Sakarya University Journal of Science
SAUJS

e-ISSN 2147-835X Period Bimonthly Founded 1997 Publisher Sakarya University
http://www.saujs.sakarya.edu.tr/

Title: Laboratory Experiments on Performance Evaluation of Geocomposite Drainage Materials

Authors: Ayşe ÖZDOĞAN DÖLÇEK

Recieved: 2021-07-05 00:00:00

Accepted: 2021-12-15 00:00:00

Article Type: Research Article

Volume: 26
Issue: 1
Month: February
Year: 2022
Pages: 38-53

How to cite
Ayşe ÖZDOĞAN DÖLÇEK; (2022), Laboratory Experiments on Performance Evaluation of Geocomposite Drainage Materials . Sakarya University Journal of Science, 26(1), 38-53, DOI: 10.16984/saufenbilder.962783
Access link
http://www.saujs.sakarya.edu.tr/tr/pub/issue/67934/962783

Sakarya University Journal of Science 26(1), 38-53, 2022

Laboratory Experiments on Performance Evaluation of Geocomposite Drainage Materials

Ayşe ÖZDOĞAN DÖLÇEK*[1]

Abstract

Method of geocomposite drainage systems (GCDs) is relatively new and has been used as an alternative drainage system for geotechnical applications. The advantages of this system are cost- and time efficiency, environmentally sustainable, and at the same time, having comparable or higher drainage capability compared to current practices. However, the geocomposite materials, which are the main products of the GCD systems, need to meet certain criteria that are required for the sufficient drainage systems. These criteria are mainly related to their hydraulic and mechanical parameters that control the drainage capacity and durability of the systems during/after the construction. In this study, laboratory testing and evaluation of five different commercially available geocomposite products are conducted to improve the understanding of their physical, hydraulic and mechanical properties. Physical properties are defined by measuring their thicknesses and apparent opening sizes. Hydraulic parameters; permittivity (volumetric flow rate of water in normal direction) under various hydraulic head was measured using a constant-head equipment. Additional transmissivity and flow rate are defined under various hydraulic gradient and normal compressive stresses using in-plane flow rate testing apparatus. A number of strength testing; compressive strength, grab tensile strength, elongations, trapezoidal and puncture strength are conducted to evaluate the mechanical behavior of the geocomposite products. Results show that the parameters defined for each product are in the same order of magnitude in corresponding testing program, yet some differences are observed when compared with the manufacturer values. The reason of differences and recommendations on the selection of standard testing methods are discussed. Use of a factor of safety (FS) was suggested in the design of geocomposite drainage system when selecting the geocomposite materials.

Keywords: Geocomposite drain materials, gecomposite drainage systems (GCDs), earth retaining structures, geotextile

1. INTRODUCTION

A main reason for failures of earth retaining walls is related to drainage [1-5]. Most retaining wall failures occur after heavy rainfalls due to surface infiltration or rise of groundwater level. Poor drainage system behind abutment and retaining walls will allow the water built-up behind the wall, thus increasing the hydrostatic pressures that will apply a tremendous amount of additional force on the walls. This reduces soil strength that can lead to catastrophic failure such as soil

---

* Corresponding author: aodolcek@balikesir.edu.tr

[1] Balıkesir University, Faculty of Engineering, Department of Geology Engineering

ORCID: https://orcid.org/0000-0001-9740-2273

collapse or erosion. These conditions therefore can result in damage of the abutment and retaining walls and can cause damage or settlement at locations adjacent to these walls, such as at the approach slabs and expansion and contraction joints. To prevent such damage, it is crucial to have a proper drainage system that permits water away from behind the abutment and retaining walls. A typical retaining wall structures with drainage components are shown in Fig.1.

A proper drainage system must perform the following two functions: 1) to relieve the hydrostatic pressure by allowing water to flow freely throughout the life of the structure, and 2) to prevent settlement by retaining the soil backfill and preventing the migration of soil particles [6]. For the proper drainage systems, geocomposite drainage material should meet the retention, permeability and clogging resistant criteria to perform these function properly [7]. Based on previous drainage application in the design of earth retaining structures, three different drainage method is currently utilized by USA transportation agencies (1) porous backfill around drainage pipe (Figure 2a), (2) porous backfill with filter fabric (geotextile) (Figure 2b), and (3) a geocomposite drainage system along the wall face (Figure 2c) [7].

The first method of porous backfill around drainage pipe requires high-quality graded porous materials that is predefined by the department of transportation agency. However, not all state agency has a sufficient quality control to meet the drainage criteria that prevent the drainage pipes from soil plugging during the construction. The method of porous backfill with geotextile provides better retention and clogging resistance to the drainage systems in the long run [2]. Due to their comparable performance and cost advantages, geotextile have been used successfully to replace the graded porous material [6].

Besides these three drainage systems, there is conventional methods being used commonly for retaining wall drainage system. Drainage system contains weep holes that is drilled through the wall, which relieve hydrostatic pressure by creating a controlled seepage path through the wall. Another method uses perforated pipe behind the wall placed through the length of wall to control drainage. Using a cohesionless granular soil as backfill material is also another method allowing water to penetrate the soil to reach the drain or weep pipes rather than trapping in the structure [2, 6].

In general, the conventional porous backfill drainage system has been well performing except for the fact that it typically requires a high-quality porous material, skilled workers, and considerable time for installation. Thus, alternative drainage systems that are more cost- and time effective, durable, and at the same time, have comparable or superior drainage capability compared to current practice should be evaluated. This study introduces the GCD system that has been used as an alternative drainage method for abutments and retaining walls. Different commercially available geocomposites, which is the main product used in the design of GCD systems are presented.

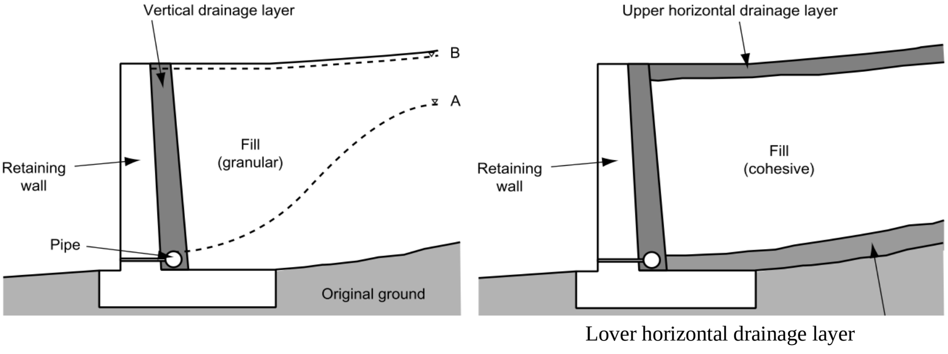


Figure 1 Schematically view of typical retaining wall structures: (a) a wall backfilled with granular resulting in vertical drainage, (b) a wall backfilled with fines resulting in horizontal drainage [2]

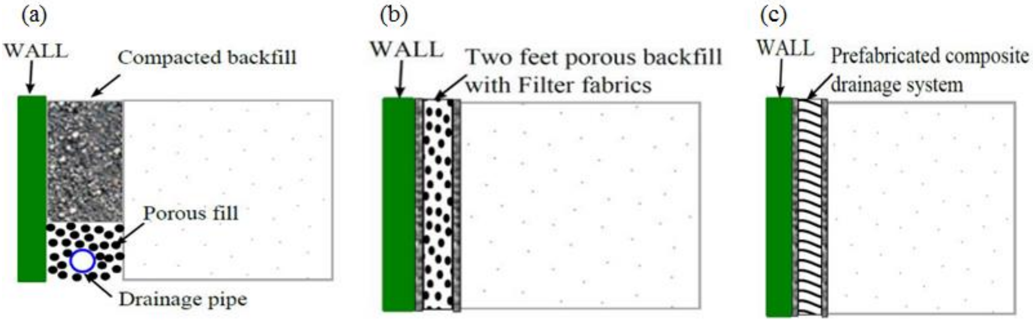


Figure 2 Different drainage methods: (a) porous backfill around drainage pipe, (b) porous backfill with geotextile, (c) geocomposite drainage system [5]

A number of laboratory experiments are conducted to define the drainage and strength properties required for selection of geocomposite materials and to improve the understanding of their functional use in drainage applications. Fig. 3a shows the product of geotextile used in this method. The method of geocomposite drainage (GCD) systems consist of a plastic drainage core bonded with geotextiles (Fig. 3b). Although the application of GCDs is relatively new, it has become increasingly accepted as an alternative drainage method for the structures due to its comparable performance, lower cost, consistent properties, and ease of placement.

1.1. Geocomposite Drainage Systems (GCDs)

GCD systems are defined as the state-of-art application that has been used as an alternative drainage systems in many states in the USA. A detailed assesment of the use of GCD systems behind vertical retaining structures was first published in 1995 by the Geosynthetic Research Institute (GRI) [10]. Similarly, usage of GCDs by various state Department of Transportaions (DOTs) are later uptaded by PenDOT. The report by OhioODOT showed the most current GCDs applications and their spesifications for the states where the GCDs are used [5].

Geocomposites are prefabricated product made by combining different geosynthetic materials including geotextile-geogrids, geotextile-geomembranes and geotextile with nonsynthetics materials (e.g. bentonite clay) which is called as geosynthetic clay liners. Other forms of geocomposite materials are available in literature [11]. Geocomposites are composed of plastic drainage core that is bonded to a geotextile (Fig.3). They are capable of providing more than one function at the same time such as filtration, drainage, separation, barrier and protection. While geotextile filter is preventing soil migration into the drainage systems the drainage core is allowing water to flow. A schematic view of GCD system design and its functions are shown in Fig. 4. They are placed adjacent to foundations and behind retaining walls to mitigate any hydrostatic pressures beneath and behind these structures.

Drainage and strength properties of the geocomposite are the most important parameter for the successful drainage design. A previous study showed that 51% of retaining wall failures was from backfill soil (e.g. clay) used, and 33% of failures was due to insufficient drainage systems [12]. The case study presented the failue of retaining wall occured after heavy rain due to improper backfill soil and poor drainage systems used in the construction [13]. Fig.1 and 2 show the importance of backfill materials and drainage systems used when retaining wall is constructed [2]. To choose proper geocomposite materials for maximum drainage performance, physical, hydraulic and mechanical parameters should meet these requirements; (1) hydraulic requirements, (2) constructability requirements and (3) longevity (durability) requirements [5, 14, 15]. Therefore, a series of laboratory experiment on the hydraulic, mechanical and physical properties of the geocomposite are conducted to ensure that the geocomposite drain meets those design criteria.

Aforementioned design criteria (retention, permeability, and clogging resistance) should be properly met and at the same time the strength and resilience to survive construction and survivability of the drainage system during life of the project must also met in the application of geotextile and geocomposite drainage method [9]. Some states have developed specifications for the method of GCD systems design and construction, including those in California, Colorado, Indiana, Louisiana, Missouri, Nebraska, and New York [5].

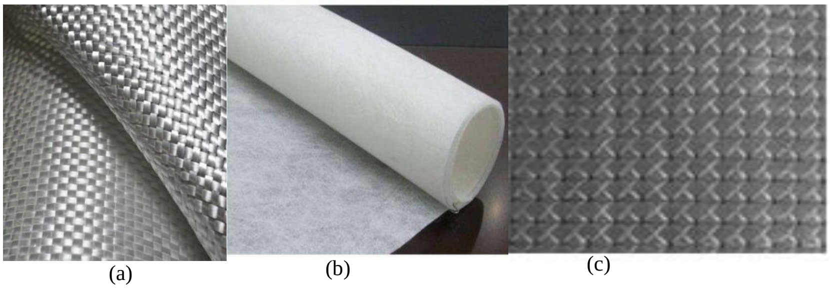
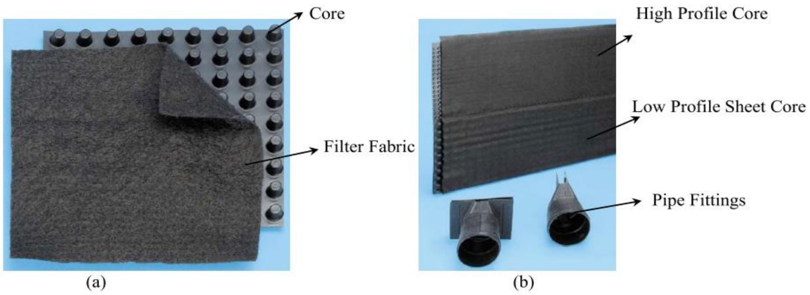
Geotextile (a) woven, (b) non-woven, (c) knitted	
Geocomposite (a) sheet drain, (b) pipe combination drain	

Figure 3 Types of geotextile: (a) woven, (b) nonwoven and (c) knitted and Geocomposite products: (a) sheet drain, (b) pipe drain

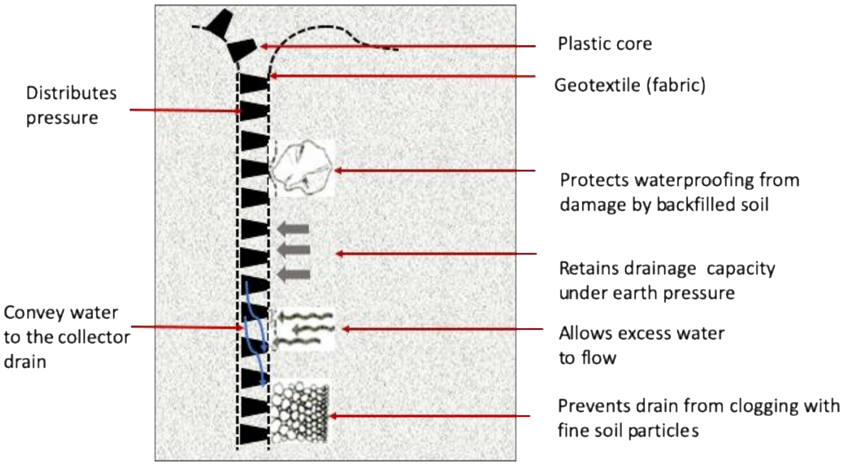


Figure 4 GCD system and its functions in the field (remodified from Maccaferri Geosynthetics [16])

2. MATERIALS AND METHODS

As discussed, the criteria for an efficient drainage system include permeability criteria for both the core and fabric as well as retention and clogging resistance criteria for the fabric. Additionally, the system should have enough strength to survive during construction process and perform satisfactorily during its design life. Therefore, a series of laboratory experiment are conducted to ensure that the geocomposite drain meets those design criteria. Details regarding to each testing procedures can be found in the study by [5].

2.1. Testing Materials

Five drainage geocomposite product were used for the laboratory experiments. All samples were shipped from different suppliers as composites with fabric bonded to the plastic core (Fig. 5). The basic physical features of the five products tested are listed for separate core and fabric in Table 1. The material properties listed in the manufacturer data sheets are for separate core and fabric. In order to compare the tested values with the ones listed by the manufacturers, separate components were requested. However, only separate fabric materials for Products A, C and E were obtained. Since the bonded materials will actually be used in the field, direct testing with the bonded composites is more appropriate. This was particularly the case for the in-plane flow and compressive strength, where only bonded materials were used in this study. The laboratory tests were conducted at the University of Wisconsin-Madison (UW). The test results can be used for design and selection of proper geocomposite drainage systems, and they can also provide a measure for acceptance or rejection of commercial products.

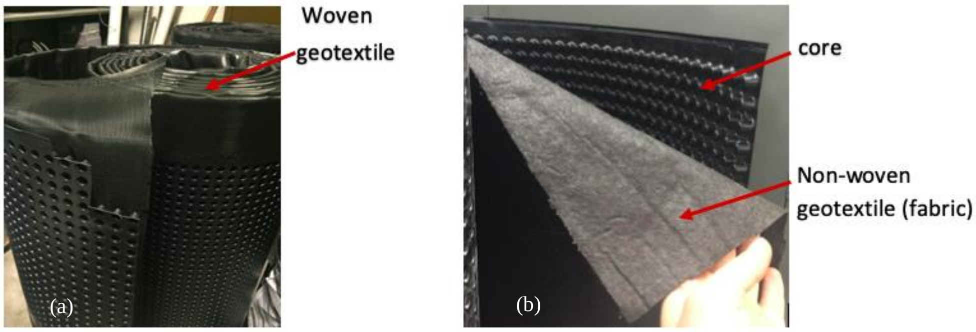


Figure 5 Types of geocomposites used in this study: (a) Woven, (b) non-woven (fabric)

Table 1
Tested products and corresponding material types for separate core and fabric

Products	Core Type	Fabric Type
A	Dimpled drainage core	Needle punched nonwoven
B	Dimpled drainage core	Woven Monofilament FW402
C	Dimpled polystyrene core	Needle punched nonwoven
D	Dimpled drainage core	Nonwoven filter fabric
E	Formed polystyrene core	Nonwoven filter fabric

2.2. Physical Properties of Geocomposite Drainage Materials

Two testing procedures was applied to define the physical properties of the geocomposites as follows:

Thickness measurement for the fabric and core: Nominal thickness of the geosynthetics was determined following ASTM D5199-12 [17] by measuring the distance between two parallel surfaces of test specimens confined under specified normal stress (20 kPa or 2 kPa; Fig. 6). Thickness from manufacturer product sheet are defined for separate core and fabric, but thickness for both composite and separate products were measured in this study. Table 2 summarizes the results that the tested average composite thicknesses under two different levels of normal stress were very close to each other. For the separate core, three samples were received, and the tested thicknesses were slightly less than the values reported by the manufacturer.

Apparent opening size of fabric (AOS): AOS indicates the largest particle that would effectively pass through the geotextile (fabric) and determines the ability of geotextile to retain soil particles. Tests were conducted following ASTM D 4751-12 [18]. Five replicate circular specimens were cut to fit in a sieve (20 cm in diameter) along a diagonal line on the fabric rolls. Specimens were placed in a sieve frame and size-fractioned glass beads were placed on the geotextile surface. Using a mechanical sieve shaker, the specimen and frame were shaken laterally for 15 minutes such that the jarring motion induced the beads to pass through the specimen (Fig. 7). Table 3 summarizes the results.

Figure 6 Testing equipment for geocomposite thickness measuremen

Figure 6 Testing equipment for geocomposite thickness measuremen

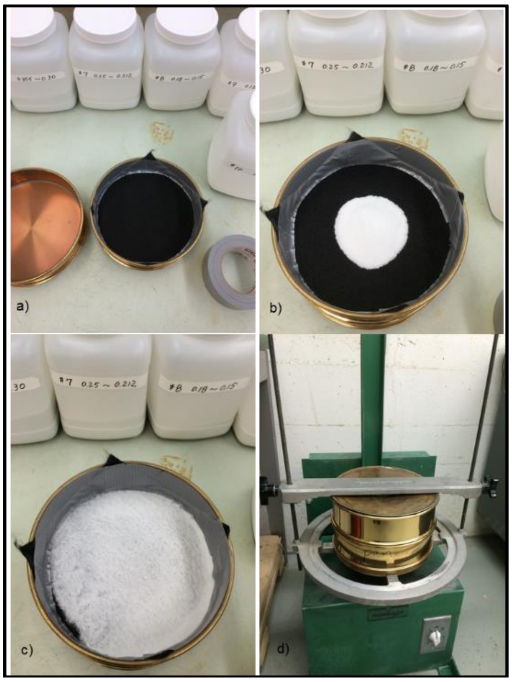


Figure 7 Apparatus for apparent opening size: (a) specimen placed in sieve, (b and c) specimen with glass beads, (d) mechanical sieve shaker

Table 2
Thickness of the composite and separate fabric and core, comparison with manufacturer value

Products	Fabric[1]	Core		Composite		Difference (tested vs. manufac.) %
	Tested (Avg) (mm)	Tested (Avg) (mm)	Manufacturer value (mm)	Tested (Avg.) mm		Core
				at 2 kPa	at 20 kPa	
A	1.21	10.5	11	11	11.2	-4.6
B	0.68	9.3	10.2	10	10	-8.8
C[2]	1.21	ND	10.2	10	10.4	ND
D[2]	ND	ND	10.2	11	11	ND
E	1.06	10	11	11	11	-9.1

[1] No fabric thickness was defined in the manufacturer data.[2]No separate core samples were obtained
ND=not determined

Table 3
Comparison of AOS to manufacturer value

Products	Tested Avg. mm (US Sieve)	Manufac. Value, mm (US Sieve)	Difference (tested vs. manufac.) %
A	0.32 (50)	0.212 (70)	51
B	ND	0.43 (40)	ND
C	0.33 (50)	0.212 (70)	56

D	0.42 (40)	0.425 (40)	-1.2
E	0.36 (50)	0.212 (70)	70

ND= Not determined

2.3. Hydraulic Properties of Geocomposite drainage materials

Main function of the geocomposite products is drainage. In this testing program, permittivity and flow rate in normal direction to fabric of the geocomposite products, and transmissivity or in-plane flow rate of the geocomposite (fabric+core) are conducted to evaluate the hydraulic behavior of each products.

Permittivity and flow rate: The permittivity of separated fabric samples was measured using constant head test procedures following ASTM D4491-99a [19] (Fig. 8a). However, most products have both the permittivity and flow rate values listed on the manufacturer data sheet. Permittivity (Ψ) is the volumetric flow rate of water per unit cross-sectional area per unit head under laminar flow conditions, in the normal direction through a geotextile (fabric) as follows:

$$\Psi = \frac{Q}{A\Delta h} \tag{1}$$

Where ψ is permittivity (sec^{-1}), Q is flow rate of water passed through specimen (cm^3/s), Δh is the measured hydraulic head loss across the specimen (cm), and A is area of the specimen perpendicular to the direction of flow (cm^2). Four products (Products A, B, C and E) were tested for permittivity and flow rate. Four replicate specimens with 5.1 cm in diameter were taken diagonally from a 1-m long section of each full-width fabric roll (Fig. 8b). Hydraulic head was maintained in the range from 10 mm to 75 mm and five readings of flow rate were obtained at each hydraulic head. Head was increased by 5 mm after every five readings. These data were used to define the region of laminar flow for each specimen.

In-plane flow rate: This test was conducted to measure the flow rate per unit width within the manufactured plane of geosynthetics under varying normal compressive stresses and a constant head under the guidance of ASTM D4716/D4716M-14 [20]. The flow rate per unit width was determined by measuring the quantity of water that passes through a test specimen in a specific time interval. Figure 9 shows the constant head (in-plane) flow rate testing device used for this test. Following equation was used to calculate the in-plane flow rate:

$$q = \frac{Q_t}{t\,W} \tag{2}$$

Where q is the flow rate per unit width, m^3/s-m [gpm/ft], Q_t is a measured quantity of water collected during collection time t [s], and W is width of specimen [0.304 m or 1 ft]. Hydraulic transmissivity, which is the volumetric flow rate per unit width of specimen per unit gradient in a direction parallel to the plane of the specimen was calculated from:

$$\theta = \frac{Q_t L}{WH} \tag{3}$$

Where θ is the hydraulic transmissivity [m^2/s] Q_t is a measured quantity of fluid discharged per unit time [m^3/s] L is the length of specimen subjected to the normal load [m], W is the width of the specimen [m], and H is the head difference. A number of specimens from each products were cut in size of 30.5 by 35.5 cm from the roll in two directions; parallel to machine direction (MD) and cross to machine direction (CD) as shown in Fig. 9.

Tested value defined herein in the lab or the value listed by the manufacturer is the ultimate transmissivity value. For field application, reduction factors should be applied to calculate the allowable transmissivity because the drainage capacity can decrease due to various reasons such as infiltration of the fabric into core space [21,5].

Geotextile intrusion occurs under the confining pressure resulting from weight of the soil backfill material. According to ASTM D4716 [20], for index testing, the contact surfaces in the construction should be prescribed by the material specification. In the absence of a specification, rigid sub and superstrates can be used to minimize the variables impacting the test results. In this study only a rigid platen was used. Thus, effects of fabric intrusion on in-plane flow rate was evaluated. The specimen seating period under the applied load was selected as 0.25 h. Additionally, to see the time dependent structural instability of the specimen seating period of 100 hour was used. Testing was performed at various hydraulic gradients of 0.1, 0.5 and 1.0 with normal compressive stresses of 35, 96 and 172 kPa. Test was conducted on fully saturated specimen with standard room temperature.

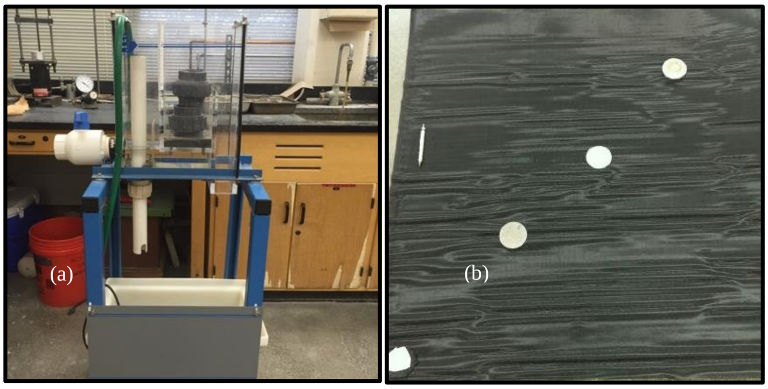


Figure 8 (a) Constant-head permittivity apparatus; (b) example locations of specimens sampled from fabric roll

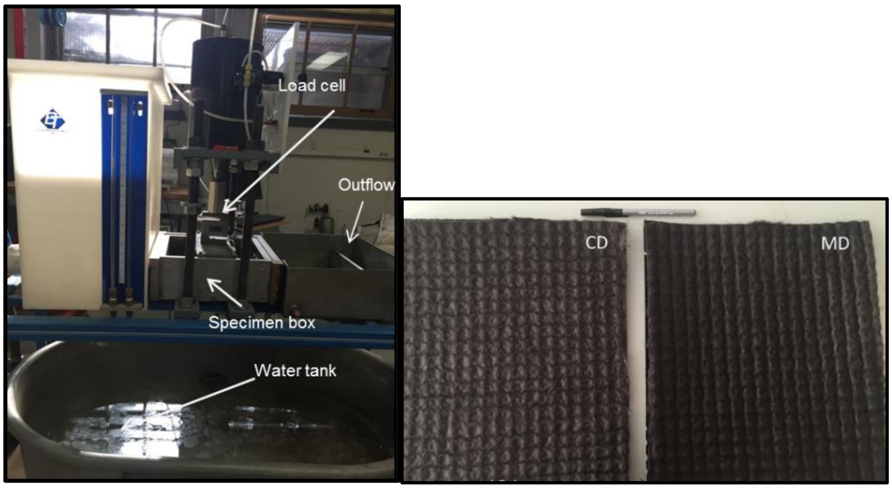


Figure 9 (a) Constant head (in-plane) flow rate testing device; (b) specimen cut into two directions and used for in-plane flow rate test

2.4. Mechanical Properties of Geocomposite Drainage Materials

Geocomposite drainage material should meet the strength criteria for an adequate lifelong drainage system design. To investigate the strength performance of the geocomposites used in this study, strength parameters for separate core and fabric are defined using the testing methods of compressive strength, grab tensile strength and elongation, trapezoidal tear strength, and puncture strength testing as follows.

Compressive strength of the core: This test method is used to determine the compressive properties of the geocomposite products under compressive loads according to ASTM D1621-10 [22]. Typical soil compression testing equipment by GeoTac was used (Fig. 10a). Compressive load and a displacement during test were accurately recorded using load measurement system, and a linear variable differential transformer (LVDT) displacement transducer, respectively. Five square specimens for each geosynthetic product (fabric + core) were prepared within a size of 10 by 10 cm (Fig. 10b). Load was applied with the rate of crosshead displacement of 0.25 mm/min.

Grab tensile strength and elongation of the fabric: Tests were performed according to ASTM Standard D4632/D4632M-15a [23] to quantify breaking load (grab strength) and elongation (grab elongation) of fabric samples separated from the composite fabric. A tension testing machine was used to perform the grab tensile/elongation tests (Fig. 11). Tests were conducted on dry samples at room temperature. The length of the specimen between the clamps at the start of test was set to 7.6 cm. Displacement rate was 30.5 cm/min.

Trapezoidal tear strength of the fabric: Tests were conducted according to ASTM D4533/D4533M-15 [24] to measure the force required to continue to propagate a tear in woven and non-woven geotextiles using the trapezoidal method. Apparatus and specimen preparation were the same as the grab tensile strength test described in the previous section. Tests were conducted on dry samples at room temperature. The length of the specimen between the clamps at the start of test was 2.5 cm and the machine was operated at a displacement rate of 30.5 cm/min.

Puncture strength of fabric: There are two different standards specified to define the puncture strength: ASTM D4833 [25] "Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products" or ASTM D6241 [26] "Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer-Matrix Composite to a Concentrated Quasi-Static Indentation Force." While ASTM D4833 [25] was used in this study, some of the manufacturers used ASTM D6241 [26].

Fabric samples were cut into a diameter of 10 cm and clamped without tension between circular plates of a ring clamp attachment secured in a compressive loading machine (Fig. 12).

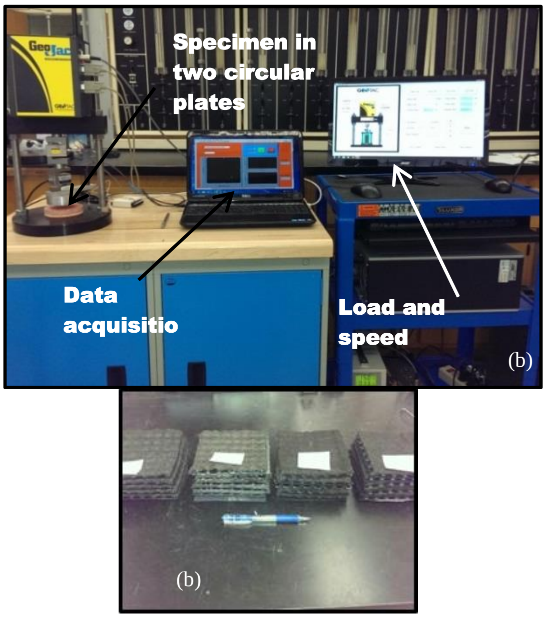


Figure 10 (a) Apparatus for measuring compressive strength of composite geosynthetics (bonded fabric and core); (b) five replicate specimens sampled with dimensions of 10 cm x 10 cm

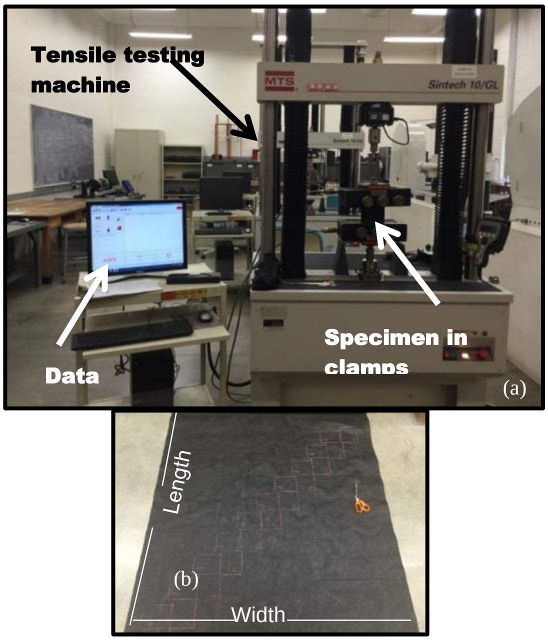


Figure 11 (a) Tensile testing machine used for grab strength and elongation tests; (b) specimens were obtained along a diagonal line across the entire width of the fabric roll and in the machine direction (MD) and cross machine direction (CD)

Force was applied with a solid steel rod and recorded with a load indicator until rupture of the specimen occurred. The maximum force was recorded as puncture strength of the specimen. Tested strength using ASTM D4833 [25] is also called *pin puncture strength*. However, manufacturer values for puncture resistance values are defined using ASTM D6241 [26] is also called *CBR puncture strength*.

There is a correlation between the pin and CBR puncture strengths, considering different geotextile types and test conditions [27]. For nonwoven geotextile under common test conditions (using constant rates of compression of 300 mm/min and 50 mm/min for pin and CBR tests, respectively), the following equation can be used to estimate the CBR puncture strength for nonwoven geotextiles:

$$\text{Strength}_{\text{CBR,estimated}} = 5.27 \times \text{Strength}_{\text{pin,measured}} \quad (4)$$

The tested strength using ASTM D4833 [25] were converted to CBR puncture strength for nonwoven products (A, C, and D) used in this study.

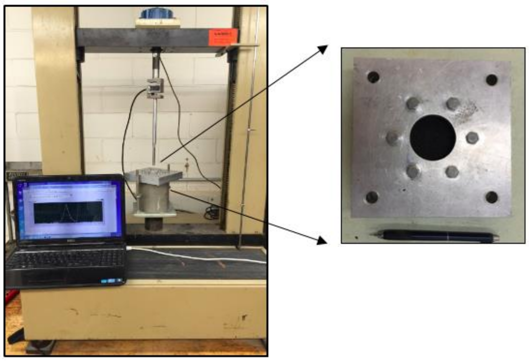


Figure 12 Testing equipment for puncture strength testing

3. RESULTS AND DISCUSSIONS

3.1. Results of Hydraulic Properties of Geocomposite Products

Results of permittivity: Permittivity and flow rate measured with the varying hydraulic head was plotted in Fig. 13. As expected permittivity decreases and flow rate increases with increased head values. Each measurement was confirmed based on the regime of laminar flow defined from the plot of volumetric flow rate versus head as described in ASTM D4491 [19]. Average permittivity value of five readings set at the head of 50 mm was summarized in Table 4. All nonwoven textiles (Products A, C and D) showed lower permittivity than the manufacturer values. Product B has the highest permittivity and flow rate in both tested and manufacturer case. That can be attributed to the fabric type, which is the only sample being woven, and having a highest apparent opening size of 0.43 mm.

Results of in-plane flow rate: Results are presented in three different sections according to effects of fabric intrusion, normal stresses, and time period used for the specimen seating period (short term for 0.25 h and time depended for 100 h) on in-plane flow rate and transmissivity.

Effects of fabric intrusion: Results shows that the existence of the fabric in the specimen tends to reduce the in-plane flow rate significantly in Table 5. In this tested case, the reduction is about 42%. This is caused by the fact that the fabric on the core would go into the part of the clearance space of the core due to the load applied during the test. For the core alone, the tested value was comparable (slightly larger in this case) to the manufacturer value.

Effects of normal stress: The results of in-plane flow rate and transmissivity for the five products (tested on core only) under three levels of hydraulic gradients (i.e., 0.1, 0.5, and 1) and three levels of normal stresses (i.e., 35 kPa, 96 kPa and 172 kPa) are plotted in Fig.14 and 15. It is clear that flow rate nearly linearly increases and transmissivity decreases with increasing hydraulic gradient but not significant change seen with the tested stress levels, which shows that the stress levels used are not sufficient to deform the core. That is similar to previous study showing no structural and hydraulic change occurred up to the compressive stress of 200 kPa [28].

Effects of seating period (creep): For each product, both short-term and long-term in-plane flow rates were tested. The short-term test was conducted with a seating period of 0.25 hours (15 minutes), while the long-term test was conducted with a seating period of 100 hours. This test was conducted to determine if the product shows any performance degradation (creep) with time. Variation of flow rate (in-plane) and transmissivity values in various gradient under different normal stresses for short term and long term are plotted in Fig.14 and Fig. 15, respectively. Table 6 summarizes the results that there were no significant differences between the flow rates for the seating periods of 0.25 hours and 100 hours for Products A, B and E, which showed no deformation or creep under the test loading. Most of the tested products actually showed a higher flow rate for the longer seating period, a result that was not expected. In particular, the flow rates for Products C and D were not well matched for the 0.25- hour and 100-hour seating periods. The flow rates increased by 42% and 9% for Products C and D, respectively, under a normal stress of 3,600 psf (172 kPa) and a hydraulic gradient of 1.0. These results can be attributed to the measurement uncertainty, as it is certain that all testing procedures were conducted under the same conditions, and no problems were encountered during the tests. However, results from longer seating period are more consistent and closer the manufacturer values than the short term period.

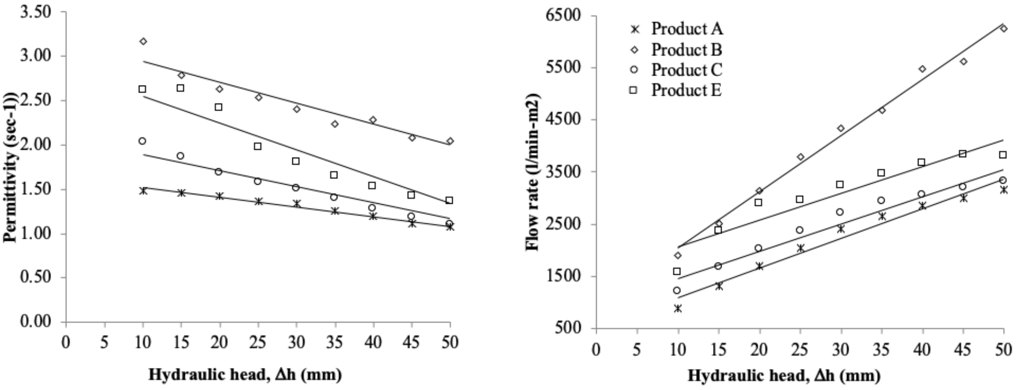


Figure 13 Permittivity and flow rate of geocomposites at various hydraulic gradient

Table 4
Comparison of permittivity and flow rate to the manufacturer value

Products	Tested		Manufac. Values		Difference (tested vs. manufac.)	
	Permittivity sec^{-1}	Flow rate l/min/m^{2}	Permittivity sec^{-1}	Flow rate l/min/m^{2}	Permittivity %	Flow Rate %
A	1.08	3233	1.5	4481	-28	-27.9
B	2.04	6124	2.1	5904	-2.86	3.7
C	1.08	3233	1.5	4481	-28	-27.9
D	ND	ND	NA	5700	ND	ND
E	1.4	4074	1.8	4483	-22.2	-9.12

ND= Not determined;NA= Not applicable

Table 5
Effect of fabric (geotextile) inclusion on the in-plane flow rate of Product A

Products	In-Plane Flow rate (l/min/m)			
	Tested (core+fabric)	Tested (core only)	Difference %	Manufac. Val. (core)
A	180	308	42	282

Table 6
Effects of seating period on in-plain flow rate

Products	In-Plane Flow rate (l/min/m)			
	Tested (core+fabric)			Manufac. Val. (core)
	Short Term 15 min	Long Term 100 hr	Difference %	
A	180.22	185.42	3	281.93
B	217.45	224.62	3	260.82
C	181.42	207.39	13	211.14
D	179.84	195.93	8	223.56
E	217.85	214.66	-1	260.82

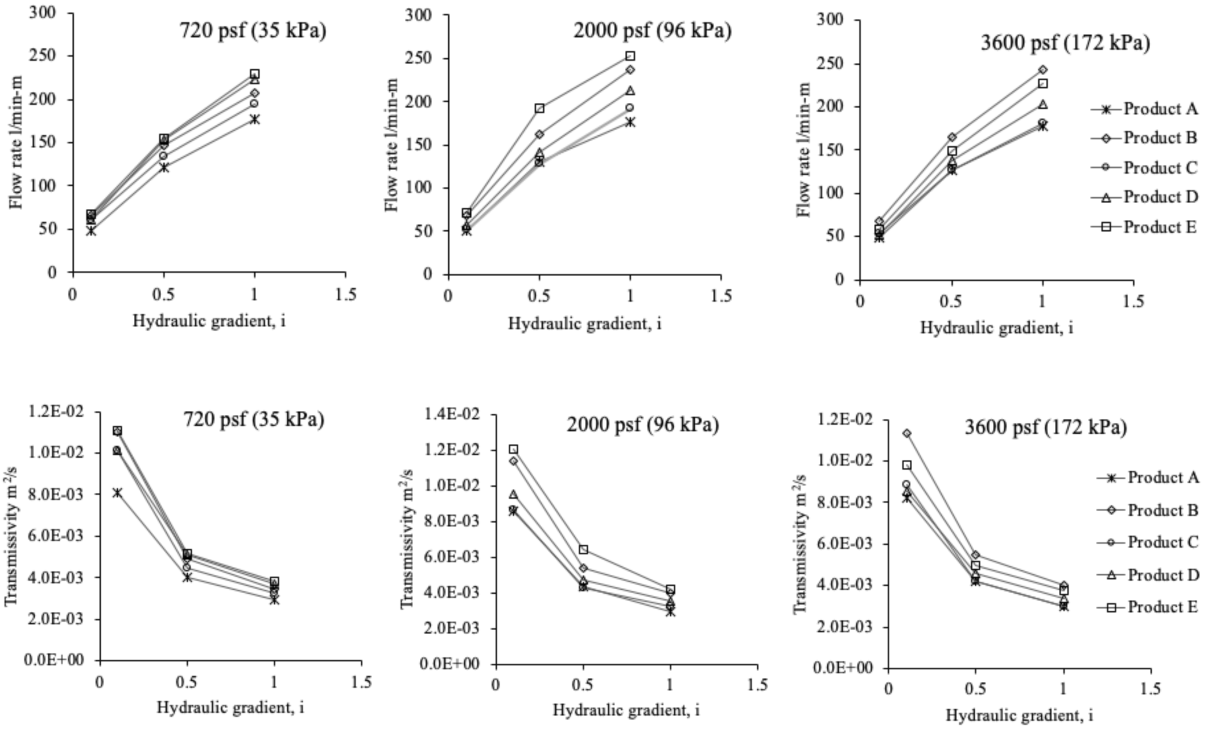


Figure 14 Short term in-plane flow rate (top) and transmissivity (bottom) at the hydraulic gradient of 0.1, 0.5 and 1 under three different normal stresses

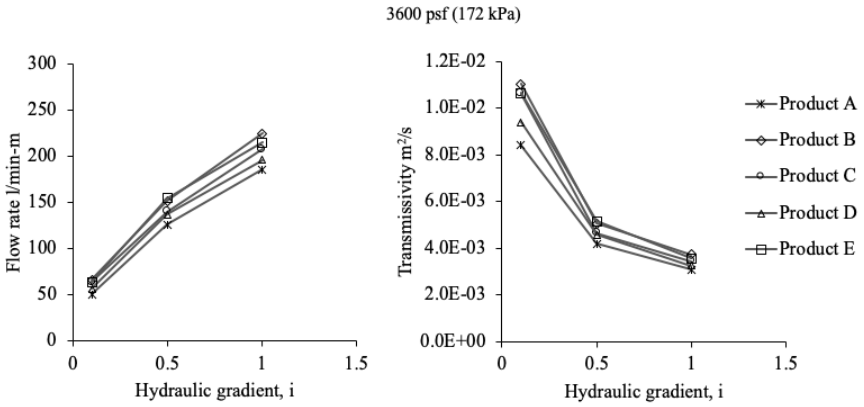


Figure 15 Long term in-plane flow rate and transmissivity for hydraulic gradients of 0.1, 0.5, 1 under a normal stress of 3600 psf (172 kPa)

3.2. Results of Strength Properties of the Geocomposite

All strength parameters defined in the laboratory are summarized in Table 7. The maximum average compressive strengths of five geosynthetics products (fabric + core) and the values from manufacturer (core only) are summarized in the first column in Table 10. The tested compressive strength values for the composite (fabric+core) deviate from the manufacturer values for the core alone. The differences vary from -25.5% to +12.6%. For four of the five tested products, the tested values were lower than the manufacturer values. Possible reasons could be: 1) the manufacturers typically report the strength of the core only; 2) the tests were performed using a single layer of the composite, which has a thickness less than 1 in (2.54 cm) minimum thickness requirement by ASTM D1621 [22]; and 3) a loading rate of 0.1 in (0.254 cm)/min was used, which was a relatively high loading rate for a sample that is thinner than 1 in. Note that the tested products in this study were about 0.4 in (1 cm) in thickness. ASTM D6364 [29] is designed specifically for geosynthetics, and it requires the specimen to be tested at a strain rate of 10% of the nominal thickness per minute or 1 mm/min (0.04 in/min), whichever is greater. Theoretically, ASTM D6364 [29] is more suitable for geocomposite drains. But to be consistent with the manufacturers' tests, ASTM D1621 [22] is followed in this study. It is recommended, however, that ASTM D6364 [29] should be adopted in future testing plan.

For grab tensile and elongation parameters, three products (Products A, C and E) were tested. Two of them (Products A and C) showed higher tested values in the weaker principle direction as compared to the manufacturer values. They also exhibited larger apparent elongation at the breaking load. For trapezoidal strength parameters, three products (Products A, C and E) were tested. The average value of 8 set of tested strength parameters are reported. Two of them (Products A and C) showed higher tested values as compared to the manufacturer values. The trapezoidal tear strength for Product E was not listed in the manufacturer data sheet, so no comparison was done. For puncture strength parameters, the CBR puncture strengths were estimated using the pin puncture strengths using Eq. 4 for nonwoven products (A, C and D). They show higher tested values compared to the manufacturer values. Product D is significantly higher (47%) than the manufacturer value. Product E showed a lower value in the test as compared to the value listed by the manufacturer.

4. CONCLUSIONS

Five geocomposite drain products from different vendors were acquired for index property testing in the laboratory. Physical, hydraulic and strength properties of these geocomposites were tested according to the corresponding ASTM standards. Regarding to the physical properties, thickness for the core and fabric and apparent opening size (AOS) of the products were defined. The tested average composite thicknesses under two different levels of normal stress were very close to each other. For the separate core, three samples were received, and the tested thicknesses were slightly lower than the manufacture values. The thickness of a core is an indirect indicator for the drainage capacity. For every tested product, the tested AOS was significantly larger than the listed value.

The hydraulic parameters were defined from the permittivity and the in-plane flow rate testing for the fabric and core were conducted. All nonwoven products showed lower tested permittivity than the listed values. Since the permittivity and flow rate of a geotextile product are correlated and the permittivity is a value normalized by the differential head across the fabric, it is also recommended to use permittivity, instead of the flow rate, in the specification. Regarding the in-plane flow of the core, it was observed that the presence of fabric tends to reduce the in-plane flow rate significantly. In this tested case, the reduction is about 42%. There were no significant differences between the flow rates for the seating periods of 0.25 hours and 100 hours under the normal stresses levels used in this study. In-plane flow increases nearly linearly with hydraulic gradient but does not change much with the tested normal stress levels, which are not sufficient to significantly deform the core. Compared to the manufacturer-listed values, the tested in-plane flows fall short for all products when the fabric is bonded. When tested using the core only, the tested value exceeded the listed value. Testing the products as a composite (fabric+core) are more suitable as it performs in the field as fabric bounded geocomposites.

Regarding the compressive strength, the tested values for the composite deviated from the manufacturer values for the core alone. The differences varied from –25.5% to +12.6%. For four of the five tested products, the tested values were lower than the manufacturer values. It was later realized that this result may due to the testing method and conditions used. It is recommended that ASTM D6364 [29] “Standard Test Method for Determining Short- Term Compression Behavior of Geosynthetics” be used to test the compressive strength of PCDS, in place of ASTM D1621 [22].

Regarding the puncture strength properties of the fabric, only one product showed significantly higher values than the manufacturer values among the three products tested. It was found that different manufacturers test the puncture strength of the fabric using different ASTM standards. ASTM D6241 [26] is actually more suitable than ASTM D4833 [25] for geotextile materials.

The differences observed between the tested and listed values in most cases could suggest use of a factor of safety (FS) in the design of geocomposite drainage system when selecting the geocomposite materials. Based on the differences, a proposed FS of 3 could be reasonable.

Table 7
The summary of results for the strength parameters and comparison with manufacturer values

Products	Compressive Strength kPa			Grab Tensile Strength N			Elongation %			Trapezoidal Tear Strength N			Puncture Strength N			
	Measured value	Manufac. Value	Difference (measured vs. manufac.)	Measured value	Manufac. Value	Difference (measured vs. manufac.)	Measured value	Manufac. Value	Difference (measured vs. manufac.)	Measured value	Manufac. Value	Difference (measured vs. manufac.)	Measured value	Estimated CBR	Manufac. Value	Difference (measured vs. manufac.)
A	664	892	-25.6%	752	712	5.6%	50.2	50	0.4%	300	267	12.4%	398.7	2101.3	1824.5	15.2%
B	838	862	-2.8%	ND	NR	ND	ND	NR	ND	ND	NR	ND	ND	ND	3003.8	ND
C	674	718	-6.1%	752	712	5.6%	50.2	50	0.4%	300	267	12.4%	398.7	2101.3	1824.5	15.2%
D	809	718	12.7%	ND	NR	ND	ND	NR	ND	ND	NR	ND	309.3	1629.9	1112.5	46.5%
E	839	862	-2.7%	511	712	-28.2%	43.6	70	-37.7%	267	NR	ND	378.7	1995.7	400.5	-5.4%

ND= Not determined; NR= Not recorded

Acknowledgments

This study was conducted with the University of Akron under the project titled “Performance Comparison of Abutment and Retaining Wall Drainage Systems”, which was cooperating with Ohio Department of Transportation (ODOT) and the Federal Highway Administration. Author would like to thanks Prof. Junliang Tao from University of Akron and Prof. William Likos from University of Wisconsin-Madison for their time and professional help throughout the study. Special thanks go to the instrument technologist Xiaodong Wang in the Department of Civil Engineering at University of Wisconsin-Madison for his guidance and help in using the laboratory equipment.

Funding

This study is supported by Ohio Department of Transportation (ODOT) and the Federal Highway Administration. Project Number: 2016-01-02-001.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

Authors' Contribution

The author solemly performed the experimental work and wrote the manuscript.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the article and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

REFERENCES

[1] A. Bobet, “Guidelines for Use and Types of Retaining Devices”, Purdue, IN, Prepared in Cooperation with the Indiana Department of Transportation and the U.S. Department of Transportation Federal Highway Administration, FHWA/IN/JTRP-2001/28, 2001.

[2] G. West, “Review of drainage behind retaining walls,” TRL Report 483, 2001.

[3] H. Moayedi, A. Asadi, and B.Huat, "Effect of Embedding Drainage System on Retaining Wall Structure Stability," Electronic Journal of Engineering Geotechnical Engineering., vol. 16, pp. 157-163, January 2011. [Online]. Available: https://citeseerx.ist.psu.edu/IEEE Xplore, http://www.ieee.org. [Accessed June 28, 2021].

[4] A. Boeckmann and J. E. Loehr, “Design of Maintainable Drains for Earth Retaining Structures,” Department of Civil and Environmental Engineering University of Missouri-Columbia MO, Part of DTRT13-G-UTC37, 2017.

[5] R. Liang, A. Ozdogan-Dolcek, and W. Likos, “Performance Comparison of Abutment and Retaining Wall Drainage Systems,” 2017.

[6] R.D. Holtz, B.R. Christopher, and R.R.Berg, “Geosynthetics Design and Constraction Guidelines,” DTFH61-93-C-00120, 1998.

[7] B.R. Christopher and G.R. Fischer, “Geotextile Filtration Principlas, Practices and Problems,” *Geotextile and Geomembrane*, vol.11,pp. 337-353, 1992.

[8] D.White, S. Sritharan, M. Suleiman, M. Mekkawy, and S. Chetlur, “Identıfıcatıon of the Best Practices for Design, Constructıon, And Repair of Bridge Approaches, Iowa State University, TR 481, 2005.

[9] U.S. Army Corp of Engineers, “Engineering Use of Geotextile,” Departments of The Army And The Air

Force, ARMY TM 5-818-8, 1995.

[10] R.F. Wilson-Fahmy and R.M. Koerner, “Experimental Behaviour of Polymeric Geogrids in Pullout,” *Journal of Geotechnical Engineering,* vol. 120, pp. 661, 1995.

[11] A. Patel, *Geotechnical Investigations and Improvement of Ground Conditions*. Woodhead Publishing Series in Civil and Structural Engineering, 2019.

[12] US Army Corps of Engineers, *Retaining and flood walls*. New York: American Society of Civil Engineers Press, 1994.

[13] S. V Abhishek and V. Tarachand, “Case Study of Failure of Retaining Wall At Dwarakanagar , Visakhapatnam,” 2013, no. December, pp. 1–4.

[14] H. R. Cedergren, *Seepage, Drainage, and Flow Nets,* Third Edit. New York: John Wiley & Sons, 1989.

[15] B. Christopher and A. Zhao, “Design Manual for Roadway Geocomposite Underdrain Systems, Contech Construction Product Inc. Clough,” 2001.

[16] Online Available : https://geosynt.files.wordpress.com/2013/04/maccaferri.pdf) [Accessed June 25, 2021].

[17] ASTM- DESIGNATION: D5199 - 12 “Determination of Nominal Thickness of Geosynthetics” Annual Book of ASTM Standards.

[18] ASTM- DESIGNATION: D4751 “Standard Test Method for Determining Apparent Opening Size of Geotextile. ” Annual Book of ASTM Standards.

[19] ASTM-DESIGNATION: D4491. “Standard Test Methods for Water Permeability of Geotextiles by Permittivity.” Annual Book of ASTM Standards.

[20] ASTM- DESIGNATION: D4716 “Standard Test Method for Determining In-Plane flow Rate of Geosynthetics” Annual Book of ASTM Standards.

[21] A. Bamforth, “Interpretation of In-Plane Flow Capacity of Geocomposite Drainage by Tests to ISO 12958 with Soft Foam and ASTM D4716 with Various Natural Backfill,” 2012.

[22] ASTM- DESIGNATION: D1621“ Standard Test Method for Compressive Properties of Rigid Cellular Plastics” Annual Book of ASTM Standards.

[23] ASTM-DESIGNATION: D4632. " Standard Test Method for Grab Breaking Load and Elongation of Geotextile" Annual Book of ASTM Standards.

[24] ASTM-DESIGNATION: D4533 “Standard Test Method for Trepozoidal Tearing Strength of Geotextile” Annual Book of ASTM Standards.

[25] ASTM-DESIGNATION: D4833/D4833M “Standard Test Method for Index Puncture Resistance of Geomembrane and Related Products” Annual Book of ASTM Standards.

[26] ASTM-DESIGNATION: D6241 “Standart Test Method for CBR Puncture Strength Test of Geotextile” Annual Book of ASTM Standards.

[27] S. Van Dyke, “Comparison of California bearing ratio and pin puncture strength testing used in the evaluation of geotextiles,” 2014.

[28] N. Yarahmadi, I. Gratchev, and D.-S. Jeng, “The Effect of Structural Configuration on Hydraulic Capacity of Geonet Drains Used in Landfills,” *Electron. J. Geotech. Eng.*, vol. 22.15, no. 2, pp. 31-40., 2017.