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The Effect of Structural Configuration on Hydraulic Capacity of Geonet Drains Used in Landfills

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ABSTRACT

The collection and effective removal of leachate represents an important element in the successful functioning of a landfill facility. Geonets are quickly becoming one of the most commonly used drainage materials in leachate collection and removal systems of landfills. According to their geometry and structural configuration, geonets are classified to two main categories named tri-planar geonets and bi-planar geonets. In this research, the effect of ribs configuration on geonets drainage capacity is investigated under different values of compressive stress and hydraulic gradient. The results show that ribs geometry considerably impacts the geonet performance under the range of compressive stress that a drainage material in a leachate collection system is likely to experience during its lifetime. Therefore, the selection of a geonet to maximize flow capacity in the long-term must consider not only the thickness of the strands but also the pattern of the liquid flow channels.

KEYWORDS: Tri-planar geonet, Bi -planar geonet, Drainage capacity, Landfills, Leachate collection systems

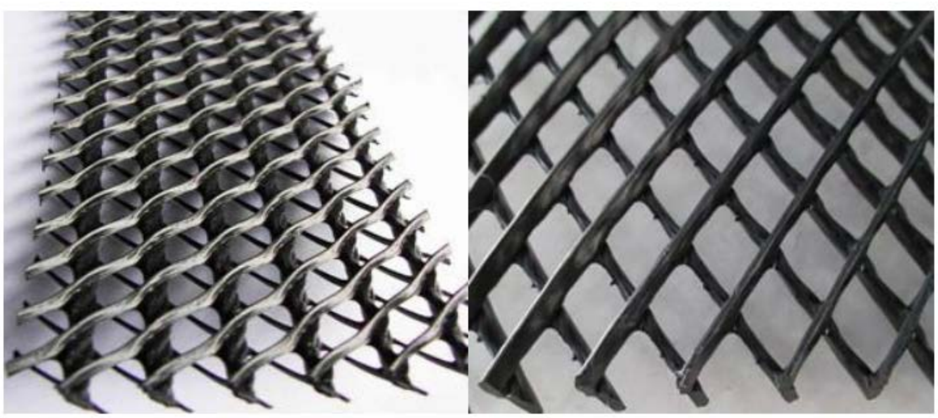
INTRODUCTION

Inappropriate disposal of Municipal Solid Waste (MSW) has been identified as the major part of environmental problems (1). Despite great advances in resource recovery, landfill remains a critically important part of the waste management infrastructure. The technology and performance of MSW landfill facilities has progressively improved in order to address risks to human health, the environment, and operator health and safety. Today, most developed countries have regulations controlling the location, design and operation of landfills. This typically involves limiting the type of waste that can be disposed in the landfill and requiring a barrier system to separate the waste and the associated contaminants from the groundwater system. A barrier system is one of the main components of modern landfills. The system is designed to control contaminant transport and ensure negligible long-term environmental impact for the contaminating lifespan of the landfill. A barrier system typically involves many different components, including protection layers, filtration/separation layers, one or more low permeability liner and a Leachate Collection System (LCS) (2). LCSs are designed in landfills to remove leachate for treatment, disposal, and/or recirculation and to control the head of leachate on the liner system to minimize the quantity of leakage (3). The system should consist of drainage material of adequate long-term hydraulic conductivity to effectively collect the leachate being transmitted through the waste mass.

Geosynthetics are polymeric sheets which are used in civil, geotechnical and environmental projects. These materials are nowadays an accepted and well established component of the waste containment industry. Geosynthetic drainage materials are quickly becoming one of the most commonly used drainage materials in leachate collection and removal systems since they normally offer many advantages over natural soil such as easy quality control, low likelihood of puncture to the adjacent geosynthetic liner, easy placement, stability in slopes, limited space requirement, and generally lower cost (4,5).

According to ASTM D4439: "Standard Terminology for Geosynthetics", a geonet is defined as a geosynthetic consisting of integrally connected parallel sets of ribs overlying similar sets at various angles for planar drainage of liquid or gases. Geonets are usually formed by a continuous extrusion process into a netlike configuration of parallel sets of interconnected ribs (7). In-plane flow capacity is the most important design parameter of geonets used for drainage applications (8). The LCS is one of the most vulnerable components of landfills and most likely to fail during the landfill lifetime (9). To design an efficient LCS, the hydraulic capacity of the geonet used should be investigated over the service lifetime of the landfill which is typically extremely long. Misrepresentation of drainage capacity can result in leachate build-up on the liner system and undesirable functioning of LCS. The serious nature of leachate head on the liner system is concerned as a potential stability issue (10).

According to their geometry and structural configuration, geonets are classified to two main categories named tri-planar geonets and bi-planar geonets. A typical tri-planar geonet consists of three sets of ribs, the first set being the major ribs, which run parallel to the direction of flow, and is sandwiched between two sets of minor ribs bonded on the top and bottom of the major ribs as shown in Figure 1a. A bi-planar geonet, on the other hand, consists of two equally sized sets of extruded parallel ribs on top of each other at different orientations as illustrated in Figure 1b.



(a) (b)

Figure 1: (a) Tri-planar geonet; and (b) bi-planar geonet

In this study the effect of ribs geometry on hydraulic behavior of geonet materials is investigated. For this purpose, the range of compressive stress which geonet is likely to experience during its lifetime in LCSs is first discussed. Then the in-plane flow capacity of tri-planar and bi-planar geonet samples under these compressive stresses is found by performing transmissivity tests. Based on the results, the performance of these two types of geonet is compared in landfills leachate collection and removal systems.

THE RANGE OF COMPRESSIVE STRESS IMPOSED ON GEONETS IN LEACHATE COLLECTION SYSTEMS

The geonet used in a LCS is generally located underneath layers of compacted soil and waste. Thus, there will be dead load over the geonet which is the summation of the weight of each one of the layers on top of it and is calculated using Equation 1:

$$\sigma_{DL} = \sum \gamma_i h_i \quad (1)$$

where σ_{DL} (kPa) is the dead load over the geonet; γ_i (kN/m^3) is the specific weight of each one of the layers on top of geonet material; and h_i (m) is the thickness of the layer.

In typical landfills the volume of waste is considerably more than compacted soil layers which are used in landfills' cover systems to control water and gas movement and to minimize odors, disease vectors and other nuisances. Therefore, to calculate the dead load value, instead of apparent waste unit weight -which is determined by dividing waste total weight by the total landfill volume- usually total waste unit weight is considered (11). To calculate total waste unit weights, it is assumed that a definite percentage of the total landfill volume is occupied by cover soil with a unit weigh generally a few times more than apparent waste unit weight. Multiplying total waste unit in waste height the dead load over the geonet is obtained. Several studies are conducted to determine the total unit weight of waste in landfills. Zornberg et al. (12) utilized spectral surface wave analysis surveys in an effort to describe the total landfill density profile of a MSW landfill by direct field measurements, and found a range of 10 to 14.9kN/m^3 at depths between 7.9 and 50m. Qian et al. (13) reported that a typical total landfill waste unit weight is within the range of 8.6 to 11kN/m^3. Based on in situ measurements, Zekkos et al. (14) reported total unit weights ranging from approximately 11 to 18kN/m^3, generally increasing with depth. Timmoson et al. (11) found a range of 7.3 to 9.1kN/m^3 for apparent unit weight landfill wastes. Assuming the volume occupied by cover soil to be 15% of the total landfill volume with a soil unit weight of 17.3kN/m^3, the estimated total unit weight was calculated to fall in a range of 9.9 to 11.7kN/m^3, with an average of 10.5kN/m^3. It is also important to note that in some cases, the unit weight of waste can be considerably more than the unit weight of common wastes even up to 16kN/m^3 (15). Considering these ranges recommended for waste density and the height of MSW landfills which is often between 25 to 100m (10), it can be concluded that in a normal sized landfill, the dead load imposed over the drainage geonet generally falls in the range of 200-700kPa (15).

In addition to dead load, there will also be live loads imposed on drainage material such as construction loads. If there are layers of compacted soil on top of the geonet, construction and compacting equipment will have to ride on top of the layer. This construction live load may even reach values of 500kPa (15). Considering the value range of dead and live loads, the experiments were performed under compressive stresses ranging from 10 to 1000kPa in this study.

MATERIALS AND METHOD OF TESTING

Test Material

A tri-planar and a bi-planar geonet sample were used in this research to investigate the effect of ribs configuration on geonets hydraulic performance under different values of compressive stress. The physical properties of the samples are summarized in Table 1.

Table 1: Physical properties of tested geonet materials

Property	Unit	Tri-planar	Bi-planar
Mass per unit area (μ)	kg/m^2	0.911	0.732
Polymer density (ρ)	kg/m^3	940	940
Virgin thickness at 2 kPa	mm	6.04	5.38
Porosity	-	0.839	0.855

Transmissivity Test

Transmissivity tests were performed to investigate the effect of structural configuration of geonet materials on flow rate reduction. In the transmissivity test, in-plane flow rate per unit width is determined by measuring the quantity of water that passes through a test specimen in a specific time interval under a specific normal stress and specific hydraulic gradient.

Figure 2 shows the transmissivity test equipment. Transmissivity tests were performed in conformance with ASTM D 4716/D4716M-14: "Standard Test Method for Determining the (in-plane) Flow Rate per Unit Width and Hydraulic Transmissivity of Geosynthetic Using a Constant Head." A geonet is placed in a central chamber between a substrate and superstrate. The loading area is 305x305mm. A hydraulic ram is used to apply compressive stress. A recirculation fluid system provided tap water by gravity feed from a water reservoir. The hydraulic gradient, i, imposed on a test specimen, is controlled through the use of a vertically adjustable standpipe within the reservoir. The difference in head height between the reservoir and weir is determined through the use of digital transducers at the rear of the equipment. The specimen is placed between substrate and superstrate and the sides are sealed parallel to the direction of flow. Then specified normal compressive stress and hydraulic gradients are applied. At least 0.5 litres of water should be allowed to flow through the specimen then the flow is measured using flow rate measurement criteria specified in the standard as a guild for minimum collection volume and maximum collection time. At least three flow measurements must be obtained. Volume of water and collection time are then recorded and used to calculate the measured flow rate. The test water should be maintained at 21 ± 2 ℃ throughout the test duration. .

In this study, Transmissivity tests were performed under four values of hydraulic gradient of 0.05, 0.1, 0.5 and 1.0 and thirteen values of compressive stress of 10, 20, 50, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000kPa.

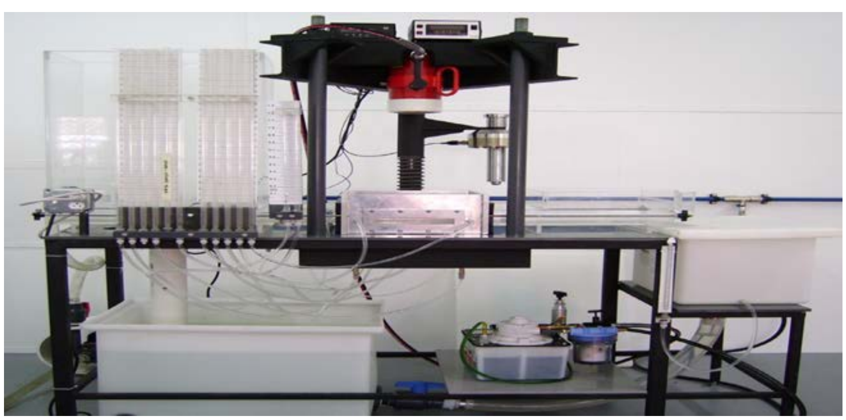


Figure 2: Transmissivity test equipment

RESULTS AND DISCUSSION

Figure 3 shows flow rate of tri-planar and bi-planar geonet samples versus compressive stress, fifteen minutes after load application under hydraulic gradient of 0.05, 0.1, 0.5 and 1.0.

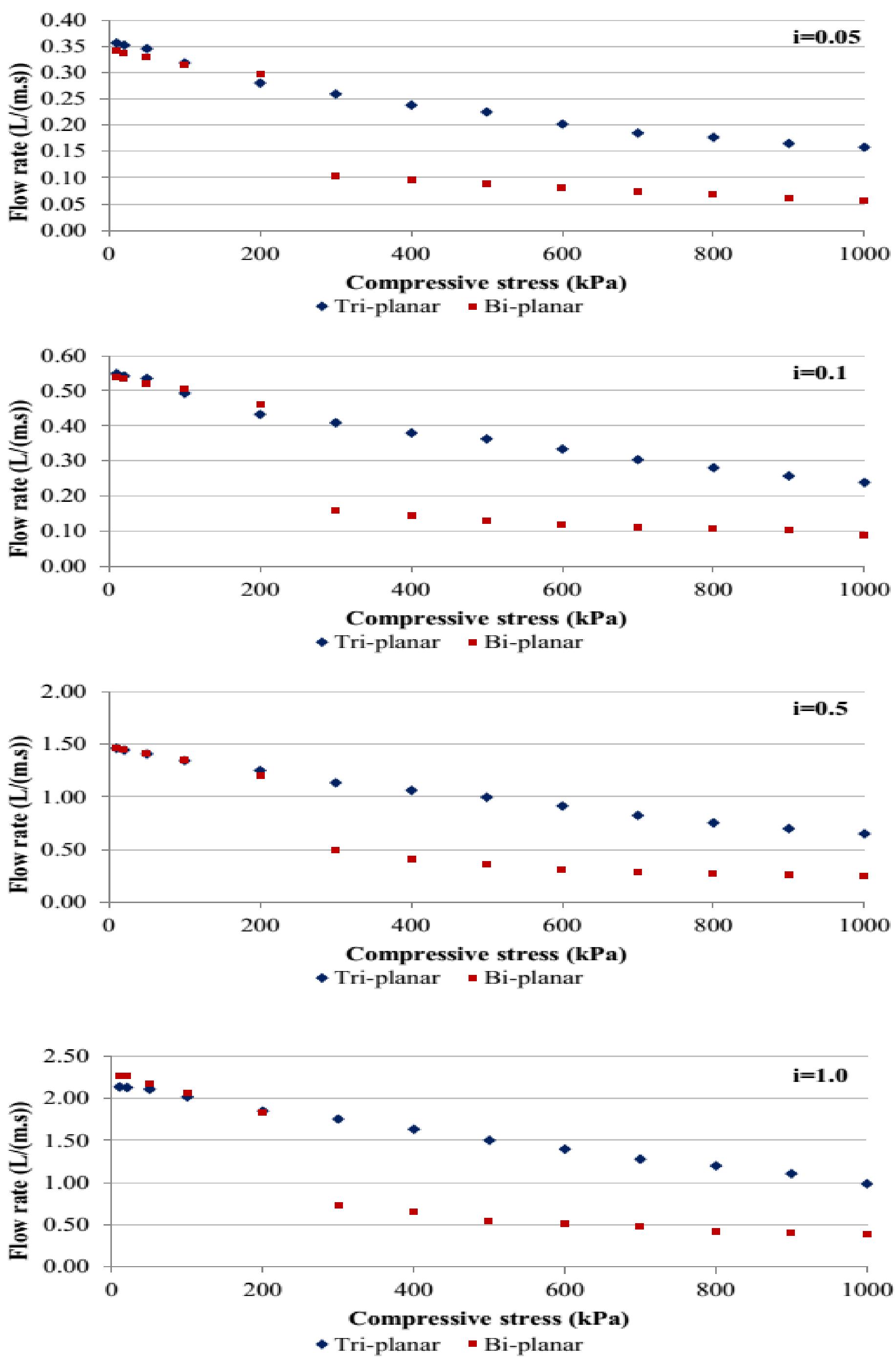


Figure 3: In-plane flow rate of tri-planar and bi-planar geonet versus compressive stress

As seen in the figure, tri-planar and bi-planar samples show almost similar hydraulic capacities under low values of compressive stress i.e. up to 200kPa, however, at higher values of compressive stress, a sudden drop is evident in flow capacity of the bi-planar sample in all four tested values of hydraulic gradient. Figure 4 shows the ratio of in-plane flow rate of the tri-planar sample to that of the bi-planar sample for different values of compressive stress and hydraulic gradient. The figure reveals that the drainage capacity of tri-planar geonet sample is 2.3-3.0 times of that of the bi-planar sample in compressive stresses higher than 200kPa.

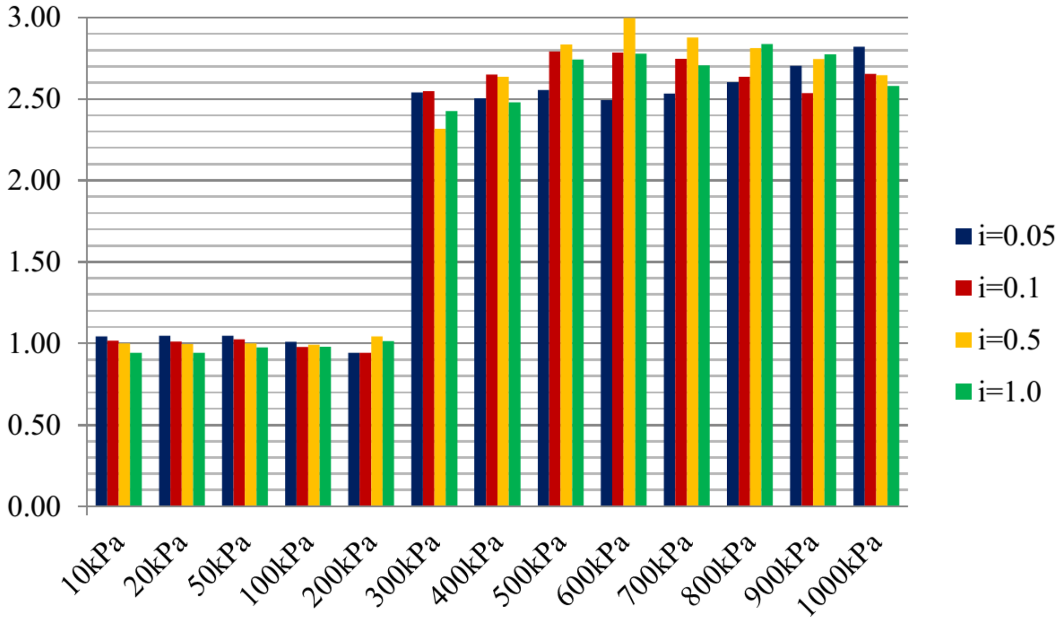


Figure 4: The ratio of drainage capacity of the tri-planar geonet sample to that of the bi-planar sample for different values of compressive stress and hydraulic gradient

Flow capacity of a geonet drain is closely related to its thickness (17). Figure 5 illustrates the thickness of the geonet samples versus compressive stress. As expected, the abrupt change is also detectable in the thickness of the bi-planar sample at compressive stresses higher than 200kPa.

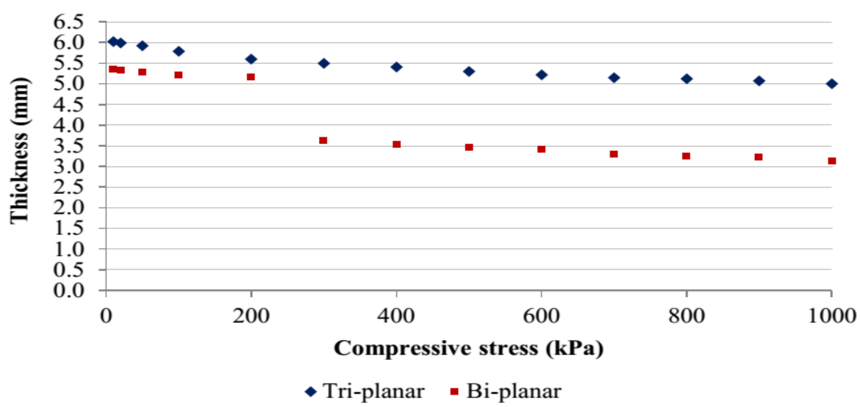


Figure 5: Thickness of tri-planar and bi-planar geonet samples versus compressive stress

As the physical properties of two geonet samples including polymer density and porosity are almost similar, the sudden thickness reduction of the bi-planar geonet sample is concluded to be attributed to configuration of the ribs. In other words, this behavior of the bi-planar geonet must have been caused by some level of collapse of the geonet structure for larger stress levels. Figure 6 shows the bi-planar and tri-planar geonet samples under compressive stress values of 100 and 1000kPa. As seen in this figure, the drop in thickness and consequently in drainage capacity of the bi-planar geonet is resulted from the ribs reorientation: in high compressive stresses, while the lower ribs orientation remains almost unchanged, upper ribs slip over the lower ones and their orientation -which is almost vertical in low compressive stresses- changes to almost horizontal. This phenomenon is known as upper rib roll-over in bi-planar geonets (18). The sets of upper and lower ribs are not exactly perpendicular to one another at the intersection point and also each rib. Because of this non-perpendicularity, when the compressive loading is applied to the bi-planar geonet, the initial response is quite stiff, however it begin to deform above critical pressure (19). This roll-over effect can influence the flow rate capacity of the bi-planar geonet. After roll-over the geonet can still transport liquid, but somewhat diminished in rate.

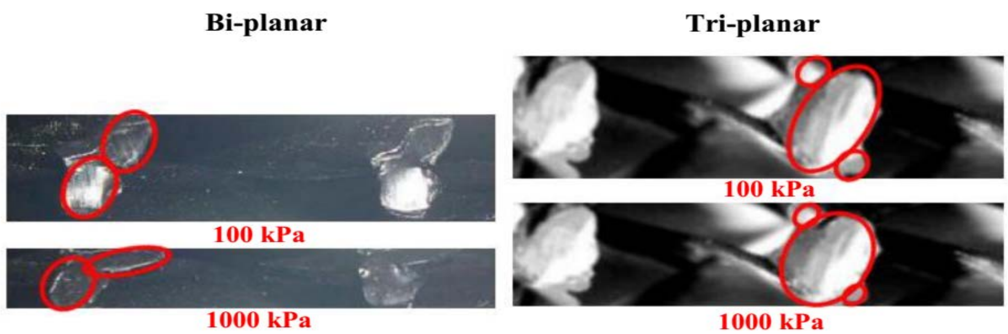


Figure 6: Bi-planar and tri-planar geonet samples under compressive stress of 100 and 1000kPa

Upper ribs roll-over phenomenon is exclusive to bi-planar geonets due to their particular ribs pattern. In tri-planar geonets, the flow is essentially governed by the ribs having a large cross section area. Therefore it is assumed that tri-planar geonets can be approximately modeled by one set of identical cylinders having a diameter equal to the geonet thickness (20). In other words, in tri-planar geonet the main ribs set acts like a single solid element under load and therefore the geonet thickness and consequently its drainage capacity decreases gradually by increasing compressive stress. Figure 7 shows a schematic view of ribs deformation pattern for tri-planar and bi-planar geonet materials.

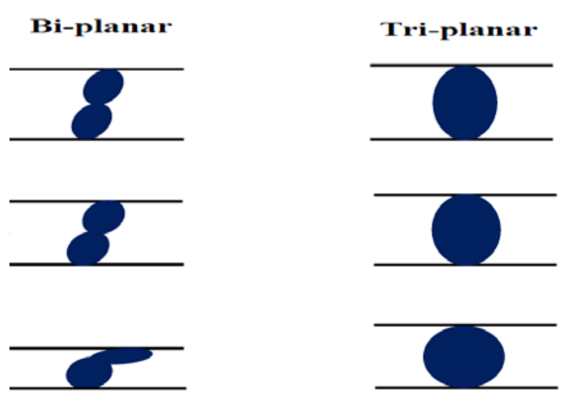


Figure 7: Schematic view of ribs deformation pattern for bi-planar and tri-planar geonets

Therefore, to have a better understanding of the hydraulic behavior of bi-planar geonets, it is important to find the compressive strength which is the start point of the roll-over (21). The application of bi-planar geonets is not recommended if the material is supposed to be subjected to a stress level higher than the compressive strength during its lifetime as the hydraulic capacity decreases dramatically beyond this point.

CONCLUSIONS

Transmissivity tests were performed on a tri-planar and a bi-planar geonet samples under a range of compressive stresses to investigate the effect of ribs configuration on geonets drainage capacity and estimate their performance in landfills leachate collection and removal systems. The results showed that:

- The hydraulic behavior of the two types of geonet was almost similar in low compressive stresses up to 200kPa regardless of their ribs geometry. However, the reduction in flow capacity was dependent on the structure of the geonet in compressive stress higher than 200kPa, and was smaller for the tri-planar geonet in which flow is governed by the main ribs set. The drainage capacity of the tri-planar sample was 2.3-3.0 times of that of the bi-planar sample at all four values of hydraulic gradient for the higher stress level.
- In bi-planar geonets, the sudden drop in drainage capacity is attributed to ribs reorientation. Although the lower ribs orientation remains almost unchanged, upper ribs slip over the lower ones and their orientation changes from almost vertical in low compressive stresses to almost horizontal in high compressive stresses. This phenomenon is known as upper ribs roll-over in bi-planar geonets. After roll-over, the bi-planar geonet can still drain liquid, but somewhat diminished in rate.
- To have a realistic estimation of the hydraulic behavior of bi-planar geonets, it is important to find the compressive strength. Extrapolation of the transmissivity test results performed under a lower compressive stress to find flow rate capacity at higher compressive stresses is not recommended in bi-planar geonets because of the potential of roll-over phenomenon
- As the normal pressure resulting from dead loads live loads in leachate collection and removal systems in landfills usually exceeds the compressive strength of bi-planar geonets, tri-planar geonet are recommended for installation in these systems. However, the utilization of bi-planar geonets still could be considered in landfills wherever the compressive stress stays in non-roll-over region e.g. landfill cover systems.

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