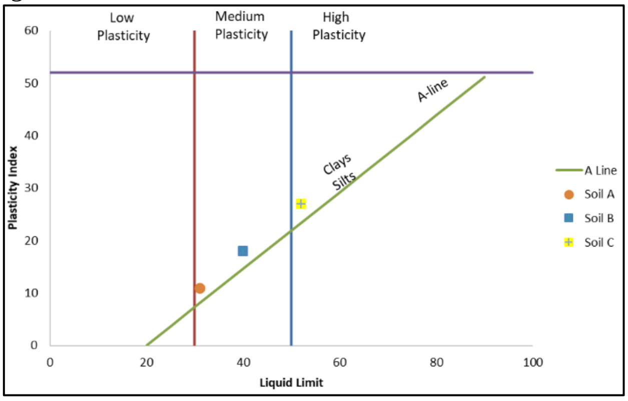

Fig. 3: Plasticity Chart

The chart reveals that soil A is having low plasticity as compared to other two types. In fact the soil almost falls on the line dividing the clay of low plasticity and intermediate plasticity. The Soil B may be classified as clay of intermediate of plasticity while the Soil C is clay of high plasticity. Specific gravity tests of the original Soil A, B and C was performed using pycnometer. The specific gravity of the Soil A, B and C was 2.77, 2.75 and 2.73 respectively. Thus it has been observed that there is no significant difference in specie gravity values of the three types of soil taken for investigation.

A. *Polymer used*

A commercial product of Acrylic Polymer was used, which is an emulsion synthetic elastic chemical substance that increases the bound with the substrate as additive in optimum moisture as well as the cohesion and the strength. Some important properties were given in Table 5 below:

Properties	Specification	Results
ppearance		Milky white liquid
Adhesion strength to concrete, N/mm2	BS 6310 Part 4:1984	38
Pot life, mins		60
Solid Content, %		47±2
Compressive Strength. N/mm2	BS 6310 Part 4:1983	10-13 at 7 days
Chloride content		Nil
PH		7.7

Table 5: Physicochemical Properties of As-Received Emulsion

The comprehensive listing of values of OMC and MDD for all the three types of soils soil A, soil B and soil C is shown in tables.6 and 7.

S.No.	Polymer (%)	Soil A	Soil B	Soil C
1	0%	17.40	17.25	15.95
2	2%	17.65	17.35	16.30
3	3%	17.88	17.55	16.70
4	4%	18.10	17.56	16.65
5	5%	17.80	17.50	16.35

Table 6: Comprehensive MDD (KN/m3) Values for Different Amount of Polymer

S.No.	Polymer (%)	Soil A	Soil B	Soil C
1	0%	13.8	14.2	17.7
2	2%	13.5	14.1	16.8
3	3%	13.1	13.9	15.8
4	4%	13.1	13.8	15.7
5	5%	12.9	14.0	16.2

Table 7: Comprehensive OMC (%) values for different amount of polymer

The plots of variations in OMC and MDD as listed in above tables have been shown in Figures 4 and 5.

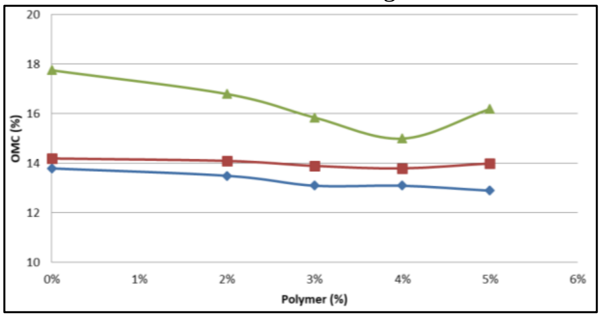

Fig. 4: Variation in OMC with Polymer Content

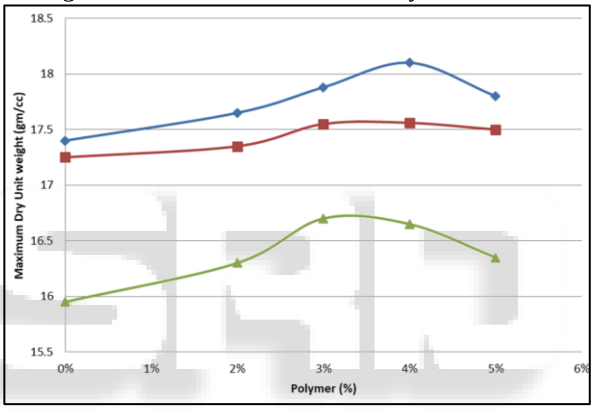

Fig. 5: Variation in MDD with Polymer Content

VI. CONCLUSIONS

It is clear from above plots that MDD increase while OMC decreases slightly with the increase in the amount of polymer. This increase in MDD and decrease in OMC is very marginal and can be ignored for all practical purposes. It may thus conclude that there was no significant change in OMC and MDD value with the addition of polymer. The similar trend was also observed by other researcher (Kolay, Dhakal, Kumar and Puri-2016). The literature also suggests no significant change in the liquid limit and plastic limit value with the addition of polymer [Onyejekwe and Ghataora-2015], [Kolay, Dhakal, Kumar, Vijay K. Puri-2016]. Thus no further liquid limit and plastic limit tests were performed with the addition of different percentages of polymer. Other conclusions from tests not reported in this paper due to space limitations are:

– There was a significant increase in UCS strength of all the three types of soils. The soil having lesser plasticity index has shown more increase in UCS as compared to soil having greater plasticity index. The optimum dose of polymer for all the three soils was around 4 %.

- There is appreciable increase in CBR value with the addition of polymer for all the three soils. The optimum dose of polymer was found around 3 %.
- Thus the overall performance of the clayey soils is increased by polymer addition in the range of 3 to 4 %.
- Marginal to no change was observed in the value of Liquid limit, Plastic limit and optimum moisture content.

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