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# Soil Stabilization Using Waste Plastic Materials

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## Abstract

Expansive clay soils are the types of soils whose volume changes with the change in water content. They have a behavior of swelling and shrinking that is a serious hazard to structures built over them. Expansive soils are abundantly existing soil types in Ethiopia, particularly Addis Ababa. This paper shows the outcomes of an attempt to reinforce and stabilize expansive clay soil with plastic bottle strips. The plastic strips were prepared and added at three different mixing ratios (0.5%, 1% and 2%) by weight and in three different aspect ratios (5 mm × 7.5 mm, 10 mm × 15 mm, 15 mm × 20 mm). The experimental results showed that there was a significant improvement in shear strength parameters. The swelling and desiccation cracking behavior of the soil were also expressively reduced. There was a substantial reduction in the optimum moisture content and slight increment in maximum dry density. The optimum plastic size (aspect ratio) and plastic content that results in optimum result can be selected based on the importance of the selection parameter for a specified engineering work. Stabilizing expansive clay soils with waste plastic bottles simultaneously solves the challenges of improper plastic waste recycling that is currently a teething problem in most developing countries. The results obtained from this study favorably suggest that inclusion of this material in expansive soils would be effective for ground improvement in geotechnical engineering.

## Keywords

Expansive Soil, Clay Soil, Plastic Strips, Soil Stabilization

## 1. Introduction

Expansive clay soils are types of soils that show a significant change in volume once they come in contact with moisture. They expand when exposed to excess water and shrink in hot weather conditions where there is scarce amount of water. They can easily be identified in the field in dry seasons as they show deep cracks of polygonal patterns. This behavior of swelling and shrinking of expansive clay soils in turn affects the stability of structures that is built over these soils causing a serious hazard. It majorly affects the bearing capacity and strength of foundations by uplift as they swell and may cause from cracks to differential movements to structural failures [1]. In order to build on expansive soils, they need to be stabilized to reduce their swelling and improve their mechanical capacities.

Soil stabilization is the process by which the engineering properties of the soil are improved and it is made more stable. It is used to decrease the soil's unqualified characteristics such as permeability and consolidation potential and increase the shear capacity [2]. The method is mainly adopted for highway and airfield construction projects. Commonly, activities such as compaction and pre-consolidation are used to improve types of soils which are already in good form. But soil stabilization goes way up to encouraging usage of weak soil and reducing the uneconomical process of weak soil replacement. Other than working on the soil mass interaction, chemically altering the soil material itself is also the focus of this process. Sometimes, soil stabilization is used for city and suburban streets to make them more noise-absorbing [3].

Different methods have been developed previously to stabilize weak and unsuitable soils. Some of these methods include mechanical (granular) stabilization, cement stabilization, lime stabilization, bituminous stabilization, chemical stabilization, thermal stabilization, electrical stabilization, as well as grouting stabilization by geotextile and fabrics. Recently, researchers have introduced another way of soil stabilization by using waste materials. Plastics are one of the leading waste materials that are found to be suitable for this purpose. They reduce the cost of stabilization at a large rate [4]. Using plastics for this purpose simultaneously solves the challenges of improper plastic waste recycling that is currently a teething problem in most developing countries.

Improper plastic waste disposal is becoming a pressing environmental issue in most African countries. They are currently covering landfills and water bodies, clogging sewerage systems, disrupting the ecological cycle and creating an aesthetically unpleasing environment. This in turn causes serious damage to animal, plant and human lives. Polyethylene Terephthalate (PET) bottles are conventional plastic bottles that currently are highly utilized. They are used to package water, soft drinks, liquid foods, and various other beverages. With their increasing demand, their disposal is becoming difficult. The degradation of waste PET bottles takes a very long time in nature (more than a hundred years) [5]. Recycling and using these plastic bottles to stabilize expansive clay soil are moves in the right direction making the construction industry an appropriate candidate with its high consumption ability. This will be a decent alternative for clearing and protecting the environment from waste plastic bottles [6].

This paper presents appropriate and easy to implement ways of recycling plastic water bottles as reinforcing material for the stabilization of expansive soil to improve and achieve the required properties for construction works. The experimental tests that were performed with the achieved results are presented.

## 2. Materials and Methods

### 2.1. Materials

There were two materials used for this study: a representative clay type soil taken from Bole area in Addis Ababa, Ethiopia and rectangular PET bottle strips. The strips were prepared from waste plastic bottles that were collected from the nearby surroundings. The bottles were cleaned properly after collection and cut into three different sized strips, manually using scissors (**Figure 1**). The strip sizes are shown in **Table 1**.

### 2.2. Methods

#### 2.2.1. Material Characterization

The characterization of the soil sample taken for this study included particle size distribution, Atterberg limit and specific gravity of soil tests. The sample soil taken was sieved in order to take out any other impurities and unnecessary particles. It was then prepared for testing according. Once sample preparation was done, sieve analysis and hydrometer analysis were conducted to study the particle size distribution of the soil. The tests were done as per [7] and [8] respectively. Plastic limit, liquid limit and plasticity index of the soil were determined

**Figure 1.** Strip preparation.

**Table 1.** Strip sizes.

| Strip | Width (mm) | Length (mm) |
|---|---|---|
| 1 | 5 | 7.5 |
| 2 | 10 | 15 |
| 3 | 15 | 20 |

by performing the Atterberg limit test. The test was carried out as per [9] using Casagrande's apparatus. Specific gravity of the soil on the other hand was determined from the specific gravity test in the geotechnical laboratory. A specific gravity beaker and vacuum pump were used to carry out the test as per [10]. The specific gravity was taken as the ratio of the density of soil to the density of water at the same temperature.

The PET fibers on the other hand were characterized as per size (length, width and thickness), surface texture, shape and color.

#### 2.2.2. Material Mixing Method and Proportions

The plastic strips, which are expected to act as soil reinforcements, were added to the soil in three different percentages (0.5%, 1% and 2%) by mass of the soil. **Table 2** shows the treatment levels used for each strip while carrying out this study. Percentage by mass represents the ratio of mass of plastic to mass of soil sample taken as a percentage.

#### 2.2.3. Methods of Testing Soil Properties

Once the characterization of both materials was complete, the plastic bottle strips were added to the soil sample in the treatment levels described above. Free swell test, standard proctor compaction test, direct shear test, Unconfined Compressive Strength (UCS) test and California Bearing Ratio (CBR) test were carried out in order to study the effects of the addition of the plastic bottle strips on clay soil. The specific standards used to perform these testes are listed in **Table 3**.

**Table 2.** Treatment levels.

| Strip Size (mm) | Treatment Level (%) |
|---|---|
| | 0.5 |
| 5 * 7.5 | 1 |
| | 2 |
| | 0.5 |
| 10 * 15 | 1 |
| | 2 |
| | 0.5 |
| 15 * 20 | 1 |
| | 2 |

**Table 3.** Test methods.

| Test Performed | Standard Used |
|---|---|
| Free swell test | [11] |
| Standard proctor compaction test | [12] |
| Direct shear test | [13] |
| Unconfined Compressive Strength (UCS) test | [14] |
| California Bearing Ratio (CBR) test | [15] |

The swelling of the soil sample was studied by conducting the free swell test. In this test, a 10 g of oven-dried soil sample passing through a number 40 sieve (425 μm) was put into a graduated free-swell jar with capacity of 100 ml, and filled with water. The sample was left until it reached its maximum swelling level. Then the recorded value was computed with respect to the original 10 ml volume and expressed in percentage. **Figure 2** shows free swell jars set for settling.

The maximum dry density and optimum moisture content were determined by conducting standard proctor compaction test. In this test, the soil was compacted using a test mold and a rammer at different water contents until the wet density started decreasing (**Figure 3**). Moisture content of the soil at different water additions was obtained, and the dry density for each compaction level was graphed with its respective water content. The peak of the curve provided the maximum dry density that the soil can be compacted to, with the optimum moisture content that can yield the maximum compaction. Equation (1) shows how dry density can be calculated, where $\gamma_d$ is dry density, $\gamma_w$ is wet density and $\omega$ is water content.

$$\gamma_d = \frac{\gamma_w}{1+\omega} \tag{1}$$

**Figure 2.** Free swell jars set for settling.

**Figure 3.** Standard proctor compaction test mold and rammer.

The response of a consolidated and drained soil sample for direct shear, and results in the shear strength of the soil were determined by conducting a direct shear test. The test was performed by deforming a specimen at a controlled strain rate on a single shear plane, which is determined by the configuration of the apparatus. Generally, three specimens were tested, each under a different normal load, to demonstrate the effect of surcharge and structural load upon shear resistance and displacement. The shear results at the three normal loads are plotted on one graph and linearly fitted to result the average shear strength (C) of the soil, whereas the angle of internal friction ($\varphi$) is calculated from the slope of the line that is used to fit the shear strength values. **Figure 4** illustrates the procedures of a direct shear test.

Cohesive soils can be evaluated based on their shear resistance when subjected to compressive load with no confinement. The unconfined compressive strength (UCS) test was used to determine shear capacity of the sample soil under compression. The sample was extruded and cut into the standard cylindrical shape. The UCS machine was used to compress the sample and both the applied load and change in length of the sample were recorded. The values were tabulated and computed to get one representative value. **Figure 5** shows the UCS test machine and sample.

**Figure 4.** Direct shear test.

**Figure 5.** Unconfined Compressive Strength (UCS) test.

CBR test was conducted to measure the penetration strength of a compacted soil relative to crushed rock, which is considered to be an excellent base-course material. The results of a CBR test help to understand the shear strength and bearing capacity of a soil sample. The test follows a compaction procedure combined with a penetration that is applied by a machine that applies a plunger load. This test was used to simulate the effect of surcharge and excessive moisture on the compacted soil by putting a standard load that represents surcharge and soaking the mold for four days

## 3. Results and Discussions

### 3.1. Characterization of Soil

The characterization of the soil sample was done according to particle size distribution, Atterberg limit tests and specific gravity of soil test.

The results showed that the soil was a fine-grained clay soil with a specific gravity of 2.78 as well as a liquid limit of 94.2%, a plastic limit of 28.3% and a plasticity index, which is the difference between the liquid and plastic limit, of 65.9%.

### 3.2. Testing Reinforced Soil Properties

#### 3.2.1. Standard Proctor Compaction Test Results

One of the ways the effect of adding plastic into the soil was checked was in terms of the soil's improvement during compaction. This improvement was expressed in the change in the maximum dry density (MDD) and optimum moisture content (OMC). The summary of the test results is given in Table 4.

All strip sizes showed reduction in optimum moisture content as the percentage of plastic increased. A largest reduction is obtained at a strip size of 5 × 7.5 (mm) at a 2% addition which yielded a 31% decrease in the moisture content. The reason for the decrement of the OMC might be because of zero absorption

**Table 4.** MDD and OMC of soil with different treatment levels of plastic strips.

| Strip Size (mm) | Treatment Level (%) | MDD ($KN/m^3$) | OMC (%) |
|---|---|---|---|
| None | 0 | 12.82 | 42 |
| | 0.5 | 11.97 | 34.4 |
| 5 * 7.5 | 1 | 12.56 | 32.5 |
| | 2 | 12.8 | 29 |
| | 0.5 | 12.38 | 36 |
| 10 * 15 | 1 | 12.12 | 35 |
| | 2 | 11.92 | 34 |
| | 0.5 | 12.22 | 36 |
| 15 * 20 | 1 | 12.25 | 35.14 |
| | 2 | 12.18 | 35 |

capacity of the plastic strips for water. Therefore, soil can be compacted to its maximum dry density at lower addition of water, which is a very good improvement. Figure 6 shows the comparisons between OMC of the soil at the different sizes and percentages of plastic addition.

A decrease in maximum dry density of the soil is also noted but it is marginal. The largest reduction occurred at a strip size of 10 mm × 15 mm at 2% content which is 7% only. Only the 2% content of 5 × 7.5 (mm) strip maintained the maximum dry density of the original soil, which is 12.8 kN/m$^3$. The addition of less dense material, which is the plastic, in the soil might have decreased the density of the soil. However, the reduction in maximum dry density is counterbalanced by the decrease in optimum moisture content. The decreased density of soil has an engineering application in light weight embankment construction. Figure 7 shows the comparisons between MDD of the soil at the different sizes and percentages of plastic addition.

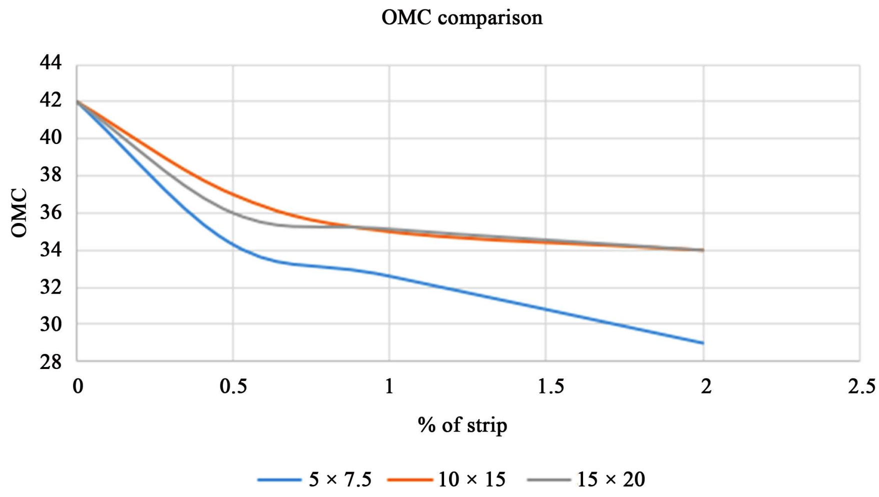


Figure 6. Comparison between OMC of soil samples.

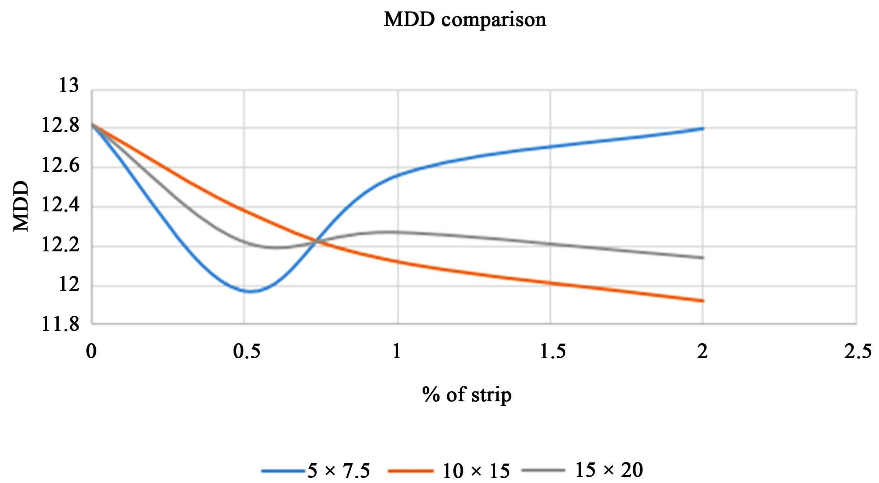


Figure 7. Comparison between MDD of soil samples.

#### 3.2.2. Free Swell Test Results

The main problem of expansive soil is its volume change in different moisture conditions. When the moisture content increases, the soil swells and its volume increases in a wide range from the original. This property happens at a particle level, when water particles break the bonds that connect the sandwich like chemical structure and penetrate between layers. This problem is particularly solved by altering the chemical characteristics of the soil using the application of different chemicals.

As for this project, the plastic strip was proposed to act as a physical agent and was expected to decrease the swelling potential of the soil. From visual inspection during experiments and the results from free-swell tests for the soil containing different percentage of plastic strips, there is no chemical bonding between the soil and the strip. Therefore, the reduction in swelling is a sole effect of the physical interaction between the soil and the strip.

The free swell of unreinforced soil is observed to be 160% which according to ASTM is classified as very highly expansive soils. A substantial reduction in the free swell of the soil is observed due to the addition of plastic strip. A 30% reduction in swell occurs at strip size of 5 × 7.5 (mm) and strip content of 2%. Table 5 gives a summarized version of the swelling test results for each plastic strip size and treatment level (percentage).

The free-swell test uses 10 g of sample in a standard graduated free-swell jar. On the addition of the plastic in the soil, the mass of the soil has to decrease so that the total mass of the plastic and the soil will become 10 g. The reason for the decrease in the swelling potential was not because of chemical interaction. But it was due to the amount of soil mass decreased, which is equal to the mass of the plastic added. Since decreased mass of the soil was replaced by non-swelling material, the swelling showed some improvement. The soil-plastic interaction might also have an effect in reducing the free swell.

**Table 5.** Free swell test results.

| Strip Size (mm) | Treatment Level (%) | Swelling (%) |
|---|---|---|
| None | 0% | 160 |
| | 0.5 | 136.3 |
| 5 * 7.5 | 1 | 126.3 |
| | 2 | 112.5 |
| | 0.5 | 134 |
| 10 * 15 | 1 | 121 |
| | 2 | 116 |
| | 0.5 | 135 |
| 15 * 20 | 1 | 127.5 |
| | 2 | 117.5 |

#### 3.2.3. Direct Shear Test Results

It was possible to conclude from the test results that the arrangement of the plastic strips in the soil affects the shear capacity of the reinforced soil. If the surface of the strip is parallel to the shear plane, the shearing will be enhanced and the capacity will fail. But any other arrangement will improve the shear capacity of the soil. On the other hand, it was difficult to arrange the larger sizes of strips in on the direct shear machine, as their surface area was close to that of the shear box.

The shear capacity from the tests is presented in terms of the shear strength parameters, cohesion (C) and angle of internal friction ($\varphi$). Both improvement and drop of shear capacity were recorded for C and $\varphi$. The angle of internal friction and cohesion intercept of the unreinforced soil was found to be 5.710 and 49.83 kPa respectively. The small value of friction angle is attributed to the cohesiveness of the soil. The largest values of C and $\varphi$ for the reinforced soil was obtained as 8.980 and 62.67 Kpa which was a 57% and 26% improvement respectively. These results were obtained for the 15 * 20 strip size at 0.5%. Table 6 gives the C and $\varphi$ results obtained for each treatment level and strip sizes.

Increasing the plastic content for the same plastic strip size has increased both the friction angle and cohesion for 5 × 7.5 (mm) and 10 × 15 (mm) strips but decreased for 15 × 20 (mm). However, increasing the plastic size for the same content increases the friction angle and cohesion.

#### 3.2.4. Unconfined Compressive Strength (UCS) Test Results

The results found from the unconfined compressive strength (UCS) test, were different from the direct shear results. The UCS of unreinforced soil was found to be 151.8 kPa. The largest improvement in the UCS is 316.4 kPa that is a net increase of 108% which is a tremendous growth. The rise in UCS is obtained at small strip contents and sizes. Increase in size generally reduces the UCS value.

**Table 6.** Direct shear test results.

| Strip Size (mm) | Treatment Level (%) | $\varphi$ | C (kPa) |
|---|---|---|---|
| None | 0 | 5.71 | 49.83 |
| | 0.5 | 6.66 | 51.64 |
| 5 * 7.5 | 1 | 7.15 | 54.43 |
| | 2 | 7.64 | 56.88 |
| | 0.5 | 7.31 | 60.84 |
| 10 * 15 | 1 | 7.76 | 61.17 |
| | 2 | 8.36 | 61.87 |
| | 0.5 | 8.98 | 62.67 |
| 15 * 20 | 1 | 8.75 | 62.50 |
| | 2 | 8.28 | 62.00 |

When the applied compressive stress forced the soil mass to slide over the surface of plastic strips and the lack of confinement might have contributed for the reduction of the UCS value. The UCS mold is also small and it might have caused large un-compacted shear planes. Table 7 summarizes the UCS values for the different plastic strip size and percentage reinforced soil samples.

**Cracking and Shrinking**

The decrease in moisture content of expansive soil results in wide and deep cracking. This phenomenon results decrease in volume, and consequently the soil is excessively compressed. Many structures lost their stability and failed due to less awareness and treatment of this character of expansive soil.

The addition of plastic strips can help reduce the cracking and shrinking characters of the soil by bridging between the cracks. This was witnessed when the compacted soil was extruded from the mold and left to air dry until it fully cracked. The cracks outlined on the surface of the molded soil and its ability to maintain its original spherical shape were compared by visual inspection. The strip size of 5 × 7.5 (mm) resulted a very considerable reduction of cracking, while larger sizes especially at higher percentages decreased the ability of the soil to maintain its spherical shape of mold. It was obvious that the larger surface area of the plastic, the easier for the soil to crack. Figure 8 shows the cracking mode of the soil for strip sizes 15 * 20, 10 * 15, and 5 * 7.5 from left to right. It can clearly be seen from the figure that the sample containing 15 * 20 plastic strip sizes showed excessive cracking.

Figure 8. Comparison of cracking between soil samples.

Table 7. UCS test results (kN).

| Treatment Level | Strip Sizes (mm) | | |
|---|---|---|---|
| | 5 * 7.5 | 10 * 15 | 15 * 20 |
| 0 | 151.8 | 151.8 | 151.8 |
| 0.5 | 257.2 | 316.4 | 173.4 |
| 1 | 273.7 | 287.5 | 153.4 |
| 2 | 307.4 | 246.3 | 134.5 |

### 3.2.5. California Bearing Ratio (CBR) Test Results

The bearing capacity of the soil was measured indirectly by conducting the CBR test. The Soaked CBR is only tested in this study because it is only test that simulate actual site condition. Also, the study was focused in investigating the effect of water on expansive soils CBR value. The load penetration curve has shown that there is an improvement in the CBR value. The soaked CBR of unreinforced soil was found to be 1.58 which is small. The principal enhancement is attained at a strip size and content of 15 × 20 (mm) and 1% respectively and is of value 3.23. This is a total of 104% increment. The results are summarized in Table 8.

Increase in plastic size for the same percentage has resulted in an increase in soaked CBR value but increase in plastic content for the same plastic size increases the soaked CBR then decreases. The improvement in CBR can attributed to the ability of the strips in resisting swelling prior to penetration and load exerted by the plunger during penetration.

## 4. Conclusions

This paper assessed the method of stabilizing clay soils using plastic bottle strips. The following conclusions are drawn based on the analysis and interpretation of the results obtained.

A significant and marginal reduction was recorded in the *optimum moisture content* and in the *maximum dry density* results respectively. The *angle of internal friction* and the *cohesion intercept* increased significantly as the reinforcement percentages and sizes increased. A huge improvement in *UCS* has been noted for smaller strip size and content. Any further increase in size and content has brought reduction in UCS because increase in size causes in un-compacted weak shear planes. The *swelling* of the soil was reduced significantly at high percentages of strip content because of replacement in an equal mass of expansive soil by non-expansive plastic. Physical anchorage has also some effect in reducing the free swell. The swelling reduction is in some way similar for different sizes at the same percentage which shows that the dominant factor that contributes to reduction in swelling is percent by weight of plastic content. Increase in plastic size for the same percentage has resulted in an increase in *soaked CBR* value but increase in plastic content for the same plastic size increases the soaked CBR then decreases. The optimum plastic size and plastic content that results in optimum result can be selected based on the

**Table 8.** CBR values (%).

| Treatment Level | Strip Sizes (mm) | | |
|---|---|---|---|
| | 5 * 7.5 | 10 * 15 | 15 * 20 |
| 0 | 1.58 | 1.58 | 1.58 |
| 0.5 | 1.71 | 2.28 | 2.85 |
| 1 | 2.09 | 2.66 | 3.23 |
| 2 | 1.96 | 2.47 | 3.04 |

importance of the selection parameter for a specified engineering work.

In nutshell, stabilizing expansive clay soil with waste plastic bottle strips is a reliable alternative as it improves the volume fluctuation problems of the soil. The strips were acting as reinforcements playing a role of arresting volume changes with change in water content. Incorporating waste plastic bottles in the construction industry also is a crucial way to solve the issue of insufficient plastic waste disposal.

The laboratory results presented in the study favorably suggest the possibility of utilizing plastic material as tensile inclusions in expansive soil to increase the resistance to shear, CBR value and reduction in swelling. However, a better understanding of the interaction mechanism in soils reinforced with the plastic material would be essential to properly document the engineering behavior of the soil-plastic composite.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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