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Study of the Influence of Groundwater Table in Mechanical Behavior of a Full-Scale Pavement Structure Modeled in a Test-Pit

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Abstract: The mechanical characteristics of road pavement layers are influenced by moisture conditions. Drying and wetting change the moisture content of the materials used in pavement structures, consequently affecting the mechanical response. An experimental program was conducted to evaluate elastic deformations of a road pavement structure utilizing repetitive rigid plate load tests in a model test-pit facility. A typical Brazilian pavement (a multilayer system composed of a concrete asphalt and coarse base, and subbase) was simulated in this test-pit with devices for measuring humidity (TDR (time domain reflectometry)) and suction (tensiometers) installed every 20.0 cm along the profile. A pair of displacement transducers was attached on the surface of the pavement structure to record deformations due to dynamic loads. Two levels of groundwater table were analyzed, verifying that the pavement structure displacement increases with groundwater table growth. The structural response was evaluated and compared in physical and numerical models, and the results confirmed that the higher groundwater levels caused the greatest pavement displacements.

Key words: Pavement structure, resilient modulus, suction.

1. Introduction

The moisture existing in a road pavement layer plays a significant role in defining the mechanical behavior of the pavement material. Depending on the subgrade material, the local environmental characteristics and the road design, resilient modulus and suction alterations may occur with the presence of moisture. In the latest analyses, these factors are shown to regulate the mechanical behavior and fatigue life of the road pavement.

In this paper, a typical Brazilian road pavement structure, as shown in Fig. 1, was subjected to moisture changes in a concrete test-pit, with extensive instrumentation, monitoring and analysis of the predicted performance, when subjected to a GWT (groundwater table) and capillary rise.

2. Previous Studies

Ping et al. [1] tested three types of granular subgrades, submitting them to moisture oscillations and observing the damage they cause to mechanical performance of its base. They observed that an A-3 soil type, when used as subgrade, supplied greater protection than the other two tested soils (other A-3 and one A-2-4 soil). In addition, despite the greater values of suction that were present in A-2-4 soil, A-2-4 soil was more sensitive to a moisture variation than the A-3. The authors also conclude that the percentile of fines existing in the subgrade soil governs the influence of moisture on its resilient modulus.

Medina and Motta [2] mentioned the mechanisms, by which the moisture interferes in a pavement, showing that the groundwater table oscillation, due to

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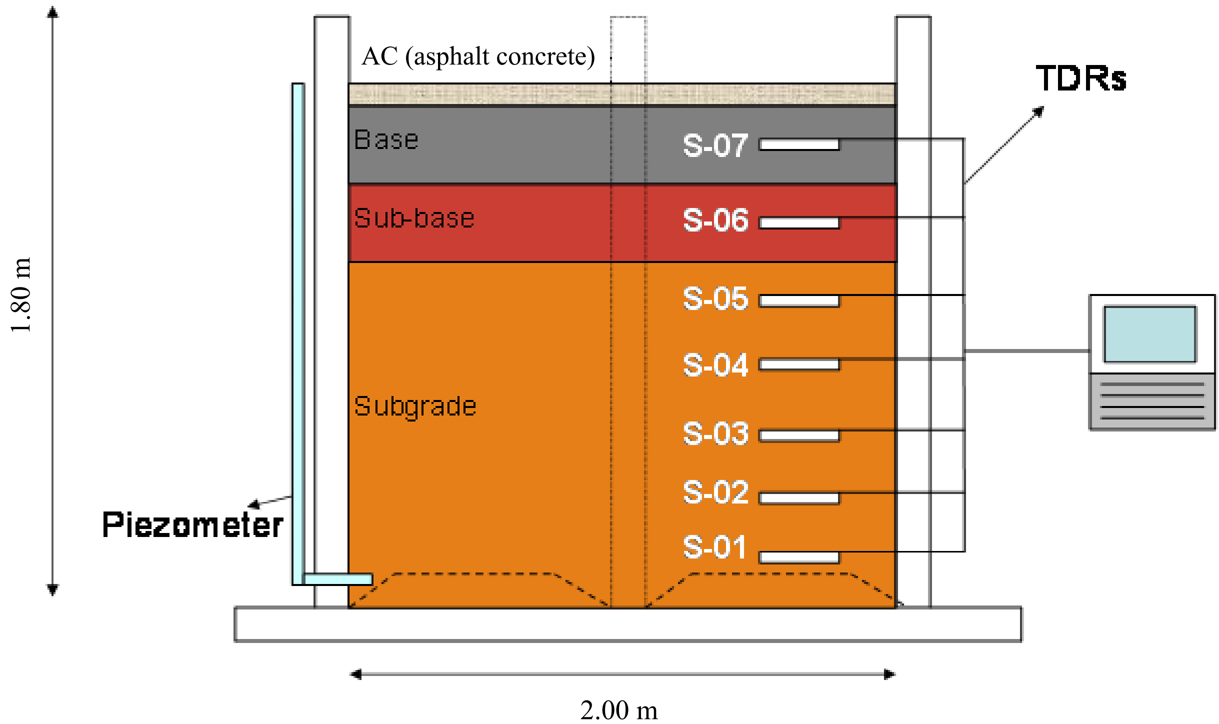

Fig. 1 Lateral view of test-pit with the installations of TDRs (time domain reflectometry).

the rain water access, can cause moisture variations in subgrade in the case of groundwater table being at a small depth (about 1.0 m or less). Medina and Motta [2] also noted that the migration of salt existing in soil or in aggregates of pavement layers can occur by capillarity (with dissolved salts) to upper layers. When it reaches the surface, the water evaporates depositing the salts. This phenomenon creates stains in asphalt concrete's cracks and confirms the capillarity ascension in pavement layers.

Perera et al. [3] collected foundation pavement soils from various parts of the USA and studied the moisture equilibrium of road foundation soils. They concluded that moisture directly influences the stress and strain in pavement layer systems. The authors also concluded that the matric suction measured in situ shows a good correlation with the Thornthwaite index and with soil type, a very similar result obtained previously by Russam and Coleman [4].

Ping and Ling [5] highlighted the problems faced by road constructions in Florida. They showed that the typical constituents of pavement foundation (A-1, A-3 and A-2-4) attract an excessive amount of water and will become hard during drying and compaction. The experimental results also show that the soil suction and its relative humidity have a direct effect on the soil drainage. The suction values in this study varied significantly with the amount of water when the percentage passing #200 sieve was greater than 20%. They have also concluded that drainage decreases with the increase of soil suction for each type of soil and with the increase of fine percentile. Based on their findings in this study, the authors suggest that moisture influences the drainage of soil more significantly than temperature.

Silva [6] said that drying and wetting processes in soils give rise to variability in suction values, which change the resilient characteristics of constituent materials within pavement layers. These changes are so significant that drying a material to a moisture 2% below the optimum moisture can duplicate its resilient modulus. On the other hand, the opposite is also valid, i.e., a moisture gain, especially in fine soils (more sensitive to moisture changes), decreases its resilient modulus.

Sadasivam and Morian [7] studied the effect of the groundwater table on pavement performance (cracking from top to bottom, bottom to top and sinking of wheel trail) using simulations in four different levels of groundwater table (1.52, 3.05, 6.10 and 9.15 m), six different subgrade soils and two typical pavement structures. They pointed out that the groundwater table level is an input parameter in AASHTO (American Association of State Highway and Transportation Officials) Design Guide 2002 and in EICM (enhanced integrated climate model) software. The subgrade permanent deformations forecasted were compared with the Ayres model for permanent deformations in granular materials. They concluded that:

- With a rising GWT, the cracking from top to bottom in pavement surface decreases, while the cracking by fatigue in the base of the bituminous layer increases;
- The groundwater table does not significantly influence the sinking of wheel trail of the bituminous layer;
- The subgrade permanent deformation is much more affected by changes in groundwater table, depending on the subgrade soil type (silt or clay).

Liang and Rabab'ah [8] said that the majority of fine soils show a decreasing resilient modulus pattern with the increase of moisture and that the matric suction has been a suitable state variable to predict the dependence of resilient modulus with moisture for clayey soils.

Therefore, considering the possible hazardous effects in pavement performance caused by moisture conditions, this study aimed to evaluate the consequence of two levels of moisture conditions for a specific pavement structure, constructed with common materials used in Brazilian pavements.

3. Materials and Methods Employed

3.1 Test-Pit

In this paper, the variation of the GWT position on the elastic vertical displacements measured at the top of the pavement, when it is subjected to cyclic loading with five levels of pressure and two possible positions of GWT, will be studied.

The test-pit used for this experiment was made with concrete walls of 20.0 cm thickness and had internal dimensions of 2.0 m × 2.0 m. Two of the opposing walls were doubled and a water entrance consisting of a hole (at 15.0 cm height) allowed water to flow from bottom to top of the inserted pavement.

A load application structure was built at the top of the test-pit using metallic beams through which loads up to 200.0 t could be applied to the middle of the 2.0 m space. A compressed air installation was used for applying dynamic loads.

The load was applied at the top of pavement by a rigid plate in contact with pavement surface. This rigid plate had a 15.2 cm diameter and the load levels applied to the structure were 0.28, 0.44, 0.61, 0.77 and 0.94 MPa.

The GWT levels considered were: (1) the pavement material newly compacted in optimum moisture content, i.e., simulating the non-existence or non-influence of GWT; and (2) the subgrade completely saturated.

In addition, holes were drilled in one of the walls at 20.0 cm increments to allow the passage of instrument cables into the pavement structure. One of these instruments was the TDR (time domain reflectometry) sensor, which was used to assess moisture content at 20.0 cm increments along the pavement profile.

This evaluation was necessary to define the time at which the capillary fringe stopped rising, thus defining the equilibrium of the water table at that position. This equilibrium was defined as the point at which two consecutive measurements did not indicate any change greater than 0.5% in the moisture profile of the structure. The load and strain measurement applications on the pavement were only conducted after the advance and capillary fringe development measurements were completed. The instrumentation also included an external piezometer to verify the exact level of water in the test-pit before the tests. It was observed that for the pavement materials tested, it took 25 days to advance and attain an equilibrium condition of the capillary fringe.

Two faucets and two drains were installed to control inflow and egress of water in order to verify the hysteresis of the phenomena (resilient modulus and suction) studied. A reinforced blanket and a 10.0 cm stone layer acted as a filter to avoid the blockage of the drain by fine particles of soil.

Fig. 1 shows a schematic design of test-pit. It shows the pavement structure, the installation of the TDRs and the load application for the whole pavement profile. Figs. 2 and 3 show the test-pit with the systems of load application, reaction beam, deformation measurement (LVDTs (linear variable displacement transducers)) and water entrance position.

3.2 Materials Employed

The subgrade, subbase and base materials employed were chosen from common pavement structure used in Brazil. The physical characteristics are specified in Table 1.

4. Results and Discussion

Fig. 4 shows the resilient modulus variation with moisture content.

Fig. 2 Overview of test-pit with the systems installed.

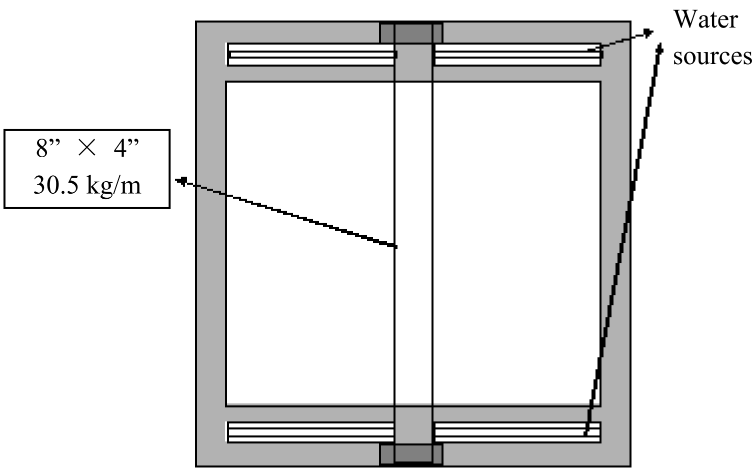

Fig. 3 Upper view of test-pit with the metallic beam to support the load (dynamic and static).

Table 1 Classification and physical characteristics of employed materials.

	AASHTO	USCS	PI (plasticity index)	δ_g (grain density)
Subgrade	A-1b	SW	NP	2.68
Subbase	A-1a	GW	NP	2.73
Base	A-1b	GW	NP	2.65

USCS is the unified soil classification system; SW means sand well-graded; GW means gravel well-graded; NP means non plastic.

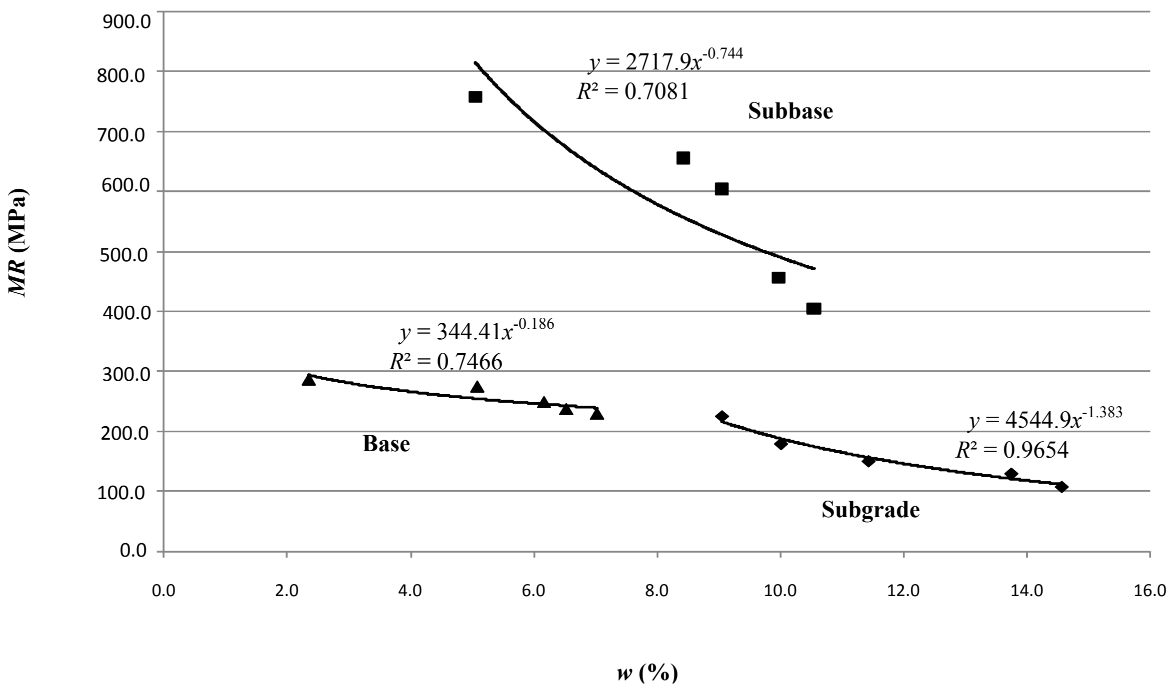

Fig. 4 Resilient modulus (*MR*) versus moisture content (*w*) for pavement materials.

Resilient modulus is the ratio between the vertical stress and its correspondent elastic strain ($MR = \sigma/\varepsilon$). It is proportional to the vertical and confining pressures and is calculated by regression.

The results of dynamic loads applied to the structure under conditions of OMC (optimum moisture content) of all layers, i.e., without raising the water table and that for the groundwater table completely saturating the subgrade, are shown in Fig. 5.

The condition without the water table simulates the situation of a pavement recently built, i.e., the compliance of design technical requirements, in which the pavement is newly compacted at the OMC, with no seasonal influence caused by the oscillation of the GWT.

The total saturation of the subgrade depicts a critical situation that can be attributed to several factors: failure in the drainage system, design errors and accidents or floods that might occur in the life of the highway.

4.1 The EFin3D Software

EFin3D (three dimensions finite element) is a free use software, which contributes to the establishment of a mechanistic-empiric method. EFin3D is part of another program called SisPav (pavement system), which is the subject of a doctoral thesis [9]. This program is used for evaluating stresses, strains and displacements using three-dimensional finite element method.

In this paper, the EFin3D software was used to evaluate numerically the results obtained physically by the test-pit facility. The entrance data of the software are: height, Poisson coefficient, resilient modulus of each pavement layers and load characteristics (pressure and plate diameter).

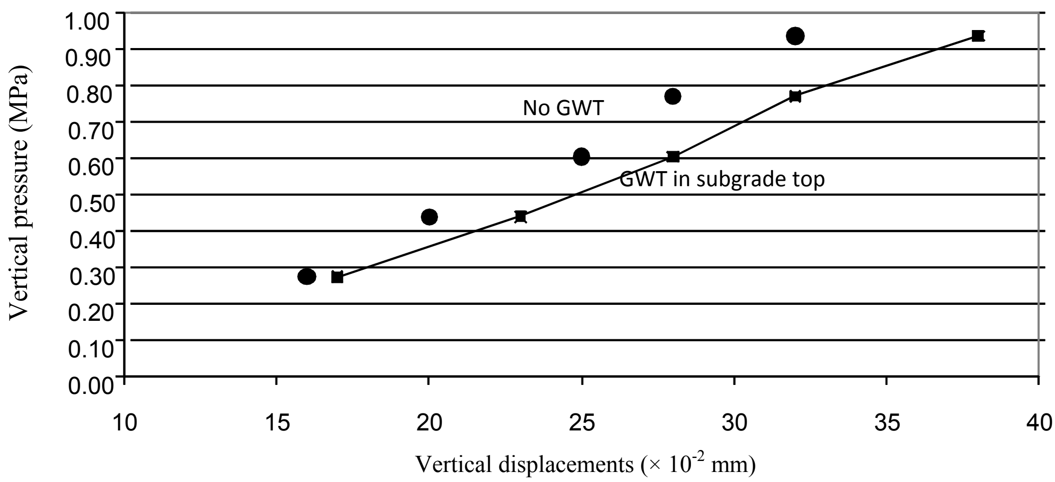

Fig. 5 Total elastic vertical displacements at the top of the pavement (× 10^{-2} mm) with vertical pressures (MPa).

Table 2 Difference between numerical and physical models.

Numerical (× 10^{-2} mm)	Physical (× 10^{-2} mm)
30.4	28.0

4.2 Comparison between Numerical and Physical Models

Table 2 shows the difference deflections obtained by numerical (EFin3D) and physical models for the same conditions (moistures and stresses).

From the results shown in Table 2, we observe that the software EFin3D can provide good and fast notion of pavement structure behavior from the knowledge of moisture, resilient modulus (mechanical behavior) of the layers and the traffic pattern.

5. Conclusions

The comparison between the results obtained by vertical displacement in test-pit facility and those obtained by physical modeling by finite elements in three dimensions showed that the physical model developed is an excellent tool for studying the mechanical behavior of pavement, with the option of leveling the GWT at any point in pavement structure.

The values of total elastic vertical displacements also showed that the materials used in this study were sensitive to moisture content, and developed a greater deformability as the moisture increased.

Thus, the results of studies in the test-pit may lead to the development of highway designs, which consider moisture changes in pavement layers, especially in humid and extremely humid areas, where it is common to find pavement layers with moisture contents much higher than optimum level. In these areas, as we know how much moisture can affect a material's performance, we can use the test-pit to design pavement structures, considering the local materials and traffic conditions.

It will also allow that other non-conventional materials can be tested as pavement layers.

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