Effect of Polymer Treatment on the Plastic Limits of Clay Soils

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Abstract: In this study clay soils with the plastic limit range of 18% to36% were treated with water soluble polymer (acrylamide) to investigate the effect on the changes in the plastic limit. Both field soils (total of 7) and a commercially available soil (kaolinite) were tested in this study. In this investigation 2.25% and 4.5% of polymers (by the weight of solids in the soil) were used to treat the moist field clay soils. The treated field soils and kaolinite were tested for the changes in the plastic limits 24 hours after polymer treatment, considered to be a rapid treatment compared to the other conventional methods. The plastic limits of the soils of the treated soils increased by 1% to 3% based on the soil and amount of polymer used. Compared to the 2.25% polymer treatment, 4.5% polymer treatment showed greater increase in the plastic limits of all the soils tested.

1. Introduction:

Depending on its water content, a soil may appear in one of four states: solid, semi-solid, plastic and liquid. The water content at which the soils change from one state to the other are known as consistency limits or Atterberg's limit. These limits were created by Albert Atterberg, a Swedish chemist and agronomist in 1911. They were later refined by Arthur Casagrande, an Austrian-born American geotechnical engineer and close collaborator of Karl Terzaghi.

Clay soils are encountered in all types of surface and underground constructions. Based on the geological formation, the clay soils have highly varying short-term (shrinkage, swelling, strength) and long-term properties such as consolidation with fluctuating shrinkage, swelling and strength that will influence the construction and durability of the long-term stability of the supporting structures and pipelines. Clay soils cover one-fourth of the surface area of the United States and are found in every state (Jones et al., 1987). Compared to other natural disasters and damages due to clay soils is probably the least publicized natural hazard. The expansive clay soils alone inflict at least $2.3 billion per year in damages to houses, buildings, roads, and pipelines. Also it has been reported that damages from expansive soils are more than twice that which is caused by floods, tornadoes, and earthquakes (Jones et al., 1987).

Clay soils cause problems in certain areas with repeated periods of rainfalls and droughts. Expansion of clays in the presence of moisture is a problem that causes extensive damages to physical infrastructure, such as dams, irrigation canals and roads (Inyang et al., 2007). Wet and dry cycles in clayey soils would cause volumetric changes which may result in considerable damage to the surrounding structures. To overcome the swelling problems caused by expansive soils, many innovative techniques such as stabilization by chemical additives, pre-wetting, squeezing control, overloading, and moisture control have been suggested (Al-Rawas et al., 2005). Stabilization of these problematic soils by employing a suitable additive is one of the preferred techniques of dealing with such soils (Inyang et al., 2007; Vipulanandan et al. 2016, 2020).

As such, a variety of additives, which are being employed to stabilize the expansive soils for some time, can broadly be classified into three main categories: cementitious, non-cementitious and chemical additives. Many studies have shown that addition of lime increases optimum water content, shrinkage limit, shear strength, and reduces maximum dry density, swelling potential, liquid limit, and plasticity index of the soil (Bell et al., 1996; Al-Rawas et al., 2005). Although, lime stabilization is well suited for almost any

type of expansive soil and is economically available additive, constructability issues and long-term durability issues often make its usage not feasible for all conditions. In addition, effective lime-soil reaction demands elevated temperature that is greater than 40°F. Below this temperature, lime usually remains in a dormant state and does not initiate the reaction (Reddy et al., 2015). A new method of stabilization has been developed using water soluble acrylamide polymer (Mohammed et al. 2014; Vipulanandan et al. 2016, 2020) which was found to be effective, economical and time saving.

2. Objectives:

Overall object was to investigate rapidly treating CL and CH soils using polymer solutions to change the plastic limits of the field clay soils and compare it to commercially available kaolinite clay.

3. Materials and Method:

The moist field soils were treated with 2.25% and 4.5% polymer (based on the weight of solids in the soil). The clays used for the study included kaolinite and field soils. To examine the range of application of the proposed polymer treatment required testing of soils representing a wide range of liquid limit.

Plastic Limit: The liquid limit test on the commercial and field soils were performed using the ASTM D4318-17 before and after treatment.

Polymer: The acrylamide polymer had two solutions, A and B, to polymerize the product. Solution A was acrylamide monomer with triethanolamine (accelerator/promotor) in water and Solution B was ammonium persulfate (initiator/catalyst) in water (Table 1). When 15% polymer solution was used in varying amounts, 15% and 20% by the weight of solids in the soil, it represented polymer addition of 2.25% (Mix C) and 4.5% (Mix D) of polymer addition respectively.

Table 1 Compositions of 15% Polymer Solutions

Polymer Solution	SOLUTION A (50 g)			SOLUTION B (50 g)		Remarks
	Monomer AV 100 (g)	Accelerator AV101 (g)	Water (g)	Initiator AV102 (g)	Water (g)	
15%	15	0.2	34.8	0.5	49.5	Solutions A and B were used separately to treat the soils

15% polymer solution: In this mix solution A was mixed with solution B and the polymer content (monomer) was 15% by weight. The setting time of the polymer was 840 sec (14 min). In order to investigate the effect of this polymer solution, two percentages (based on the weight) were used with respect to the solid content in the soil. When 15% (by weight) of the polymer solution was used to treat the soil, it amounted to addition of 2.25% of polymer (by weight) to the soil (Mix C). When 30% (by weight) of the polymer solution was used to treat the soil, it amounted to addition of 4.5% of polymer (by weight) to the soil (Mix D). In this study, solution A was first added to the soil and mixed thoroughly. Later, solution B was added, and it had higher amount of water compared to solution A, to ensure better mixing (workability) and effective distribution of the additive in the soil.

3.2 Methods of Testing

Mixing polymer with kaolinite clay: Solution A was introduced into the soil and mixed homogeneously using a spatula, for a time period of 15 min to ensure uniform distribution. Later, solution B was poured into the sample and ensured that it is distributed and results in polymerizing the soil. The

sample was left for a curing period of 24 hours to ensure effective polymerization and then was used for the proposed methods of testing.

Mixing polymer with field clay:

The field soil samples were broken down into small lumps to ensure uniform distribution of the polymer components when mixed. Solution A and solution B were added with a time lapse of 15 min and a suitable polymerization time was selected to improve the efficiency of mixing and polymerization. After 24 hours of curing the liquid limit tests were performed.

Concentration and Dosage of Polymer

Various combinations of polymer concentration and dosage have been used and the study was narrowed those which proved to treat the problem of this study effectively. The details have been summarized in Table 2.

Table 2 Concentration and dosage of polymer

Mixes	**Concentration (X%) Of polymer solution** (X g of polymer in 100 mL of water)	**Solution Amount (Y%)** (Y g of polymer solution mixed to 100 g of solids)	**Polymer Dosage (Z%)** (Z g of pure polymer added to 100 g of solids)
Mix C	15 %	15	2.25
Mix D	15 %	30	4.5

4. Results and Discussion

Kaolinite: The liquid limit was 48%, a CL soil.

Field Clay Soils: Total of 7 field clay soils were tested. The Plastic limits varied from 18.0% to 35.9% (Table 3). The natural moisture contents in the soils varied from 17% to 28%.

Polymer Treatment: After treatment with 2.25% and 4.5% pure polymer dosage to the weight of solids, the plastic limits increased (percentage based on the initial PL) by 1.6% to 14% based on the soil and amount of polymer and the results are summarized in Table 3. With 2.25% polymer treatment the plastic limit increased varied from 1.6 % to 6.7%. With 4.5% polymer treatment the liquid limit reduction varied from 4.7 % to 14.4%. The, kaolinite showed an increase in plastic limit from 32% to 34% and 36.5%, change of 6.3% and 14.1% with dosage of 2.25% and 4.5% polymer respectively.

Table 3 Changes in Plastic Limit (PL) for Polymer Treated Clay Soils

Sample No.	**Polymer Content**						
	0%	**2.25%**			**4.50%**		
	PL	**PL**	**Change in PL**	**% Change**	**PL**	**Change in PL**	**% Change**
1 (CL)	18.0	19.2	1.2	6.7%	20.6	2.6	14.4%
2 (CL)	20.3	20.9	0.6	3.0%	21.6	1.3	6.4%
3 (CH)	23.9	24.9	1.0	4.2%	26.1	2.2	9.2%
4 (CH)	25.8	26.2	0.4	1.6%	27	1.2	4.7%
5 (CH)	28.6	30.4	1.8	6.3%	31.6	3.0	10.5%
6 (CH)	30.1	31.6	1.5	5.0%	32.8	2.7	9.0%
7 (CH)	35.9	37.2	1.3	3.6%	38.7	2.8	7.8%
Kaolinite	32.0	34	2.0	6.3%	36.5	4.5	14.1%

5. Conclusions

After 2.25% and 4.5% polymer treatment, the plastic limit (PL) of the clay soils increase. The following conclusions are advanced:

(1) Polymer treatment was effective 24 hours after treatment and increased the plastic limits of the field clay soils treated with the natural moisture contents.

(2) Amount of increase in the liquid limit varied with the initial plastic limit of the clay soils and the amount of polymer used for treatment. With 2.25% polymer treatment the plastic limit limit increase varied from 1.6 % to 6.7% for the field clay soils. With 4.5% polymer treatment the plastic limit increase varied from 4.7 % to 14.4% for the field clay soils.

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7. References

1. Al-Rawas, A. A., Hago, A. W. and Al-Sarmi, H. (2005). Effect of lime, cement and Sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman. Building and Environment, 40(5), 681-687.
2. Bell, F. G. (1996). Lime stabilization of clay minerals and soils. Engineering geology, 42(4), 223-237.
3. Inyang, H. I., Bae, S., Mbamalu, G. and Park, S. W. (2007). Aqueous polymer effects on volumetric swelling of Na-montmorillonite. Journal of Materials in Civil Engineering, 19(1), 84-90.
4. Jones, D. E., and Jones, K. A. (1987). Treating expansive soils. Civil Engineering-ASCE, 57(8), 62-65.
5. Mohammed, A. S. and Vipulanandan, C. (2014). Compressive and tensile behavior of polymer treated sulfate contaminated CL soil. Geotechnical and Geological Engineering, 32(1), 71-83.
6. Reddy, N. G., Tahasildar, J., and Rao, B. H. (2015). Evaluating the influence of additives on swelling characteristics of expansive soils. International Journal of Geosynthetics and Ground Engineering, 1(1), Article No. 7, https://doi.org/10.1007/s40891-015-0010-x
7. Vipulanandan, C., and Mohammed, A. (2016). XRD and TGA, Swelling and Compacted Properties of Polymer Treated Sulfate Contaminated CL Soil. ASTM Journal of Testing and Evaluation, 44(6) No. 6, pp. 1-16.
8. Vipulanandan, C. and Mohammed, A. (2020), Characterizing the Index Properties, Free Swelling, Stress-Strain Relationship, Strength and Compacted Properties of Polymer Treated Expansive CH Clay Soil Using Vipulanandan Models, Geotechnical and Geological Engineering, Volume: 38 Issue: 5, pp. 5589-5602.