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ASPHALT PAVEMENT DESIGN ALTERNATIVES FOR ROADS WITH LOW AND MEDIUM TRAFFIC VOLUMES IN CLAYEY SOILS IN THE CITY OF SINCELEJO

Fernando Jove[1], Carlos Millán[2], Jhon J. Feria Díaz[3]

[1,2,3]Department of Civil Engineering, Universidad de Sucre, Sincelejo, Sucre, Colombia.

Abstract

The design of pavements is a work of civil engineers, who seeks provide structures that are resistant to traffic loads and the effects adverse effects of the environment, so that they can be built properly and manage to provide their users with a comfortable and safe experience, at the least possible cost. To achieve this objective, it is necessary to choose a design methodology according to the characteristics of the project and determine as precisely as possible, each of the variables involved in the design, taking into consideration that many of the design methodologies are empirical in nature, which in some way puts try the designer experience. It is for this reason that designs require multiple studies, which are usually costly in financial resources and time. All of the above, many institutions have taken on the task of developing design primers that allow obtain pavement structures based on the input of few parameters and obtain applicable solutions for most projects; however, they must be taken into account the limitations of these primers and their application environment, given the case, that many of them must be calibrated, to certain particular conditions of the project area, with the aim of objective of optimizing resources and guaranteeing lasting works. The objective of this work is to make an asphalt pavement design primer based on the methodology of AASTHO 1993 design, which allows finding a suitable design alternative for projects located in the city of Sincelejo, north of Colombia. For this purpose, it carried out studies of soils in clayey subgrades, which predominate in the town of study and that they classify as CL to obtain their bearing capacity values (CBR). Additionally, various levels of traffic were selected, which can occur and are defined the typical pavement structures. For method design parameters, the typical values expected in the study area were used, which resulted in, a design primer that is made up of twenty transit levels and four pavement structure alternatives, for each case, that satisfy these requests.

Keywords: pavement design, construction material, design handbook, subgrade

1. INTRODUCTION

The civil engineering profession since its inception has been involved in the development, construction and operation of works that make it easier and improve the quality of life of people. For a long time, transportation has been one of the areas in which the engineering has directly and positively influenced, through the construction of works such as roads, bridges, pipelines, tunnels, canals, railways, ports and docks, which they have given shape and importance to the profession. The responsibility of engineers civilians, focuses on providing transport infrastructure that is commensurate with demand of the growing population [1]. It should be noted that road infrastructure works have a great relevance in the development of today's society, which is why it should tend to for carrying out optimal designs, which must be complemented with adequate construction processes and maintenance, aimed at guaranteeing adequate translatability and project durability.

Pavements are structures made up of superimposed layers that are located resting on the subgrade or natural soil. The main function of pavements consists of distributing the loads exerted by the vehicles on the structure, towards the foundation or subgrade surface, without affecting the integrity or condition of the pavement structure or foundation soil. Therefore, within the main characteristics of the pavements, priority is given to the fact that they must have a sufficient thickness, that is capable of withstanding the efforts of the vehicles and the climatic conditions of the environment, as well as provide a comfortable experience by providing a smooth surface, with good coefficient of friction and low noise level and, additionally, there is a long-life design at low maintenance cost [2].

The design of the pavements must be designed to meet the needs of traffic current and future, so that it can be provided to the different road users, a mobilization in a safe, lasting and cost-effective manner [3]. That is why the activities pavement design, should be focused on making different combinations of Subbase, base, and bearing surface material alternatives that provide and guarantee an adequate load capacity for project requests, taking into account into consideration factors such as: construction materials, road traffic, the climate of the project area, road drainage, design period, maintenance and cycle of life of the work [4].

The types of pavements can be very varied and present certain characteristics depending on the layers that integrate them or the rolling surface that they present, but essentially, the most common types of pavements built for the traffic of vehicles, correspond to flexible pavements and rigid pavements and, in general, both solutions can be designed for a long service life with proper maintenance [5].

Flexible pavements are characterized by having a rolling surface shaped by bituminous (or asphaltic) materials. These types of pavements receive their name because the total structure of the pavement is “folded”; or deflects, due to the loads of traffic. On the other hand, rigid pavements are lined with plain cement concrete (PCC) and are called “rigid”; because they are substantially stiffer than flexible pavements, due to the high rigidity of the wearing course [6], [7], [8]. Both types of pavements, present advantages and disadvantages; therefore, it is of vital importance select the most suitable type of pavement for the road project and this decision is can take by analyzing the current situation, with all the factors that have an impact on the future structure, considering the needs of users and the environment, through technical-economic analysis that will result in the final selection of the structure suitable pavement [9].

Asphalt pavements are the types of pavements most used in developing countries [10], in the same way are the types of pavements that are found on the roads of the United Kingdom [11] and are present in a high proportion in some cities of the United States [6]. This is due, to a certain extent, to the characteristics of this type of pavements, among which stand out a lower initial cost than the rigid pavements, although they present higher maintenance costs, as well as used to a large extent for roads with heavy load vehicles and a good performance over the years.

This study presents an asphalt pavement design handbook, obtained from of multiple pavement modeling based on the conditions of the urban area of the municipality of Sincelejo, in the department of Sucre, north of Colombia. It shows information related to geotechnical studies that were carried out based on samples of field and laboratory tests aimed at determining the main properties physical and mechanical characteristics of the foundation soils of the pavement. For this purpose, we worked with clayey soils typical of the study area, characterized by the USCS [12] as low compressibility clays or CL [13], which presented low capacity of support, for which it was necessary to make an improvement using granular materials, whose required thicknesses were estimated from the IVANOV model [14]. On the other hand, the design of flexible pavement structures was carried out using the most widely used methodology in Colombian territory, the AASHTO 1993 method [15], [16]. For the application of the method, different levels of traffic and combination of granular and asphalt mix layers. In the case of traffic, considered 20 levels, which correspond to 10,000, 50,000, 100,000, 200,000, 300.000, 400.000, 500.000, 600.000, 700.000, 800.000, 900.000, 1.000.000, 1.500.000, 2,000,000, 2,500,000, 3,000,000, 3,500,000, 4,000,000, 4,500,000 and 5,000,000 axles equivalent standard. In the case of the foundation soil, we worked with a subgrade typical improvement of the study area that yielded an approximate resilient modulus of 400 kg/cm². Finally, in the case of the layers used, we worked with four combinations: Structure 1 is composed solely of the Concrete layer asphalt; Structure 2 is composed of Asphalt Concrete and Granular Base; the structure 3, is composed of layers of Asphalt Concrete (AC), Granular Base (GB) and Granular Sub Base (GSB); and Structure 4, composed of Asphalt Concrete and Subbase Granular.

2. EXPERIMENTAL DESIGN, MATERIALS AND METHODS

2.1. Study area description

The city of Sincelejo is the capital of the Department of Sucre and is located to the northeast of the country, has a total area of 28,504 Ha, its average height above sea level sea is 213 meters. The city limits to the south with the municipality of Sampués and with the department of Cordoba; to the west with the municipalities of Palmito and Tolú; for the North with the municipalities of Tolú and Tolú Viejo and to the east with the municipalities of Corozal and Morroa [17]. The climate is hot dry, the average annual temperature is close to 27oC, with an average precipitation of 500 to 1200 millimeters; plant formation according with Holdridge is the tropical dry forest. On the other hand, the land of the municipality of Sincelejo, it is typical of the mountain landscape. It is formed by surfaces of irregular relief and complex, with variable slope and altitudes ranging from 50 to 260 meters. Includes the types of relief called hogbacks, bars and crests made up of limestone and calcareous sandstone materials. The landscape of Lomerío in the municipality of Sincelejo is the most important due to the size it occupies. It extends from the landscape of mountain, to the limits with the plain, both in the north and in the south. Likewise, in the type of relief of moderately undulating to strongly broken hills, with slopes between 7 and 50% and with light to moderate erosion [18]. The location of the area study is shown in Figure 1.

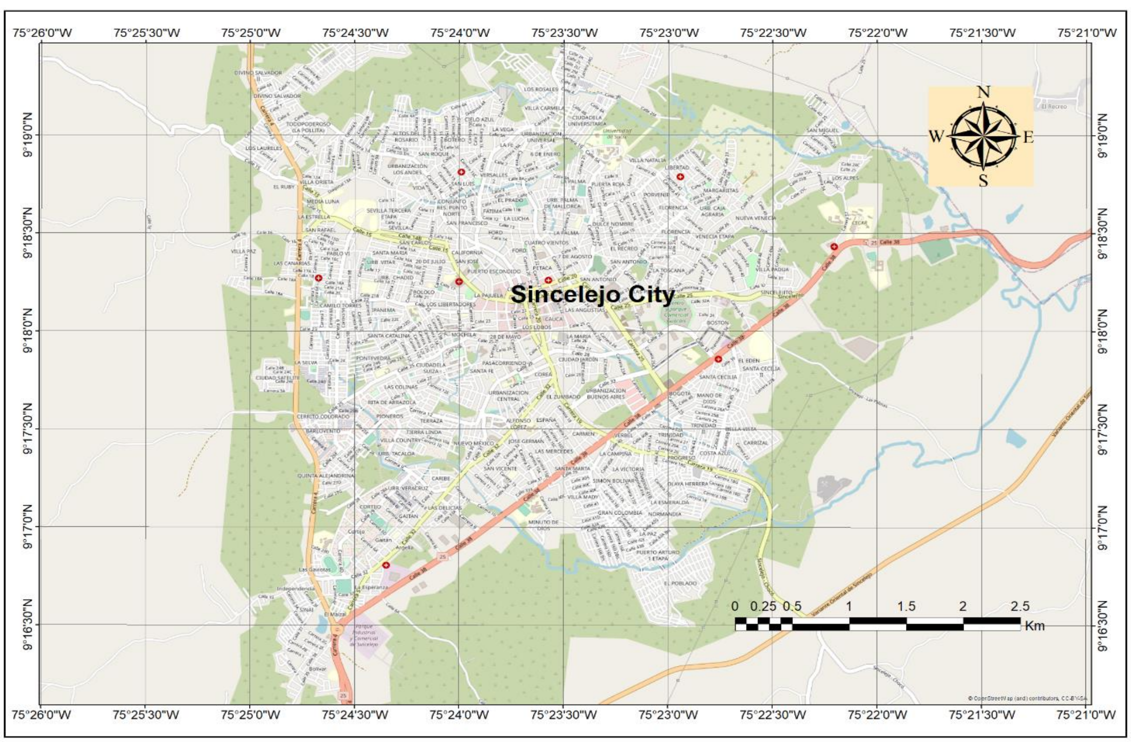


Figure 1. Location of the city of Sincelejo (research area)

2.2. Material and Methods

The methodology used to carry out this research consisted of 6 stages, which were: geotechnical exploration, characterization of subgrade soils, determination of the improvement of the foundation soils, selection of the method of design, determination of the design parameters and finally, modeling of the pavement structures. Each of the phases is presented in detail below previously mentioned.

2.2.1. Geotechnical exploration

A total of 70 representative samples of different sites of the city of Sincelejo, for their subsequent analysis in the soil laboratory, with the purpose of objective of determining its physical and mechanical properties. The soil samples are obtained up to a maximum depth of 1.50 meters and were taken altered and unaltered, and the latter, through cylinders for CBR for their respective laboratory tests. After collecting the different samples, they were transported to the laboratory facilities, following standard procedures to preserve its original conditions of humidity and density.

2.2.2. Characterization of Subgrade Soils

For this study, the disturbed samples were fractionated and dried in an oven, to then carry out the analysis tests soil granulometric and Atterberg limits (Liquid Limit and Plastic Limit) [19]. From these values, it was possible to classify the subgrade materials based on the AASHTO Soil Classification System and the Unified System Classification Soils (USCS) [12], [13]. Additionally, tests were performed to determine the natural moisture content on the altered samples. In the case of the undisturbed samples collected, the CBR assay was performed, after a previous preparation, their respective wet and dry unit weights were determined, and then, after a period of four days of immersion, they were failed following the California Bearing Ratio (CBR) standardized laboratory test procedure [20]. For the CBR of the subgrade design, the percentile criterion was used and the a value of 75%. After carrying out the laboratory tests, we proceeded to organize the information using the Excel tool.

2.2.3. Improvement of foundation soils

The characteristic foundation soils of this study, they turned out to be clayey materials with medium plasticity and low support capacity properties, which makes it necessary to use a selected filling on the fine subgrade, which allows raising the CBR of the set, in addition to preventing the contamination of the pavement layers with clayey material from the foundation soil. To carry out this activity, the IVANOV model [14] was used, in order to estimate the selected minimum fill thickness required over the existing thin subgrade and to the time, find the value of the equivalent modulus of the improved subgrade.

The Eq. 1, presents how to calculate the E1-2 combined modulus of the subgrade.

$$E_{1-2} = \frac{E_2}{1 - \frac{2}{\pi}\left(1 - \frac{1}{n^{3.5}}\right)\arctan\left(n\frac{h_1}{2a}\right)} \quad (1)$$

Where:

E2: Resilient modulus of natural terrain

E1: Resilient modulus of granular materials for upgrading

h1: Thickness of granular materials

a: Radius of the loaded area generated by a standard axis

In the same way, the value of n is obtained from Eq. 2.

$$n = \sqrt[2.5]{\frac{E_1}{E_2}} \quad (2)$$

Additionally, for the determination of the resilient modulus of the fill layer selected (E1), the SHELL criterion was used, where said Module as a function of the CBR value of the soil, as it appears in Eq. 3.

$$Mr_2 = 100 \times Mr_3 \quad (3)$$

Selection of the design method: For the design of the different pavement alternatives asphalt, the AASHTO-93 method was used, which uses a model or equation by means of from which the parameter called structural number (SN) is obtained, which is fundamental for the determination of the thicknesses of the layers that make up the pavement. These layers generally correspond to the asphalt layer and set of layers of lower quality that can be of granular materials such as bases and subbases. The equation is a function of some design variables, such as traffic, deviation standard, reliability, serviceability index, among others [21].

The methodology consists of determining the structural number (SN) required to avoid the failure of each of the support layers of the structural package, for later determine the combination of thicknesses of the different layers of the pavement, which satisfy the design conditions. Through the Eq. 4, it is possible to get the number required structural number, and then, from the required structural numbers, determine the thicknesses of the different layers that make up the pavement structure, making use of Eq. 5 [15], [16].

$$\log_{10} W18 = Z_R \cdot S_0 + 9.36 \cdot \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \cdot \log_{10} M_R - 8.07 \qquad (4)$$

Where:

W18: Predicted number of 80 kN equivalent single axle loads

ZR: Normal standard deviation associated with the design reliability R

So: Combined standard error

Pi: Initial serviceability index

Pf: Final serviceability index

SN: Structural number (inches)

MR: Effective resilient modulus of the subgrade soil (psi)

$$SN = (a_1)(D_1) + (a_2)(m_2)(D_2) + (a_3)(m_3)(D_3) \qquad (5)$$

Where:

SN: Structural number (in)

ai: Structural coefficient for the asphalt layer i

Di: Thickness of the asphalt layer i (in)

mi: Drainage coefficient of the granular layer i

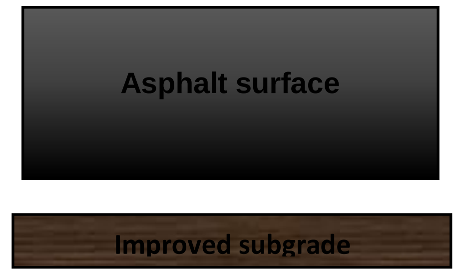
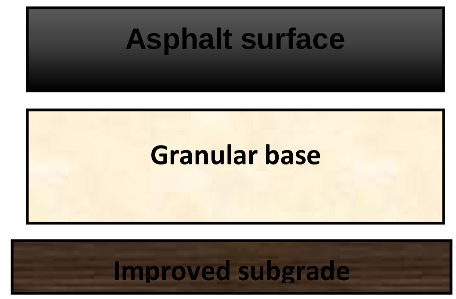
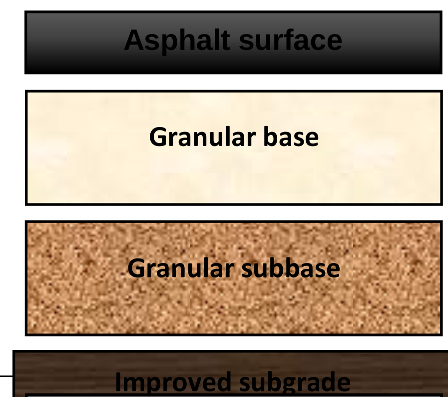
2.2.4. Determination of Design parameters

The design methodology for pavements flexible AASHTO-93, requires the definition of multiple design parameters, such as they are: traffic loads, physical and mechanical properties of the different layers that make up the pavement, the environmental characteristics of the project area, the importance of the road corridor, the initial and final state of the surface layer, among others. Subsequently, each of the considerations taken for the generation of the design primer, which corresponds to the final product obtained from this study.

Traffic: the traffic selected for the present investigation corresponds to the levels of typical traffic that cross the roads of Colombia, considering transits, from 10,000 up to 5,000,000 standard equivalent axles and ranges selected vehicles according to the design considerations recommended by the *Instituto Nacional de Vias de Colombia* (INVIAS), which resulted in the following traffic levels: 10.000, 50.000, 100.000, 200.000, 300.000, 400.000, 500.000, 600.000, 700.000, 800.000, 900.000, 1.000.000, 1.500.000, 2.000.000, 2.000000, 3.000.000, 3.500.000, 4.000.000, 4,500,000 and 5,000,000.

Design Alternatives: For this research, four alternatives have been defined of structural packages, which are described in Table 1.

Table 1. Pavement alternatives

Alternative	Description	Illustration
1	Pavement structure made up only of a layer of asphalt concrete.	
2	Pavement structure made up of the asphalt concrete surface layer, which is supported by a layer of granular material of the granular base type, which in turn rests on the improved subgrade.	
3	Conformed Pavement Structure for a Concrete Wear Course asphalt, supported on a base type granular layer that in turn is supported on a granular subbase layer and the entire pavement structure supported on the improved subgrade.	
4	Pavement structure made up of the asphalt concrete surface layer, which is supported by a layer of granular material of the subbase type granular, which in turn rests on the improved subgrade.	

Properties of the Subgrade: The characteristic soils of the study area tend to be classified as clayey or silty sands, clayey or silty gravels, and soils clayey But the type of soil that is present in most of the sites are the clays. For this reason, the present work is based on the clayey soils of the region and specifically those classified as CL (low expansive clays). For the present work, a total of 70 samples of clayey soils were taken from different sites throughout the urban area of the city of Sincelejo and obtained the values of bearing capacity of the soils, through the test of CBR laboratory after four days of immersion. It must be taken into account that this types of soils have fairly low resistance characteristics when in contact with water, which is why the resulting CBR value when carrying out the tests was quite low compared to the recommended minimums given by design guides and manuals of INVIAS. Therefore, it was decided to carry out the accepted procedure, to increase the support capacity of this type of soil through improvement with a material granular of suitable specifications. For the present case, we worked with a material of Selected Filling that can be found in the INVIAS specifiers, in the Article 220 (Embankments) and that is cataloged according to Table 220-1, as "Selected Soils", where the support capacity of this material, measured through of the CBR, it should be 10%. Then, making use of the IVANOV model, the subgrade design parameter (Improved Bearing Capacity).

Pavement Layer Properties: The pavement layers considered in the present work, as mentioned above, correspond to the types of layers most used in asphalt pavements, where the surface layer, for all alternatives, is made up of Asphalt Concrete (CA), with the intermediate layers made up of granular materials, of the Granular Base (BG) and Granular Subbase type (SBG). In this case, it was decided to work with the materials arranged in the INVIAS Materials Specifications, according to the proposed transit levels. The properties of the materials of the layers of the steel structure are detailed below.

Table 2. Properties of the materials of the pavement layers

Material	Property	Value	INVIAS Specification
Asphalt Concrete	Modulus of Elasticity (E1, psi)	320,000	Article 450 – 13
	Layer coefficient (a1)	0.37	
Granular Base	California Bearing Ratio (CBR, %)	80	Article 330 – 13
	Modulus of Elasticity (E2, psi)	28,000	
	Layer coefficient (a2)	0.13	
Granular Subbase	California Bearing Ratio (CBR, %)	30	Article 320 – 13
	Modulus of Elasticity (E3, psi)	15,000	
	Layer coefficient (a3)	0.11	

Reliability Parameters: The Empirical Character of the AASHTO 1993 Design Methodology makes it necessary to give a safety margin to the design, taking into account the degree of uncertainty in the estimation of some design variables. For this reason, it estimates the value of R, which is the inverse of the probability of failure and is associated with the level of importance of the way For the present study, a value of R = 85% is used, which corresponds, according to the AASHTO Design Guide to Collector roads or main roads in Urban areas, which is the typical case in the study area. Through the value of R, it is obtains the parameter Zr, also known as the fractal of the normal distribution, which corresponds in this particular case to Zr = -1.037. Finally, one must determine the parameter called combined normal error So, which takes into account the variation from design deviation, variation in material properties, including subgrade, variation in estimated traffic and environmental conditions. In this case, a typical value for new flexible pavements of So = 0.44 was used.

Serviceability Parameters: It is the service index that the road has with respect to the user. For this case, we worked with an initial serviceability of Po = 4.0, as it is collector roads and the economic conditions of the project area, as well as its expected traffic, it was decided to use this value for the design of the structures. For another hand, the value selected for the final serviceability was Pt = 2.0, because it is in the level of importance of the type of roads in the study area. Based on the values before mentioned, a Service Index value was obtained, ΔPSI = 2.0.

Drainage Coefficients: The drainage condition of the road is an aspect to take into account in the AASTHO 1993 asphalt pavement design method, therefore, it is necessary to define for the layers of granular materials, the values of the so-called coefficient o drainage, mi, depending on the quality of drainage of these layers and the times of exposure of the same, to adverse conditions of humidity, based on the conditions environment of the project area. For this case, an exposure time has been defined greater than 25%, which is typical of the study area and a good drainage quality, for the Granular Base layer and a regular drainage quality, for the Granular Subbase. Based on these considerations, the following values were obtained:

Drainage Coefficient for Granular Base, m2= 1.0

Drainage Coefficient for the Granular Subbase, m3= 0.8

2.2.5. Pavement Structure Modeling

For the design of pavement structures pavement use was made of the application AASHTO Design Equations for Flexible and Rigid Pavements from University of Idaho, which receives design data: Structural Number (SN), Normal Standard Deviation (Zr), Standard Deviation (So), Initial Serviceability (Po), Final Serviceability (Pt) and Soil Resilient Modulus (Mr), resulting in the Structural Number (SN). From the required structural number value, for each case, the thicknesses of the pavement layers are calculated, taking into account the characteristics of layers modules and drainage coefficients. This last step is performed in a spreadsheet of the Microsoft Excel tool. Figure 2 presents the graphic interface of the application.

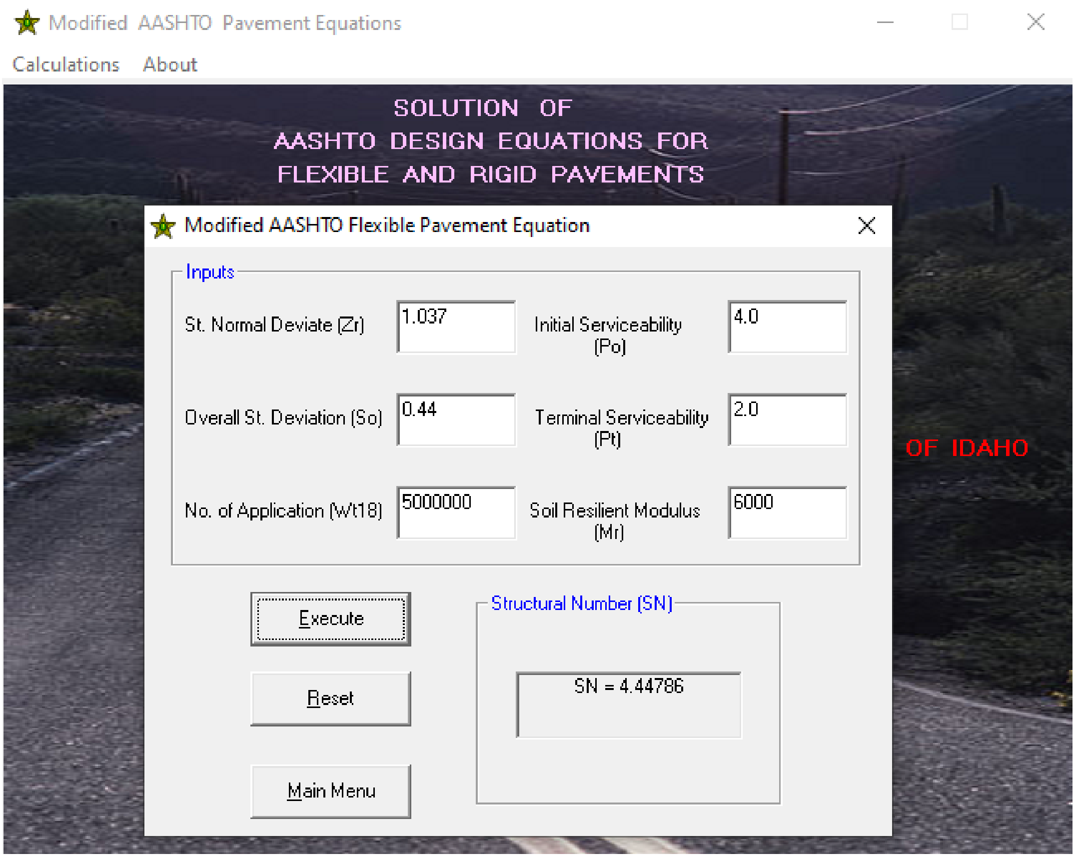


Figure 2. Calculation of SN values - AASHTO Design Equations for Flexible and Rigid Pavements Software

The results obtained in this study are aimed at building a primer of design of flexible pavements, for different load levels, depending on the characteristics of the urban roads of the city of Sincelejo; of the typical soils of subgrade, classified as low compressibility clays (CL) and conditions environment of the study area.

Table 3 presents a summary of the results of the laboratory tests carried out on a total of 70 soil samples characteristic of the area. In said table can be observed, values related to the granulometry of the sample, limits of Atterberg, classification by Unified system and AASTHO system, moisture content of the sample in the field and CBR values after four days of immersion.

Table 3. Results of laboratory tests

Sampl e	**Liquid Limit (%)**	**Plastic Limit (%)**	**Plasticit y Index (%)**	**AASHTO Soil Classificatio n**	**USCS Soil Classificatio n**	**Natural moistur e content (%)**	**Penetratio n moisture content (%)**	**CBR (%)**
1	40.0	16.5	23.5	A-6	CL	33.8	40.5	0.4

Sample	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	AASHTO Soil Classification	USCS Soil Classification	Natural moisture content (%)	Penetration moisture content (%)	CBR (%)
2	35.7	18.6	17.1	A-7	CL	23.9	24.5	2.5
3	32.3	18.5	13.8	A-6	CL	26.2	29.2	1.6
4	49.6	21.8	27.8	A-7-6	CL	18.7	25.1	2.5
5	33.4	17.0	16.4	A-6	CL	13.4	39.0	1.6
6	48.9	23.4	25.5	A-7-6	CL	23.8	26.8	1.6
7	49.5	20.4	29.1	A-7-6	CL	18.3	29.8	1.9
8	35.3	17.7	17.6	A-6	CL	22.7	32.7	2.2
9	34.1	16.6	17.5	A-6	CL	26.1	39.9	1.7
10	45.6	17.4	28.2	A-7-6	CL	24.8	30.6	1.8
11	43.0	20.6	22.4	A-7-6	CL	23.7	26.3	2.1
12	42.8	18.6	24.2	A-7-6	CL	25.0	32.6	2.5
13	48.5	22.2	26.3	A-7-6	CL	35.3	41.0	1.9
14	27.4	14.1	13.3	A-6	CL	19.6	83.1	3.2
15	34.0	17.3	16.7	A-6	CL	7.6	17.7	2.0
16	45.1	19.7	25.4	A-7-6	CL	40.4	47.4	3.3
17	26.7	14.4	12.3	A-6	CL	30.3	78.3	4.0
18	44.3	22.5	21.8	A-7-6	CL	23.8	33.3	1.5
19	44.9	24.7	20.2	A-7-6	CL	11.8	22.9	3.7
20	40.6	22.4	18.2	A-7-6	CL	14.3	19.0	2.5
21	41.0	19.0	22.0	A-7-6	CL	17.8	25.5	4.1
22	38.1	14.5	23.6	A-6	CL	25.1	25.7	4.9
23	38.5	13.7	24.8	A-6	CL	17.6	26.4	3.5
24	43.6	15.6	28.0	A-7-6	CL	26.8	36.9	1.4
25	33.9	20.1	13.8	A-6	CL	13.4	23.8	1.5
26	33.3	19.5	13.8	A-6	CL	13.3	29.2	0.9
27	35.2	16.9	18.3	A-6	CL	15.3	25.9	3.5
28	48.6	25.0	23.6	A-7-6	CL	14.4	35.2	3.4

Sample	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	AASHTO Soil Classification	USCS Soil Classification	Natural moisture content (%)	Penetration moisture content (%)	CBR (%)
29	38.9	16.3	22.6	A-6	CL	14.0	28.9	3.7
30	48.0	20.3	27.7	A-7-6	CL	15.2	26.9	2.3
31	35.7	19.5	16.2	A-6	CL	24.4	36.6	2.5
32	47.7	20.2	27.5	A-7-6	CL	21.3	32.0	4.0
33	49.9	24.5	25.4	A-7-6	CL	27.9	36.8	1.3
34	47.1	21.3	25.8	A-7-6	CL	16.4	22.1	2.3
35	39.5	20.3	19.2	A-6	CL	19.2	27.7	1.7
36	32.4	16.7	15.7	A-6	CL	15.3	23.3	3.7
37	36.2	19.4	16.8	A-6	CL	13.1	34.1	4.6
38	33.9	19.5	14.4	A-6	CL	22.9	24.5	3.7
39	36.2	19.4	16.8	A-6	CL	19.1	23.4	3.8
40	35.4	19.2	16.2	A-6	CL	21.8	27.9	4.0
41	37.0	17.3	19.7	A-6	CL	20.3	24.1	5.0
42	34.4	19.6	14.8	A-6	CL	38.0	43.9	2.1
43	35.0	18.0	17.0	A-6	CL	27.5	40.1	2.4
44	40.0	20.3	19.7	A-6	CL	12.4	24.2	2.4
45	41.8	17.6	24.2	A-7-6	CL	19.3	21.1	2.0
46	40.8	19.1	21.7	A-7-6	CL	26.2	29.5	1.6
47	37.0	16.4	20.6	A-6	CL	20.1	22.5	3.4
48	48.9	22.8	26.1	A-7-6	CL	13.2	24.9	1.9
49	44.6	20.6	24.0	A-7-6	CL	25.4	29.8	2.2
50	39.4	16.3	23.1	A-6	CL	27.0	30.5	1.5
51	36.3	19.6	16.7	A-6	CL	22.4	29.4	0.8
52	46.8	19.9	26.9	A-7-6	CL	18.1	33.9	0.9
53	30.1	12.8	17.3	A-6	CL	33.6	38.5	0.5
54	46.9	21.8	25.1	A-7-6	CL	29.9	30.4	2.7
55	40.8	18.0	22.8	A-7-6	CL	29.4	33.8	2.4

Sample	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	AASHTO Soil Classification	USCS Soil Classification	Natural moisture content (%)	Penetration moisture content (%)	CBR (%)
56	39.1	21.4	17.7	A-6	CL	18.6	30.2	1.6
57	38.9	23.4	15.5	A-6	CL	18.8	37.1	2.2
58	47.5	21.9	25.6	A-7-6	CL	9.5	29.3	1.3
59	47.9	21.5	26.4	A-7-6	CL	29.1	29.3	0.9
60	49.5	22.3	27.2	A-7-6	CL	24.0	33.5	0.9
61	48.2	22.5	25.7	A-7-6	CL	30.5	33.4	1.4
62	36.8	18.0	18.8	A-6	CL	18.4	28.4	2.2
63	41.3	19.8	21.5	A-7-6	CL	22.8	31.6	1.5
64	29.5	15.3	14.2	A-6	CL	19.0	24.6	1.3
65	45.1	20.7	24.4	A-7-6	CL	22.4	23.0	3.4
66	41.4	19.5	21.9	A-7-6	CL	29.5	31.3	1.4
67	43.7	25.5	18.2	A-7-6	CL	20.4	33.8	2.1
68	41.1	21.1	20.0	A-7-6	CL	21.3	24.9	1.6
69	40.5	20.9	19.6	A-7-6	CL	28.4	32.2	0.8
70	49.6	22.7	26.9	A-7-6	CL	29.6	33.0	1.5

The geotechnical information in Table 3 is part of the study by Jove Wilches et al., 2022, in the which the geotechnical characterization of the fine soils of subgrade of the city was carried out from Sincelejo, from undisturbed samples of submerged CBR [22].

On the other hand, in Figure 3, the values of the Plasticity Index and Liquid Limit of the 70 soil samples, where it can be observed that all the points fall in the region of CL soils.

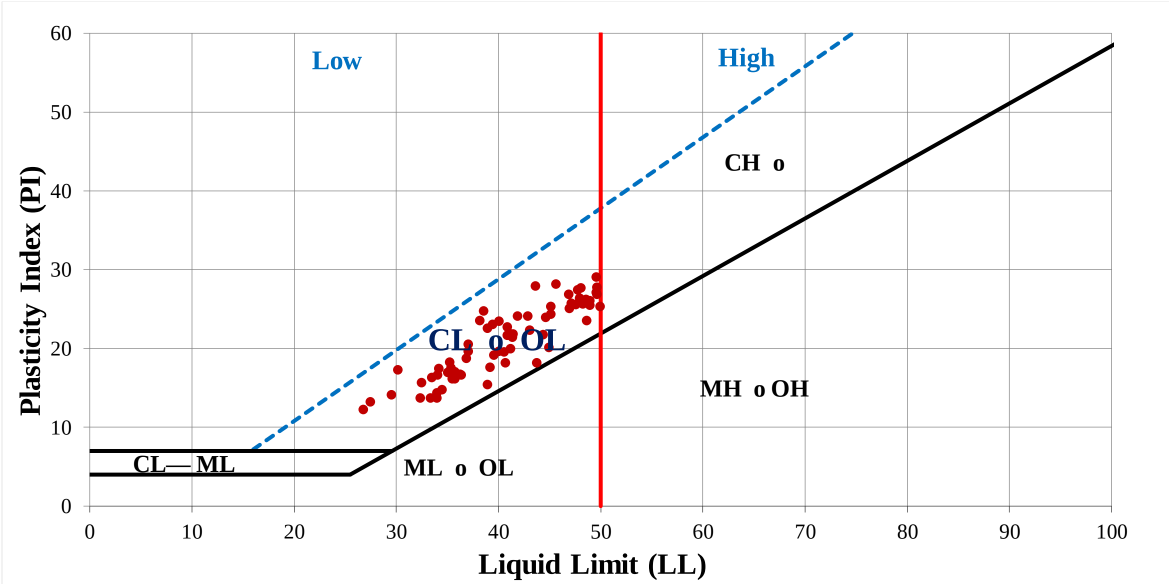


Figure 3. Soil plasticity chart

For the case of CBR values, a curve was constructed to obtain the CBR value of design through the criteria of the perceptibles. In Figure 4, the 70 graphs are shown CBR values and 75% is selected as the design percentile, a value that is consistent with the important characteristics of the roads of the project. Entering at the 75th percentile, was able to obtain a Design CBR value of 1.50%. The CBR value determined through from the figure mentioned above, is a typical value of subgrade soils, reason by which the IVANOV Method is used to calculate the material thickness granular required to increase the CBR value from 1.50 to 4.00%. In Table 4 it is presents the results of applying this methodology.

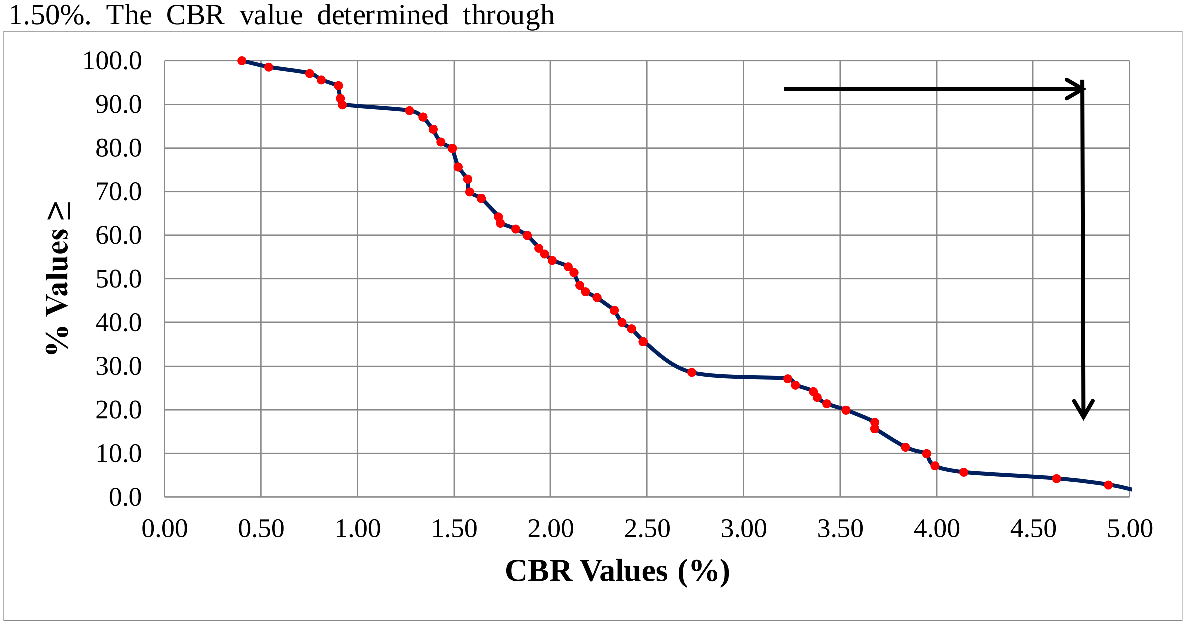


Figure 4. Percentile curve to determine CBR

Table 4. CBR of the subgrade set – selected fill

Material	CBR-2	E2-deduted	h1	CBR-1	E1	n	E1-2	CBR1-2
No.	Subgrade (%)	Kg/cm²	(mm)	(%)	Kg/cm²		Kg/cm²	(%)
1	1.50	150	200	10.00	1000	2.14	431.85	4.32

As can be seen in Table 4, placing a layer of 0.20 m. Filling Selected above the Subsurface, its CBR value can be increased from 1.50% up to slightly more than 4.0%, with which it is estimated that the resilient modulus of the improved subgrade is 6,000psi.

Based on the previous results, the bearing capacity of the subgrade and all the design parameters defined and selected in the previous section, we proceeded to carry out the modeling of the structural packages of the pavement solutions, resulting in the Design Primer that is presented in Table 5.

Table 5. Design Handbook

Traffic	Pavement Structure 1	Pavement Structure 2	Pavement Structure 3	Pavement Structure 4
10,000	12 CA	6 CA 16 BG	6 CA 12 BG 15 SBG	8 CA 15 SBG
50,000	15 CA	8 CA 20 BG	8 CA 12 BG 15 SBG	10.5 CA 19 SBG
100,000	17 CA	9.5 CA 21 BG	9.5 CA 12 BG 15 SBG	12 CA 20 SBG
200,000	19 CA	10.5 CA 24 BG	10.5 CA 12 BG	13.5 CA 22 SBG

Traffic	Pavement Structure 1	Pavement Structure 2	Pavement Structure 3	Pavement Structure 4
			17 SBG	
300,000	20 CA	11.5 CA 25 BG	11.5 CA 12 BG 18 SBG	14.5 CA 23 SBG
400,000	21 CA	12 CA 26 BG	12 CA 12 BG 20 SBG	15 CA 25 SBG
500,000	22 CA	12.5 CA 26 BG	12.5 CA 12 BG 21 SBG	15.5 CA 26 SBG
600,000	23 CA	12.6 CA 28 BG	12.5 CA 12 BG 24 SBG	16 CA 27 SBG
700,000	23 CA	13 CA 28 BG	13 CA 12 BG 24 SBG	16.5 CA 27 SBG
800,000	24 CA	13.5 CA 28 BG	13.5 CA 12 BG 24 SBG	17 CA 27 SBG
900,000	24 CA	13.5 CA 30 BG	13.5 CA 12 BG	17 CA 28 SBG

Traffic	Pavement Structure 1	Pavement Structure 2	Pavement Structure 3	Pavement Structure 4
			25 SBG	
1,000,000	25 CA	14 CA 30 BG	14 CA 12 BG 25 SBG	17.5 CA 28 SBG
1,500,000	26 CA	15 CA 31 BG	15 CA 12 BG 27 SBG	18.5 CA 30 SBG
2,000,000	27 CA	15.5 CA 32 BG	15.5 CA 12 BG 30 SBG	19.5 CA 31 SBG
2,500,000	28 CA	16 CA 34 BG	16 CA 12 BG 32 SBG	20 CA 32 SBG
3,000,000	29 CA	16.5 CA 34 BG	16.5 CA 12 BG 33 SBG	20.5 CA 34 SBG
3,500,000	29 CA	17 CA 35 BG	17 CA 12 BG 33 SBG	21 CA 34 SBG
4,000,000	30 CA	17.5 CA 35 BG	17.5 CA 12 BG	21.5 CA 34 SBG

Traffic	Pavement Structure 1	Pavement Structure 2	Pavement Structure 3	Pavement Structure 4
			34 SBG	
4,500,000	31 CA	18 CA 35 BG	18 CA 12 BG 34 SBG	22 CA 34 SBG
5,000,000	31 CA	18 CA 36 BG	18 CA 12 BG 35 SBG	22.5 CA 34 SBG

Note: The thicknesses of the layers are given in centimeters

8. CONCLUSIONS

As a result of this study, it has been possible to obtain a design letter for a solution in asphalt pavements, which can be applied to the city of Sincelejo, both at an urban level, in the case of streets within the city, and at a rural level, designed for roads or highways that allow transit outside the city of Sincelejo. It is important to say that the design letters apply in those cases in which there are clayey subgrades, cataloged within the Unified Soil Classification System as CL type clays. It is important to highlight that for solutions at the urban level, the so-called structure 2, made up of asphalt concrete and a granular base, turns out to be the most interesting solution alternative for its implementation, since it could be cheaper than alternative 1, composed of only for asphalt concrete and in turn, in general, it has less thickness than alternatives 3 and 4, which is convenient during the construction phase, since at the urban level there are many public service networks, such as aqueduct, sewerage, gas natural, among others, that can be compromised, when it is required to intervene at greater depths. In any case, the decision to take one of the four alternatives presented for each level of traffic must be based on a technical and economic analysis that must be carried out by the project engineer in each particular case, since this document serves as a guide of design and does not replace the criteria of the specialized engineer.

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