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EXPANSIVE CLAYEY SOIL IMPROVEMENT USING POLYETHYLENE HIGH DENSITY POLYMER

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ABSTRACT

Some clayey soils are generally classified as expansive soils which cause extensive damage to civil engineering structures. Expansive clays often vary in density and moisture content from the wet season to the dry season. For example, near-or at-surface, clays often dry out during periods of drought but then expand during the rainy season or when irrigation water or water from leaky pipes wets them. Soil improvement has been widely used as an alternative to substitute the lack of suitable material on site. In this study the effect of using non-traditional chemical stabilizers in soil improvement is investigated. Various tests are performed to study the effect of using different percentages of polyethylene high density polymer (6%, 9%, and 12%) as a stabilizing agent on both structure and geotechnical clay properties. The laboratory tests include sieve analysis, hydrometer, Atterberg limits, modified compaction, swelling potential and swelling pressure, unconfined compression strength, consolidation test and California bearing ratio (CBR) test. The results indicated that the polymer significantly improved physical properties of expansive clay soil which have susceptibility of swelling.

Keywords: expansive clay, polymer stabilization, PEHD polymer, geotechnical properties.

1. INTRODUCTION

Expansive soils or swelling clays are mostly found in arid and semiarid regions of the world. For all engineering structures constructed on clayey soils, these soils create swelling when they are exposed to water and shrink once water is squeezed out. These volumetric changes cause considerable failure to the foundation and damage to the civil infrastructure; these types of structure which are damaged are foundations, retaining walls, pavements, airports, sidewalks, canal beds, and linings. The types of problems that have caused the damage are cracks above doors and windows, pavement cracking, and heaving of floors. The cost of repair the damage caused by expansive soils to civil engineering structures is estimated many billions of dollars worldwide (1).

Many plastic clays swell considerably when water is added to them and then shrink with the loss of water. Foundations constructed on such clays are subjected to large uplifting forces caused by the swelling. So, these forces induce heaving, cracking, and the breakup of both building foundations and slab-on-grade members. In general, expansive clays have liquid limits and plasticity indices greater than about 40 and 15, respectively. In addition, these clayey soils contain clay minerals that have the potential for swelling and shrinkage under changing moisture contents (2).

There are many methods of stabilizing soil to gain required engineering specifications. These methods range from mechanical to chemical stabilization. Most of these methods are relatively expensive to be implemented by slowly developing nations and the best way is to use locally available materials with relatively cheap costs affordable by their internal funds (3). Polymer stabilization is a new stabilizing agent developed to improve the mechanical performance and applicability of expansive clayey soils. The use of nontraditional polymer materials in soil improvement is growing daily.

In this study, a chemical method for treating the swelling of prepared expansive clayey soil is presented using Polyethylene high density polymer material (PEHD). The full experimental program is carried out for studying the effect of adding Polyethylene (PEHD) with different percentage by weight on the grain size distribution, consistency limits, specific gravity, compaction characteristics, unconfined compressive strength with curing, swelling and swelling pressure, consolidation and California Bearing Ratio values.

2. MATERIALS AND METHODS

2.1 Bentonite

The Bentonite manufactured by Turkey Co.Ltd, was used throughout this research in order to prepare the expansive soil

2.2 Clayey soil

The disturbed clay soil used in this study is brought from Sahat Al-Andalusdistrict in Baghdad at a depth of (1.5-2) m below the existing ground level. The soil used in this study was silty clay (52%clay+48%silt). Therefore, several tests were carried out in the laboratories of Civil Engineering Department of Al-Nahrain University for this soil to obtain its engineering properties.

2.3 Polyethylene (PE)

Is one of the most widely used thermoplastic polymers because of its peculiar combination of low cost, high chemical resistance, relatively good mechanical properties and hydrophobic and chemically inert nature which does not absorb or react with soil moisture or leachate.

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Polyethylene is the simplest polymer, composed of chains of repeating -CH2- units that produced by the addition polymerization of ethylene, CH2=CH2 (ethene). Thus, the properties of polyethylene depend on the manner in which ethylene is polymerized. When catalyzed by organometallic compounds at moderate pressure (15 to 30 atm), the product is high density polyethylene (HDPE). So, under these conditions the polymer chains grow to very great length and molar masses average many hundred thousand. As well, HDPE is hard, tough, and resilient (4).

2.4 Prepared expansive soil

To fulfill the research goals for characterize the effect of polymer materials on expansive soil properties and as the swell of the natural soil was obtained to be 1% and the soil is classified as CL. Thus, to investigate the polymer effect on the swelling behavior, the expansive clayey soil was prepared in laboratory by mixing 30% of bentonite with 70% of natural soil. The swell of the prepared soil was obtained to be 18 % and it is classified as CH according to Unified Classification System (UCS).

2.5 Preparation of the soil mixture for testing

The soil is first dried in the oven at 105 ˚C for 24 hours before using in the mixtures and then pulverized by Los Angeles machine. Then 70% of dried natural soil was mixed with 30% of bentonite to prepare expansive clayey soil (high plasticity index) .Polyethylene (HDPE) polymer powder as shown in Figure (1-a)is mixed thoroughly with pepared soil and with the various percentages of polymers by mixer, then the mixture was mixed carefully at each percent until a homogeneous color was obtained. Figure (1-b) showed the mixer used in the study.

(a) PEHD polymer. **(b)**Mixer used.

Figure-1. (a) PEHD polymer used in this study (b) Mixer used for preparation samples.

3. EXPERIMENTAL WORK

Classification tests [5], Atterberg limit [6], compaction test [7], chemical test inGeneral Company of Geological Survey and Mining, unconfined compression test [8], consolidation test [9] and California bearing ratio (CBR) [10] test are conducted on expansive soil and stabilized soil. Physical and chemical propertieswere conducted on natural expansive clayey soilare shown in Table-1 and Table-2 respectively and Table-3 present the chemical tests results for HDPE polymer.

Table-1. The summary of physical and classification tests for prepared expansive clayey soil.

properties	standard	Expansive soil
Sand (%)	ASTM D 422	0
Silt (%)	ASTM D 422	37
Clay (%)	ASTM D 422	63
Liquid limit	ASTM D4318	82
Plastic limit	ASTM D4318	30
Plasticity index	ASTM D4318	52
Optimum moisture content (%)	ASTM D 698	27.7
Max. dry density (kN/m^3) Specific gravity, Gs	ASTM D 698 ASTM D 854	1.49 2.68

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Table-2. Chemical tests results for prepared expansive clayey soil.

Chemical element	Percent (%)
SiO_2	58.5
Al_2O_3	14.4
CaO	8.1
MgO	3.8
Na_2O	2.2
FeO	1.7
K_2O	1.2
BaO	0.8

Table-3. Chemical tests results for PEHD polymer.

Chemical Element	Percent (%)
Na_2O	49.8
Al_2O_3	3.5
SiO_2	2.5
Nitrogen	39.7
Chlorine	4.5

4. RESULTS

Physical tests, swelling potential and swelling pressure, unconfined compression strength, consolidation and California bearing ratio (CBR) testsare conducted on expansive clayey soil and stabilized expansive soil. The following are the results of these tests:

4.1 Atterberg limits

Liquid limit tests are carried out using the Casagrande method according to [6] and then the plastic limits were obtained for the soil samples. In Table-4 it can be noticed thatthe liquid limit (LL) values decreased due to the addition of PEHD and the lowest value occurs in the percentage of 6%, after this percentage it begins to slightly increase, this may be attributed to the activity of polyethylene polymer which may become more active at this percentage of PEHD and from the results it has been indicated that plasticity index (PI) decreased with increasing PEHD content, while plastic limit (PL) increases with increasing amount of PEHD polymer. The maximum increase in plastic limit and decrease in plasticity index is found with the addition of 12% PEHD these additions increased the plastic limit (PL) by 47.4% and (PI) by 28.6% as shown in Table-4. Figure-2 shows the effect of PEHD polymer on plasticity index of stabilized soil.

Table-4. Results of expansive soil Atterberg limits.

Property	Prepared expansive soil	Treated soil with 6% PEHD polymer	Treated soil with 9% PEHD polymer	Treated soil with 12% PEHD polymer
Liquid limit (%)	82	71.8	73.4	76.0
Plastic limit (%)	30	36.4	41.3	47.4
Plasticity index (%)	52	35.4	32.1	28.6

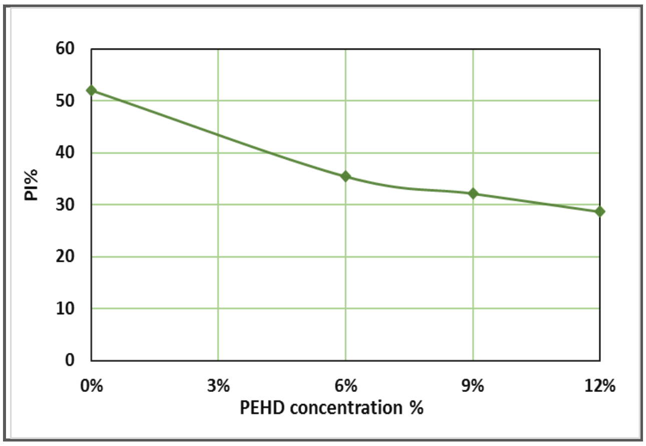

Figure-2. The effect of adding PEHD on plasticity index of stabilized soil.

4.2 Compaction test

Standard compaction test were carried out on the soil using hammer of 2.5 kg, drop of 350 mm and mold of 105 mm in diameter and 115.5 mm in height, with three layers of soil and 25 blows according to [7]. The test was carried out on prepared expansive soil and stabilized soil samples. The compaction curves are plotted in Figure-3 and the values of optimum water content and maximum dry unit weight determined for different percentages of polymer-clayey soil mixtures are summarized in Table-5. The maximum dry density has been slightly reduced whereas optimum water content is also slightly decreased by inclusion PEHD polymer, this can be attributed to the reduction of average unit weight of solids in the soil-PEHD mixture.

Table-5. Results ofexpansive soil compaction test.

Property	Prepared expansive soil	Treated soil With 6% PEHD polymer	Treated soil with 9% PEHD polymer	Treated soil with 12% PEHD polymer
Max. dry density (g/cm^3)	1.49	1.46	1.43	1.4
Optimum moisture content %	27.7	26.8	26	25

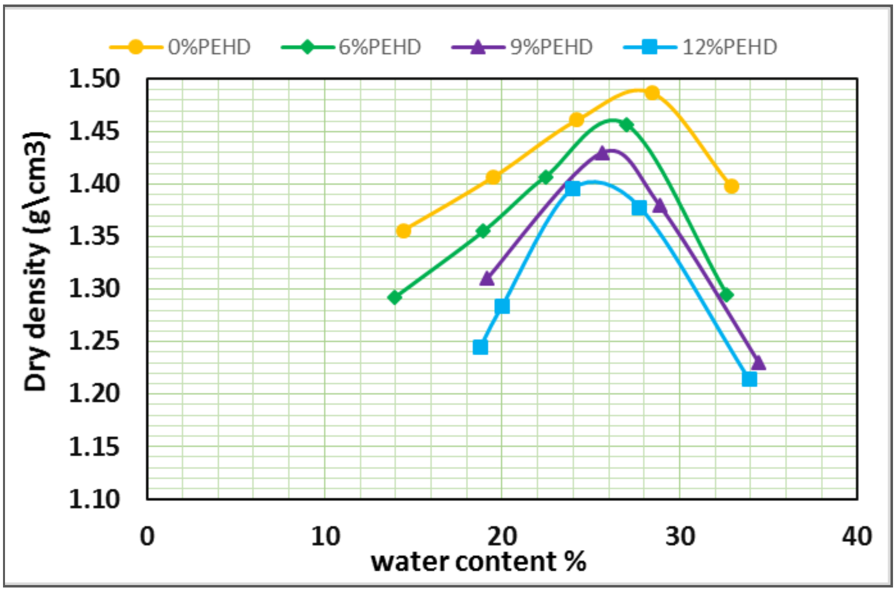

Figure-3. The effect of adding PEHD on dry density-water content relationship.

4.3 Swelling and swelling pressure test

The values of swelling of the prepared clayey soil and polymer soil composites are shown in Figure (4-a), as it can be seen from the results, the addition of PEHD decreased the swelling of clayey soil–polymer mixtures. The free swell decreased from 18% to 2.3% by adding 12% PEHD polymer. Thus, addition of PEHD polymer would decrease the permeability of expansive clayey soil. So, that material property is found to be improved the swell by inclusion of polymer, then swelling has to be controlled by inclusion of these filler polymer in soil matrix [11].In general the swelling pressure values decreased with increasing PEHD polymer percentage. Figures (4-b) indicate that the lowest values were reached at 12% PEHD contents, with the addition of PEHD polymer, the swelling pressure of stabilized samples containing 12% decreased from an initial value of 280.112 kPa for the prepared expansive clayey soil to 18.88 kPa for the treated soil sample.

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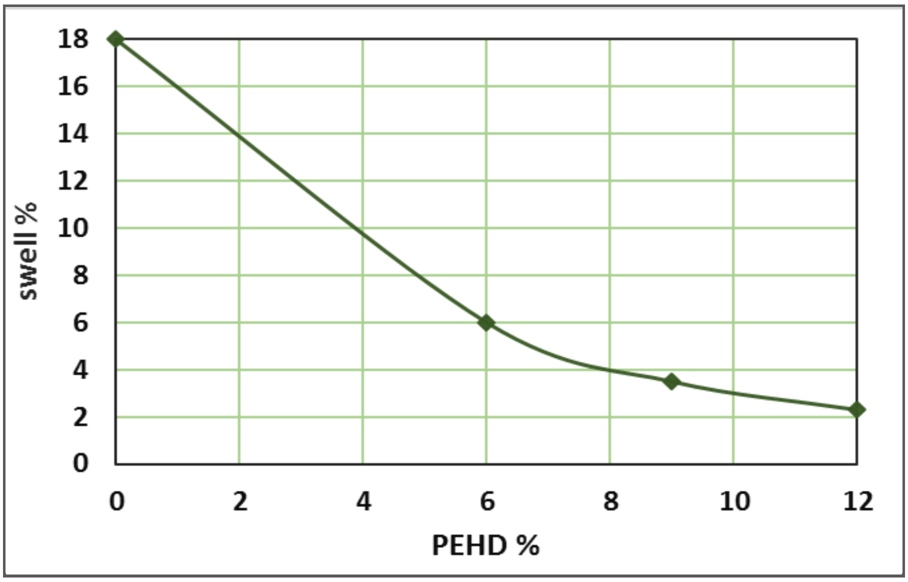
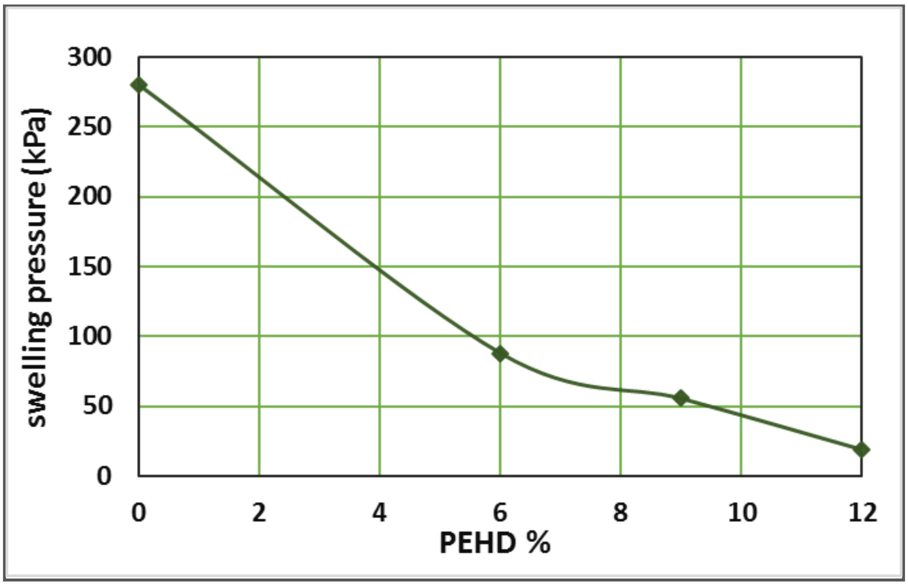


(a)Swell % of stabilized soil



(b)Swelling pressure of stabilized soil

Figure-4. The effect of adding different percentages of polymer on (a) swell for stabilized soil (b) swell pressure for stabilized soil.

4.4 Unconfined compression test

Unconfined compressive strength tests were conducted according to [8] on samples of prepared expansive soil and stabilized soil with the different content of PEHD polymer at different curing intervals of 7 and 21 days and the same tests on these soils were conducted on samples at zero days are shown in Figures (5a,b and c). It is observed that the increase in PEHD content significantly increase the unconfined compressive strength while the curing period are slightly effect on the unconfined compressive strength. The maximum percent for PEHD that achieves the maximum strength was obtained to be 12% for 7 days and 21 days which increased the UCS up to 416.22 kPa and 424.3kPa respectively. It is observed that the induced PEHD led to a significant increase in unconfined compressive strength and this justified the formation of filler composites through the void which acted as a hydrophobic material that are main features of polymer. Thus, PEHD polymer has effect on reducing the inter-assembling pores and increasing the vertical effective yield stress and decreasing the compressibility characteristics of the treated samples [12].

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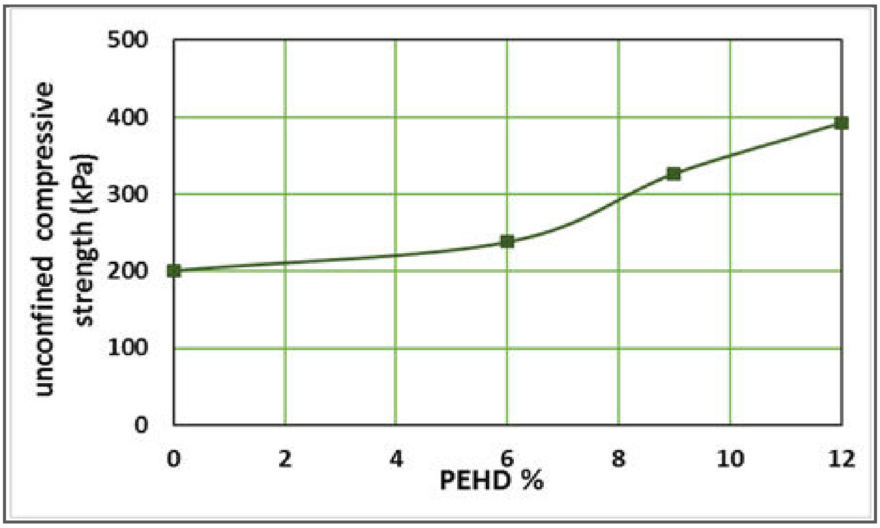
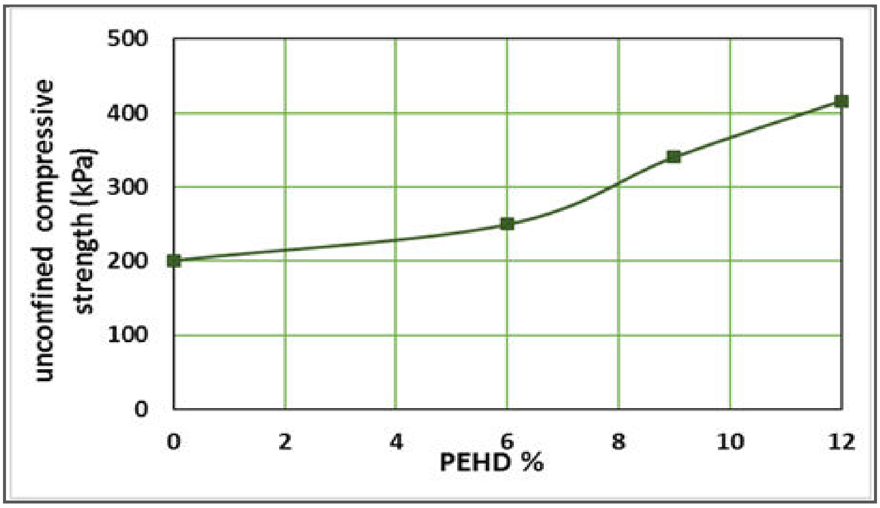
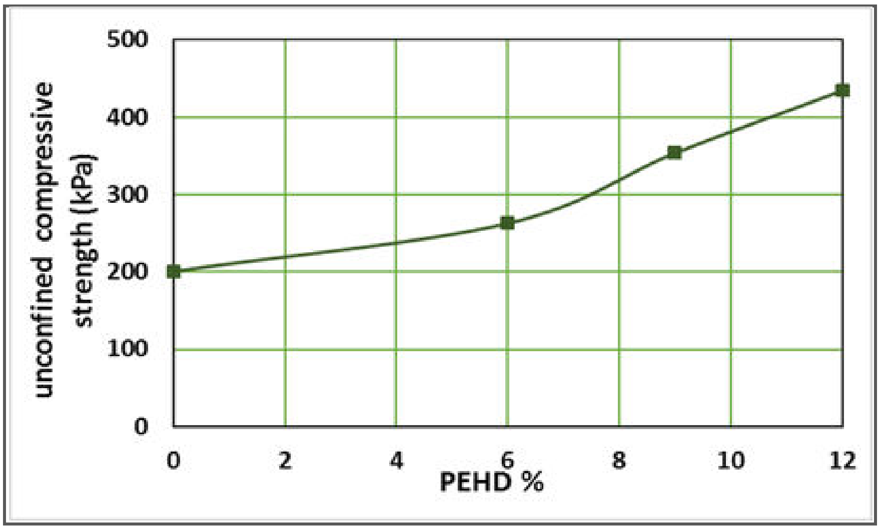


(a) USC for stabilized soil at zero curing period



(b) USC for stabilizedsoil at 7 days curing period



(c): USC for stabilizedsoil at 21 days curing period

Figures-5. The effect of different percentages of polymer on UCS (Kpa) at (a) zero days curing period (b) 7 days curing period (c) 21 days curing period.

4.5 Consolidation test

These tests are conducted to study the compressibility of prepared expansive clayey soil and stabilized soil with various content of polymer by determining the compression parameters (compression index C_c, swelling index $C_s$and coefficient of consolidationCv).

4.5.1 Effect of polymer content on compression index (C_c), swelling index (C_s) and coefficient of consolidation $_{(Cv)}$

The compression index (Cc), swelling Index (Cr) and coefficient of consolidation (Cv) values of expansive clayey soil treated with different percentages of PEHD polymer are shown in Figure-6. The value of (Cc) decrease with the increase of addition PEHD content for up to 9% and then the (Cc) value is start to increase for 12% PEHD .This may be due to that the existence of such PEHD filler can significantly increase the clay stiffness and reduce the compression index. The swelling index value (Cr) decrease with increase of addition of PEHD content for all soil samples. This may be attributed to that the PEHD polymer acted as a hydrophobic material and then the induced filler through the voids can effectively reduce the inter-assembling voids and prevented the affectivity of the Montmorillonite for expansive soil [11]. The coefficient of consolidation (Cv) increase with increase amount of PEHD addition as shown in Figure-6.

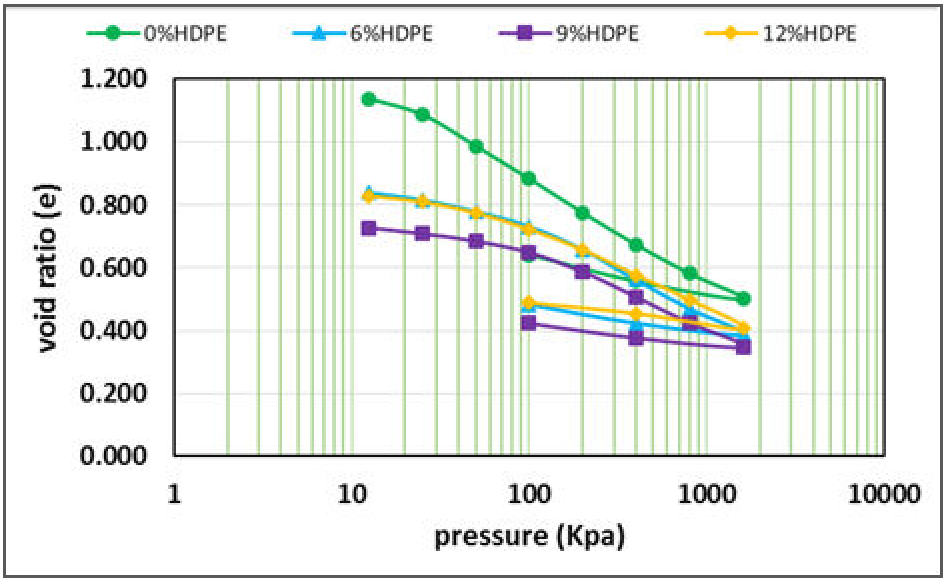


Figure-6. Consolidation test for different HDPE content.

4.6 Effect of adding PEHD polymer on California bearing ratio (CBR)

The effect of adding PEHD polymer on California Bearing Ratio (CBR) values for the expansive clayey soil is shown in Figure-7. Generally CBR value increases with increasing percentage of PEHD polymer and the results show that the addition of PEHD is effective on CBR values and the optimum addition of PEHD polymer that gives higher value of CBR is 12%. But, the increasing in PEHD polymer from 6% up to 9% gives improvement in CBR value by 38.1%, while increasing addition of PEHD from 9% to 12% is start to decrease the CBR value by 27.5%.Thus it can said that maximum improvement of CBR value of clayey soil samples has occurred at 9% PEHD content. Thus the existence of such polymer that acts as filler can significantly increase the clay stiffness and increased the strength of treated samples [13].

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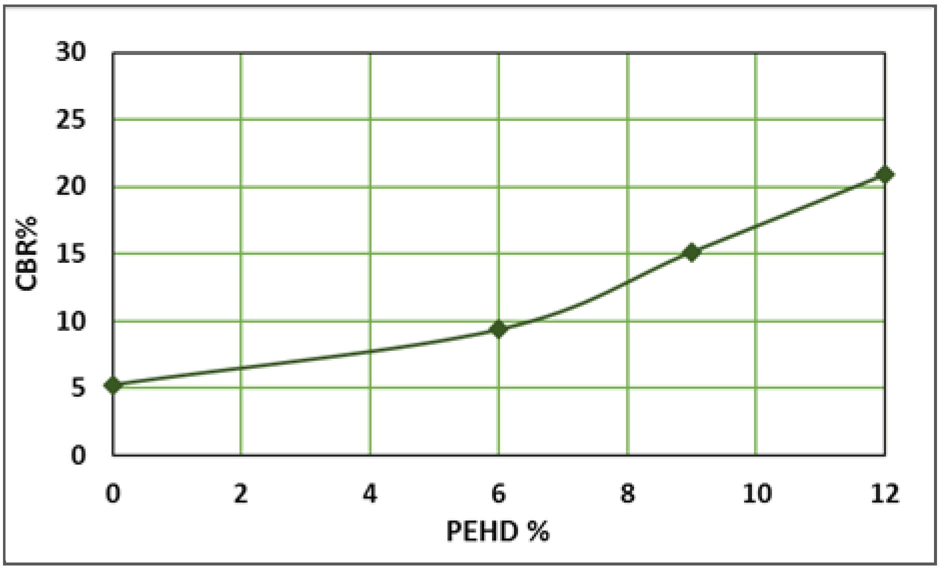

Figure-7. Effect of various percentages of PEHD polymer on California bearing ratio (CBR).

5. CONCLUSIONS

The effect of PEHD polymer on expansive clayey soil can be concluded as follows:

a) The addition of PEHD polymer decrease the liquid limit (LL) and the plasticity index (PI) whilst the plastic limit (PL) increases with increasing PEHD polymer amount. The maximum increase of plastic limit and maximum decrease in plasticity index with the addition of PEHD of up to 12% is found to be about 47.4% and 28.6 % respectively.

b) The addition of 12% PEHD polymer is slightly decrease the maximum dry unit and the optimum moisture content from 1.49 gm/cm^3 to 1.4 gm\cm^3 and from 27.7% to 25% respectively in the same compaction effort.

c) The swelling potential and swelling pressure values extremely decrease with increasing PEHD polymer content and the maximum percentage of PEHD that has effectiveness on free swell and swelling is at 12%which reduced the free swell to 2.3% and swelling pressure to 18.88 kPa.

d) The addition of PEHD polymer improved the unconfined compressive strength by 18.5 % when increasing percentage from 0% to 6%, and then the unconfined compressive strength increased by another 37.3 % at 9% of PEHD content while the unconfined compressive strength is then slightly increased by another 20.1% with increasing the PEHD percentage by 12%.

e) The compression index (Cc) is decrease and the coefficient of consolidation is increases with the addition of PEHD polymer percentage. Maximum decrease in (Cc) value and increase in (Cv) is found to be at about 9% PEHD percentage. This addition reduces the (Cc) from0.305 to0.266 and increase (Cv) from 0.234 to 0.365.

f) The rebound index (Cr) decreases with increasing addition of PEHD percentage and the maximum percentage of polymer causes the higher reduction in Cr is found with 12% PEHD content.

g) The value of CBR increase with increasing addition of PEHD polymer. The maximum percent for PEHD that achieves the maximum improvement in CBR value is at 12% PEHD amount. This addition increases CBR value from 5.27 % to 20.9 %.

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