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Laboratory evaluation of flexible pavement structures containing geocomposite drainage layers using light weight deflectometer

Jean-Pascal Bilodeau [a, *], Guy Doré [a, 1], Catherine Savoie [b, 2]

[a] *Civil Engineering Department, Université Laval, Quebec, QC G1V 0A6, Canada*
[b] *Service de l'exploitation des CS de la Capitale Nationale, Ministère des Transports du Québec, 5353, boulevard Pierre-Bertrand, Québec, QC G2K1 M1, Canada*

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ABSTRACT

The behaviour of flexible pavement structures in wet environments is significantly influenced by the infiltration of excess water. The use of geocomposite drainage layers is an alternative to promote rapid removal of any infiltration of excess water. Using four small-scale flexible pavement test sections, this laboratory study focused on measuring the effectiveness of the different configurations of geocomposite drainage layers in terms of reduction in water content and improvement of mechanical properties during a drainage period. The experiment allowed measuring the significant effects of each drainage configuration on pavement structural strength in the short-term and long-term drainage behaviour of each experimental pavement structure. The shallow drainage blanket, as well as the vertical drain, showed a more pronounced effect in the top layer of the structures, while the deep drainage blanket showed a limited effect. From the results obtained, a drainage configuration combining a shallow drainage blanket with a vertical drain may be optimal.

1. Introduction

Flexible pavement performance is significantly influenced by climatic conditions, especially in northern environments where freeze-thaw cycles and abundant precipitations are frequent (Doré and Zubeck, 2009). In pavement design, water is recognized as one of the key parameters that needs to be controlled in order to ensure good performance (Uthus, 2007; Uthus et al., 2006; Witczak et al., 2000; Richter, 2006; Lebeau, 2006; Doré and Zubeck, 2009; Bilodeau and Doré, 2012; Savoie et al., 2012; Ekblad, 2007; Carrera et al., 2009), and modern pavement geometry and design techniques are focused on providing adequate drainage to eliminate water underneath the pavement surface. However, to a certain extent, the presence of moisture in the pores of unbound granular materials and soils can have a positive effect. This is due to a confining stress, referred to as matric suction, generated under the unsaturated state at the air–water interface (Fredlund and Rahardjo, 1993; Lebeau, 2006). The matric suction increases with a decrease of the degree of saturation. Geomaterial mechanical properties are influenced to varying degrees by this stress parameter. An increase of matric suction is generally associated with an increase of stiffness and bearing capacity (Witczak et al., 2000; Bilodeau et al., 2010; Arnold et al., 2002; Bilodeau and Doré, 2012; Theyse, 2002; Uthus, 2007). Water infiltration through pavement surface produces excess water in pavement geomaterials due to subhorizontal flow, capillary rise and frost suction (Doré and Zubeck, 2009; Lebeau, 2006; Swanson, 1985; Brandl, 2001). As a result, their mechanical properties may decrease as the environment changes through the yearly cycle (Doré and Zubeck, 2009; Huang, 2004). Because of that, the rapid removal of excess water is vital to ensure good behaviour of soils and materials in the layered pavement system.

Geotextile drainage layers have been used over the last decades to remove excess water from the pavement structures. These layers typically have a hydraulic conductivity significantly higher than geomaterials. They are typically used in the pavement system as drainage blankets at various depths in the pavement layers or as vertical drains at the pavement edge. Good results were generally obtained in previous experimental or modelling projects where geotextile layers were used to improve the drainage of pavement

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* Corresponding author. Tel.: +1 418 656 2131x7242; fax: +1 418 656 2928.
E-mail addresses: jean-pascal.bilodeau@gci.ulaval.ca (J.-P. Bilodeau), guy.dore@gci.ulaval.ca (G. Doré), catherine.savoie@mtq.gouv.qc.ca (C. Savoie).
[1] Tel.: +1 418 656 2203; fax: +1 418 656 2928.
[2] Tel.: +1 418 643 0095x229.

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test sections (Bilodeau et al., 2014; Lebeau, 2006; Lafleur and Savard, 1995; Collins et al., 2005; Christopher et al., 2000; Al-Qadi and Appea, 2003; Loulizi et al., 1999; Perkins et al., 2005; Scott et al., 1998; Evans et al., 2002; Bahador et al., 2013). The work done by Christopher et al. (2000), Evans et al. (2002) and Scott et al. (1998) showed that geotextile drainage blankets placed in the lower part of the pavement structures can effectively remove excess water. This conclusion is partly supported by the work done by Collins et al. (2005), who concluded that geotextile may contribute to base materials stiffening over time for thinner pavement sections, while there were no significant effects on thicker pavement sections. Geotextile used as vertical drains on the pavement sides also effectively reduced water infiltration from the shoulders (Blond and Mlynarek, 1999; Blond et al., 2000) and would correspond to the best pavement configuration regarding pavement structural response following a saturation event (Bilodeau et al. 2014). However, limited data are found on experimental research work done in controlled laboratory environments. Therefore, this research aims to quantify the mechanical properties and drainage capacity of laboratory small-scale flexible pavements constructed in the laboratory with geosynthetic drainage layers. It is proposed to use the light weight deflectometer (LWD) to measure the surface deflections and mechanical properties of the pavement structure.

2. Materials and methods

Four experimental small-scale flexible pavement sections were built in the laboratory. One of the test sections is the control section without any drainage layer. The other three sections were built with three different drainage configurations: drainage blanket between the base and the subbase (DB-B-SB), drainage blanket between the subbase and the subgrade (DB-SB-SG) and a vertical drain (VD). The 7 mm thick vertical drains are non-woven geotextiles assembled by the needling process and made of polypropylene. The filter opening size (FOS) was 150 μm and the weight was 900 g m^{-2}. The materials used for the drainage blankets are made of non-woven polypropylene fibers assembled by the needling process. Each blanket consisted of a drainage layer and perforated drainage tubes positioned every 300 mm (20 mm external diameter), both inserted between filtration layers (FOS of 120 μm). The weight of the drainage blanket product is 400 g m^{-2} and its total thickness (excluding the drainage tubes) is 3.9 mm. For the test conditions, the transmissivity is 2×10^{-4} and 5×10^{-4} m^2 s^{-1} for the vertical drain and the drainage blanket, respectively.

The sections were built inside a circular container having a height of 1.3 m and a diameter of 1.2 m as shown in Fig. 1. A 200 mm open-graded drainage layer (OGDL) was placed at the bottom of the container and connected to a drainage line. A geotextile was placed at the top of the OGDL prior to the construction of the other pavement layers. The pavement structures that were tested for the four configurations consisted of a four-layer system: 500 mm of subgrade (SM), 300 mm of subbase (SP), 200 mm of base (GW) and 50 mm of dense graded asphalt concrete (classified as EB10S, a surfacing asphalt concrete used in Quebec with a nominal maximal particle diameter of 10 mm). This structure is similar to full scale regional and local pavement structures encountered in Quebec built for low traffic conditions and medium subgrade soil frost sensitivity. For example, a local pavement designed for 1×10^5 ESALs (Equivalent Single Axle Loads) on a silty sand soil (SM) (with a fines content lower than 30%) would consist of 60 mm of asphalt concrete, 200 mm of granular base and 300 mm of granular subbase. As Quebec road network includes many kilometers of low volume regional and local roads, the tested pavement structure in the laboratory are of great interest. Fig. 2 presents the grain-size distribution of the materials used for the test sections. This figure also summarizes the main gradation parameters, such as the uniformity coefficient Cu, the mean diameter d_{50} and the fine particles percentage $\%F$. According to USCS soil classification, the base, subbase and subgrade soil are classified as GW, SP and SM respectively. The hydraulic conductivity of the three materials was measured in a previous study (Savoie et al., 2012) and is equal to 9×10^{-6}, 5×10^{-5} and 2×10^{-6} m s^{-1} for the base, subbase and subgrade materials, respectively.

For each experimental section, the subgrade, subbase and base were compacted approximately at 90, 95 and 98% of their respective modified optimum proctor. In order to verify the compaction level of the layer during construction, the mass and average water content of the soil placed in the tank was measured, as well as the thickness of each layer. This was done by weighing the mass of soil inside each bucket added in the tank, by measuring the water content of each compacted layer using the microwave method and by measuring the average depth difference before the soil was added and after the soil was compacted. A slope of 2% was profiled at the top of each layer between the centre and the wall of the container. Most of the time, the water contents of the compacted layers were slightly less than the optimum moisture content. After compaction of the asphalt concrete, nine drainage holes were drilled inside this layer to ensure adequate air circulation. As shown in Fig. 1, the test sections were equipped with individual volumetric water content transducers at the centre of each layer. The volumetric water content θ_V is expressed as

$$\theta_V = \frac{V_W}{V_T} = n \times \mathrm{Sr} \tag{1}$$

in which V_W is the water volume, V_T is the total volume, n is the porosity and Sr is the degree of saturation. Referring to Fig. 1, the DB-B-SB was positioned along the horizontal plane in which the line a–b is included, the DB-SB-SG was positioned along the horizontal plane in which the line c–d is included and the VD was positioned along the vertical plane a–b–c–d–e–f. Because of the particular container geometry and configuration, when a drainage blanket was used, a vertical drain was used from the blanket level to the bottom of the subgrade layer in order to make the configuration work. For full-scale pavements, the drainage blanket would be able to drain at the pavement sides. In the container, as water evacuation is located at the bottom of the container, the drainage blankets were connected to vertical drains to ensure that the blanket system worked properly.

Following construction of the test sections, each of them was saturated using a water reservoir connected to the bottom drainage line. The water level was gradually increased using a water head of 6 inches until the water level reached the bottom of the asphalt concrete layer. This was verified using the piezometer (Fig. 1). Measurements of the mechanical behaviour of the experimental small-scale pavement structures were made when saturation had completed. The mechanical behaviour was measured by a light weight deflectometer (LWD) equipped with a loading plate having a diameter of 150 mm. The plate diameter was selected in order to ensure minimized stress levels at the tank edges during LWD loading. Previous studies (Boutet et al., 2010; Nazzal et al., 2004) showed that the selected configuration is adequate for this container, as the zone of significant stress does not reach the tank wall. A mass of 20 kg was used and the drop height was adjusted in order to obtain a contact stress of approximately 560 kPa. A rubbermat was used between the asphalt concrete surface and the LWD as recommended by the manufacturer. It was demonstrated by Nazzal et al. (2004) that the depth at which the LWD induces