Study of Expansive Soil Stabilization by Polymers

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1. Abstract: This review study was on evaluating the effects of various polymer treatments on expansive clay soils. The polymers that were used for treating clay soils were polymer vinyl copolymers, polypropylene homopolymer, Urea Formaldehyde and Melamine Formaldehyde. The clay liquid limits varied from 50% to 96%. Amount of polymer used varied from 3% to 10% based weight of the solids in the soil. Addition of polymer changed the liquid limit and plastic limits of the soils.

2. Introduction

Soil stabilization technology is extremely important in road construction industry. It can be adopted in the construction of roads to utilize the locally available soil resource effectively. Expansive soil is prone to large volume changes when soil experiences change in water content. Expansive soil is subjected to physical and chemical treatments to improve soil properties. For any expansive soil – stabilizer Mixture, the mechanical properties such as resilient modulus and plastic deformation potential needs to be improved (Petry & Little, 2002). Shrinkage problem in stabilization and its propagation to asphalt layer needs to be considered a as key issue while selecting any stabilizing agent for the subbase materials under supporting the pavements (Petry & Little, 2002).

3. Objective

The objective was to summarize the effects of adding polymers to stabilize the expansive clay soils based on literature reviews.

4. Literature Review

Study 1: From a study, four different polymer vinyl copolymers were used with expansive soil in 55.0% (Polymer 1 - P1), 57.5% (Polymer 2 - P2), 57.5% (Polymer 3 - P3), and 37.0% (Polymer 4 - P4) percentage of polymer solids, respectively. Based on FHWA-RD-77-94 the soil was classified as High swell classification expansive soil. For this study, high expansive soil was prepared using a local clay from Fort Collins, USA, having a liquid limit (LL) of 31.0% and plasticity limit (PL) of 18.1%, mixed with 15% (dry mass basis) Natural Sodium Bentonite of LL 420.0% and PL 381%. These polymers were compared with traditional lime and Class C fly ash. The swell mitigation from different stabilizers was assessed using one dimensional swelling test (ASTM D4546-14 - ASTM 2014), unconfined compressive test (ASTM D5102-09- ASTM-2009) and hydraulic conductivity (ASTM D5084-16a -ASTM 2016). For an initial Swelling test, dry soil sample was mixed with 5% polymers and 24 hours curing was allowed at 20 ˚C. From the results of Swelling test, swelling potential was identified as 8.7, 8.0, 7.9, and 4.7% for P1, P2, P3 and P4 polymers, respectively. Thus, for further investigations P4 polymer was selected. Lime, fly ash and polymer treated samples were cured for 7 days at 40˚C and 1 day at 20 ˚C.
Table 1 shows the properties of base, expansive, lime, fly ash, P4 polymer treated soil. Reduction in liquid limit and plastic limit was achieved in 5% P4 polymer.

Table 1 Properties of untreated and treated soil (Scalia , Taher, & Bareither, 2020)

	Base Soil	Expansive Soil (15% Bentonite Added)	3% Lime Treated Soil	15% Fly ash Treated Soil	5% P4 Polymer Treated Soil
Liquid Limit	31.0 %	75.8%	50.5	56.4	70.3%
Plastic Limit	18.1 %	17.7%	32.6	17.6	19.5%
Plasticity Index	12.9%	58.1%	17.9%	38.8%	50.8%

Swell potential was 14.9% and 4.5% for untreated and P4-polymer treated soil, respectively. Swell pressure was 139.0 kPa and 120 kPa for untreated and P4-polymer treated soil, respectively. But for lime and fly ash treated soil, the swell potential and swell pressure are less than 1% and less than 35 kPa respectively. Unconfined Compressive Strength of lime, fly ash and P4 polymer treated soil (for 7 days of curing at 40˚C and 24 hours soaking) were 1260 kPa, 382 kPa and 46 kPa respectively. Hydraulic Conductivity of lime, fly ash, P4 polymer treated soil and untreated soil were 1.5×10^{-6} and 3.1×10^{-8} m/s, 6×10^{-11} and 2.9×10^{-11} respectively.

It was found that vinyl copolymer increased the unconfined compressive strength and hydraulic conductivity while reducing the swell potential and swell pressure of the polymer modified expansive soil (Scalia , Taher, & Bareither, 2020).

Study 2: In a study by Azzam (2014), polypropylene homopolymer (H030SG) was used as a stabilizing agent. Clay soil samples were collected from Egypt with LL of 48-50% and plasticity index (PI) of 23-27%. Based on Unified Soil Classification System (USCS), the clay sample was classified as CH type. Samples were prepared by mixing the polymer with oven dried sample in the percentages of 0%, 3%, 6% and 10% and Protector compaction test was carried out according to ASTM (D-1557). It was found that with the increase of polymer, the maximum dry density was increased from 16.9 kN/m^3 to 17.2 kN/m^3 to non-stabilized soil and 10% polymer content treated soil, respectively. The optimum moisture content was reduced from 6.1% to 5.5% to non-stabilized soil and 10% polymer content treated soil, respectively. The Oven dried soil mixed with 0%, 3%, 6% and 10% and Atterberg Limit Test was carried out. The Table 2 shows the changes in Liquid Limit, Plastic Limit and Plasticity Index with different percentages of polymers. It can be clearly seen that, with the addition of polymer the liquid limit, plastic limit and plasticity index were reduced.

Table 2 Changes of Liquid Limit, Plastic Limit and Plasticity Index with addition of Polymer (Azzam, 2014)

Polymer Content	Liquid Limit LL%	Plastic Limit LL%	Plasticity Index PI %
0	50	23	27
3	46	20	26
6	38	17	21
10	33	14	19

Unconfined compression test and odometer cell was used to analyze the compressibility and mechanical characteristics of stabilized samples. The Compression Index for the sample was obtained as 0.24, 0.172, 0.132, 0.12 for 0%, 3%, 6% and 10% polymer treated soil sample, respectively. The swelling index for the non-stabilized sample and for 10% polymer content treated sample were 0.052 and 0.001, respectively. The hydraulic conductivity of the non-stabilized soil and 10% polymer content soil sample were found as 5×10^{-5} m/s and 16×10^{-7} m/s, respectively.
From the study, it was found that polymers can generate nano-composite soil structure thus strength and the resistant to volume change can be improved. Further, clay stiffness of the nano-composite increased and compression index and plasticity index reduced.

Study 3: In another research by Yazdandoust & Yasrobi (2010,) the influence of cyclic wetting and drying on expansive soil was studied. Soil samples were collected from Tehran, Iran. According to USCS, the soil was classified as Inorganic Clay of High Plasticity (CH). For the study three soil groups with a LL of 65 and PI of 41 (Group 1 - G1), LL of 71 and PI of 48 Group 2 – G2) and LL of 96 and PI of 67 (Group 3 - G3) and two polymers, Urea Formaldehyde and Melamine Formaldehyde were used. Urea Formaldehyde was mixed in in the propotion of 3% (Polimer 1 - P1) and 5% (Polimer 2 - P2) by the dry soil mass and Melamine Formaldehyde was mixed in propotion of 5% (Polimer 3 - P3) by dry soil mass. For the sample preparation, dry soil was taken and mixed with polymer and water to obtain the predetermined level of water content in the mix. Swelling test was conducted accoding to ASTM D4546 Standard. Table 3 shows the swelling potential of different types of soil and polymer mixes. It can be seen that compared to untreated G1, G2, G3 soil, swelling potential of treated soil mix are lesser. Swelling potential of 3% Urea Formaldehyde treated soil was lowest compared to any other mixes.

Table 3 Swelling Potential After 1st and 6th Cycle (Yazdandoust & Yasrobi, 2010)

Soil Type	G1	G1-P1	G1-P2	G3-P3	G2	G2-P1	G2-P2	G2-P3	G3	G3-P1	G3-P2	G3-P3
Swelling Potential After 1st Cycle	11%	4.1 %	2.2 %	4.1 %	16.1 %	6%	4.2 %	7%	22%	12%	10%	8%
Swelling Potential After 6th Cycle	5%	1.0 %	0.4 %	1.8 %	5.2 %	1%	0.5 %	1%	10%	5.5 %	4%	5%

From the results of cyclic swelling pressure tests of group 1 soil, the untreated soil and 5% Urea Formaldehyde treated soil swelling pressure were identified as 66 kPa and 24 kPa. From the studies, it was concluded that, compared to unstabilized soil, the swelling potential and swelling pressure reduced for soil stabilized with the polymers.

5. Discussion

The literatue review is based on using different polymers to treat the expansive clays. The polymer treatment reduced the liquid limit and plasticity idex of the clay soils.

6. Conclusions

Based on the limited literature review following conclusions are advanced:

(1) For vinyl copolymers polymer, liquid limits and plasticity index were reduced by 7.25 % and 12.56% compared to the liquid limit of 75.8% and plasticity index 58.1% of the untreated expansive soil. For polypropylene homopolymer, maximum liquid limit and plasticity index reduction were achieved to 10% polymer treated soil, where liquid limit was reduced by 34% compared to the expansive soil liquid limit 50% and plasticity index was reduced by 29.62% compared to the expansive soil plasticity index 27%.

(2) Swell potential and swell pressure were reduced by 69.79% and 13.66% for vinyl copolymers polymer compared to the untreated soil. Hydraulic Conductivity of the vinyl copolymers polymer treated soil is 2 times of the untreated soil. Compression Index and Swelling Index were reduced from 0.24 to 0.12 and 0.052 to 0.001 respectively while treating with 10% polypropylene homopolymer. Hydraulic Conductivity of the 10% polypropylene homopolymer treated soil reduced from $5 \times 10-5$ m/s to $16 \times 10-7$ m/s compared to untreated soil.

(3) Swelling potential of 3% and 5% of Urea Formaldehyde and 5% Melamine Formaldehyde were reduced compared to untreated soil samples. Lowest swelling potential was achieved for 3% Urea Formaldehyde treated soil. Swelling pressure of the 5% Urea Formaldehyde treated soil was reduced by 63.6% of untreated soil swelling pressure of 66 kPa.

7. Acknowledgement

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8. References

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