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Modelling of Asphalt Pavement Structures for Different Design Conditions on Roads in Northern Colombia

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Abstract

The purpose of this manuscript is to present a collection of data showing the different variables involved in the design of asphalt pavements, obtained from 84 road sectors located in urban and rural roads in the department of Sucre, north of Colombia. The dataset presents the results of geotechnical studies obtained from soil samples taken in the field and from laboratory tests. Among the most relevant information, the characterization of the subgrade soils was determined, based on particle size analysis testing, Atterberg limits, natural moisture and the classification of soils based in the AASHTO system and the USCS system. The bearing capacity of the subgrade is also presented, from undisturbed samples, for the realization of the laboratory California Bearing Ratio. On the other hand, there is information related to design traffic for each of the evaluated road sectors, expressed in terms of the number of equivalent single axle loads (ESALs). Finally, the information was supplemented with the results of the pavement structures modeled and chosen as design alternatives, for which a rational design methodology was used and the fatigue laws of the TRRL (Transport and Road Research Laboratory) were followed, making use of the Pitra PAVE software to model pavement structures.

Keywords: Soil characterization, subgrade, pavement design, rational methodology, flexible pavements

I. INTRODUCTION

The main objective sought in the design of a pavement is to provide alternative structures that are feasible to implement, from a technical, economic and environmental point of view, and that allow optimizing the level of service offered to users [1]. For this purpose, it is necessary to combine the thicknesses of the layers and the qualities of their constituent materials, in such a way that they adjust to the anticipated conditions of traffic and environment, maintaining reasonable costs both in the construction phase and in the operation construction phase[1].

With regard to flexible pavement structures, these are made up of an asphalt layer generally supported on two non-rigid layers of base and granular sub-base, or one of these two intermediate layers, or both, can be dispensed with, depending on the particular needs of the project [2].

To carry out a good design, the different variables that directly affect its structural performance must be adequately characterized, such as traffic, subgrade, climate, mechanical properties of materials, as well as safety factors [3].

For the purposes of the structural analysis of a pavement, the traffic variable is considered one of the most relevant [2] and in the case of flexible pavement, it is represented through the number of equivalent single axle loads of 8.2 tons expected in the design lane during the design period [4]. In the case of the subgrade or support layer of the pavement, it is characterized through the resilient module; However, due to the limited availability of equipment required to carry out these tests and the high cost they represent, in Colombia it is generally accepted to determine the modulus based on the characteristic CBR of the subgrade soils of the design unit, from of recognized correlations [5].

In this work, 84 combinations of flexible pavement structures are proposed, taking as a reference for structural modeling purposes, different levels of traffic, subgrade support capacity and combination of structural layers. Regarding traffic, seven levels were considered, representative of different numbers of repetitions of equivalent standard axles: 50,000, 100,000, 150,000, 200,000, 300,000, 400,000 and 500,000. In the case of the subgrade, we worked with three levels of resilient modulus: 300, 400 and 500 kg / cm², and with regard to the layers used, we worked with four combinations: structure 1, is composed of layers of Asphalt Concrete (AC), Granular Base (GB) and Granular Subbase (GSB); Structure 2 is made up of Asphalt Concrete and Granular Base; Structure 3, composed of Asphalt Concrete and Granular Subbase and, Structure 4, is only composed of the Asphalt Concrete layer. In Figure 1 the location of the study area is presented.

II. EXPERIMENTAL DESIGN, MATERIALS AND METHODS

II.I Study area description

The territory of the department of Sucre is located in the north of Colombia, in the intermediate part of the region of the Caribbean Plain and has an area of 10,917 km2. A little more than a third of its territory forms the flood-prone depression of the Bajo Magdalena, Cauca and San Jorge rivers, characterized by numerous swamps, especially along the San Jorge River. Its location extends in North latitude between 10 ° 08 '03 ”in the vicinity of the Pueblo Nuevo site and the Caño Sangre de Toro (municipality of San Onofre), corresponding to the most extreme North point and 08° 16' 46" in the site of concurrence with the Córdoba and Bolívar departments, corresponding to the most extreme South point. In west longitude, it extends between 7° 32'35" on the banks of the Cauca River and near the municipal seat of Guaranda, and 75° 42' 25" at San Bernardo point, to the west (municipality of San Onofre). The department of Sucre borders on the North and East with the department of Bolívar; to the south, with the departments of Bolívar and Córdoba, and to the west, with the department of Córdoba and the Caribbean Sea, show in Fig. 1. The departmental boundary perimeter has an approximate length of 671 km, which are discriminated as follows: 100 kilometres with the Caribbean Sea, equivalent to 14.9% of the total perimeter; 345 kilometres with the department of Córdoba, equivalent to 51.4% of the total perimeter, and 226 kilometres with the department of Bolívar, equivalent to 33.7% of the total departmental perimeter. The department of Sucre is made up of five subregions, which are the following: Morrosquillo, Montes de María, Sabanas, Mojana and San Jorge Subregions [6], [7].

The location of the study area is shown in Figure 1.

Fig. 1. Location of department of Sucre (research zone).

II.II Material and Methods

The information collected that served as input for the preparation of this work corresponds to the results of geotechnical road investigations, various levels of design traffic and modeling for the design of asphalt pavement structures. From the geotechnical studies, soil samples were collected from geotechnical surveys carried out in various sectors of roads in the department of Sucre. Then they were analyzed in the laboratory, using for this purpose standard soil analysis methods. From the characterization of the subgrade soils and various levels of traffic, different design alternatives were obtained in asphalt pavement structure. For the structural modeling of pavements, a rational methodology and the TRRL fatigue laws were used. To determine the state of stresses and deformation generated in the models, the Pitra PAVE Software was used.

The input data used in the modeling correspond to the characterization and bearing capacity properties of the subgrade soils, to the design traffic values obtained from the characterization of the vehicular flows of the evaluated road sectors and to the properties of the materials that make up the pavement structures considered. For the characterization of the soils, samples were taken at different sites located along the road corridors under study. The samples were transported to the laboratory, to carry out tests and analysis to determine some physical and mechanical properties, for which, standard soil laboratory methods were used. The tests carried out consisted in the determination of the granulometry, the natural moisture, the Atterberg limits and the California Bearing Ratio (CBR). The design traffic data correspond to the number of equivalent single axle loads (ESALs), determined from field measurements of the number of heavy vehicles that travel on the roads, and their projection through a design period of 10 years, applying the ASTHOO methodology, through the law of the fourth power. The data of flexible pavement designs were obtained based on the bearing capacity of the subgrade, the design traffic and the mechanical characteristics of the materials of the different layers of the structure, applying for this purpose, mechanistic analysis using the Pitra PAVE software and TRRL fatigue laws.

Regarding the geotechnical characterization, a total of 84 representative samples of clay subgrade soils were taken along various road sectors located in different sites in the department of Sucre, in order to establish their physical and mechanical properties through standardized laboratory tests. Each geotechnical survey carried out was carried out manually and extended to a depth of 1.50 meters with respect to the existing surface, and in each one, both altered and undisturbed samples were taken. The altered samples collected were processed in the laboratory to obtain information related to the particle size analysis of soils, by sieving [8] and the Atterberg limits, using the Casagrande pan, in the case of the liquid limit, and the realization of rolls manually, in the case of the plastic limit [9], in order to determine the classification of soils through the Unified Soil Classification System (USCS) [10] and the AASHTO Soil Classification System [11]. The unaltered samples were taken through standardized cylindrical molds, in order to carry out the laboratory test of the California Bearing Ratio (CBR) [12], for which, the samples were previously subjected to a curing process by immersion during a four day period. Prior to the time of submerging the samples for CBR, the natural humidity was determined and their respective wet and dry unit weights were calculated for each CBR mold.

For the characterization of the materials of the pavement structure, it proceeded as follows: for the case of the hot asphalt mix, a dynamic modulus value representative of the particular conditions of the mixes used in the area of project and regarding the granular layers, we worked with the correlations established by the design methodology for flexible pavements of the AASHTO [13], based on the CBR values required by the technical specifications of the Instituto Nacional de Vias (INVIAS) of Colombia [14], for the case of sub-bases and granular bases. Regarding the Poisson's ratios, the values recommended in the document "Investigation of performance of subbase and subgrade and design guidelines for concrete pavement" [15] were taken.

With regard to traffic, vehicle gauges were made and based on these results and considering the damage factors obtained in previous studies carried out by the INVIAS, the design traffic could be obtained in terms of the number of standard axles equivalents expected in the design lane for a design period of 10 years. For modeling purposes, seven traffic categories were considered, ranging between 50,000 and 500,000 repetitions of equivalent standard axles, a range that encompasses different levels of vehicle heavy traffic for roads considered with low volumes of traffic, which are nevertheless of utmost importance, since they allow land communication between the agricultural and livestock production centers with the departmental capitals.

Once the design parameters were defined for each case, the structure was modeled, with the traffic input data, the mechanical characteristics of the structure's materials and the bearing capacity of the subgrade. For this purpose, a rational methodology was used to obtain the critical stresses and strains and the TRRL fatigue laws, to determine the number of admissible repetitions, in such a way that it was possible to define the combination of thickness of layers that will provide a satisfactory solution.

III. RESULTS

For the modeling of the structures obtained, the fatigue laws proposed by the TRRL of Great Britain were used, through Equations 1 and 2, which allowed obtaining the admissible repetition values for the two deterioration criteria considered for purposes of design, which are related to the fatigue cracking in the asphalt layers and the permanent deformation of the subgrade, respectively.

$$N_f = f_1 \varepsilon_t^{-f_2} \quad (1)$$

Where:

Nf = Number of admissible repetitions, for the criterion of maximum stress deformation in asphalt layers.

$f1=1.66x10^{-10}$ $f2= 4.32$

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$$N_d = f_4 \varepsilon_c^{-f_5} \quad (2)$$

Where:

Nd = Number of admissible repetitions, for the criterion of maximum compression deformation on the subgrade.

$f4 = 6.18x10^{-8}$ f5 = 3.97

Table 1 shows the summary of the characterization of the subgrade soils, the admissible traffic flows and the thickness of the layers of the pavement structures obtained from the modeling.

Table 1. Summary of subgrade soils, vehicular flows and flexible pavement structures.

Road Section	Design Traffic (ESALs)	Improvement Module (kg/cm²)	Pavement Solution	Pavement Structure Layers (mm)			Sub-grade Improvement Layer (mm)
				Asphalt Concrete (AC)	Granular Base (GB)	Granular Subbase (GSB)	
1	100581	488	AC+GB+GSB	50	300	300	150
2	412612	554	AC+GB+GSB	110	250	250	150
3	554722	401	AC+GB	120	350		250
4	101400	402	AC+GSB	110		350	250
5	103264	422	AC+GB+GSB	50	300	300	250
6	598768	297	AC+GB+GSB	130	200	250	200
7	304167	393	AC+GB+GSB	100	250	250	200
8	280606	528	AC	160			300
9	154274	299	AC	160			350
10	178190	333	AC+GB	80	350		300
11	117483	316	AC+GB+GSB	70	200	200	250
12	528094	300	AC+GB	120	350		250
13	148911	430	AC+GB	70	300		300
14	305832	309	AC+GSB	140		500	250
15	201191	430	AC+GB	80	450		300
16	150051	403	AC	150			300
17	54340	411	AC+GB+GSB	50	150	150	250
18	427355	300	AC	190			300
19	231035	288	AC+GB	90	350		250
20	214221	403	AC	160			300
21	307872	325	AC	180			350
22	54503	415	AC+GB	50	250		300
24	107059	319	AC	150			400
25	431400	517	AC+GB	110	350		250
26	219303	299	AC	170			350
27	50245	300	AC+GSB	90		400	250
28	419737	309	AC+GSB	150		500	250
29	101007	300	AC+GSB	110		400	250
30	301713	403	AC	170			300
31	199155	332	AC+GB+GSB	90	200	250	250
32	153364	322	AC+GB+GSB	80	200	250	250
33	52052	313	AC+GB+GSB	50	150	200	250
34	392603	477	AC	180			250

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Road Section	Design Traffic (ESALs)	Improvement Module (kg/cm²)	Pavement Solution	Pavement Structure Layers (mm)			Sub-grade Improvement Layer (mm)
				Asphalt Concrete (AC)	Granular Base (GB)	Granular Subbase (GSB)	
35	73151	310	AC	140			450
36	56850	320	AC+GB	70	250		300
37	150692	300	AC+GSB	120		450	250
38	197751	305	AC+GSB	130		400	250
39	313254	396	AC+GB	100	350		250
40	149883	438	AC+GB+GSB	80	200	200	250
41	303316	298	AC+GB	100	350		250
42	212829	409	AC+GSB	130		400	250
43	52312	522	AC+GSB	90		350	250
44	206644	386	AC+GB+GSB	90	200	300	200
45	542759	480	AC	180			250
46	102099	522	AC+GSB	110		300	250
47	577756	413	AC	190			300
48	309974	409	AC+GSB	140		450	250
49	301313	497	AC+GSB	140		350	200
50	407302	409	AC+GSB	150		400	250
51	406724	393	AC+GB+GSB	110	250	250	200
52	200438	516	AC+GB	80	450		250
53	70364	484	AC+GB+GSB	50	150	150	150
54	94187	516	AC	130			300
55	456391	290	AC+GB+GSB	120	200	250	200
56	509404	309	AC+GSB	160		400	250
57	70261	398	AC	130			300
58	419804	403	AC	180			300
59	519511	517	AC+GB	120	250		250
60	542759	482	AC	180			250
61	197909	524	AC	150			300
62	524921	409	AC+GSB	160		350	250
63	347256	332	AC+GB+GSB	110	200	250	250
64	103537	401	AC	140			300
65	82915	488	AC+GB	50	250		250
66	307008	499	AC+GB+GSB	100	250	250	150
67	416486	522	AC+GSB	150		350	200
68	153326	526	AC+GSB	120		350	250
69	508305	537	AC+GSB	160		250	200
70	152652	510	AC+GB	70	450		250
71	137600	522	AC	140			300
72	151811	408	AC+GSB	120		400	250
73	199448	497	AC+GB+GSB	90	200	200	150

Road Section	Design Traffic (ESALs)	Improvement Module (kg/cm²)	Pavement Solution	Pavement Structure Layers (mm)			Sub-grade Improvement Layer (mm)
				Asphalt Concrete (AC)	Granular Base (GB)	Granular Subbase (GSB)	
74	97562	425	AC+GB	50	300		300
75	541662	393	AC+GB+GSB	120	250	250	200
76	204513	492	AC+GSB	130		300	200
77	321716	516	AC+GB	100	350		250
78	104098	495	AC+GB	50	400		250
79	417279	396	AC+GB	110	350		250
80	103784	331	AC+GB	70	300		300
81	400687	298	AC+GB	110	350		250
82	587138	311	AC	200			300
83	151583	488	AC+GB+GSB	80	200	200	150
84	552191	554	AC+GB+GSB	120	250	250	150

The results of the alternative solutions for flexible pavement structures are shown in Fig. 2, Fig. 3, Fig. 4 and Fig. 5. In the figures, the abscissa axis shows the design transits in terms of ESALs, divided into categories of 50.000, 100.000, 150.000, 200.000, 300.000, 400.000 and 500.000. These values were selected taking into account the different traffic categories observed in the different evaluated road corridors. On the ordinate axis, the thicknesses of each layers of the pavement structures are shown, measured in millimeters. For the purposes of this article, 4 types of structures are presented: structure 1, is composed of layers of Asphalt Concrete (AC), Granular Base (GB) and Granular Subbase (GSB), shown in Fig. 2; Structure 2 is made up of Asphalt Concrete and Granular Base (Fig. 3); Structure 3, composed of Asphalt Concrete and Granular Subbase (Fig. 4) and, Structure 4, is only composed of the Asphalt Concrete layer (Fig. 5). In a complementary way, for each traffic range, three pavement structures are presented, which are a function of the three different Improvement Module of the Sub-grade Improvement layer, which were 300, 400 and 500 kg/cm².

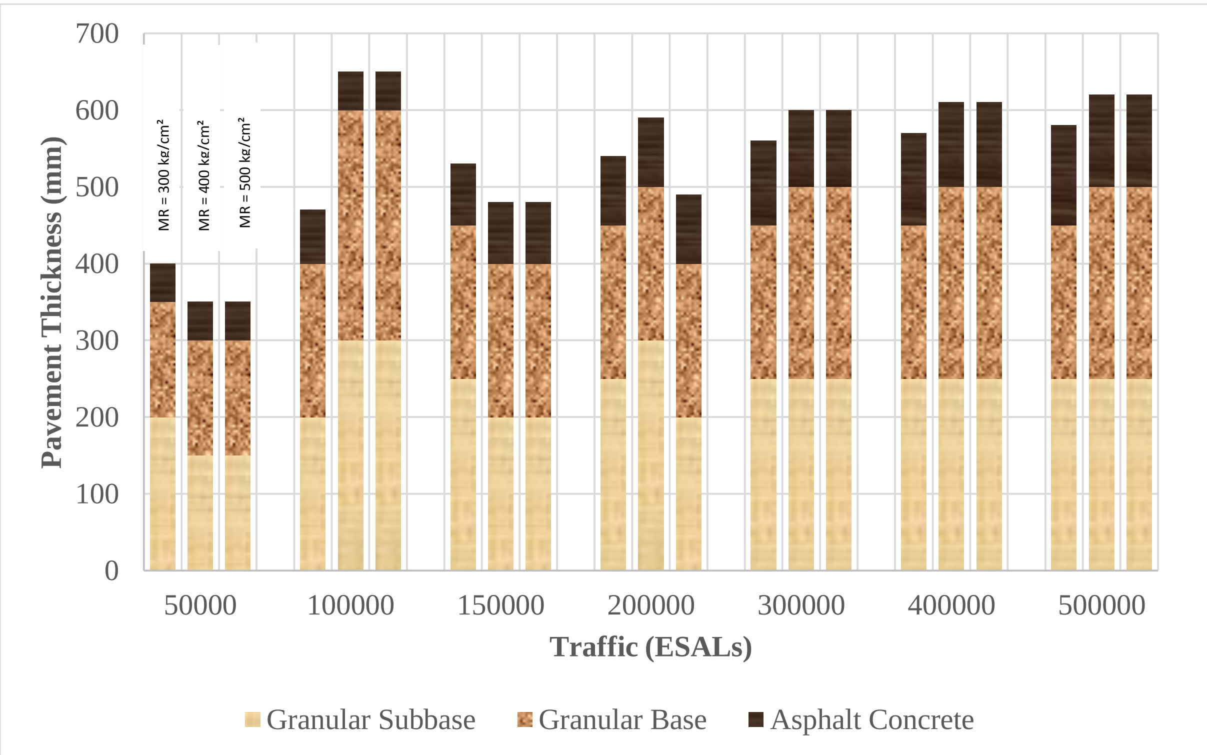

Fig. 2. Flexible pavement structures composed of AC, GB and GSB layers.

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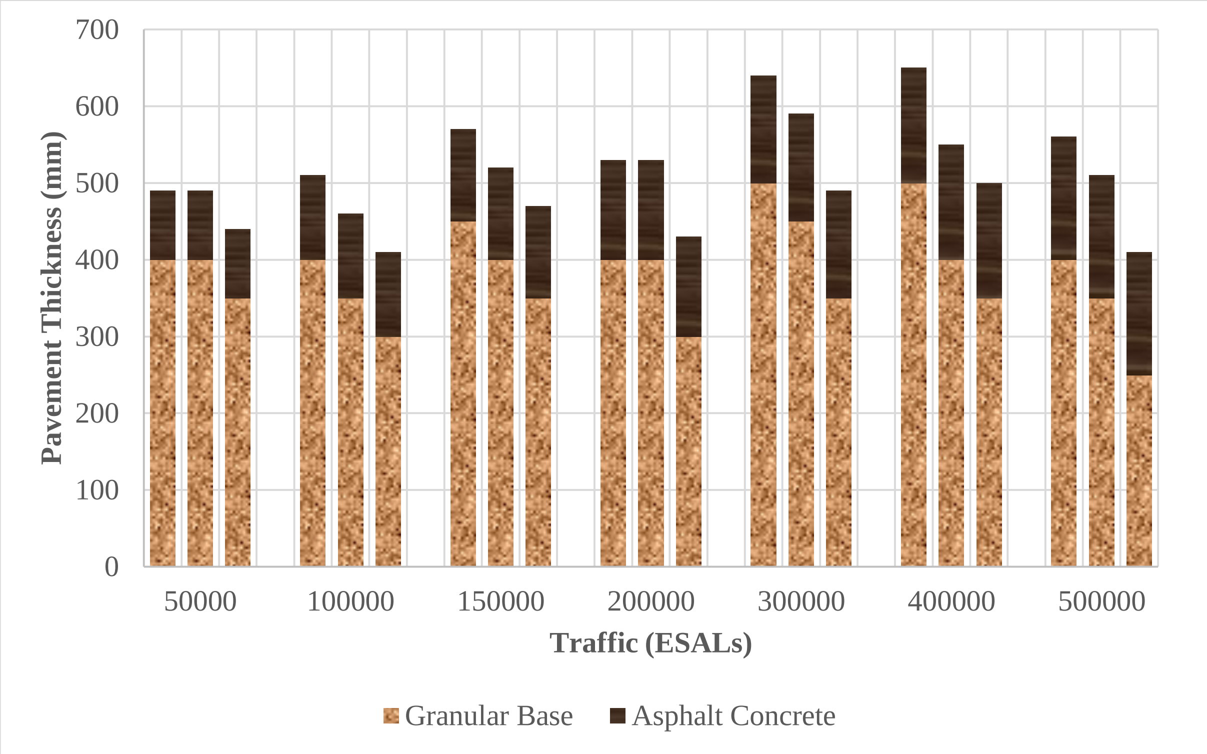

Fig. 3. Flexible pavement structures composed of AC and GB layers.

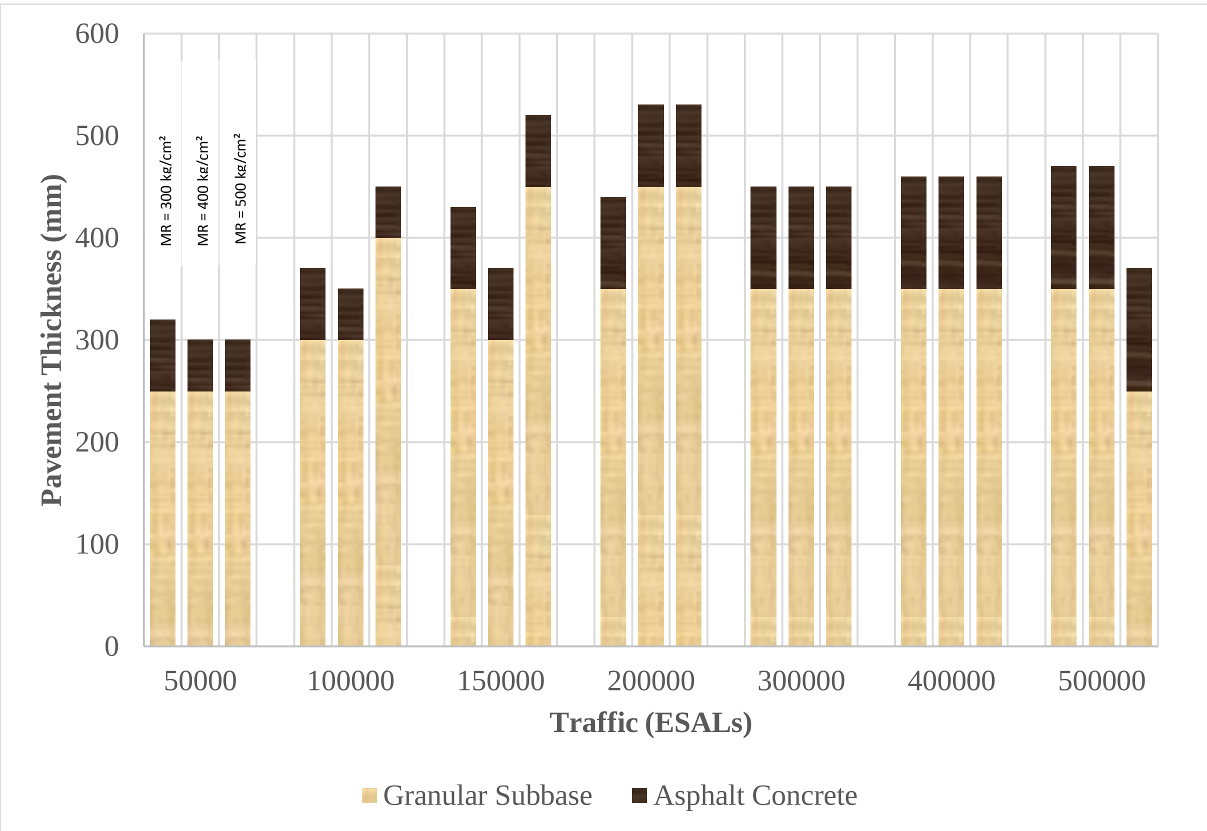

Fig. 4. Flexible pavement structures composed of AC and GSB layers.

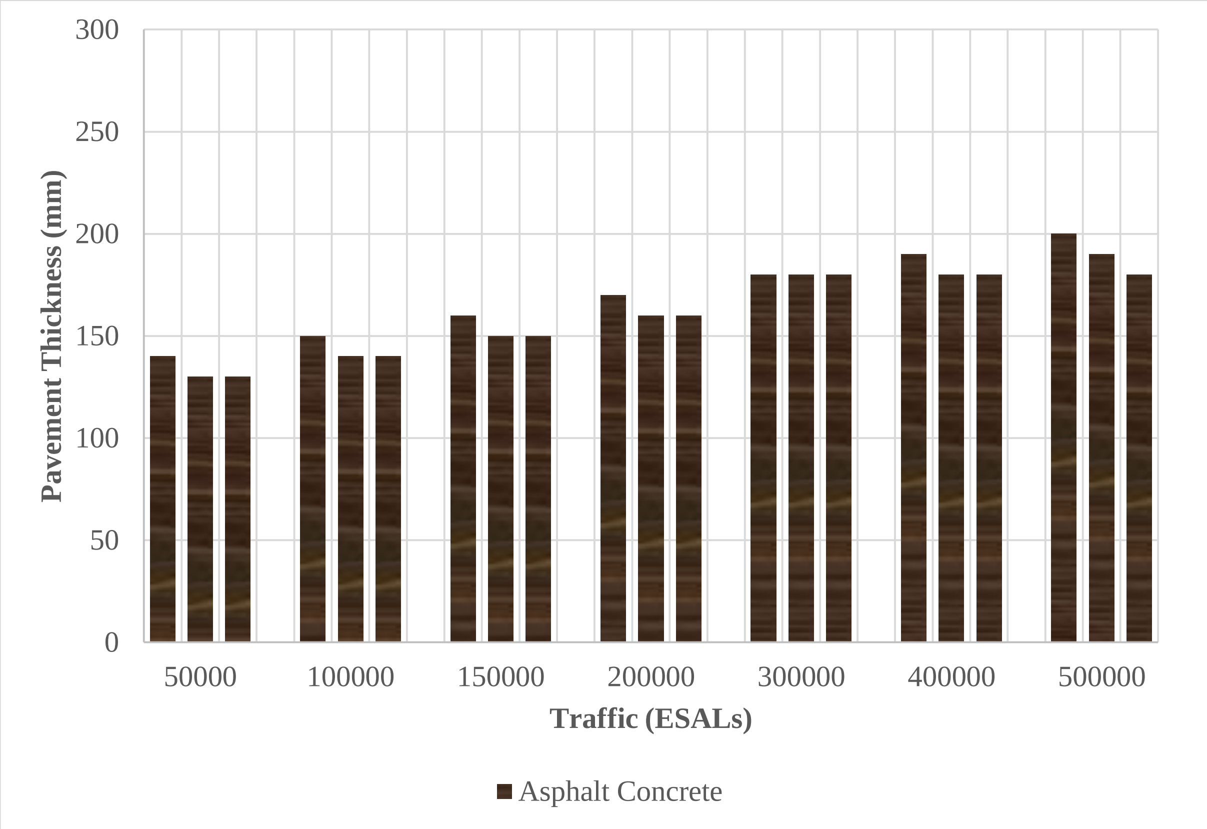

Fig. 5. Flexible pavement structures composed of AC layer.

VI. CONCLUSION

As a result of this work, it was possible to obtain different solution alternatives in a flexible pavement structure for a region in the North of Colombia. The alternatives presented, from the modeling of the structures with mechanistic methodology, satisfy the design conditions, for a combination of characteristic factors of the roads categorized as low traffic of cargo vehicles by the Instituto Nacional de vias of Colombia. It should be noted that the proposed solution alternatives can be very useful for institutions, research groups, analysts, expert professionals and consultants in Highway Engineering who participate in projects related to soil characterization, traffic characterization and design of pavements, for roads with transits between 50,000 and 500,000 repetitions of equivalent standard axles of 8.2 tons.

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