Effect of variation of the average daily volume and traffic growth rate on flexible pavements performance

Efecto de la variación del volumen diario medio y de la tasa de crecimiento del tráfico en el desempeño de los pavimentos flexibles

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ABSTRACT

Pavement design, initially based on empirical methods, has been improved and, currently, there is a tendency to replace these methods by mechanistic-empirical ones. This new methodology uses detailed information on traffic, climate and pavement structure to obtain accurate performance predictions, providing a better design. In this study, it was performed a sensitivity analysis of flexible pavements to investigate the effect that the variation of annual average daily traffic (AADT) and traffic growth rate has on structural pavement responses. Therefore, simulations were done using two computer programs, MEPDG and AASHTOWare Pavement ME Design, whose results indicated that the pavement has sensitivity to both variations that were studied (AADT and traffic growth rate), demonstrating higher deterioration values when the traffic growth rate was nonlinear. It was also concluded that the difference between sensitivity values obtained by both programs was insignificant.

Keywords: Mechanistic-empirical software, MEPDG, AASHTOWare Pavement ME Design.

RESUMEN

El diseño del pavimento, inicialmente basado en métodos empíricos, ha sido mejorado y, actualmente hay una tendencia a sustituir estos métodos por métodos empírico-mecánicos. Esta nueva metodología utiliza la información detallada del tráfico, del clima y de la estructura del pavimento para obtener predicciones precisas de desempeño, proporcionando un mejor diseño. En este trabajo, se realizó un análisis de sensibilidad de los pavimentos flexibles para investigar el efecto que tiene la variación del tránsito promedio diario anual (TPDA) y la tasa de crecimiento del tráfico en las respuestas estructurales al pavimento. Por lo tanto, las simulaciones se realizaron mediante dos programas de ordenador, el programa MEPDG y el AASHTOWare Pavement ME Design, cuyos resultados indicaron que el pavimento tiene sensibilidad a ambas variaciones estudiadas (TPDA y tasa de crecimiento del tráfico), demostrando mayores valores de deterioro cuando la tasa de crecimiento del tráfico fue no lineal. También se concluyó que la diferencia entre los valores de sensibilidad obtenidos por los dos programas era insignificante.

Palabras clave: Mechanistic-empirical software, MEPDG, AASHTOWare Pavement ME Design.

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INTRODUCTION

Several factors may contribute to the pavement degradation, such as environmental and climatic agents, quality of used materials and design parameters. It is therefore of great importance to study the traffic volume, which indicates the number of vehicles passing the road; as well as their growth rate to understand how the variation of these parameters affects the quality of the pavement structure. Also, depending on these parameters, it is necessary to analyze the sensitivity of the pavement using computer programs to optimize pavement design.

The pavement design is defined as a process to determine the thicknesses of the constituent layers (surface, subbase and subgrade) so that these resist, transmit and distribute the load imposed by traffic, avoiding excessive deformation, including the pavement rupture. Therefore, the design should ensure adequate performance during operating life.

In recent years, the design of pavement has been based on empirical methods, which were developed in the 60s. Such methods were defined as those based solely on experimental data or experience. It is noteworthy that over time, however, the characteristics of the types of vehicles and transported loads changed, limiting the use of this method [1].

The analysis of the pavement by the mechanistic-empirical method, on the other hand, is made with the aid of computer programs. The process of analysis starts from a pre-dimensioned structure in which different values of design parameters are inserted, such as tire pressure; traffic volume; materials used on the pavement; thickness of the layers; weather data; among others. From these data, the program determines the structural responses and calculates the damages on the pavement, which are then compared to the performance criteria set by the regulation. If these criteria are not met, it is necessary to vary the design parameters until the ideal condition is achieved [4-5].

In this study, the MEPDG and AASHTOWare Pavement ME Design software were used. In a simplified manner, MEPDG can be described as a program which analyzes the input data inserted therein, such as traffic characteristics, weather and materials used in the structure; applying numerical models to estimate accumulated damage during the

pavement life [6-7]. In 2008, MEPDG underwent a transition to the AASHTOWare program package, coming to be called Darwin ME. In 2013, this software became commercially available under a new name: AASHTOWare Pavement ME Design [9].

Studies of pavement sensitivity related to the variation of the design parameters, using the mechanistic-empirical method, indicate that the variation of the traffic volume parameters has a greater influence on bottom-up fatigue cracking. As for the traffic growth rate, some authors state that the variation on the traffic growth factors has low interference in roughness, permanent deformation and fatigue cracking issues [8].

MATERIAL AND METHODS

For this study, it was defined the design parameters to be varied, in order to determine the influence of these variations on the performance of flexible pavements. Therefore, it was decided to change the following parameters: annual average daily traffic (AADT) and traffic growth rate.

With the results of the performance curves obtained by the pavement analysis program, which were generated from the input data that considered the variation of the design parameters, graphical representations were made relating the variations of design parameters with various pavements deformities accumulated over the 20 years project period, such as longitudinal cracking, fatigue cracking, permanent deformation and roughness index.

Traffic

A study conducted by the Regulatory Agency of Transportation of São Paulo State determined, from counts made in the SP 160 highway in 2009, that the AADT was 10,993 vehicles/day. Thus, for the analyzes of this research, the study above was taken as basis, considering five AADT values: 8,993 vehicles/day; 9,993 vehicles/day; 10,993 vehicles/day; 11,993 vehicles/day and 12,993 vehicles/day. While the AADT values were varied, the other parameters were kept fixed (linear traffic growth of 4%).

Furthermore, the variation of traffic growth rate was made adopting the following values: 4%, 6%, 8%, 10% and 12%. These values were used since, in Brazil, the traffic growth factor to be used as a reference for pavement

design is 3% [2]. It was also examined two types of growth rate, linear and nonlinear. In this case, the value of the AADT was kept fixed at 10,993 vehicles/day.

In Brazil, it is still widely used the design method that deliberates a tire pressure of 552 kPa (80 psi). A situation that is far from reality, which presents much higher values. Studies indicate that the average tire pressure in Brazil is 827 kPa (120psi) [3], therefore, all analyzes were made considering two pressures: 552 kPa (80 psi) and 827 kPa (120 psi).

Structure

It was considered a hypothetical pavement structure with three layers settled above the subgrade (Table 1).

Table 1. Characteristics of the hypothetical pavement structure.

Layer	Thickness (cm)	Poisson Coefic.	Modulus of elasticity (Mpa)
1 (surface)	12.5	0.3	-
2 (base)	20	0.4	400
3 (subbase)	25	0.4	200
4 (subgrade)	∞	0.45	70

Climate

The weather condition of Orlando (Florida – USA) was adopted due to the rainfall similarity to the Immigrants highway region, considering a depth of 10 m to the water table.

RESULTS AND DISCUSSION

The graphs of deteriorations according to the variation of the AADT, the linear traffic growth rate and the nonlinear traffic growth rate are shown in Figures 1, 2 and 3, respectively. From the data of each graph is possible to check the sensitivity values related to each variation of the design parameter.

In Figure 1, the results of the longitudinal cracking (surface-down) provided by MEPDG related to the adoption of the tire pressure of 552 kPa (80 psi), there is a variation of 22.65% in the deterioration of the pavement when the AADT increased from 8,993 vehicles/day to 12,993 vehicles/day. When the analysis was performed with AASHTOWare Pavement ME Design, the change was of 22.98%. Regarding the application of 827 kPa (120 psi) pressure, the longitudinal cracking shows the same behavior, again with higher values in the analyzes with MEPDG, presenting a variation of 21.44%. The results obtained with AASHTOWare Pavement ME Design, in turn, showed a variation of 23.26%.

When evaluating the results obtained by MEPDG for the various pressures, in the case of longitudinal cracking (surface-down), it was observed that the deterioration from the pressure of 827 kPa (120 psi) exceeded by more than 10% the deterioration resulting from the pressure of 552 kPa (80 psi). However, the AASHTOWare Pavement ME Design displayed an opposite behavior, the values obtained for pressures of 827 kPa (120 psi) were lower than the pressures of 552 kPa (80 psi), resulting in a reduction of more than 2%.

The fatigue cracking (bottom-up), considering the pressure of 552 kPa (80 psi), presents a variation of 20.20% when analyzed by MEPDG. When the tire pressure was elevated to 827 kPa (120 psi), the variation increased to 20.13%. With AASHTOWare Pavement ME Design, the variation was 19.89% for the pressure of 552 kPa (80 psi), while for pressure of 827 kPa (120 psi) was 20.43%.

For the results obtained considering different pressures, in the case of fatigue cracking (bottom-up), it was observed that the deterioration from the 827 kPa (120 psi) pressure exceeded by more than 15% the deterioration resulting from the pressure of 552 kPa (80 psi) when analyzed by MEPDG. When using AASHTO Ware Pavement ME Design, in turn, the increase was of approximately 12%.

Figure 1. Deteriorations values caused in the pavement related to the variation of the annual average daily traffic (AADT).

Evaluating permanent deformation on the surface course with MEPDG to the pressure of 552 kPa (80 psi), there is little variation between the minimum and maximum values, reaching only 2.82%. Even increasing the pressure to 827 kPa (120 psi), there was little effect, since the values fluctuated from 3.6 mm to 3.7 mm. Thus, the increase in deterioration had not reached 2% when the tire pressure was increased from 552 kPa (80 psi) to 827 kPa (120 psi).

The permanent deformation on the subgrade, in turn, showed higher sensitivity than on the surface. Considering the pressure of 552 kPa (80 psi) with analysis by MEPDG, there was a variation of 4.57%. When the pressure was changed to 827 kPa (120 psi) there was an identical behavior at the pressure of 552 kPa (80 psi), with no difference between the obtained values. When the analysis was performed with AASHTOWare Pavement ME Design, the program obtained slightly higher deterioration values, but the same behavior was observed, reaching a variation between the predicted values of 4.66%.

It is expected that the total permanent deformation is superior to the deformation on the surface and subgrade. In this case, the variation of the values of deterioration provided by both programs was almost the same, being 19.25% to the pressure of 552 kPa (80 psi) and 19.27% for the pressure of 827 kPa (120 psi). For this situation, it was possible to verify that the deformation values obtained by MEPDG were higher than AASHTOWare Pavement ME Design only for the permanent deformation on the surface.

Moreover, it became clear that the pressure of 827 kPa (120 psi), compared to the deterioration caused by the 552 kPa tire pressure (80 psi), always induces higher deterioration in the pavements, except the permanent deformation on the subgrade, which was not influenced by the pressure variation. It was also observed an increase of almost 60% in total permanent deformation when analyzed by MEPDG and approximately 45% for analysis with AASHTOWare Pavement ME Design.

The International Roughness Index (IRI) calculated by MEPDG showed a variation of 6.08% between the maximum and minimum values for the pressure of 552 kPa (80 psi). With the growth of the pressure to 827 kPa (120 psi), a variation of 7.63% was observed. Thus, it was noticed an increase of almost 10% as the

pressure was raised from 552 kPa (80 psi) to 827 kPa (120 psi). However, when the analysis was done using AASHTOWare Pavement ME Design, variations were lower, being 5.36% to the pressure of 552 kPa (80 psi) and 6.23% for the pressure of 827 kPa (120 psi).

In Figure 2, the results of the longitudinal cracking (surface-down) provided by MEPDG related to the adoption of 552 kPa tire pressure (80 psi), a variation of 24.92% was observed in the deterioration of the pavement when the growth rate increased from 4% to 12%. When the analysis was performed with AASHTOWare Pavement ME Design, the change was of 25.41%. Concerning the application of 827 kPa (120 psi) pressure, the longitudinal cracking shows the same behavior, again with higher values in the analyzes with MEPDG, displaying a variation of 22.71%. The results obtained with AASHTOWare Pavement ME Design showed a variation of 25.73%.

When analyzing the results obtained by MEPDG for the various pressures in the case of longitudinal cracking (surface-down), it was observed that the deterioration from the 827 kPa (120 psi) pressure exceeded by more than 7% the deterioration resulting from the pressure of 552 kPa (80 psi). However, the AASHTOWare Pavement ME Design provided an opposite behavior, the values obtained for pressures of 827 kPa (120 psi) were lower than the pressures of 552 kPa (80 psi), resulting in a reduction of more than 2%.

The fatigue cracking (bottom-up), considering the pressure of 552 kPa (80 psi), presents a variation of 24.30% when analyzed by MEPDG. When the tire pressure was elevated to 827 kPa (120 psi), the variation increased to 23.43%. With AASHTOWare Pavement ME Design, variation was 24.19% for the pressure of 552 kPa (80 psi), while for the pressure of 827 kPa (120 psi) was 23.95%.

When assessing the results obtained for the various pressures, in the case of fatigue cracking (bottom-up), it was observed that the deterioration from the 827 kPa pressure (120 psi) exceeded by more than 15% the deterioration resulting from 552 kPa pressure (80 psi) when analyzed by MEPDG. Using AASHTOWare Pavement ME Design, in turn, the increase was of approximately 12%.

Figure 2. Deteriorations values caused in the pavement related to the variation of the linear traffic growth rate.

Evaluating permanent deformation on the surface course with MEPDG to the pressure of 552 kPa (80 psi), there is little variation between the minimum and maximum values, reaching only 3.22%. Even increasing the pressure to 827 kPa (120 psi), there was little effect, since the values ranged from 3.6 mm to 3.7 mm. When the analyzes were made with AASHTOWare Pavement ME Design, variations values were similar to those obtained with MEPDG.

The permanent deformation on the subgrade, in turn, showed higher sensitivity than on the surface. Considering the pressure of 552 kPa (80 psi) with analysis by MEPDG, there was a variation of 5.33%. When the pressure was changed to 827 kPa (120 psi) there was an identical behavior as at the pressure of 552 kPa (80 psi), with no difference between the obtained values. When the analysis was performed with AASHTOWare Pavement ME Design, the program obtained slightly higher deterioration values, but the same behavior was observed, reaching a variation between the predicted values of 5.44%.

In the case of total permanent deformation, the variation between the values of the deterioration obtained by both programs continued to be similar, being 23.01% for the pressure of 552 kPa (80 psi) with analysis by MEPDG and 23.10% for the pressure of 827 kPa (120 psi). When using AASHTOWare Pavement ME Design, the variations changes were 23.04% for the pressure of 552 kPa (80 psi) and 22.95% for the pressure of 827 kPa (120 psi). It is important to observe that the increase in tire pressure caused a large growth in this type of deterioration, exceeding by almost 60% when analyzed by MEPDG, and getting around 45% when analyzed by AASHTOWare Pavement ME Design.

Moreover, it became clear that the pressure of 827 kPa (120 psi), compared to the deterioration caused by the 552 kPa tire pressure (80 psi), always provokes higher deterioration in the pavements, except the permanent deformation on the subgrade, which was not influenced by the tire pressure variation.

The International Roughness Index (IRI) calculated by MEPDG, showed a variation of 8.29% between the maximum and minimum values for the pressure of 552 kPa (80 psi). With the growth of the pressure to 827 kPa (120 psi), a variation of 10.32% was observed. Thus, it was noticed an increase of almost

12% as the pressure was raised from 552 kPa (80 psi) to 827 kPa (120 psi). However, when the analysis was done using AASHTOWare Pavement ME Design, variations were lower, being 6.77% for the pressure of 552 kPa (80 psi) and 7.79% for the pressure of 827 kPa (120 psi).

In Figure 3, the results of the longitudinal cracking (surface-down) provided by MEPDG related to the adoption of 552 kPa tire pressure (80 psi), a variation of 46.89% was observed in the pavement deformation values when the growth rate increased from 4% to 12%. When the analysis was performed with the AASHTOWare Pavement ME Design, the change was 49.05%. In relation to the application of 827 kPa (120 psi) pressure, the longitudinal cracking shows the same behavior, again with higher values in the analyzes with MEPDG indicating a variation of 40.75%. The results obtained with AASHTOWare Pavement ME Design showed a variation of 50.43%.

When analyzing the results obtained by MEPDG for the various pressures, in the case of longitudinal cracking (surface-down), it was observed that the deterioration from the 827 kPa (120 psi) pressure exceeded by more than 5% the deterioration resulting from pressures of 552 kPa (80 psi). However, the AASHTOWare Pavement ME Design displayed an opposite behavior, the values obtained for pressures of 827 kPa (120 psi) were lower than the pressures of 552 kPa (80 psi), resulting in a reduction of more than 1%.

The fatigue cracking (bottom-up), considering the pressure of 552 kPa (80 psi), presents a variation of 52.22% when analyzed by MEPDG. When the tire pressure was increased to 827 kPa (120 psi), the variation increased to 47.39%. With AASHTOWare Pavement ME Design, variation was 53.56% for the pressure of 552 kPa (80 psi), while for the pressure of 827 kPa (120 psi) was 50.63%.

When analyzing the results obtained for the different pressures, in the case of fatigue cracking (bottom-up), it was observed that the deterioration from the pressures of 827 kPa (120 psi) exceeded by more than 12% the deterioration resulting from 552 kPa (80 psi) pressure when analyzed by MEPDG. Using AASHTOWare Pavement ME Design, in turn, the increase was over 10%.

It is noteworthy that the pressure of 827 kPa (120 psi), compared to the deterioration caused by the 552 kPa tire pressure (80 psi), causes higher deterioration in the pavements, except the longitudinal cracking when analyzed by AASHTOWare Pavement ME Design. Assessing the permanent deformation on the surface with MEPDG for the pressure of 552 kPa (80 psi), there

is relatively little variation between the minimum and maximum values, reaching 6.52%. By increasing the pressure to 827 kPa (120 psi), there was little effect, since the values ranged from 3.6 mm to 3.9 mm. When the analyzes were made with AASHTOW are Pavement ME Design, variations values were very close to those obtained with MEPDG.

Figure 3. Deteriorations values caused in the pavement related to the variation of the nonlinear traffic growth rate.

is relatively little variation between the minimum and maximum values, reaching 6.52%. By increasing the pressure to 827 kPa (120 psi), there was little effect, since the values ranged from 3.6 mm to 3.9 mm. When the analyzes were made with AASHTOWare Pavement ME Design, variations values were very close to those obtained with MEPDG.

The permanent deformation on the subgrade, in turn, showed higher sensitivity than on the surface. Considering the pressure of 552 kPa (80 psi) with analysis by MEPDG, there was a variation of 10.86%. When the tire pressure was changed to 827 kPa (120 psi) there was an identical behavior as at the pressure of 552 kPa (80 psi), with no difference between the obtained values. When the analysis was performed with the AASHTOWare Pavement ME Design, the program obtained slightly higher deformation values, but the same behavior was observed, reaching a variation between the predicted values of 11.03%.

In the case of total permanent deformation, the variation values obtained by both programs continued to be similar, being 52.48% for the pressure of 552 kPa (80 psi) with analysis by MEPDG and 52.65% for the pressure of 827 kPa (120 psi). When using AASHTOWare Pavement ME Design, the variation changes were 52.39% for the pressure of 552 kPa (80 psi) and 52.05% for the pressure of 827 kPa (120 psi). It is noteworthy that the increase in tire pressure caused a large elevation in this type of deterioration, exceeding by almost 60% when analyzed by MEPDG, and getting around 45% when analyzed by AASHTOWare Pavement ME Design.

The International Roughness Index (IRI) showed a variation of 20.71% between the maximum and minimum values when analyzed by MEPDG to a pressure of 552 kPa (80 psi). With the growth of the pressure to 827 kPa (120 psi), a variation of 26.37% was observed. Thus, it was noticed a rise of almost 15% as the pressure of 552 kPa (80 psi) increased to 827 kPa (120 psi). However, when the analysis was done using AASHTOWare Pavement ME Design, variations were lower, being 15.10% to the pressure of 552 kPa (80 psi) and 17.11% for the pressure of 827 kPa (120 psi).

The graphs of Figure 4, in turn, represent variations of deterioration according to the change of the traffic growth behavior. When comparing the results related

to different growth rates; it was observed that the deterioration values obtained for the growth rate of nonlinear behavior were always higher than the deterioration values of the linear growth rate. Such behavior was observed both in the results obtained by MEPDG, as in the results obtained by AASHTOWare Pavement ME Design. Furthermore, it was noticed a significant variation between the minimum and maximum values, revealing a higher sensitivity of the pavement to the traffic growth of nonlinear behavior, as represented in the graphs of Figure 4.

It is verified that the sensitivity of deteriorations almost doubled in all cases when the traffic growth rate was nonlinear. This occurrence may be explained by the fact that the nonlinear growth is based on an exponential function, which represents superior variation than the linear function.

CONCLUSIONS

Comparing both software versions, in general, there were minor differences in the sensitivity values obtained by MEPDG and AASHTOWare Pavement ME Design. Nevertheless, these differences may be due to some disparity in the program settings, since there were changes from MEPDG to AASHTOWare Pavement ME Design. It is noteworthy that AASHTOWare Pavement ME Design is still in development and undergoes periodic changes, so it is possible that the model for some predictions is still being improved.

Analyzing the results found herein, it can be concluded that the AADT variation has an influence on the pavement performance. Among all evaluated deteriorations, the longitudinal cracking and fatigue cracking were those which presented greater sensitivity. Hence, it is recommended conducting an appropriate traffic survey with a historical basis to achieve a reliable AADT value that must be compatible with a realistic situation. An adequate AADT value would lead to an accurate deterioration prediction and, thus, enable the development of a pavement design with good performance.

The variation of the linear growth rates also influenced the pavement performance, presenting a similar behavior to the variation of AADT, but with slightly higher sensitivity. The highest sensitivity, however, occurred when there was a variation in the growth

Figure 4. Deteriorations sensitivity related to the linear and nonlinear growth rates.

rates of nonlinear behavior. In this case, it was obtained values that exceeded approximately in 50% the values of variation regarding the linear growth rate. Based on this, it is assured the importance of considering the nonlinear growth behavior in traffic study, since the use of linear growth rate would result in improper pavement design. Therefore, it is

necessary to perform appropriate traffic surveys as well as statistical studies with a historical basis to obtain the correct growth rate.

In Brazil, 827 kPa (120 psi) tire pressure portrays the reality of today's cargo vehicles, thus it is important to update the pavement design process. It is still

widely used that method that considers a standard axis of 8.2 tf with a tire pressure of 552 kPa (80 psi), which is far from the real situation, causing improper pavement dimensioning and, that way, reducing its operating life.

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