Improvement in Durability and Service of Asphalt Pavements

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Develop a pavement design procedure that allows calibrating the design variables of asphalt pavements using regionalized conditions, to obtain efficient pavement performance for developing countries with limited resources and data.

Keywords: asphalt pavement ; infrastructure planning ; Pavement section catalog ; Pavement design

1. Introduction

A pavement is durable if it maintains its structural and functional integrity to a satisfactory level throughout its nominal design life; this, when exposed to the environmental effects and traffic loads [1]. The deterioration in the pavements, overwhelmingly, is attributed to the poor quality of the materials, inefficiency of construction processes, or designs that underestimate the real traffic, subsequently, the design is inadequate regarding the structure of the pavement and the asphalt layer [2]. It is important to mention that pavement is doomed to fail because the materials that constitute it obey to the fatigue laws, that is, a certain number of admitted loads that make the pavement weaker and fail [3]. Therefore, it is necessary to correctly establish design variables, which contribute to the pavement achieving optimum serviceability during the life which they were designed for [4]. According to Andersen [5], one of the key components for the analysis of pavement structural behavior is the response model used to estimate the stresses, deformations, and displacements of the pavement structure subjected to existing traffic, taking into account the properties of the material and predominant environmental conditions. Based on these considerations, the optimum pavement structure must be defined by a design that provides a satisfactory level of performance to the user, an acceptable level of reliability, sustainability in using natural resources, environmental care, and a minimum total cost [6][7][8].

To achieve the above, the mechanistic pavement design method and mechanistic- empirical design method contemplate all the components mentioned. In this sense, current literature has shown that they are the most suitable for maintaining pavements structural and functional integrity [9][10][11][12].

These design methods are powerful tools, but their main problem lies in their eminently empirical nature. The import of the methods into other countries is quite difficult, because it requires a solid database, which is normally not available in most of the developing countries [13][14]. According to Das [15], each region, state, county, and country may be following a particular pavement design guideline, somewhat different than the rest others. The input parameters, the equations, the design recommendations, and thickness values provided in these guidelines may vary widely. For example, the different design methods between counties in the United States of America, the adaptations of these methods in some Latin American countries, and the development of the South African mechanistic pavement design method, the French method, United Kingdom and Shell methods currently in use in Europe, to mention a few.

In Mexico, examples of these tools are the Structural Pavement Sections Catalog for Roads of the Mexican Republic supported by the Ministry of Communications and Transport (SCT for its acronym in Spanish) and a design program promoted by the National Autonomous University of Mexico (UNAM) and funded by the SCT, named as Dispav-5; however, these tools were developed under specific load and climate conditions of the central region of the country, leaving some territorial areas out of reach. Likewise, regarding the already mentioned catalog, it is a document focused on Mexican highways, mostly under federal jurisdiction, where the generalized weight and calculations of the traffic are reflected and also, where the regional temperature is involved [16].

2. Background

According to the Federal Highway Administration [17], a balanced and comprehensive pavement condition rating system should be based on two types of pavement conditions, structural and functional. The first one is the pavement's capacity to receive the traffic and the environmental conditions. The second is the functional condition that is based on ride quality and safety rated by its users.

Various factors influence asphalt pavements durability built on roads; this is because construction processes, quality of materials, design aspects, weather conditions as well as operating conditions directly contribute to asphalt pavements durability [18]. It is important to mention that the present research focuses on highways and roads, mainly in the design stage.

Most of the studies where factors that impact asphalt pavements durability are identified, mainly focus on (1) traffic effects and vehicular loads, (2) characteristics and properties of the materials that make up the structure of the pavements, and (3) weather and road operation effects.

In the first one of these, various studies have analyzed the traffic effects on pavement surface deterioration and the loss of its structural capacity [19][20][21][22]. It is important to mention that vehicular traffic and its solicitations directly affect the structure that constitutes the pavement, for this reason, it is essential to quantify loads magnitude by distributing the different types of vehicles, contact areas, and distribution of tire inflation pressures on the pavement [23].

For existing traffic sizing, AASHTO implements the concept of equivalent single axle load (ESAL) in order to provide a more precise and rational point of view regarding the structural capacity of a pavement [18]. This concept represents the predicted damage unit induced by repetitions of a single axis of 8.2 tons with an inflation pressure of 5.8 kg/cm^2 in a time frame [24][25]. According to Lavin [26], the number of equivalent axles is a key aspect in estimating the useful life and design of pavement. As mentioned above, requesting traffic is a contributing factor in predicting damage the pavement will suffer over a time frame. Nevertheless, the characterization of solicitations produced by the traffic on the pavements is quite complex, due not only to the variability and periodicity of the vehicles that drive on them but also to the vehicle-pavement interactions and driving speeds [3].

In the second one of them, several studies point out the importance of the characteristics of the materials that make up pavement structures, since mechanistic methods involve the analysis of stresses and deformations in an elastic multilayer system [27][28][29][30][31].

Regarding the above, asphalt pavements are a system of layers built with different mechanical properties. Usually, upper layers of pavements have the best quality and, with this, decreases with depth until reaching the natural ground [32]. According to Rengifo and Vargas [33], asphalt pavement stability, in order to withstand loads and to resist stresses, depends directly on the internal friction and cohesion of the aggregates used. If those values are adequate, the movement of aggregates is prevented due to the forces exerted by traffic. The determination of the properties and performance of the materials is achieved from a set of established tests or trials, to verify that these materials work correctly according to ranges, limits, and/or standard values for similar or equivalent conditions [34].

Regarding the third factor, studies have analyzed the climatic variable as an aspect in consideration since this directly affects the behavior of the design and evaluation of asphalt pavement durability [35][36][37][38][39]. This condition modifies pavement stiffness due to the thermoplastic properties of the material that constitutes the asphalt layers [40]. Asphalt pavement surfaces progressively deteriorate when exposed to repeated loads caused by traffic and environmental conditions, such as heat, wind, rain, and separation of the asphalt layer by moisture or ultraviolet radiation. All of these factors lead to the cracking of asphalt surfaces in the pavement structure, which leads to failure [41]. In accordance with the above, there is ample evidence that the presence of different climatic phenomena significantly contributes to the deterioration of road pavements. Therefore, the consideration of these events is essential in the planning of design projects.

Besides durability, it is necessary to provide road infrastructure that offers quality, safety, and comfort [42]. The functional quality is rated by users, primarily for surface smoothness, safety, comfort, and infrastructure overall appearance [43]. Furthermore, the elapsed time of failure impacts the pavement life cycle, giving rise to a behavior curve reflecting the service level provided to the user, which in turn has significant economic implications [44].

Due to the above, AASTHO developed a test in 1959. This test establishes serviceability based on the average of the evaluations of the users participating in the study [4][45]. The evaluation of this parameter defines the concept of the

Present Serviceability Index (PSI), which qualifies the pavement surface according to a scale of values from 0 to 5 [24]. This index has been used in various studies to optimize the useful life of the pavement through models and decision-making procedures that consider multiple objectives, such as reducing maintenance and rehabilitation costs, preserving the quality of the pavement surface during its useful life, optimal resource allocation, pavement management, as well as equip users with safer and more comfortable roads [46][47][48][49]. Thus, the serviceability evaluation is fundamental for maintenance and rehabilitation decision-making, as well as providing a quality transportation system, optimizing resources, and reducing the costs of road infrastructure during its useful life.

Therefore, a pavement with good performance can reduce costs and risks through the whole life cycle of road infrastructure while keeping users safe. However, the inaccessibility of some countries to apply mechanistic and empirical mechanistic methods, the designer could modify variables in favor of the structure design with lower construction costs, which do not include maintenance work on the pavement [13]. For this reason, generating regionalized pavement structures for road construction is considered essential, eliminating the possibility of manipulating the design variables. Additionally, the Marshall design is widely used in Latin American countries asphalt pavements design. This procedure has substantial drawbacks with respect to replicating the real or actual behavior of asphalt during construction and in actual in-service conditions [50].

That is why several authors have made proposals for the regionalization of variables to design pavements. In this sense, Yang et al. [51] developed an asphalt pavement regionalization multi-index method in China. They conclude that the method's accuracy and reliability help in ensuring asphalt pavement life service and adequate performance.

Guerrero & Albitres [52] concluded that weather and operating conditions directly influence asphalt pavements' durability. Therefore, it is necessary to develop techniques that improve the design processes of asphalt pavements and be resilient to the area's requirements. In fact, since the implementation of the design method Superior Performing Asphalt Pavement (SUPERPAVE), many studies worldwide focus on calibration climatic zones for the PG for asphalt binders, significantly improving the behavior of this material to the environmental conditions of the analysis regions [50][53][54][55][56].

On the other hand, Villacorta et al. [57] carried out a study in Mexico using aging asphalt modeling, concluding that the omission of regionalized factors in predicting asphalt pavements' mechanical properties presents numerous errors compared to the actual performance. Finally, it is important to mention that in several Latin American countries, pavement design is performed by using adaptations of the AASHTO-93 empirical design method obtaining reliable results [15].

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