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Deflection characteristics of Unbound Base Course during a Large Scale Model Experiment

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Abstract

This paper evaluates de deflections (measured at the surface and/or at the top of the subgrade) of unbound pavement materials under cyclic loading. Deflections of three base course materials (Bakel Red Quartzite, Bakel Black Quartzite and Diack Basalt) were investigated using a large-scale model experiment (LSME). The LSME is a prototype-scale pavement test apparatus where cyclic loading is applied and deflections are measured. The LSME replicates field conditions and accounts for scale effects. The LSME results showed that the total, plastic and net plastic deflections of a pavement increase progressively as the number of loading cycles increases. The total deflection decreases as the thickness of the base layer increases. Plastics deflections at the top of the subgrade decrease progressively as the thickness of the base layer is increased. The elastic deflections of the surface and of the base layer decrease gradually with the increasing loading cycles. The elastic deflection at the top of the subgrade decreases with increasing thickness of the base layer. So, rutting can be limited by limiting the elastic deflection at the top of the subgrade. However, this criterion does not account for the rutting caused by the unbound base layers and that of the asphalt concrete.

Keywords: Deflection, Unbound Base Course, Large Scale Model Experiment

1.Introduction

The road network is an essential factor for the development of a particular region, and country in general. Developing countries invest more in the construction of road infrastructures that contribute to economic growth and the opening up of remote areas. For the design, a number of parameters are used including the bearing capacity of the subgrade, the quality of materials used in pavement layers and the level of traffic. However, in Senegal, roads are usually characterized by a short life evidenced by premature damage (Fall, Senghor, &Lakhoune, 2002).

The characteristics of the pavement materials must meet minimum quality requirements. For base and subbase layers, several categories of materials may be used. However, road engineers, for reasons of economy, are forced to consider the transport distances and operating deposits means. This led them to use very particular or lower quality materials in all pavement layers.

In sub-Saharan Africa, lateritic soils are the most abundant resource materials “economically” available (according to the “Centre Expérimental de Recherches et d’Etudes du Batiment et des Travaux Publics” [CEBTP], 1984). These materials once extracted are delivered directly to customers without incurring industrial processes, thus reducing their cost. In Senegal, it has been always relied on these lateritic soils to produce the base courses of roads.

To improve the quality of pavement layers, many studies and discussions were conducted in Senegal to use other types of materials for base layer where the quality requirements are more stringent. These solutions include the use of crushed aggregates such as Diack Basalt, Bakel Quartzites, Bandia and Bargny Limestones, and Taiba Chert (a byproduct in the exploitation of Taiba phosphate deposit). Thus, in order to diversify the technical solutions for base layers, it is necessary to improve the mechanical performance of local materials by a good study of their characteristics, but also to search for materials substitution that can withstand the stresses of traffic and avoid the high costs of transport.

Determining the appropriate thickness of the pavement layers based on engineering properties is a critical task in the design of pavements (Yoder & Witczak, 1975; Huang, 2004).The objective of this research is to determine the total, elastic, plastic and net deflections of a prototype of pavement structure. An apparatus for simulating cyclic loading on a pavement structure established in the laboratory was developed by the Department of Civil and Environmental

Engineering (University of Wisconsin-Madison, USA) to assess the performance of different materials to be used as a base layer of pavement in West Africa. The system assesses the deflections under cyclic loading of the materials tested.

2.Material

The base-course aggregates were collected from varying geographical locations within Senegal. Three base-course materials including Bakel Black Quartzite (GNB), Bakel Red Quartzite (GRB), Diack Basalt (BAS), were characterized in this study (Ba, Fall, Samb, Sarr, & Ndiaye, 2011; Ba, Fall, Sall, & Samb, 2012; Ba, Nokkaew, Fall, & Tinjum, 2013). Grain size distributions of tested materials are shown in figure 1. Compaction characteristics, some physical and mechanical properties are presented in table 1. The Micro-Deval test provides a measure of abrasion resistance and durability of mineral aggregates through the actions of abrasion between aggregate particles and small steel balls in the presence of water. It is a good indicator of the quality of aggregates that will be exposed to water. Aggregate used in base courses must resist the effects of traffic and the environment.

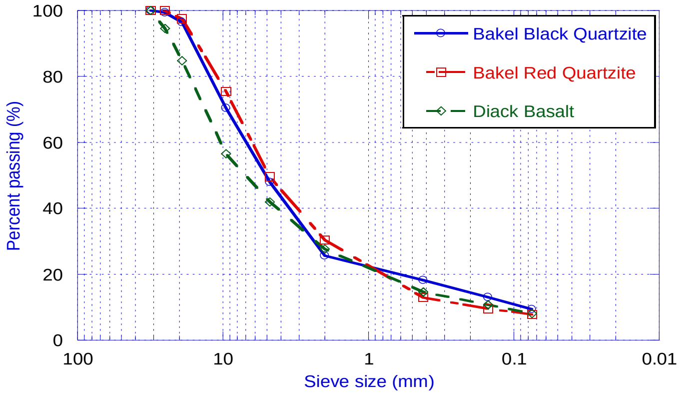

Figure 1. Particles size distribution of the aggregates

Table 1.Compaction andphysical properties of the aggregates

Materials	γ_{dmax} (kN/m^3)	w_{opt} (%)	G_s	MDE (%)	USCS	Fines (%)
Bakel Red Quartzite	21.00	5.5	2.65	3.1	GW	7.7
Bakel Black Quartzite	21.09	4.5	2.65	4.2	GW	9.4
Diack Basalt	23.74	4.2	2.95	5.6	GP	7.1

Symbols: ρ_{dmax} = modified Proctor maximum dry density, w_{opt} = modified Proctor optimum water content, G_s = specific gravity, MDE = Micro Deval (with water), USCS = Unified Soil Classification System.

3.Large Scale Model Experiment (LSME)

The Large-Scale Model Experiment (LSME) configuration consists of a pavement profile in a 3 x 3 x 3 m test pit (figure 2). The pavement profile consists of 2.5 m of uniform sand, simulating a deep subgrade, and a base course layer. A loading frame (100 kN actuator with 165 mm stroke) and a steel loading plate (125 mm radius and 25 mm thickness) were used to apply cyclic loading to the surface of the pavement. Elastic and plastic deformations of base course materials were measured. The LSME allows determination of the resilient modulus and plastic strain of the base course materials under cyclic loading similar to the field conditions. The LSME accounts for scale effects and allows the evaluation of the effect of strain amplitude due to varying layer thickness and accumulated plastic deformation (Tanyu, Kim, Edil, & Benson, 2003; Kootstra, Ebrahimi, Edil, & Benson, 2010).

Bakel Black Quartzite, Bakel Red Quartzite and Diack Basalt were tested in three base course thicknesses (0.1, 0.2 and 0.3 m) to account for the effect of strain amplitude on the resilient modulus and plastic deformations. Each material was compacted to 98% of modified Proctor maximum dry unit weight at Wopt – 2% using a plate vibratory compactor.

During the test, there is no surface layer on the base course. In the absence of surface layer, the stress applied at the surface of the base course was estimated by conducting nonlinear finite-element simulations of a pavement profile similar to the one in the LSME but with a 0.125 m thick HMA layer using the program MICHPAVE (Harichandran, Baladi, & Yeh, 1989). MIPCHPAVE accounts for the stress dependency of base course modulus. The simulated pavement was subjected to traffic wheel loads corresponding to 4-axle trucks (70 kN per axle and 35 kN per wheel set) with a tire pressure of 700 kPa.

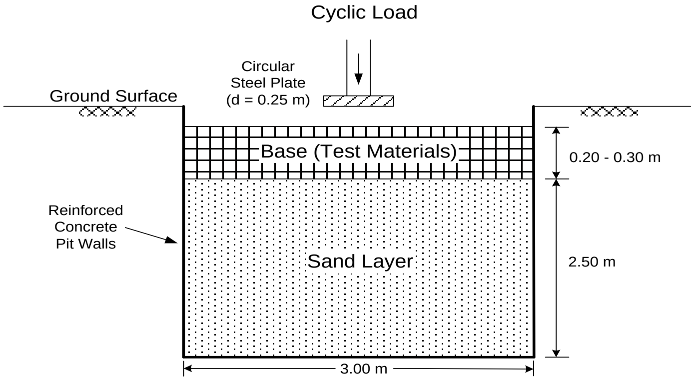

Figure 2. Large-scale model experiment (LSME) used for prototype pavement testing (Tanyu, Kim, Edil & Benson, 2003).

4.Results and Analyses

4. 1 Total Deflections

The evolution of the total surface and subgrade deflections as function of the number of loading cycles are given in figures 3, 4 and 5. The total deflection at the tops of the subgrade and the surface increases as the number of loading cycles increases. The deflections of the surface are higher than the deflections of the subgrade which is reasonable since the deflection of the surface is the sum of the deflections of the subgrade and the base layer. The deflections at the subgrade decrease gradually as the thickness of the base layer is increased. Indeed, a thicker base layer distributes over the stresses generated by the load and thus leads to smaller deflections at the top of the subgrade. The total surface deflection is higher when the thickness of the base layer is low (10 cm) and decreases when it increases to 20 cm. Beyond 20 cm, the deflection gradually increases with increasing the thickness of the base layer. This is because a base layer thickness of 10 cm is a case of under-sizing because the calculation of the load applied by the truck is made for a base layer thickness of 20 cm. So, when the thickness is reduced from 20 cm to 10 cm, it is expected to increase deflections. Thus, coming back to a base thickness of 20 cm, the deflections are reduced. In contrast, upon increasing the thickness of the base layer from 20 cm to 30 cm, the surface deflections increase due to increasing base deflections and not to those observed at the top of the subgrade as they decrease with increasing thickness of the base layer. In contrast, the basalt shows no notable changes in the total deflection when the thickness of the base layer increases from 10 cm to 20 cm; 10 cm is sufficient to distribute the stresses and lead to low levels of stress and therefore low deflections at the top of the subgrade.

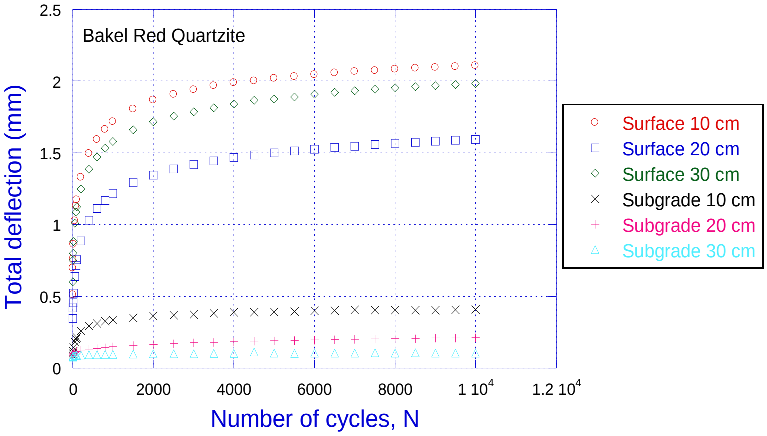

Figure 3. Evolution of the total deflection according to the number of cycles (Bakel Red Quartzite)

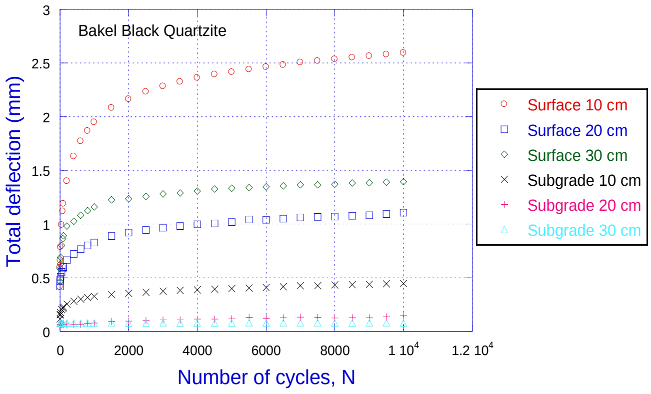

Figure 4. Evolution of the total deflection according to the number of cycles (Bakel Black Quartzite)

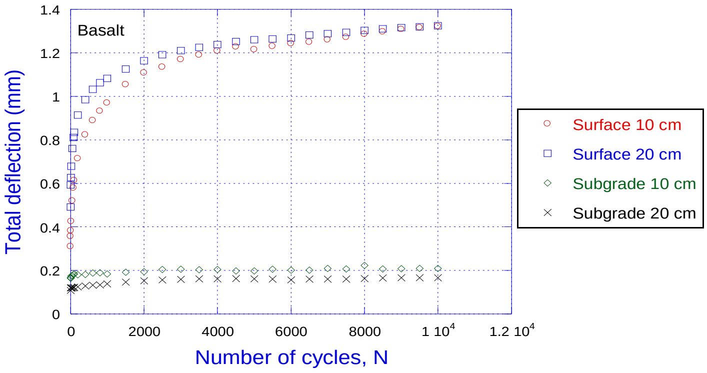

Figure 5. Evolution of the total deflection according to the number of cycles (Diack Basalt)

4.2 Plastic Deflections

Figures 6, 7 and 8 show changes in the surface plastic deflections of the subgrade according to the number of loading cycles and the thickness of the base layer for the various materials tested. The plastic deflections increase gradually as the number of loading cycles increases. As for the total deflection, the plastic deflection at the top of the subgrade decreases gradually as the thickness of the base layer increases due to a higher stress distribution. In contrast, the plastic surface deflection decreases when the thickness of the base layer increases from 10 cm to 20 cm, and then increases as the base thickness increases from 20 cm to 30 cm for the same reasons stated above. For basalt, there is a very slight deflection of the plastic decrease with increasing thickness of the base layer, which would result in smaller thicknesses if this material is used in the base layer.

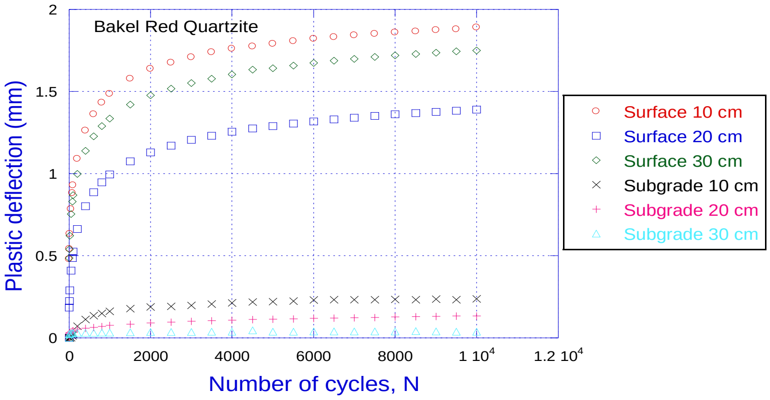

Figure 6. Evolution of the plastic deflection according to the number of cycles (Bake Red Quartzite)

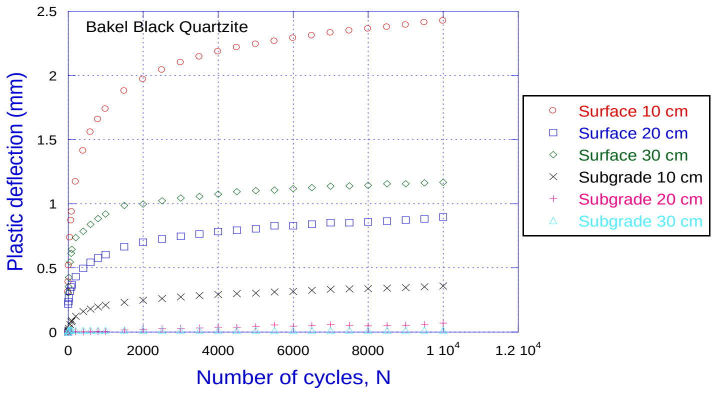

Figure 7. Evolution of the plastic deflection according to the number of cycles (Bakel Black Quartzite)

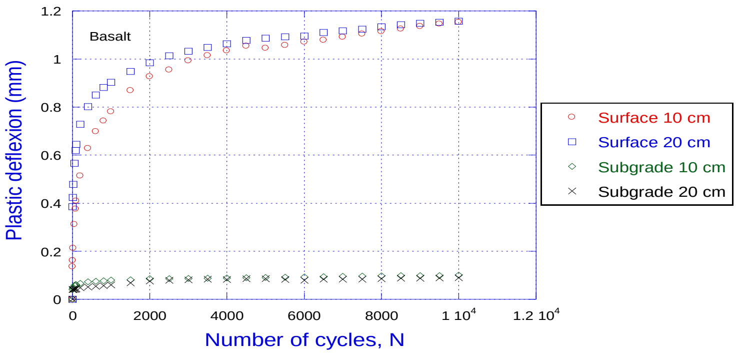

Figure 8. Evolution of the plastic deflection according to the number of cycles (Basalt)

4.3 Elastic Deflection

The evolution of the elastic (or recoverable) deflection of the surface the subgrade according to the number of loading cycles and the thickness of the base layer are given in figures 9, 10 and 11. The elastic deflections of the subgrade remain substantially constant as the number of cycles increases. In contrast, the elastic deflections of the surface and the base layer decrease gradually as the number of loading cycles increases. This is due to the progressive compaction, reducing voids and generating a progressive hardening of the material, which reduces the elastic deflections, thereby increasing the resilient modulus of the layer. The rate of decrease in elastic deflection is strongly related to the density of the layer. A layer of low density leads to a strong decrease of the elastic deflection, increasing gradually the modulus of elasticity of the layer. The resilient deflection at the top of the subgrade decreases with increasing thickness of the base layer. This causes an increase in the modulus of the subgrade and thus a reduction of the plastic deflection of the top of the subgrade. Indeed, this is the rutting criteria of the current method of pavement design in Senegal. This method limits the rutting by limiting elastic deflection at the top of the subgrade. Thus, by increasing the thickness of the base layer, the elastic deflection is reduced at the top of the soil substrate, thereby increasing the modulus and decreasing the plastic deflection and thus rutting at the top of the subgrade. But this criterion does not take into account the rutting caused by the unbound base layer or that of the surface layer of bituminous materials (high rutting in hot climates).

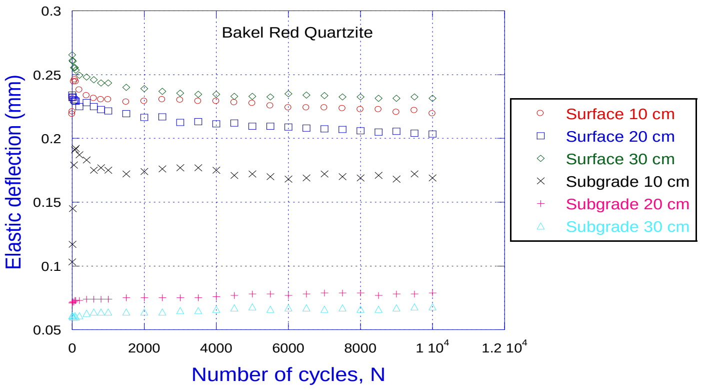

Figure 9.Evolution of the elastic deflection according to the number of cycles (Bakel Red Quartzite).

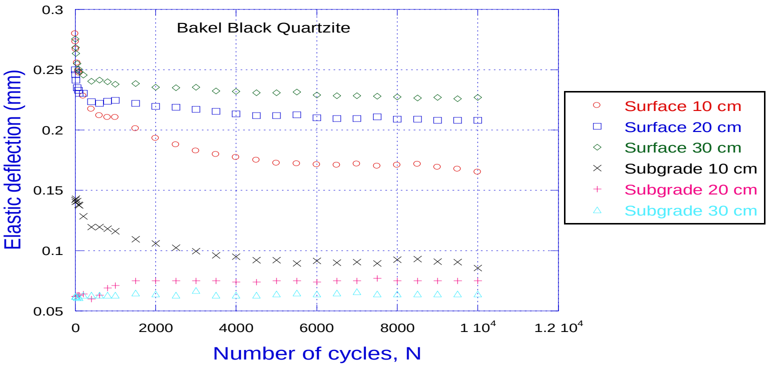

Figure 10.Evolution of the elastic deflection according to the number of cycles (Bakel Black Quartzite).

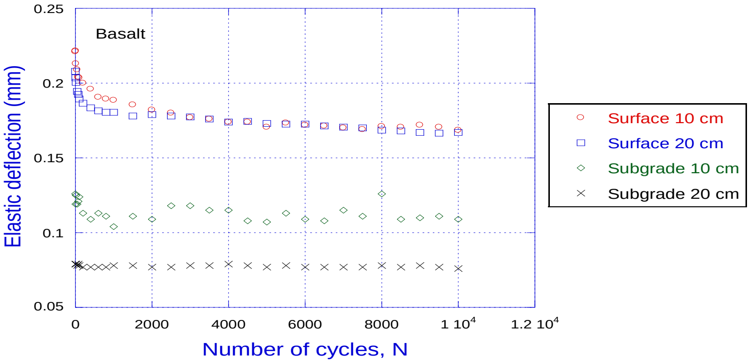

Figure 11.Evolution of the elastic deflection according to the number of cycles (Basalt).

4.4 Net Plastic Deflection

Figures 12, 13 and 14 give variation of the net plastic deflection as function of the number of cycles and the thickness of the base layer. The net plastic deflection is the plastic deflection of the base layer. It is obtained by subtracting the plastic deflection of the subgrade to the plastic deflection of the surface. These figures show that a pavement undersizing (for Bakel Quartzite corresponding to 10 cm thick) generates very high net plastic deflections. On the contrary, when the thickness of the base layer increases from 20 to 30 cm, the plastic deflections thereof increase. Thus, a too thick unbound base layer accumulates more plastic deflections requiring its consideration in road design to limit the plastic deflection to an acceptable level. This consideration is made by determining the intrinsic material parameters that characterize the evolution of the plastic deformation as function of the number of loading cycles.

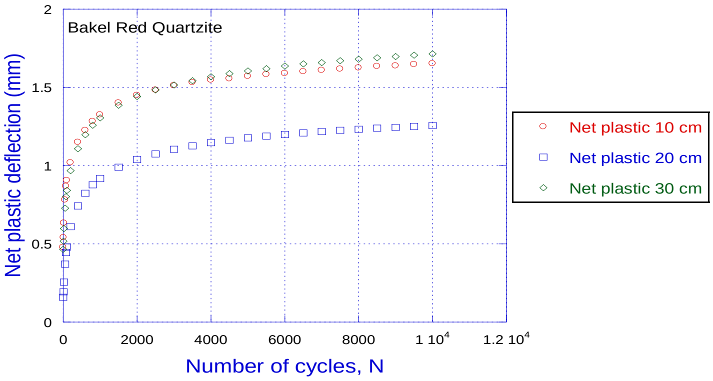

Figure 12.Evolution of the net plastic deflection according to the number of cycles (Bakel Red Quartzite).

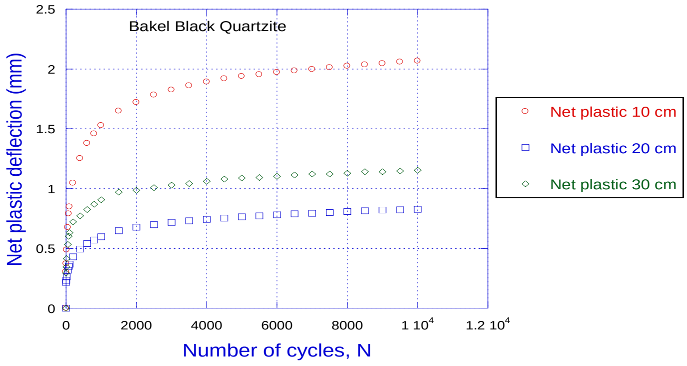

Figure 13.Evolution of the net plastic deflection according to the number of cycles (Bakel Black Quartzite).

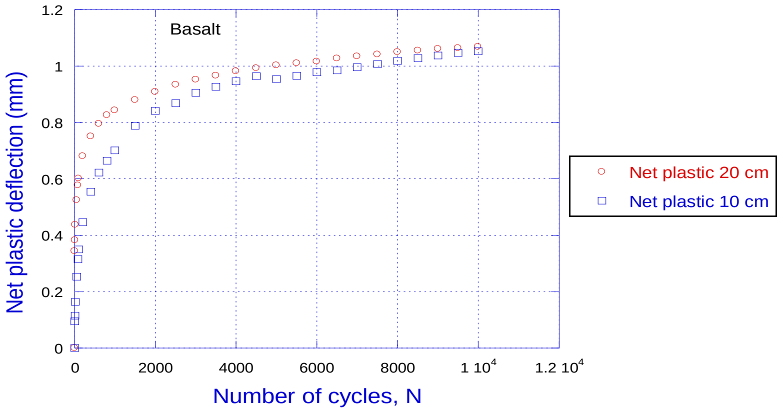

Figure 14.Evolution of the net plastic deflection according to the number of cycles (Basalt).

5. **Conclusion**

Findings of this study indicate that the total deflection at the subgrade and at the surface increases progressively as the number of loading cycles increases. The total deflections of the surface are higher than the total deflections of the subgrade and that they decrease as the thickness of the base layer increases. Diack Basalt has total deflections lower than those of Bakel Quartzites.

Plastic deflections increase gradually as the number of loading cycles increases. As for total deflections, plastic deflections at the top of the subgrade decrease progressively as the thickness of the base layer is increased. Diack Basalt shows a slight decrease of the plastic deflection with increasing the thickness of the base layer, which would result in smaller thicknesses if this material is used in the base layer.

The elastic deflections of the subgrade remain substantially constant as the number of cycles increases, while the elastic deflections of the surface and therefore of the base layer decrease gradually with the increasing number of load cycles. The elastic deflection at the top of the subgrade decreases with increasing thickness of the base layer, where the criterion of limiting rutting by limiting only the elastic deflection at the top of the subgrade. However, this criterion does not take into account the rutting caused by the unbound base layers, nor that of the asphalt concrete (high rutting in hot climates).

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