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Research paper

Analysis of CBR design value selection methods on flexible pavement design: Colombia case study

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Abstract

A comparative analysis was carried out to observe the variation of a flexible pavement structural thickness, due to the use of different methods to calculate the CBR design value, as an essential variable to estimate the Subgrade Resilient Modulus (Mr) through an empirical correlation. The Asphalt Institute Method and the Mean Criterion Method were applied to calculate de Design CBR value of a homogeneous roadway division from a representative track section located in the Bolivar Department, Colombia. As a result, the Design Percentiles of the CBR design unit were expanded for the Asphalt Institute method, thus, allowing the approach of more reliable and safe designs, considering that this method limits the selection percentiles to three traffic levels.

Keywords: *Asphalt; CBR; Design; Flexible Pavement; Pavement Design.*

1. Introduction

The flexible pavement design has been studied during the last years, considering that the methodologies adopted to establish the pavement structure thickness were mainly developed by the United States of America, searching for optimal roadways designs. Still, the empirically-based methods cause variable results due to its experimentation dependence.

A designing pavement process requires the most economical combination of layers and materials which guarantee the correct traffic stress distribution across its structure, for the pavement not to presents excessive stress or deformations through its useful life [1]. Similarly, it's essential to consider other fundamentals variables in the pavement design as the subgrade, which conditions the thickness of pavement structural layers directly. In the AASHTO Method [2], this variable is characterized through the Resilient Modulus, although, in Colombia, the related test is costly, and very few engineers use it; instead, correlations between de Resilient Modulus and CBR are used frequently.

In Colombia, every pavement engineer designs using the criteria that are considered adequate for a specific project. The design criteria based on CBR is broad: some engineers follow the recommendations gave by the Asphalt Institute, and others use Mean Criterion to approach the selection of a functional or optimal CBR to be used in a pavement track. Therefore, it is highly probable to obtaining several layers thickness depending on the method used, even having the same input information. The lack of a precise and quantitative description of the pavement failure definition, in conjunction with the few comprehension of each method confidence level, has led to the gap widening between methods [3].

We aimed to compare the variability of layers thickness and the structural number of a pavement structure obtained using the same data input. Still, two different criteria to a 90 km vial track localize within the Bolívar Department (Colombia). The AASHTO 93 method was used to make the calculations.

2. Theoretical fundaments

In Colombia, the most commonly used method to design new flexible pavement is AASHTO 93. The Subgrade Resilient Modulus (Mr) is a fundamental input variable that represents the subgrade capacity to support repetitive stress, produced by traffic charges [4]. Correspondingly, the number of 18 kip equivalent single axle loads (W_{18} or ESALs), the allowable serviceability loss at the end of design life (DPSI), and other drainage factors are also relevant inputs of the AASTHO 93 Procedure [11]. In contrast, the Structural Number "SN" and layers thickness are the output.

The Subgrade Resilient Modulus (M_r) and the California Bearing Ratio (CBR) test are the main parameters to characterize the granular layers of the flexible pavement [5], [12], [13]. The Subgrade Resilient Modulus M_r qualifies the elastic deformation behavior of the soil from a repeated triaxial test using a constant confining pressure, obtaining a relation between the deviator stress and the axial strain (unit deformation). Thus, Mr determination is an essential factor in the design of structures against repetitive stress [6]. Nevertheless, pavement designers in Colombia use correlations equations of M_r that depend on CBR (**Error! Reference source not found.**).

Table 1: Correlations between MR and CBR

Correlation	Reference
$M_r(psi)=1500 \cdot CBR$ for $CBR<7.2\%$	AASHTO 93
$M_r(MPa)=22,1 \cdot CBR^{0,55} \geq 12\%$	TRRL
$M_r(MPa)=10 \cdot CBR$	Heukelom & Foster, 1960
$M_r(MPa)=10 \cdot CBR^{0,73}$	Poulsen & Stubstad
$M_r(MPa)=130 \cdot (CBR_{Design\ Value})^{\frac{1}{1.4}}$	National Cooperative Highway Research Program

This research used the National Cooperative Highway Research Program Correlation, according to the area type of soil. The use of one equation allows the reduction of the variables number and focusing the analysis on the CBR behaviour depending on the selected design criteria. The Structural Number (SN) was calculated using Equation 1.

$$\log W_{18}=Z_r \cdot S_0+9.36 \cdot \log(SN+1)-0.20+\frac{\log\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40+\left(\frac{1094}{(SN+1)^{5.19}}\right)}+2.32 \cdot \log M_r-8.07 \tag{1}$$

The design CBR value for a pavement track of a project could be challenging to select since every 250 m a pit is excavated to characterized the soil through grain size analysis, consistency limits test, and CBR test. Therefore, it's not possible to make a pavement design using all CBR values obtained in the field investigation phase; as a result, the selection of the CBR design value can be made using various methodologies. In this research, the methods used to make the comparison between CBR design values were those recommended by the Asphalt Institute and "the mean criterion".

The Asphalt Institute [7] recommends that the 60, 75, or 87.5% of CBR individual values be equal or higher than the CBR design value, depending on the expected traffic, which will move over the pavement (Figure 4). According to the transit (Table 2) and having established the CBR values of each pit, the last are ordered in an ascendant way, obtaining a percentage of values higher or equal for each one. The CBR values are graphed versus the percentages to select the CBR design value.

Table 1: Percentiles to Determine the CBR Design Value Using the Asphalt Institute Criteria [8]

ESALs	Percentile to select the CBR design value
$\leq 10^4$	60.0
$10^4 - 10^6$	75.0
$\geq 10^6$	87.5

The Mean Criterion method selects the value for which half of CBR values are higher, and half of the CBR values are lower. The chosen CBR value is diminished in Z times the standard deviation. The standard deviation Z depends on the confidence level used in the design (Table 3).

Table 2: Standard Normal Deviation According to Confidence Level [8]

Confidence Level (CL %)	Standard normal deviation (Z)
50	0.00
85	1.00
90	1.282
95	1.645
98	2.054

The CBR design value is calculated using **Error! Reference source not found.**.

$$CBR_{design\ value}=\overline{CBR}-(Z \cdot \sigma) \tag{2}$$

3. Study area

Nowadays, in Colombia is taking place the reconstruction and paving of roadways previously controlled by illegal armed groups and now recovered by the nation after the peace agreement signed in 2016. Within these are located the roadways object of this research: 90 km divided into five main track sections (Figure 1). Only the calculation memories of the Track five will be showed in this article, due to its representative character for the research.

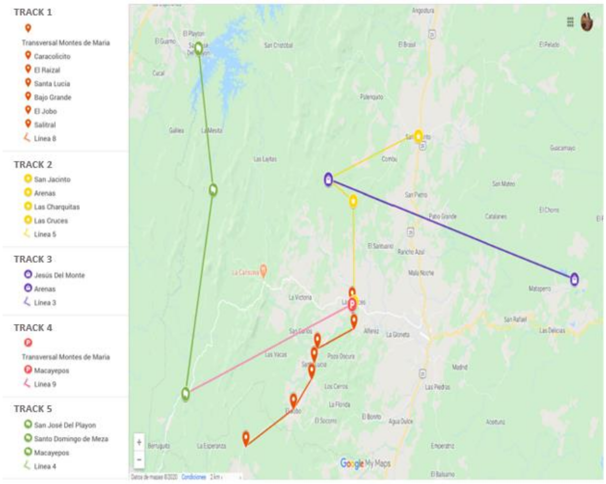

Fig. 1: Vial Tracks Used in the Study Identification.

Track section five of the research project is located near San José de Playón, Santo Domingo de Meza and Macapeyo, Bolivar Department, and has a 37.5 km length. Seventy-two pits were excavated in this track section, recovering soil samples used for classifying and CBR Test. The soil in this track was classified varying from lean Clay (CL) and clayey sand (SC) to well-graded gravel (GW), according to the Unified Soil Classification System (USCS), while the CBR test results were in a range between 5.3% and 28.8%.

4. Methods

In the first place, a selection of homogeneous track sections was made to establish adequate design units, following the ASSHTO93 [2, 14, 15] procedure for pavement design. The cumulated differences method, recommended by the "Instituto Nacional de Vías" –INVIAS [9], was selected to divide track section five. This method includes the Zx variable as a statistic measurement of the data and takes into account slope changes of the vertical alignment (Figure 2).

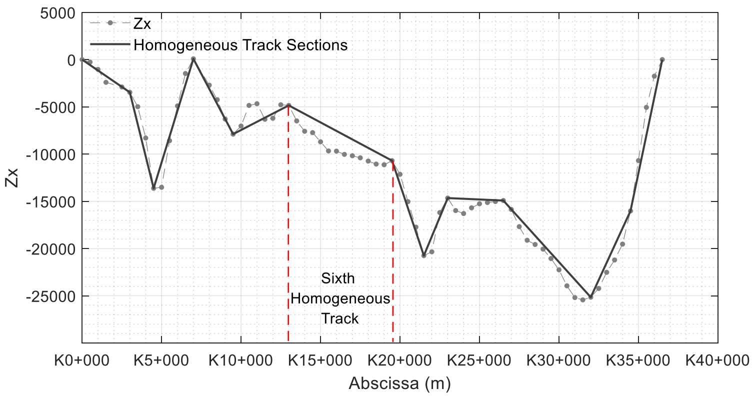

Fig. 2: Homogeneous Track Five-Section Selection. the Analysed Sixth Section Is Shown.

Ten homogeneous divisions were taken from track section five, but just one division was analysed: the sixth one (K13+000 to K19+500). Two CBR design values were calculated for the sixth division using both described methodologies: Asphalt Institute Method and Mean Criterion Method. Then, a comparison between calculated CBR design values was made by establishing, in the first place, an equivalence between the design percentile used in the Asphalt Institute Method, and the confidence level used in the Mean Criterion Method, associating seven different design traffic levels (Table 4). Hence, the Mean Criterion requires a redefinition of the standard normal deviation associated with each confidence level established in Table 4.

Table 3: Equivalency between Design Percentile (Asphalt Institute Method) and Confidence Level (Mean Criterion Method)

ESALs	Asphalt Institute Method Design percentile	Mean Criterion Method Equivalent confidence level
50.000	60%	20%
500.000	75%	50%
1.000.000	87,50%	75%
2.000.000	90%	80%
3.000.000	93%	85%
5.000.000	95%	90%
10.000.000	99%	98%

Table 4 includes the standard normal deviation used according to the equivalent confidence level and ESALs.

Table 4: Standard Normal Deviation Associated with Confidence Level

ESALs	Equivalent confidence level	Standard normal deviation
50.000	20%	0
500.000	50%	0

1.000.000	75%	0,674
2.000.000	80%	0,841
3.000.000	85%	1,037
5.000.000	90%	1,282
10.000.000	98%	2,054

The layer thickness was designed using the AASHTO93 Design Guide [2], fixing the values including in Table 5, according to project characteristics.

Table 5: Values for AASHTO93 Flexible Pavement Design Variables

Variable	Value	Observation
T (°C)	30	Mean Temperature of Study Area
R	80%	Rural Road
Zr	0,841	Rural Road
So	0,49	Considering traffic variation
Po	4,2	Flexible Pavement
Pt	2,5	Main Roadway

5. Results

CBR Design Value comparative analysis revealed non-homogeneous differences between selected methods in the sixth homogeneous division of the number five track section, located at the Bolivar Department, Colombia. The results of the study are shown following the traffic, represented on ESALs because it's considered a fundamental parameter in the design and behaviour prediction of pavement structure [10]. Table 7 contains the results of the CBR Design Values calculated using the Asphalt Institute Method, while Table 8 presents the CBR Design Values calculated with the Mean Criterion Method.

Table 6: CBR Design Value Calculated According to the Asphalt Institute Method

ESALs	Design percentile	% CBR design value
50.000	60%	15,2
500.000	75%	15
1.000.000	87,50%	12,9
2.000.000	90%	12,8
3.000.000	93%	12,7
5.000.000	95%	12,5
10.000.000	99%	12

Table 7: CBR Design Value Calculated According to the Mean Criterion Method

ESALs	Design percentile	% CBR design value
50.000	20%	15,22
500.000	50%	15,22
1.000.000	75%	14,15
2.000.000	80%	13,94
3.000.000	85%	13,65
5.000.000	90%	13,21
10.000.000	98%	12

A comparison was made between CBR Design Value calculated by both methods (Table 8), indicating the CBR variation percentage between procedures, according to traffic; obtaining a range of variation from 0.14% to 9.50%, which minimum differences were found to be in the extreme ESALs: 50.000 (0.14%) and 10.000.000 (0.14%). In comparison, the significant difference of 9.5% locates at 1.000.000 ESALs.

Table 8: The Variation between CBR Design Values Calculated Using the Asphalt Institute Method and Mean Criterion Method

ESALs	Asphalt Institute Method	Mean Criterion Method	CBR Variation Between Methods [%]
	% CBR design value		
50.000	15,2	15,22	0,14
500.000	14,95	15,22	1,82
1.000.000	12,93	14,15	9,5
2.000.000	12,82	13,94	8,73
3.000.000	12,7	13,65	7,49
5.000.000	12,46	13,21	6
10.000.000	12,01	12	0,14

The objective of this research was the comparative analysis of flexible pavement layer thickness and Structural Numbers, calculated using the Subgrade Resilient Modulus Mr obtained with the mentioned methods. In this light, the next step was to estimate the Resilient Modulus for each CBR Design Value, followed by Structural Number (Table 9) and layer thickness calculation (Table 10).

Table 9: SN Obtained Considering CBR Design Values

ESALs	Asphalt Institute Method Structural Number	Mean Criterion Method	Structural Number Variation Between Methods [%]
50	1.56	1.56	0%
500	2.30	2.29	0%
1,000,000	2.67	2.60	3%
2,000,000	2.97	2.91	2%

3,000,000	3.17	3.11	2%
5,000,000	3.43	3.38	1%
10,000,000	3.83	3.84	0%

Table 10: Pavement Thickness Obtained Considering CBR Design Values

ESALs	Asphalt Institute Method Pavement Thickness	Mean Criterion Method	Thickness Variation Between Methods [%]
50	18.73	18.73	0%
500	26.93	26.67	1%
1,000,000	32.56	30.77	5%
2,000,000	36	34.47	4%
3,000,000	38.44	36.91	4%
5,000,000	41.6	40.33	3%
10,000,000	46.69	46.95	1%

According to the information previously displayed, Figure 3 presents the Structural Number variation versus traffic information. In the same way, Figure 4 includes the Pavement Structure thickness variation versus traffic information. In both cases, the results from the comparison between the Asphalt Institute Method and the Mean Criterion Method are shown. The higher difference is found for the pavement structure thickness between 1,000,000 to 5,000,000 ESALs.

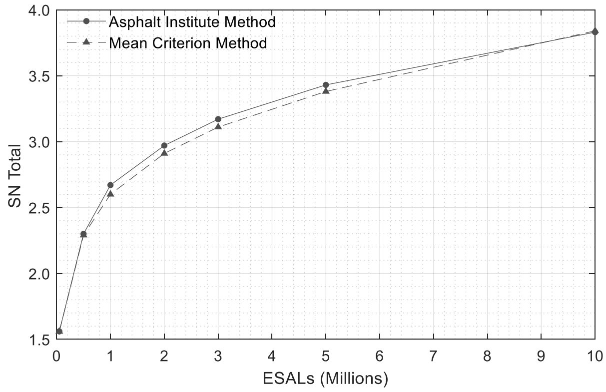

Fig. 3: Structural Number Vs. Esals Comparison between the Used Methods.

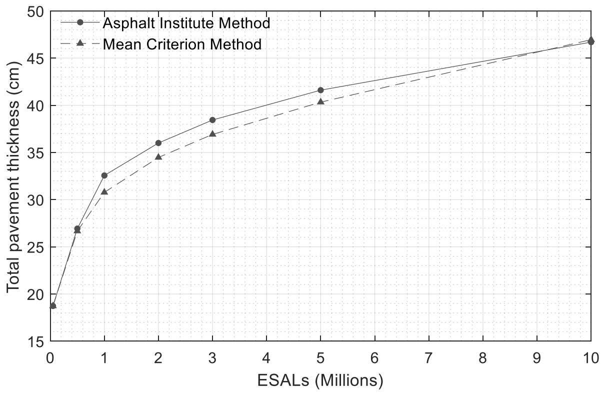

Fig. 4: Pavement Structure Thickness Vs. Esals Comparison between the Used Methods.

6. Conclusions

The selection of the method to calculate the CBR Design Value is a Designer Engineer decision that will affect the thickness and, thus, the cost of a project directly.

This research widened the selection Percentiles for the CBR Design Value calculated according to the Asphalt Institute Method, allowing the pursuit of more reliable and safe designs. The increase in the traffic levels up to 10.000.000 ESALs is significant, considering that the original Method uses only three levels: less than 100.000, range between 100.000 and 1.000.000 ESALs, and higher than 1.000.000 ESALs.

In the same way, this research provides an equivalency table between the confidence level of the Mean Criterion Method and the Design Percentile of the Asphalt Institute Method, which allows the comparison between the CBR Design Value, Structural Number, and Pavement Thickness coming from the calculation made with each method.

The variation percentages of Structural Number and Pavement thickness between methods are low for 50,000 and 10,000,000 axels' number, indicating that the expected traffic is a variable to taking into account for selecting a CBR Design value calculation Method. Therefore, it's not essential the chosen method when expected traffic is located at the extremes.

The most notable variations between methods are evident in the range from one to five million ESALs, which may be explained due to the sensitivity in the selection of the confidence levels or design percentiles.

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