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The effect of thickness reduction on the hydraulic transmissivity of geonet drains using rigid and non-rigid flow boundaries

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ABSTRACT

In this paper, relationships between in-plane flow capacity reduction and thickness reduction are presented in tri-planar and bi-planar geonets for rigid and non-rigid flow boundaries. Using these equations, the long-term flow capacity of geonets can be determined using creep test results. To validate these relationships, geonet thickness was measured under different conditions and the theoretical values of the transmissivity reduction ratios were calculated by substituting the results in the equations. Transmissivity tests were then performed under the same conditions to obtain experimental values of the reduction ratios. A comparison showed that the theoretical and experimental values of the transmissivity reduction ratios were in agreement, and the relationships provide a useful tool to predict the drainage capacity of both tri-planar and bi-planar geonets influenced by loading pressure. However, special precautions must be taken when applying the equations to investigate the hydraulic capacity of other types of geosynthetic drains as well as when the geonet is covered by geotextile material acting as a filter between the geonet and adjacent soil, is overlain by geosynthetic clay liner material where the swelling potential of the bentonite in the geonet exists, is placed in inclined positions or is subjected to complex combinations of load.

1. Introduction

Geosynthetics have been effectively used as drains in civil and environmental works (Jang et al., 2015) including landfill, mining, landscaping and any kind of construction that requires the management of liquid or gas infiltration. Geonets are quickly becoming one of the most commonly used drainage materials because of their limited space requirements, factory-controlled properties and generally lower cost (Eith and Koerner, 1992) ease of transport and installation (Da Silva and Palmeira, 2013), and also contributions to bearing capacity of soft soils (Bazne et al., 2015).

Hydraulic transmissivity is the most important design parameter of geocomposites used for in-plane drainage applications (Bourges-Gastaud et al., 2013). For a geonet to function efficiently in drainage systems, proper knowledge of the geonet's hydraulic behaviour over the service lifetime is required. If the flow capacity of the geonet is underestimated, the system design will be too conservative and thus lead to unnecessary costs. Conversely, overestimation of a geonet's flow capacity can result in undesirable functioning of the drainage system.

The flow capacity of geonets is affected by various factors. A series of environmentally related issues can have an impact on the flow rate performance of geosynthetic drains (Koerner, 2012). Long-term clogging of drain openings can significantly affect the drainage capacity of geonets. Clogging involves a combination of biological, chemical and physical processes (Rowe, 2005). Physical clogging results from an accumulation of inorganic particles that were originally suspended in passing fluid. Chemical clogging usually occurs because of the production of substances such as calcium carbonate, which results in precipitation of inert material that accumulates on available solid surfaces and blocks voids. Biological clogging is usually initiated by forming a biological system known as biofilm where bacteria are organized into a coordinated community (Correia et al., 2017). As biofilms grow larger, they can combine with other neighbouring biofilms and create a natural biological filter that contributes to the reduction of pore space and the hydraulic conductivity of the material (Mlynarek and Rollin, 1995). A one dimensional numerical model, Bioclog, which was developed and extended to two dimensions (Cooke et al., 2005; Cooke and Rowe, 2008; Rowe and Yu, 2013) allows the

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modelling of the clogging of porous media and can be used effectively to quantify the effect of clogging on the hydraulic capacity. Temperature is another environmental factor that influences the hydraulic behaviour of geonet materials. In standardized laboratory test conditions, under a high temperature, flow rate increases as expected according to the theoretical effect of temperature on hydraulic conductivity. Temperature also has a significant effect on the rate of clogging because of the increased biological activity associated with increasing temperature (Armstrong, 1998). It has also been shown that geonet transmissivity can be substantially reduced by an increase in temperature when the geonet is in contact with a geosynthetic clay liner (GCL) because of the higher swelling potential of bentonite (Davies and Legge, 2003). Other factors such as placement on a side slope where a combination of normal and shear stress acts on the drainage material (Yeo, 2007), dynamic loading, and lateral displacement can also affect the in-plane flow capacity of geonets.

Disregarding the above-mentioned factors, the parameters that mainly control the geonet hydraulic capacity include the intensity and duration of applied stress, the physical and structural characteristics of the geonet and the properties of adjacent construction materials (Fannin and Choy, 1995).

Although the hydraulic transmissivity test is the most common method to investigate geonet flow capacity, conducting the test over a long period to obtain the long-term flow capacity of a geonet is too time consuming and is typically considered impractical. Conducting a short-term transmissivity test and using reduction factors to consider the impact of local deformations and compressive creep behaviour was the first design recommendation to calculate long-term flow capacity; however, later studies showed that real decrease in water flow capacity can be much higher than is taken into account by short-term generated reduction factors (Zanzinger et al., 2010). Moreover, recommended reduction factors are not categorized based on geonet physical properties. In other words, the same values of reduction factors are recommended for all types of geonets. Further, wide ranges of values are usually recommended for reduction factors, and choosing the appropriate value is another routine problem. However, by performing creep tests, a geonet's long-term thickness can be reached easily and reliably. Applying methods such as the stepped isothermal method can reduce the creep test time to within a day. The results of this short-term accelerated test have shown it has high reliability to its real long-term creep tests for geonets (Mok et al., 2012), and it is approved and explained by standards, for example, ASTM D7361–07 (2012): Standard Test Method for Accelerated Compressive Creep of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method. Simulation of service conditions—for example, by putting the geonet specimen in an inclined position or between different materials—is also more practical in a creep test than in a transmissivity test. Therefore, theoretical relationships that relate geonet in-plane flow capacity to its thickness can contribute considerably to better estimation of long-term hydraulic behaviour and consequently the efficient and safe design of geonets. Using such equations, the long-term flow capacity of geonets can be determined using creep test results.

In this study, theoretical relationships that quantify the effect of thickness reduction on transmissivity reduction in low hydraulic gradients were first derived for two different types of geonets. Geonet thickness was then measured under different conditions and the results were substituted in the equations to find the theoretical values of the transmissivity reduction ratios. Transmissivity tests were also conducted under the same conditions to acquire corresponding experimental values of the reduction ratios. Finally, the theoretical and the experimental values were compared to validate the proposed relationships.

2. Background

2.1. Previous research

The relationship between hydraulic behaviour and the physical properties of geosynthetic material and flow boundaries has been discussed previously in the literature. Giroud et al. (2000b) concentrated on the parameters that affect both the short- and the long-term thickness of geosynthetics and proposed a relationship between thickness and hydraulic transmissivity reduction, using Kozeny–Carman's law, which relates porosity to hydraulic conductivity. Palmeira and Gardoni (2000, 2002) showed that Giroud's equations can accurately estimate the permeability in non-woven geotextiles based on physical properties such as porosity and fibre density. Jarousseau and Gallo (2004) investigated long-term flow capacity in relation to the long-term thickness of four types of drainage geocomposites, demonstrating that flow capacity is closely related to thickness, and calculated transmissivity reduction factors based on the estimation of thickness reduction factors. Jaisi et al. (2005) also used Giroud's equation and derived transmissivity reduction factors due to creep and compression for various geonets and geocomposites to investigate their hydraulic behaviour in the Sa Kaeo landfill in Thailand. Müller et al. (2008) introduced another method to deduce long-term flow capacity from thickness reduction. In their method, residual long-term thickness is extrapolated and the pressure necessary to enforce this residual thickness in a short-term experiment is determined. The flow capacities measured under this pressure at various bedding conditions is defined as long-term flow capacity. Giroud et al. (2012a) concentrated on the impact of flow boundaries on hydraulic behaviour and quantified the effect of rigid and smooth flow boundaries on two physical characteristics of geosynthetic drains as a function of the thickness and the size of the solid constituents of the geosynthetic. The authors showed that although the effect of flow boundaries on needle-punched, non-woven geotextiles is negligible, this effect on geonets can be significant; however, the research was purely theoretical and researchers were encouraged to perform tests to evaluate the theoretical results. It was also shown that in geosynthetic drains, the degree of turbulence depends on the applied compressive stress and the material in contact with the drain (Giroud and Kavazanjian, 2014). Jeon (2014) investigated the correlation between the normal pressure and the transmissivity of bi- and tri-planar geonets and showed that a significant reduction in flow capacity was observed for the traditional bi-planar geonet. This decrease was anticipated owing to the abrupt thickness decrease in the geonet caused by roll-over. On the other hand, no significant decrease was observed in the transmissivity for the tri-planar geonet, which did not roll over.

2.2. Theoretical model

The in-plane flow capacity of geosynthetic materials is usually defined by hydraulic transmissivity, the product of hydraulic conductivity and thickness:

$$\theta = k.t \tag{1}$$

where θ (m^2/s) is the hydraulic transmissivity of the geosynthetic, k (m/s) is the hydraulic conductivity of the geosynthetic and t (m) is the thickness of the geosynthetic.

In the case of laminar flow, the hydraulic transmissivity of a porous medium can be expressed using the classical