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# GEOSYNTHETIC WITH IN-PLANE DRAINAGE AS REINFORCEMENT IN POORLY DRAINING SOIL

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## ABSTRACT

The interest in the use of geosynthetic as soil reinforced in poorly-draining soil has been growing, because this technology cost effective and sustainable as well. In this article, the use of geosynthetic with in-plane drainage (paradrain) was studied and this paper aimed to describe the behavior of the pore pressure during the consolidation time and analyze the efficiency of the paradrain. Two kinds of geosynthetic were used: paradrain and paragrid (w/o drainage system). The pullout test was used to obtain the pullout strength and displacements of the geosynthetics and pore pressure developed in the soil as well. The consolidation time ranged from 5 to 20 minutes in order to have different initial pore pressure values. It was found that the pore pressure reaches its highest value at the beginning of the consolidation. Moreover, the higher the initial pore pressure is, the more efficient the paradrain is.

**KEY WORDS:** Geosynthetics, poorly draining soil, pullout test, porous pressure

## INTRODUCTION

Sustainable technologies can be defined as the use of methods and materials that do not damage the environment and are cost effective as well. The need for sustainable solutions has been growing in the past years, especially in civil engineering which is one of the biggest aggressors of the environment due to its procedures and materials. One example of such materials is cement, which expends a huge amount of energy to produce.

In geotechnical engineering, one way to avoid the use of cement is to build mechanically stabilized earth walls rather than concrete walls. Most of these sustainable walls are constructed using freely-draining soil [1]. However, freely draining soil is not always available and, in this case, its use may not be cost effective. A solution is to use poorly draining soil reinforced with geosynthetics.

A problem found in poorly draining soil is that it has lower shear strength than freely draining material. In other words, the pullout resistance of reinforcement will decrease, and the active earth pressure coefficient will increase. Some other concerns about the use of poorly draining soils for reinforced soil construction have been [2]:

- Build up of pore pressure may reduce the backfill soil strength;
- Post construction movements may occur under sustained stresses because of the higher creep potential in poorly draining soils.

Thus, two issues have to be addressed to design a safe and economical structure using this kind of soil: the cohesive soil-reinforcement interaction (pullout strength) and the reinforcement drainage characteristics [3].

Tan et al. [1], showed that permeable geotextile has an excellent performance in dissipating the pore pressure when poorly draining soil is used as backfill material. However, it was found that the geogrid (without in-plane drainage system) does not contribute to the drainage.

Teixeira [4], showed that geogrid with in-plane drainage system contributes to the dissipation of porous pressure when the water content of the soil is higher than the optimum value. Kang and Zornberg [5] also found that geosynthetic products with in-plane drainage capacity provide an increased pullout resistance as they can dissipate shear-induced pore water pressure.

This article aimed to show that the pore pressure has its highest value at the first minutes of the consolidation time, although the results obtained thought the pore pressure transducers showed that the pore pressure increase with time. Moreover, it aimed to show that the geosynthetic with in plane drainage system is more efficient, the higher the initial pore pressure is. To obtain these results, pullout tests were executed at different consolidation times, keeping constant the initial normal pressure, water content and soil properties.

## MATERIAL AND METHODS

The tests performed in the University of Texas at Austin followed a standard procedure and materials in order to allow comparison among the tests. To pursue those tests, two kinds of geosynthetic, one kind of soil and a pullout box were used.

### *Geosynthetic*

The geogrid used had about the same ultimate tensile strength, being the difference between them the drainage properties. The geogrid with in-plane drainage layer and without were called Paradrain and Paragrid, respectively.

The Paradrain consists in a geogrid with polyester filament core with polyethylene sheath and drainage channels involving a polypropylene and polyethylene nonwoven geotextile. Properties of both geosynthetics are shown in Table 1.

**TABLE 1** - PROPERTIES OF THE GEOSYNTHETIC MATERIALS

| | | | Paragrid | Paradrain |
|---|---|---|---|---|
| Ultimate Tensile strength (kN/m) | Machine direction | | 100 | 100 |
| | Cross-machine direction | | 15 | 15 |
| Strain at rupture (Machine direction) | | (%) | 12 | 12 |
| Transmissivity under 100 kPa (Hydraulic Gradient = 1.0) | | ($m^2$/s) | - | $1.06 \times 10^{-6}$ |
| Unit mass | | (g/$m^2$) | 490 | 525 |
| Thickness | | (mm) | 1.3 | 2.5 |

### *Soil*

Silty soil, a poorly draining soil, was used. Table 2 and Figure 1 show the properties and the granulametric curve of the soil.

**TABLE 2** - SOIL PROPERTIES

| Specific gravity | 2.71 |
|---|---|
| Liquid limit (%) | 29 |
| Plastic limit (%) | 12 |
| Plasticity index (%) | 17 |
| Optimum moisture content (%)* | 12.9 |
| Maximum dry unit weight (kN/$m^3$)* | 18.67 |

* according to Standard proctor test

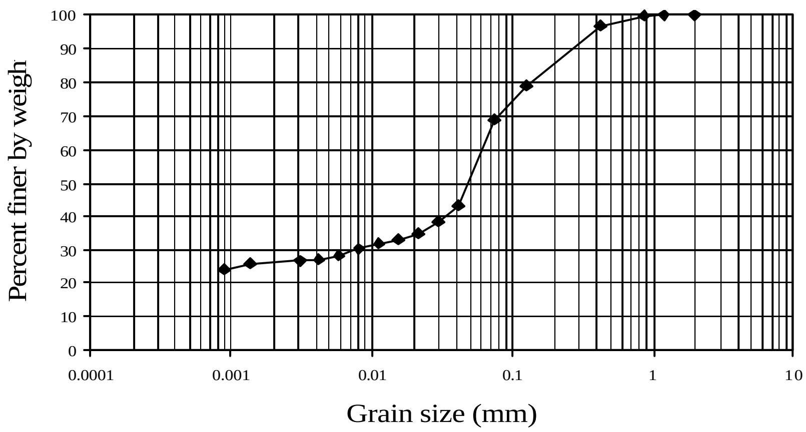


FIGURE 1 - GRANULAMETRIC CURVE OF SILTY SOIL USED IN THE TESTING PROGRAM

### *Pullout Box*

This equipment consists of a box with 1520 mm of length, 620 mm of width and 280 mm of height, which is made by plates and metallic profiles and connected to a set of two hydraulic cylinders responsible for pulling out the geogrid. The normal pressure is applied in the surface of the soil through an inflatable air bag, placed between the soil and the cover of the box.

The equipment has a 100-mm-wide steel sleeve, located at the frontal wall, which is to minimize the rigid edge effect. A changeable height opening, with 620 mm of extension, is located at the back wall of the box for using different inextensible wires thickness. These wires were used to measure the displacements along the geogrid.

The application of the normal pressure was made with an air bag. The pressure is applied in the air bag through the air injection compressed in its interior. The applied pressures are controlled by a manometer. The pressure applied in the ground surface is same as pressure in the interior of the air bag.

### *Instrumentation*

The instrumentation used in this equipment is composed for a load cell, four LVDTs and two pore-pressure transducers (PPT).

The load cell was used to measure the pullout force generated by the movement of the hydraulic cylinders. The LVDTs were used to measure the displacements of the portion embedded of geogrid. The PPTs were to measure the water pressure that was generated.

The readings of the measurement instruments are made and registered for a microcomputer that has a module of data acquisition.

### *Method*

To place the soil in the pullout box, it was divided in four layers. The water content chosen to make the test was 20% because it is quite higher than the optimum water content of the soil (12.9%) what made it possible to analyze the efficiency of the drainage system of the geosynthetic. Beside, the soil was compacted to a dry unit weight of 17.92 kN/m3, which corresponds to a relative compaction of 80%.

After the 2 first layers had been placed, the geosynthetic, LVDTs, and the 2 PPT were installed. One PPT was installed at roughly 1cm above and the other below the geosynthetic. Then, the 2 final layers of soil were placed.

Finally, the air bag was placed between soil surface and a heavy steel plate was pressurized to 12.5 psi. Two different consolidation times, 5 and 20 minutes, were used, before the pullout load was applied.

## RESULTS

The results obtained thought the pore pressure transducers showed that the pore pressure increases with time during the consolidation, an example of this is showed in Figure 2.

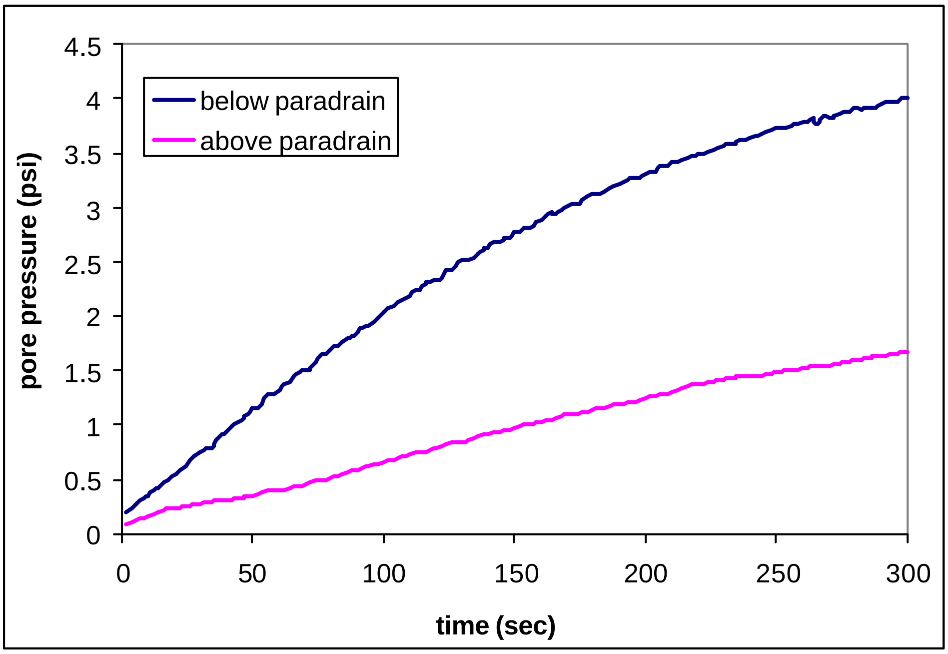


FIGURE 2 – PORE PRESSURE DURING CONSOLIDATION VERSUS TIME

However, the "friction angle" of the soil (? ) and, consequently, the maximum pullout strength of a geosynthetic depend on the pore pressure of the soil. The higher the initial pore pressure is, the lower the pullout strength is. The value of maximum pullout strength of each geosynthetic is found in Table 3.

**TABLE 3** – MAXIMUM PULLOUT STRENGTH (FMAX) OF EACH EXPERIMENT AND PERCENTAGE DIFFERENCE BETWEEN FMAX OF PD AND PG FOR 5 AND 20 MINUTES OF CONSOLIDATION

| | Fmax | % |
|---|---|---|
| PD#5min | 2900.326 | 32.56 |
| PG#5min | 2187.924 | |
| PD#20min | 3027.784 | 25.29 |
| PG#20min | 2416.617 | |

The Fmax of PD#5min is lower than the Fmax of PD#20min and the PG#5min is lower than PG#20min as well. Thus, it can be concluded that the pore pressure is higher at 5 minutes than at 20 minutes.

Figure 3 shows the pullout strength of the test versus the displacement of the geosynthetic.

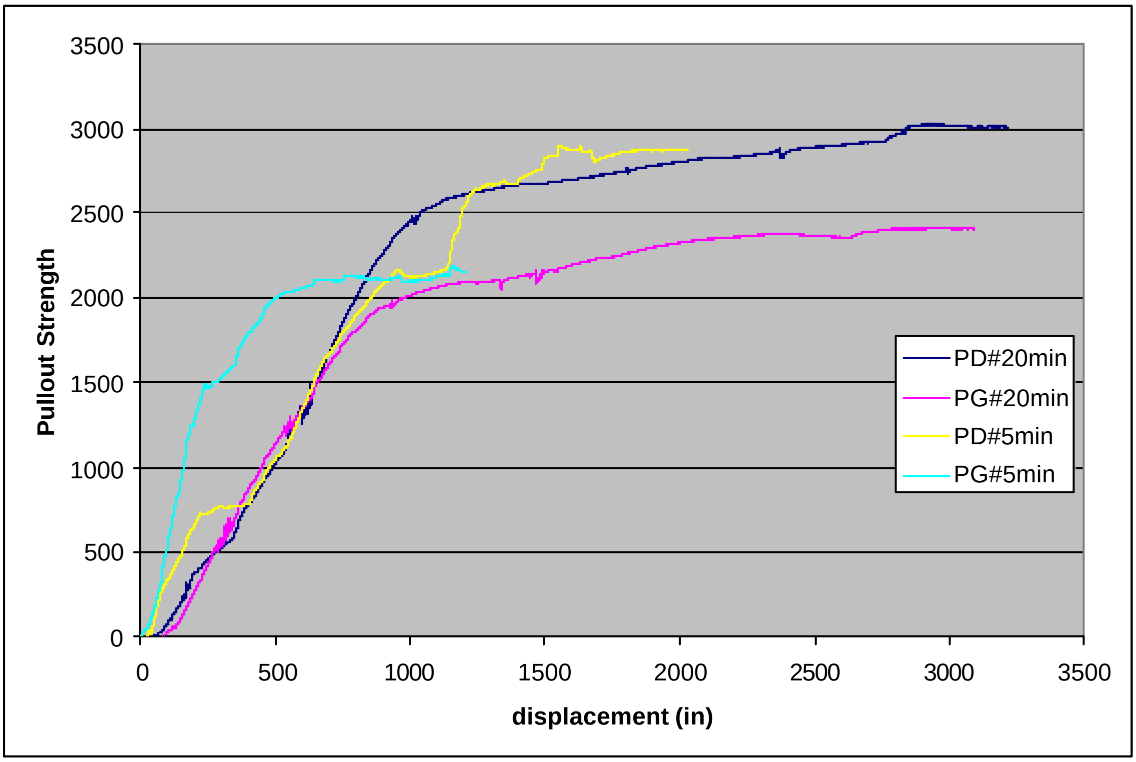


FIGURE 3 – PULLOUT STRENGTH VERSUS DISPLACEMENT (LVDT1) OF THE GEOSYNTHETIC

To show that the paradrain is more efficient at higher initial pore pressure, the relative difference between the pullout strength of the paragrid and the paradrain was analyzed.

The efficiency of the paradrain, considering pore pressure dissipation, can be defined as the difference of pullout strength achieved by paragrid and paradrain at the same initial pore pressure values. In Table 3, it is found that the % difference of the maximum pullout strength of paragrid and paradrain is higher for 5 minutes of consolidation. Therefore, the paradrain is more efficient at higher initial pore pressure values.

Another way to obtain this result of efficiency is to analyze the following equation,

$$\frac{(F_{MAX}^{D} - F^{G}(i))}{F_{MAX}^{D}} \qquad \text{(eq.1)}$$

where:

$F_{MAX}^{D}$ is the maximum pull out strength of the paradrain;

$F^{G}(i)$ is the pullout strength of the geogrid at time i.

The eq.1 is the relative difference between the maximum pullout strength of the paradrain and the pullout strength of the paragrid at time i.

It can be noticed that the higher the difference between $F_{MAX}^{D}$ and $F^{G}(i)$ is, in other words, the higher the result of eq.1 is, the more efficient the geosynthetic is.

This equation was plotted using the maximum pullout strength of the paradrain of 5 and 20 min consolidation time (Figure 4).

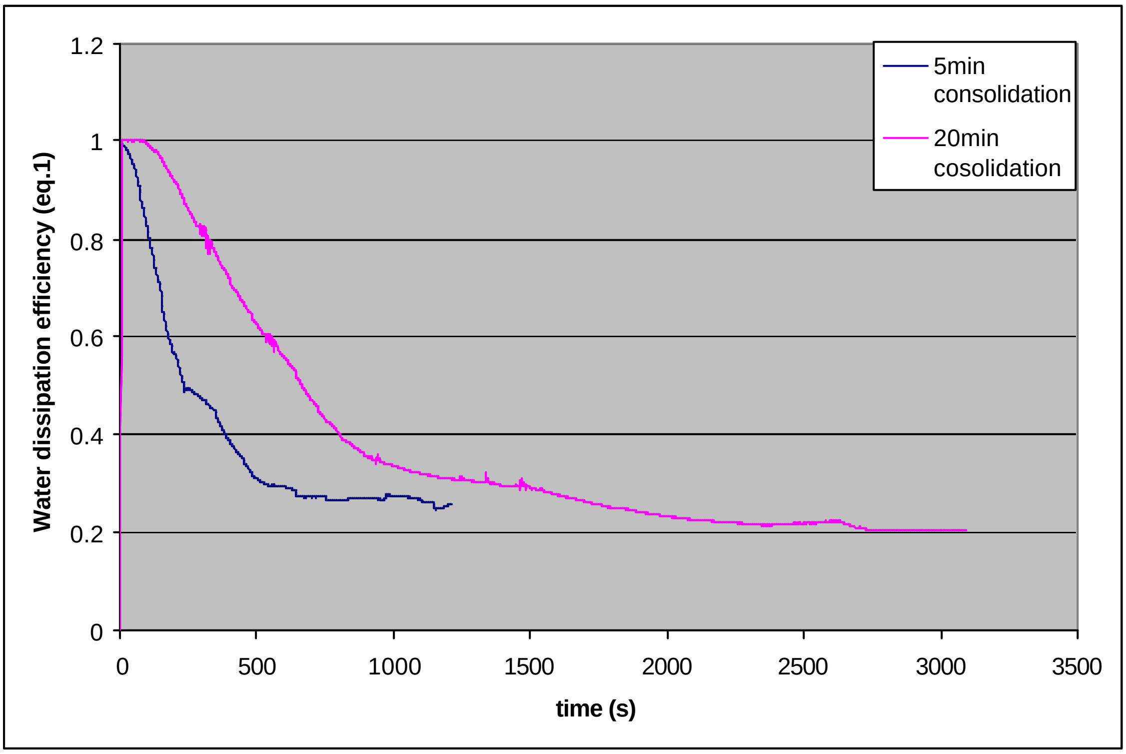


FIGURE 4 – EQ.1 PLOTTED WITH THE VALUE OF 5 AND 20 MINUTES OF CONSOLIDATION

The line of the 5min consolidation (Figure 3) stabilizes at roughly 0.25, and the line of 20min at 0.20. It can be concluded that the geosynthetic with in-plane drainage is more efficient at high initial pore pressure values.

**CONCLUSIONS**

Based on the pullout strength results the following conclusion can be drown:

- Although the pore pressure transducers show that the pore pressure begins at the zero point and increases during the consolidation time, the highest pore pressure in the pullout test is reached right after the normal pressure is applied on the soil.
- The geosynthetic with in-plane drainage is able to dissipate pore pressure
- The higher the initial pore pressure is, the more efficient the geosynthetic with in-plane drainage is.
- These results encourage the use of poorly draining soil reinforced with geosynthetic with in-plane drainage to build mechanically stabilized earth walls.

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