The Performance of Shear Strength and Volume Changes of Expansive Soils Utilizing Different Additives

Entesar Joudah Irshayyid¹ and Mohammed Yousif Fattah²

¹Assistant Lecturer, Building and Construction Technical Engineering Department, Al-Israa University College, Baghdad, Iraq. Email: entiasr_joudah@yahoo.com.
²Professor, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq.

Abstract. Some clayey soils are generally classified as expansive soils which cause extensive damage to civil engineering structures due to change in its water content and the amount and type of clay size particles. Other important factors affecting the expansion behavior include the amount of non-expansive materials. This paper based on comparing two solutions to improve the soil parameters: the first solution to improve the soil with steel fiber and the second solution to improve the soil strength and volume changes with plastic waste material. Various tests conducted to study the effect of using different percentages of steel fiber and plastic waste material (4%, 8% and 12%) for each additives by dry weight of soil. The results presents that the steel fiber and plastic waste material significantly improved the soil strength and volume changes besides the physical properties of expansive clay soil which have susceptibility of swelling.

Keywords: expansive soils, steel fiber, soil strength, volume changes, plastic waste material.

1. Introduction
Expansive soils cause major damage to many structures. These clayey soils contain minerals such as montmorillonite clay that is capable of absorbing water. When these soils absorb water they increase in volume. The more water they absorb the more their volume increases. This change in volume can exert enough force on a building, sidewalks, driveways, basement floors, pipelines and even foundations to cause damage. These distress problems have resulted in loss of billions of dollars in repairs and rehabilitation for many structures, [1]. While mechanical compaction, dewatering and earth reinforcement can improve the strength of the soils, other methods like stabilization using admixtures are more advantageous. Various admixtures available are lime, cement, fly ash, etc.

In this study, steel fiber and polyethylene waste material are utilized for stabilized the shear strength and swelling behavior of expansive soil. The full experimental program is carried out for studying the effect of adding steel fiber and plastic waste materials with different percentage by weight on the grain size distribution, consistency limits, specific gravity, compaction characteristics, unconfined compressive strength, swelling and swelling pressure and consolidation.

There are several researchers focused their studies on stabilized of expansive soils, [2] treated a swelling soil from the site Hamamuk earth dam, which is located in Koya town north of Iraq by four types of additives; cement, steel fibers, gasoline fuel and injection by cement grout. The treatment of the expansive soil with 5 % of cement or steel fibers or the injection with cement grout revealed a better improvement while 4 % of gasoline oil is sufficient to reveal the optimum treatment by this material. The angle of internal friction is not affected by the treatment while the cohesion between
particles is slightly affected by these additives due to a change in the adhesion between the additive and soil particles. [3] investigated the utilization of High Density Polyethylene (HDPE) and Glass as material stabilizer in Kuantan clayey soil stabilization. The research conducts soil engineering properties and strength test for various contents of HDPE and glass to different types of clayey soil from various sites in Kelantan. The laboratory test result were shown the engineering properties of Kuantan Clayey soil and CBR were improved by adding Cutting HDPE and Crushed Glass as stabilizer. [4] studied the effect of using non-traditional chemical stabilizers in soil improvement. 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.

[5] based on comparing two solutions to improve the soil parameters. The first solution is to improve the soil with plastic waste material and the second solution is to improve the soil with cement. Ongoing tests, performed as a part of the research program have shown the effect of the polyethylene waste material and cement on soil mechanical parameters, cohesion and internal friction angle.

2. Materials and Experimental Program

2.1 Soil used
Calcium pure bentonite which was brought from Al-Rutba city in Al-Anbar governate was mixed with sand obtained from Al-Ekther city 50 km south west Karbala and 152 km south west Baghdad with proportion 80:20 bentonite: sand used to prepare the expansive soil samples in this research.

2.2 Steel fiber
Steel concrete fibers is specifically designed to enhance the properties of concrete in its hardened state. The uniform distribution of steel fibers throughout the concrete mix transforms concrete into a more ductile composite material that increases the energy absorption capability, long-term durability and overall performance of the slab. Additionally, it provides exceptional control of long-term drying shrinkage cracking and load stability at the floor joints, where it is most needed. Steel fiber improves ductility, fracture toughness and energy absorption capacity. Steel fiber has many benefits including greater homogeny of the support structure, and simpler application logistics. So, in this study it used to enhance the engineering properties of soil, [6].

2.3 Polyethylene waste material
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. 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, [7].

2.4 Preparation of the soil mixture for testing
The sand and bentonite are first dried in the oven at 105°C for 24 hours before using in the mixtures. Then 80% of pure bentonite was mixed with 20% of dry sand to prepare expansive clayey soil (high plasticity index). Steel fiber and Polyethylene (HDPE) polymer powder are mixed thoroughly with prepared soil and with the various percentages (4%, 8% and 12%) of steel fiber and polymers for each
one by mixer, then the mixture was mixed carefully at each percent until a homogeneous color was obtained.

2.5 Laboratory tests
Classification tests [8], Atterberg limit [9], compaction test [10], swelling test [11], unconfined compression test [12] and consolidation test [13] are conducted on expansive soil and stabilized soil at optimum moisture content and maximum dry density. Physical properties were conducted on natural expansive clayey soil are shown in Table 1.

Table 1. Physical and classification tests of soils used.

| Physical properties          | Standard | Bentonite | Sand | B:S 80:20 |
|-----------------------------|----------|-----------|------|-----------|
| Specific gravity (Gs)       | [14]     | 2.83      | 2.75 | 2.82      |
| Sand (%)                    | [8]      | 2.3       | 98.6 | 25.4      |
| Silt (%)                    | [8]      | 23.2      | 1.4  | 13.6      |
| Clay (%)                    | [8]      | 74.5      | ---- | 61        |
| Liquid Limit (L.L)          | [9]      | 126       | NP   | 91        |
| Plastic Limit (P.L)         | [9]      | 40        | NP   | 25        |
| Plasticity Index (P.I)      | [9]      | 86        | NP   | 66        |
| Activity (A) %              | [15]     | 1.15      | -----| 1.08      |
| Optimum Moisture Content % (O.M.C) | [10] | 34 | ----- | 29 |
| Maximum Dry Unit Weight (γ\text{dry})_{max} (kN/m³) | [10] | 12.8 | 18.4 | 13.7 |
| Minimum Dry Unit Weight (kN/m³) | [16] | ----- | 15.75 | ----- |
| Coeff. of Uniformity (Cu)   | [16]     | -----     | 0.92 | -----     |
| Coeff. of Curvature (Cc)    | [16]     | -----     | 2.67 | -----     |
| Void Ratio (e) at O.M.C     | -----    | 1.211     | 0.494| 1.058     |
| Soil Symbols according to USCS | [17] | CH | SP  | CH      |
3. Results and Analysis

3.1 Atterberg limits

Liquid limits tests are conducted using the Casagrande method according to [9] and then the plastic limits were obtained for the soil samples. The results represent that the liquid limit values decreased with adding steel fiber and HDPE and the lowest value occurs when adding HDPE in the percentage of 8%, 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 HDPE and it can be noticed that the plasticity index decreased due to addition of HDPE and steel fiber. The maximum increase in plastic limit and decrease in plasticity index is found with the addition of 12% HDPE and the maximum decrease when add steel fiber are at 12% and the addition of HDPE is more effective in increase plastic limit about 81.2% and decrease of plasticity index about 87.5% than steel fiber which the decrease in plastic limit and decrease in plasticity index are 20% and 38.4%, respectively. Table 2 shows the effect of HDPE and steel fiber on Atterberg limits. The results is in agreement with the results of [4]. Figure 1 shows the effect of steel fiber and PEHD polymer on plasticity index of stabilized soil.

Table 2. Results of Atterberg limits of untreated and treated expansive soil.

| Property                        | Liquid limit (%) | Plastic limit (%) | Plasticity index (%) |
|---------------------------------|------------------|-------------------|----------------------|
| Prepared expansive soil         | 91               | 25                | 66                   |
| Treated soil with 4% HDPE polymer | 83.3             | 31.6              | 51.7                 |
| Treated soil with 8% HDPE polymer | 78.2             | 37.2              | 41                   |
| Treated soil with 12% HDPE polymer | 80.5             | 45.3              | 35.2                 |
| Treated soil with 4% steel fiber | 80.4             | 23.4              | 57                   |
| Treated soil with 8% steel fiber | 74.7             | 22.6              | 52.1                 |
| Treated soil with 12% steel fiber | 68.5             | 20.8              | 47.7                 |

Figure 1. The effect of HDPE polymer and steel fiber on plasticity index of stabilized soil.
3.2 Compaction test

Standard proctor test were carried out on the soil [10]. The test was conducted on prepared unsterilized and stabilized expansive soil samples. The results show that the optimum moisture content (OMC) is slightly decreased whereas the maximum dry density ($\gamma_{d(max)}$) is also reduced when adding HDPE polymer due to the reduction of solid in the soil HDPE mixture and that in a good agreement with [3]. On the other hand when adding steel fiber to the expansive soil, the optimum moisture content is increased whereas the maximum dry density is slightly increased too due to increasing of weight of solids in the model of soil steel fiber mixture. Table 3 represent the values of (OMC) and the $\gamma_{d(max)}$ for natural and stabilized soils, while the compaction curves are plotted in Figure 2 and Figure 3.

Table 3. Results of compaction test.

| Property                         | Optimum Moisture Content % (O.M.C) | Maximum Dry Unit Weight $\gamma_{d(max)}$ (KN/m³) |
|----------------------------------|-----------------------------------|-----------------------------------------------|
| Prepared expansive soil          | 29                                | 13.7                                          |
| Treated soil with 4% HDPE polymer| 28.2                              | 13.5                                          |
| Treated soil with 8% HDPE polymer| 27.3                              | 13.2                                          |
| Treated soil with 12% HDPE polymer| 26                               | 12.5                                          |
| Treated soil with 4% steel fiber | 30.4                              | 14.5                                          |
| Treated soil with 8% steel fiber | 33                                | 16                                            |
| Treated soil with 12% steel fiber| 35.6                              | 17.6                                          |

Figure 2. The effect of adding HDPE polymer on dry density-water content relationship.
Figure 3. The effect of adding steel fiber on dry density-water content relationship.

3.3 Swelling and swelling pressure test

Figure 4 represents the effect of adding HDPE polymer and steel fiber on the swelling potential and swelling pressure of prepared expansive soil, respectively. The results show that the swelling potential and the swelling pressure decrease with adding HDPE and steel fiber to the soil and that due to decreasing the interlayer of montmorillonite which absorbs the water causing an increasing in its volume and after the water uptake, the voids will be filled by the swollen montmorillonite, [18]. The results also state that the swelling potential decrease from 17.5% to 2% when adding 12% HDPE, while the swelling pressure decreases from 300 kPa to 20 kPa when adding 12% HDPE to expansive soil and that agreement with [4], as shown in Figure 4 and Figure 5. On the other hand, the treatment of the expansive soil with 4% steel fiber revealed a better improvement on swelling potential and swelling pressure and that behavior satisfied with [2] who study the treatment of expansive soil with four types of additives; cement, steel fibers, gasoline fuel and injection by cement grout, Figure-4 and Figure-5 represent the effect of adding HDPE polymer and steel fiber on swelling potential and swelling pressure.

Figure 4. The effect of adding additive on swelling potential of expansive soil.
3.4 Unconfined compression test results

Unconfined compression tests were conducted according to [12] for prepared expansive soil only and expansive soil stabilized with HDPE and steel fiber with different proportion; 4%, 8% and 12% are shown in Figure 6. It is observed from Figure 6 that the increase in HDPE content significantly increase the unconfined compressive strength while the unconfined compressive strength decrease with increasing steel fiber content due to the reduction in the soil cohesion, [2].

3.5 Consolidation test

One dimensional consolidation tests were conducted for prepared expansive soil sample and samples of expansive stabilized with HDPE polymer and steel fiber at different proportion to show the effect of types of additives on the compression index (Cφ), swelling Index (Cv) and coefficient of consolidation (Cv) of the soil.

The results represent that the compression index (Cφ) decrease with increase HDPE content up to 8% and then increase at 12% of HDPE polymer and this may be due to that the existence of such HDPE filler can significantly increase the clay stiffness and reduce the compression index. On the other hand, when adding steel fiber the compression index (Cφ) and the coefficient of consolidation Cv of the stabilized soil in both method of stabilization increase with decrease of the plasticity index, this is due to the thickness of diffuse double layer which will be relatively larger for a highly plastic soil as
compared to a less plastic soil. The thicker the diffuse double layer, the greater the reduction in the effective pore size for flow. This may be causes the hydraulic conductivity values relatively higher for less plastic soils than for more plastic soils as recommended by [19] and show in Table 4. While recompression index $C_r$ or swelling index $C_s$ for the plastic soil decreases with increase of the additive proportion. This is due to the decrement of the specific surface and the soil activity for swelling.

| Soil property | Prepared expansive soil | Treated soil with 4% HDPE polymer | Treated soil with 8% HDPE polymer | Treated soil with 12% HDPE polymer | Treated soil with 4% steel fiber | Treated soil with 8% steel fiber | Treated soil with 12% steel fiber |
|---------------|-------------------------|---------------------------------|---------------------------------|-----------------------------------|---------------------------------|---------------------------------|----------------------------------|
| Compression index, $C_c$ | 0.287 | 0.274 | 0.261 | 0.267 | 0.294 | 0.314 | 0.364 |
| Recompression index, $C_r$ | 0.054 | 0.0343 | 0.032 | 0.026 | 0.042 | 0.038 | 0.036 |
| Coefficient of consolidation, $C_v$ (m^2/sec.) under pressure of 200 kPa | 2.31*10^{-8} | 2.64*10^{-8} | 4.1*10^{-8} | 4.62*10^{-8} | 2.4*10^{-8} | 2.52*10^{-8} | 2.6*10^{-8} |

4. Conclusions
The effect of HDPE polymer and steel fiber on the prepared expansive soil can be concluded as follows:

- The liquid limit values are decreased with adding steel fiber and HDPE and the lowest value occurs when adding HDPE in the percentage of 8%, after this percentage it begins to slightly increases and it can be noticed that the plasticity index are decreased due to addition of HDPE and steel fiber.
- The addition of HDPE is more effective in increasing plastic limit about 81.2% and decreasing of plasticity index about 87.5% than steel fiber which the decrease in plastic limit and decrease in plasticity index are 20% and 38.4%, respectively.
- The results show that the optimum moisture content is slightly decreased by about 12% whereas the maximum dry density is also reduced by about 10% when adding 12% HDPE polymer due to the reduction of solid in the soil HDPE mixture. On the other hand when adding steel fiber to the expansive soil, the optimum moisture content is increased by about 23% whereas the maximum dry density is slightly increased about 28% and that due to the increase of the solid weight of the soil steel fiber mixture.
- The results state that the swelling potential is decreased from 17.5% to 2% when adding 12% HDPE, while the swelling pressure decrease from 300 kPa to 20 kPa when adding 12% HDPE to expansive soil. On the other hand, the treatment of the expansive soil with 4% steel fiber revealed a better improvement on swelling potential and swelling pressure.
- It is observed that the increasing in HDPE content significantly cause increasing the unconfined compressive strength by about 100% while the unconfined compressive strength is decreased from 200 kPa to 65 kPa with increasing steel fiber content due to the reduction in the cohesion.
- The compression index ($C_c$) is decreased with increasing HDPE content up to 8% form 0.287 to 0.261 and then increased at 12% of HDPE polymer to 0.267. On the other hand, when adding steel fiber the compression index ($C_c$) and the coefficient of consolidation $C_v$ of the stabilized soil in both method of stabilization increase with decreasing of the plasticity index by about 36% for $C_c$. 

Table 4. Results of one-dimensional consolidation test for different soils.
and the increasing in the coefficient of consolidation by about 100% for HDPE stabilization and by 30% for steel fiber stabilization.

References
[1] Nelson, J. D., and Miller, D. J., 1992 "Expansive soils: problems and practice in foundation and pavement engineering". John Wiley & Sons, Inc., New York, NY.
[2] Fattah, M. Y., Salman, F. A., and Nareeman, B. J., 2010 "A treatment of expansive soil using different additives", Acta Montanistica Slovaca Ročník 15 (4), 290-297.
[3] Fauzi, A., Abdul Rahman, W. M., and Jauhari, Z., 2013 "Utilization Waste Material as Stabilizer on Kuantan Clayey Soil Stabilization", Malaysian Technical Universities Conference on Engineering & Technology, MUCET 2012, Part 3- Civil and Chemical Engineering.
[4] Hasan, S. H., and Shafiq, Q. S., 2017 "Expansive Clayey Soil Improvement Using Polyethylene High Density Polymer", ARPN Journal of Engineering and Applied Sciences, 12(24).
[5] Ilies, N. M., Circu, A. P., Nagy, A. C., Ciubotaru, V. C., and Bak, Z. F. 2017 'Comparative Study on Soil Stabilization with Polyethylene Waste Materials and Binders' 10th International Conference Interdisciplinarity in Engineering.
[6] Wikipedia, https://fibermesh.com/our-fibers/steel-fibers/.
[7] Shakhashiri, B.Z., 2012 "Chemical polymers", A Handbook for General Chemistry. p. 241. Cited by [4].
[8] ASTM D 422-02, "Standard Test Method for Particle-Size Analysis of Soils", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
[9] ASTM D 4318-00, "Standard Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of Soils", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
[10] ASTM D 698-12, "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (600KN-m/m3)", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
[11] ASTM D 4829-03, "Standard Test Method for Expansion Index of Soils", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
[12] ASTM D 2166-00, "Standard Test Method for Unconfined Compressive Strength of Cohesive Soil", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
[13] ASTM D 2435 – 96, "Standard Test Method for One-Dimensional Consolidation Properties of Soils", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
[14] ASTM D 854-00, "Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
[15] Head, K. H., 2006 "Manual of Soil Laboratory Testing", Vol. 1, Scotland, UK, 3rd. edition.
[16] ASTM D 4254-00, "Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
[17] ASTM D 2487-00, "Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)", Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.
[18] Chalermyanont, T. and Arrykul, S., 2005 "Compacted Sand-Bentonite Mixtures for Hydraulic Containment Liners", Songklanakarin Journal of Science Technol., 27(2), pp. 313-323.
[19] Fredlund, D.G. 1969 "Consolidometer Test Procedural Factors Affecting Swell Properties", 2nd International Conference on Expansive Clay Soils, Texas, U.S.A., pp. 435-456.