Evaluation of the effectiveness of permeable paver in sight of water presence

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ABSTRACT: This article considers the evaluation of the effectiveness of permeable paver when submitted to loads and to contact with pluvial water. The use of the permeable paver is an option to assist the drainage processes. However, it has been used without considering the infiltrating water that enters in contact with the structure of the pavement, causing the pumping of fines and harming all of its stability. Therefore, it was aimed to prove through tests, the loss of the bearing loading support of the permeable paver's structure when it is saturated. Three distinct tests had been carried out through in equipment developed by Góngora (2015), which consisted of the cyclic load application on the structure with dry and saturated base, for the first and second test respectively, and in the third test the load was applied on a structure that was reinforced with a woven geotextile and then saturated. The loads were applied with a frequency of 1Hz and with an intensity of approximately 18.2kN. The test was finished when the vertical displacement of the structure reached 25 mm. The structure with the dry base bore the application of 20.230 load cycles, the saturated structure bore the application of 2.230 load cycles and the saturated reinforced structure bore 19.457 load cycles. After said tests were carried out, it was possible to verify the influence of water in the structure's stability and also the necessity of counting on reinforcement between the layers of this pavement, thus guaranteeing a larger bearing loading support.

Keywords: Permeable paver, Geosynthetics, Stormwater.

1 INTRODUCTION

The urbanization has created an increase in impermeable surfaces in the cities and consequently has been reducing the infiltration of water in the soil. Due to those problems, the permeable paver was developed; its use consists of an option to assist the drainage processes and also allows the development of cities without interfering directly in the infiltration capacity of the soil.

However, the permeable paver thickness design has been made without considering the fact that the infiltrated water enters directly in contact with its structure. Once it happens, the stability of the structure can be harmed, since the saturation of the granulate layers occurs simultaneously with the application of loads proceeding from traffic. It causes the pumping of fines, which leads to deformation and loss of the load bearing capacity of the pavement.

Since there are already reports on deformation in the interlocking pavements, caused by water presence, it is believed that the study of the behavior of the permeable paver's structure is necessary, considering that the interlocking paver allows the infiltration of only 3% of the precipitation that falls on them, whereas the permeable paver allows the infiltration of 100% of said water.

From the attainment of this knowledge about the permeable paver's structure, the identification of the layers affected by the presence of the water becomes possible and the elaboration of efficient solutions as well.

Therefore, it was aimed to prove through tests the loss of the load bearing capacity of the structure when it is saturated and the necessity of counting on reinforcement.

2 EQUIPMENT

The equipment used for the tests was developed by Góngora (2015) and is found at the University of Brasilia (UnB). Figure 1 illustrates the equipment.

Figure 1. Equipment used in tests.

The equipment consisted of a concrete cylindrical tank, with 1000 mm in internal diameter and 520 mm high, where the structure of the permeable paver was installed.

To simulate loads proceeding from the traffic, a hydraulic system composed for: joint engine-bomb; relief valve; valve directional solenoid; hydraulic high-pressure hoses; manometer, hydraulic cylinder and a timer were used. (GONGORA, 2015)

The equipment also counts on a reaction frame, that made possible the application of a vertical cyclic load with the intensity of 18.2 kN and a frequency of 1 Hz on a 200 mm diameter steel plate, that was placed on the surface of the structure.

Moreover, two displacement transducers were used to measure the platen vertical displacement and the vertical displacement at points on the surface of the structure, and a load cell measured the intensity of the vertical cyclic load applied.

In order to acquire and record the readings made from the displacement transducers and the load cell, a system of acquisition of data and a microcomputer were used.

3 MATERIALS

3.1 *Subgrade material*

The subgrade layer consisted of a silty clay soil, classified in the group A7-6 (HRB Classification), that was collected from the Ayrton Senna Sport Complex located in the National Stadium in Brasilia. In order to know the characteristics of the soil and its properties, the result of the tests supplied by the Consórcio Legado Brasília, carried out by: Reforsolo Engineering, Soltec Engineering LTDA. and Costa Brava Projects and Constructions LTDA were used.

The parameters of the soil are presented in the Table 1 and the Figure 2 brings its particle size distribution.

Table 1. Geotechnical parameters of the subgrade soil.

Soil Parameters	Value
Optimum Water Content (%)	31
Maximum Dry Density (g/cm³)	1,49
California Bearing Ratio (CBR) (%)	6,8
Liquid Limit (%)	38
Plastic Limit (%)	25,7
Plasticity Index (%)	12,3

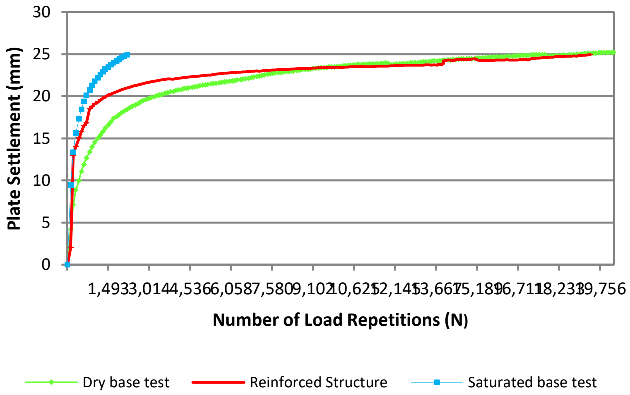

Figure 2. Particle size distribution soil subgrade.

3.2 *Base material*

In the base layer the materials used were macadam and small stones, the latter were used to fill the voids in the layer.

3.3 *Laying course material*

In the laying course, it was used a fine artificial sand with a density of 2,7. The particle size distribution curve is presented in Figure 3.

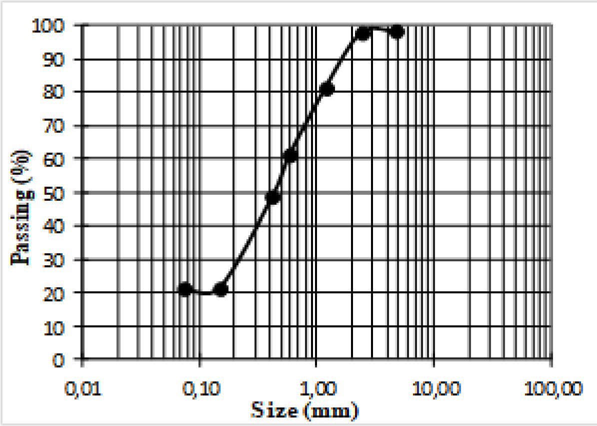

Figure 3. Particle size distribution of the laying course sand.v

3.4 *Surface layer*

In the surface layer it was used a rectangular permeable paver; that measured 20 cm in length, 10 cm in width and 8cm in high.

3.5 *Reinforcement material*

A woven geotextile was used as reinforcement for the structure. This geotextile is formed by a fabric manufactured from polyester filaments. Table 2 presents the properties of the geotextile.

Table 2. Woven geotextile properties.

Properties	Value
Longitudinal resistance traction (kN/m)	45
Transversal resistance traction (kN/m)	45
Length of the Resistance of last traction (%)	30
Mass per unit area (g/m²)	200
Geotextile AOS (mm)	1,264
Thickness (mm)	0,5
Permittivity (s-¹)	0,7

4 EXPERIMENTAL PROCEDURE

The comparison of the results of three distinct tests was used to evaluate the performance of the structure of the permeable paver. These tests consisted of the application of a cyclic load on the structure in three different situations: in the first test the base was dry; in the second it was saturated and in the third test the base was saturated and reinforced with a geotextile. The tests were interrupted when the vertical displacement of the structure reached 25mm.

The loads had simulated the loading of a single axle vehicle with dual wheels carrying a load of 80 kN, that was applied in order to have a maximum vertical stress of 560 kPa transferred to the surface of the structure.

4.1 *First test*

In the first test, as mentioned above, the load was applied on the structure with the dry base. Figure 4 presents the disposal and thickness of the layers of the structure.

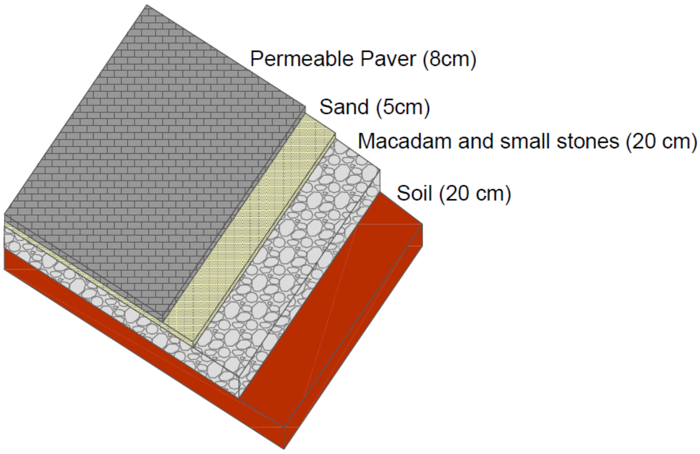

Figure 4. Schematics of the layers of the structure in the first and second test.

The structure of the permeable paver was installed in the concrete cylindrical tank. The subgrade material was compacted in two layers (100 mm each) with a static compaction, and 117,20 Kg of soil was used per layer.

In the base layer macadam was used, and after it reaching 200 mm of height the small stones were placed. A rubber hammer was used to generate a light vibration and make sure that all the voids were filled by the small stones. The laying course (50 mm high) consisted of fine artificial sand.

On the surface layer, where the permeable paver was installed, the joints of the paver should have been filled with small stones in order to interlock them, however, by an error of execution that was not done in the first test.

Once the installation of the permeable paver was finished, it was proceeded to the test with the application of loads.

4.2 *Second test*

In the second test, the load was applied on the structure with a saturated base. Since water would be used in the saturation of the structure, an asphalt blanket was applied in the concrete cylindrical tank, in order to keep the water inside the structure during the test.

The thicknesses and the procedures used in the layers were similar to the one used in the first test. After the installation of the permeable paver, the small stones were sprinkled on the paver’s surface and a rubber hammer was used to compact them.

To saturate the structure 50 L of water were used. The criterion applied to define the amount of water used to saturate the structure was the observation of the layers; once water was detected in the base layer, the test began. Figure 5 portrays the execution of the test.

Figure 5. Second test execution.

4.3 *Third test*

In the third test, the loads were applied on the surface of a saturated structure reinforced with a woven geotextile. Figure 6 presents the disposal and the thickness of the layers of the structure.

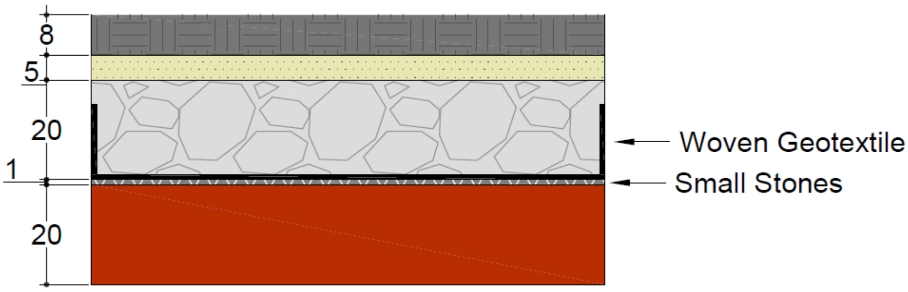

Figure 6. Schematics of the layers of the structure in the third test (dimensions in centimeters).

The geotextile was placed in the interface base-subgrade, since they are the most requested layers in the structure and, therefore, where there was a greater necessity of reinforcement.

A 1 cm layer of small stones was added over the subgrade layer, before placing the geotextile, in order to provide a better adherence of the geotextile to the structure.

The geotextile extremities were folded in the base layer to guarantee its anchorage and avoid problems during the application of the loads. After placing the geotextile, the procedures used in the other layers were similar to those mentioned above in the previous tests.

As the purpose was to submit this structure to the same conditions of the structure in the second test, 50 L of water were again used for its saturation. Once the structure was saturated, the application of the loads began.

5 RESULTS AND ANALYSIS

5.1 *Presentation of the results*

In the first test, the maximum vertical displacement (25 mm) was reached after a number of 20.230 load repetitions. Due to the error in the installation of the permeable paver, the data of this result will not be taken as relevant in the conclusion of the research, but only as means of comparison to the performance of the other structures.

In the second test, the maximum vertical displacement was reached by the saturated structure after a number of 2.230 load repetitions. And in the third test, the reinforced structure reached the vertical displacement of 25 mm after a number of 19.457 load repetitions.

5.2 *Comparison of the results*

Comparing the results of the tests, it is possible to notice the influence that the water has in the structure's stability, and also the importance of counting on a reinforcement in a pavement that was meant to allow water infiltration.

The saturated structure has reached the maximum vertical displacement after a few number of load repetitions, particularly when this number is compared with that yielded on the first test where the interlocking of the pavers was not done.

Figure 10 presents the comparison of the vertical displacements versus the number of load repetitions gotten in the tests.

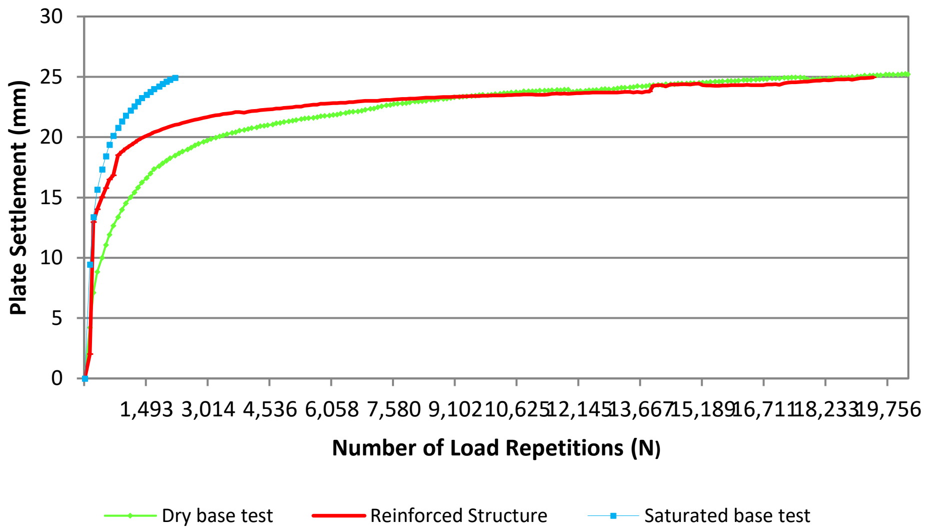

Figure 10. Plate Settlement of the structures of the three tests versus number of load repetitions.

As it was presented in Figure 10, the saturated and the reinforced structure had shown a similar behavior in the beginning of the test. However, after reaching 15 mm of vertical displacement, it was possible to notice a loss of stability on the saturated structure, that ended up reaching the maximum vertical displacement (25 mm) quickly.

The reinforced structure, on the other hand, had its performance improved by the action of the woven geotextile. The geotextile acted distributing the load applied and making the structure work together, in order to support it without harming its stability. Due to this reinforcement, the structure was capable of bearing up to eight times more numbers of load repetitions than the saturated structure.

Moreover, an analysis was made in the layers of the saturated and the reinforced structure after the tests, and it was possible to verify that each structure has presented a different type of deformation.

The layers of the saturated structure presented a deformation only where the loads had been applied, which means that the load were bore by one spot in the whole structure. It explains why the maximum vertical displacement was reached after a fewer number of load repetitions when compared with the other structures.

The reinforced structure had a completely different behavior, and while observing its layers it could be noticed the action of the geotextile in the improvement of the structure's performance. Differently from the saturated structure, the layers did not present an accented deformation in the spot where the stresses had been transferred, once the geotextile acted in the distribution of the loads.

The different deformations obtained by the structures after the tests are represented in Figure 11a and 11b, that presents the laying course of the saturated structure and the laying course of the reinforced structure, respectively.

a) b)

Figure 11. a) Laying course of the saturated structure, b) Laying course of the reinforced structure.

6 CONCLUSIONS

It was concluded that the experiment reached the expectations, and proved the necessity of including a geosynthetic in the thickness design of the permeable paver. The results of the tests show that when the structure of the permeable paver is submitted to the application of loads simultaneously with the contact of the water, it leads to the loss of the bearing loading support of the pavement.

The remarkably superior performance of the reinforced structure demonstrates the importance of the role played by the woven geotextile, that has helped in the maintenance of the stability of the structure. Moreover, the geotextile has also acted as a separator between base course and subgrade, reducing the effects of the pumping of fines produced by the application of the loads.

Furthermore, as a solution for the deformation of permeable pavers, the use of geosynthetics represents a chance of optimizing the capacity of support of such pavements, making them become more attractive and magnifying their use.

Therefore, the authors recommend that the use of a geosynthetic must be taking into account when proceeding to the thickness design of the permeable paver, given the importance of this reinforcement in order to achieve a satisfactory performance of the structure as a whole.

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