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Physical-mechanical characterization of granular materials for the construction of roads from a soil quarry in northern Colombia

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Abstract

In some regions of Colombia, there is a significant shortage of sources of suitable materials for the exploitation of mineral aggregates used in the different layers of pavement, in road infrastructure projects; this is the case of the city of Sincelejo and its surroundings, which is why it is imperative to identify and characterize the potentially exploitable materials present in the sources that are located in the immediate vicinity of the area. For that, in this work, the physical-mechanical identification and characterization of the materials present in a representative stratigraphic profile of the La Cabaña Quarry, located on the outskirts of the city of Sincelejo, is carried out. For this purpose, the sampling sites were located and the tests required by the National Institute of Highways of Colombia were carried out, in the case of granular materials, in accordance with the General Specifications of Highway Construction, following for such Indeed, the Test Standards for Road Materials. According to the results obtained, within the study area of the evaluated source of materials, it was possible to determine the presence of sand and silty gravel, which are suitable to be used as selected fillings and making the required proportions, with different materials from the different strata located within the same quarry, as well as with materials from other sources, it is possible to obtain sub-bases and granular bases for pavements.

Keywords: Granular base, Granular sub-base, Physical properties, Material characterization, Source of materials.

I. INTRODUCTION

Construction materials are the backbone of large projects that are built in the field of road infrastructure. They provide the resistance and stability that structural packages require, in order to resist loads and external effects, generated by vehicular traffic and environmental conditions; Therefore, it is of great importance that they comply with the minimum characteristics and conditions required by the regulations, in order to guarantee durable and stable works over time.

Finding suitable materials is often a difficult task, because these are generally exploited in open-cast quarries, where due to geological formations and their interaction with the environment, rocks and soils have originated that usually be arranged in different layers of materials with different engineering properties, therefore, care must be taken when carrying out their exploitation and extraction, with the aim that they are potentially usable in infrastructure works.

Soils in their natural state, generally, do not meet the minimum requirements necessary to be considered as suitable materials for the construction of the layers of a pavement, such as bases, sub-bases, selected soils, among others; so that very often, an alternative solution used, usually consists of mixing different materials, which, however, tends to increase the cost of the final product.

In any case, finding deposits of materials that meet the particular needs of a project is not an easy task, and given the requirements established in the technical specifications, it is required to carry out field and laboratory work aimed at establishing the physical-mechanical characterization of the materials, to verify their sufficiency or establish the need to carry out some type of stabilization or improvement that leads to the adjustment of the engineering properties of these materials. On the other hand, it is desirable that the sources of materials are located as close as possible to the work site, since the final cost of the project will largely depend on the hauling distances that are required to be carried out.

In the different countries of the world, it is a very common task to carry out field and laboratory investigations, prior to the exploitation of materials, whose essential objective is focused on the physical-mechanical characterization of the granular materials used in construction. Thus, for example, in the case of Ecuador, the characterization of the materials to be exploited for the construction of the western sector of the city of Guayaquil was carried out, with the aim of verifying if they were suitable as construction materials [1]. Likewise, in the Aburrá Valley (Colombia), studies were carried out that led to the establishment of maps of the location of quarries for the exploitation of materials and the predominant type of material in each of them [2]. In Cundinamarca (Colombia), similar studies have been carried out in order to have a good control of the exploitation of materials and an environmental control, in limestone deposits [3].

In the department of Sucre, in the municipality of Tolú Viejo, various studies have been carried out on aggregates to be used in the preparation of concrete, or to be mixed with other materials, which by themselves do not meet the technical construction specifications, such as the case of granular bases or sub-bases [4]. Additionally, in the same area, in quarries located in Morroa, Bremen and Sincelejo, studies have been carried out to determine the feasibility of mixing materials from the area with materials from nearby quarries, in order to improve their physical-mechanical characteristics, thus seeking a rational and sustainable exploitation [5].

The relief of the department of Sucre, according to the Geological Map (Figure 1), is predominantly of Sedimentary origin. This formation arises from deposits in a continental marine transition environment, folded and faulted during the Upper Tertiary (Andean orogeny) and then covered by extensive and powerful deposits of quaternary materials of marine, fluvial, fluvial-marine origin and lake [6]. In Corozal and Sincelejo, greyish sandstone-type materials of variable grain predominate, which are deposited in irregular banks and are altered with conglomeritic rocks, which are made up of quartz-sand boulders of variable size. Within the relief of the area, the hilly landscape predominates, corresponding to a repetition of elongated high hills, separated by a moderately dense hydrographic network; the morphogenetic environment is erosional [7].

The purpose of this work is to characterize an open-pit quarry located in the city of Sincelejo, for which open-pit field samples were taken and laboratory tests were carried out, following the guidelines and recommendations of the National Institute of Highways of Colombia in its 2013 edition of Construction Materials Speciation's guide, thus determining the characteristics of the materials in the quarry area and their suitability to be used as granular materials for the construction of road infrastructure works.

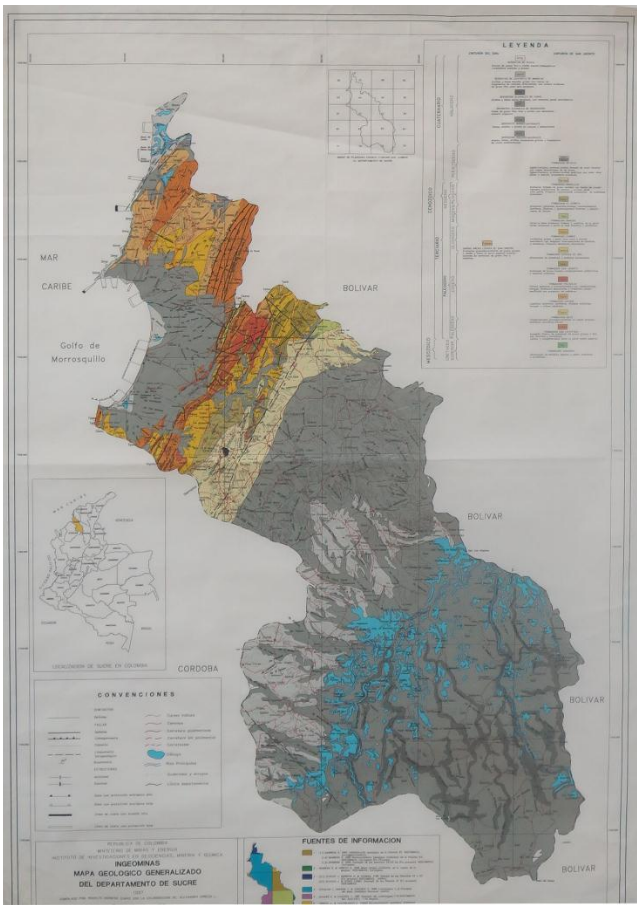

Fig. 1. Geological Map of Sucre

II. MATERIALS AND METHODS.

The methodology used to carry out the present work was based on three phases, which basically consisted of collecting the information available from the source of materials and its surroundings, the location within the source of the sites where the corresponding samples, and finally, carrying out the necessary laboratory tests on the samples taken, for the characterization of the different materials found.

II.I Collection of Available Information

A preliminary investigation was carried out to determine the geological characteristics of the area and the main properties of the materials that can be found within the region under study. In a complementary manner, the technical specifications and standards were reviewed through which the quality requirements for the granular materials used in road projects, such as structural or support layers, are classified and established. In particular, the technical standards for materials testing and the technical specifications for road construction of the National Institute of Highways of Colombia (INVIAS) were taken as a reference. From this frame of reference, it was possible to determine the recommendations for taking field samples, as well as the procedure to follow to carry out the laboratory tests of the materials found in the different sites of interest.

II.II Location of Materials and Sampling

The site selected for this work corresponds to an open-air source of materials, located near the city of Sincelejo, following the alternative route in the Sincelejo - Toluviejo section, in the Sierra Flor sector. The approximate extension of the quarry area is estimated at 75.28 Ha (Figure 2).

The extension of the quarry was established, having the support of Geographic Information Systems, resulting in the limits of the potentially exploitable zone. In a complementary way, by means of a tour and inspection carried out within the area under study, it was possible to observe the presence of an exploitation work front that covered a relatively wide area and where there was a pronounced slope, approximately parallel to one of the boundaries of the property, covering an approximate length of 230 m. Throughout the strip, the presence of different material strata was evidenced, covering different thicknesses, with excavation depths between 9 and 16 meters. Based on what was observed, it was decided to carry out a topographic survey in the quarry's exploitation area, in the same place where the different layers of materials were evident at a glance.

The extraction of the samples was carried out with manual tools and conventional methods for those homogeneous sites that were accessible, while for places near steep slopes and with difficult access, it was chosen to extract them through construction machinery, in this case for backhoes. Once the samples were obtained, they were packed following the recommendations for the conservation of their in-situ properties and transported to the soil laboratory where the different characterization and resistance tests were to be carried out.

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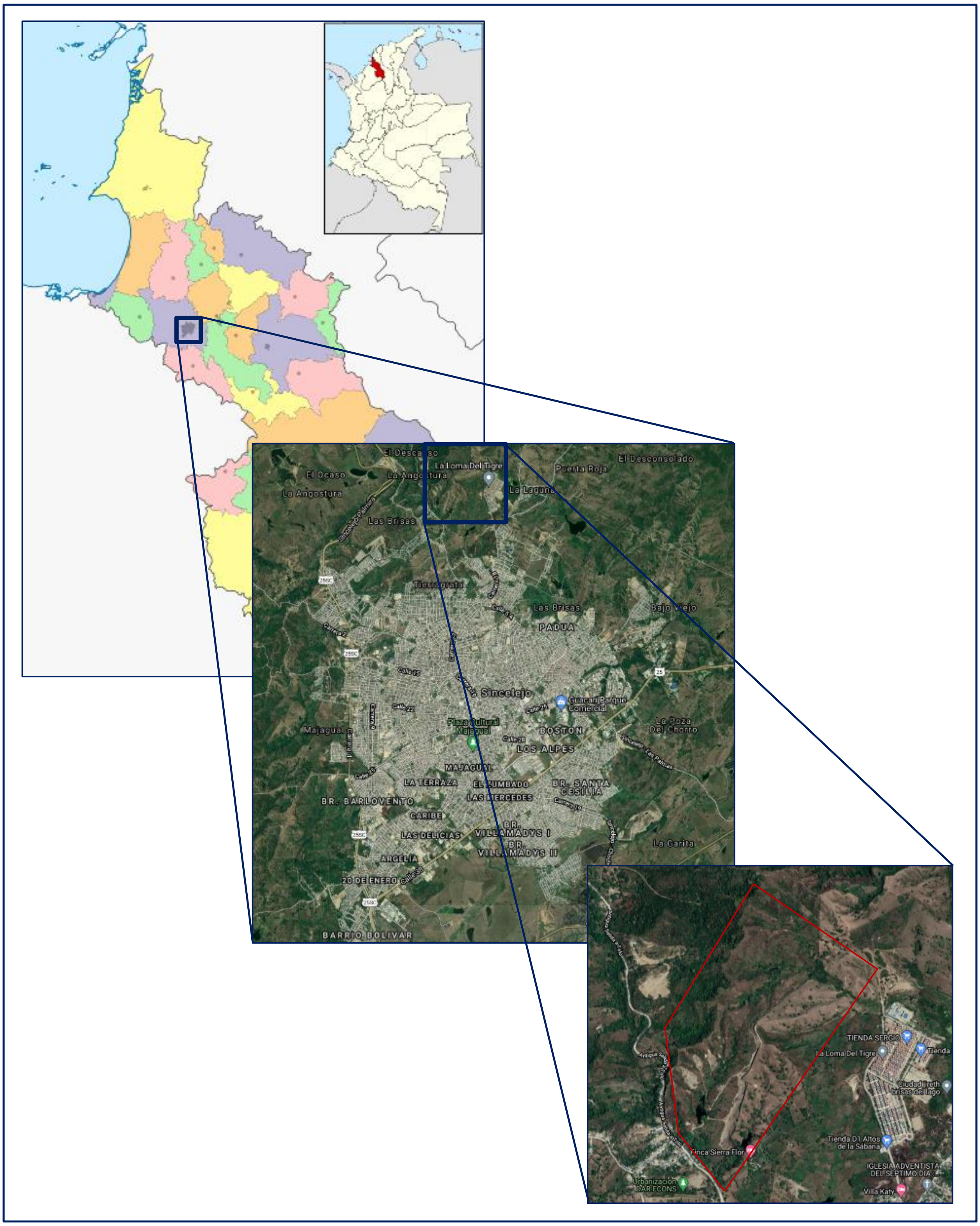

Fig. 2. Soil quarry Location - City of Sincelejo

II.III Laboratory tests

In the case of laboratory tests carried out on the samples of extracted materials, the guidelines established by the National Institute of Roads provided in the "Test Standards for Highway Materials" were followed. In accordance with the potential use that could be given to the existing materials in the evaluated source, the following tests were carried out:

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Table 1. Tests carried out on granular materials

LABORATORY TESTS			MATERIAL GRANULAR	
Test Type	**Test**	**Normative**	**"Afirmado"**	**"Sub-base"**
Composition	Granulometría	INV E-213	X	X
Hardness	Desgaste en máquina de los Ángeles	INV E-218	X	X
	Contenido de terrones de arcilla y partículas deleznables en agregados	INV E-211	-	X
Durability	Pérdidas en el ensayo de solidez por sulfatos	INV E-220	X	X
Cleanliness	Límite líquido e índice de plasticidad	INV E-125 INV E-126	X	X
	Contracción lineal	INV E-127	X	
	Equivalente de arena	INV E-133	-	X
Particle geometry	Índice de aplanamiento y de alargamiento de los agregados para carreteras	INV E – 230	-	-
	Porcentaje de caras fracturadas en los agregados	INV E – 227	-	-
Material strength	California Bearing Ratio (CBR)	INV E – 148	X	X

III. RESULTS

Figure 3 shows the stratigraphic profile on which the characterization of the granular materials of the La Cabaña quarry was carried out.

III.I Description of the Stratigraphic profile

Each section of the stratigraphic profile is arranged according to the number of strata present in each one, designated with the letter "P" followed by the number that corresponds to the section, ordered from left to right (1, 2, 3, 4 and 5, respectively). It is then preceded by the letters "M" (sample) and "E" (stratum), for those strata in which samples were taken; those that were not sampled, the "M" is omitted. Finally, the order number of the stratum from top to bottom of the profile is noted without counting the topsoil, which is 31 cm thick on average.

Table 2 shows the sections of the profile with their respective strata and depths at which they are found, classifying the materials according to SUSC and AASHTO.

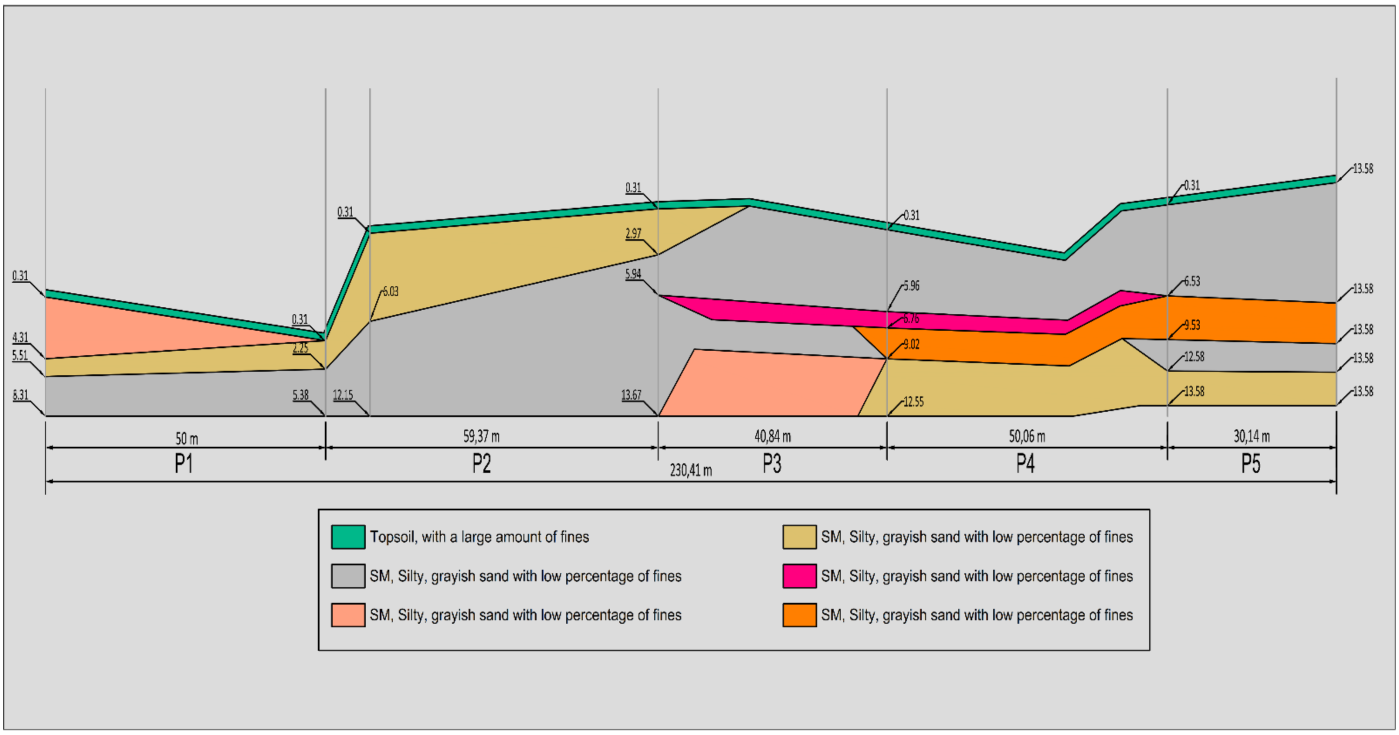

Fig. 3. Stratigraphic Profile Studied

Table 2. Summary of test results for classification of strata found

Profile	Sample	Depth (m)	Passing N° 4	Passing N° 10	Passing N° 40	Passing N° 200	TM, TMN	SUCS Classif.	AASHTO Classif.
P1M	E1	0.31-2.31	99	98	83	24	3/8", N°40	SM	A-2-4
P1M	E2	2.31-3.95	86	81	57	18	2", N°4	SM	A-2-4
P1M	E3	3.95-6.85	96	93	65	16	1 ½", N°10	SM	A-2-4
P1	E1	0.31-4.85	86	81	57	18	2", N°4	SM	A-2-4
P1	E2	4.85-12.85	96	93	65	16	1 ½", N°10	SM	A-2-4
P3	E1	0.31-6.71	96	93	65	16	1 ½", N°10	SM	A-2-4
P3	E2	6.71-7.66	39	28	17	8	2", 1"	GP-GM	A-1-a
P3	E3	7.66-9.91	96	93	65	16	1 ½", N°10	SM	A-2-4
P3	E4	9.91-13.91	99	98	83	24	3/8", N°40	SM	A-2-4
P3M	$E_{(1-4)}$	0.31-13.91	83	76	56	15	1 ½", N°10	SM	A-2-4
P4	E1	0.31-4.86	96	93	65	16	1 ½", N°10	SM	A-2-4
P4M	E2	4.86-5.66	39	28	17	8	2", 1"	GP-GM	A-1-a
P4	E3	5.66-7.91	96	93	65	16	1 ½", N°10	SM	A-2-4
P4	E4	7.91-11.21	99	98	83	24	3/8", N°40	SM	A-2-4
P5	E1	0.31-7.71	96	93	65	16	1 ½", N°10	SM	A-2-4
P5M	E2	7.71-10.36	62	51	29	9.6	2", 1"	SP-SM	A-1-b
P5M	E3	10.36-12.51	91	89	59	17	2", N°10	SM	A-2-4
P5	E4	12.51-14.56	99	98	83	24	3/8", N°40	SM	A-2-4

In Figures 4 and 5, the soil particle size distributions of the materials found in the different strata are presented and the upper and lower limits corresponding to the particle size distribution established by Specification INV 311-13 are also presented, for the case of the affirmed material.

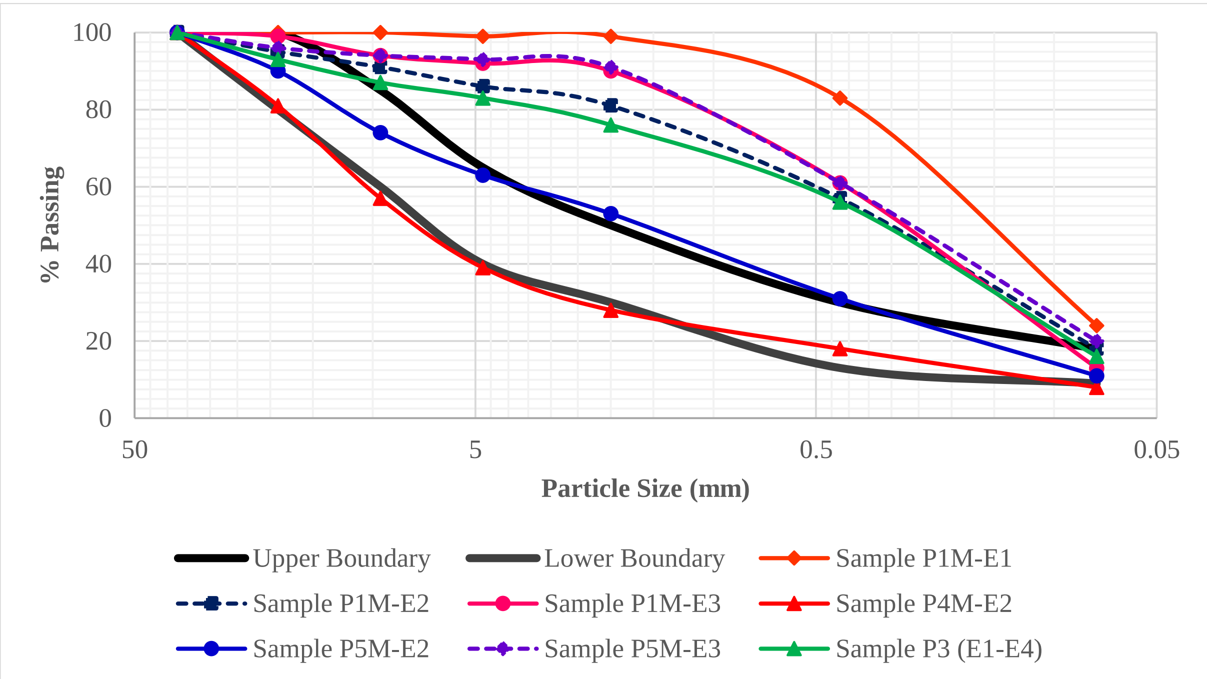

Fig. 4. Soil particle size distribution and specifications for Affirmed A-38

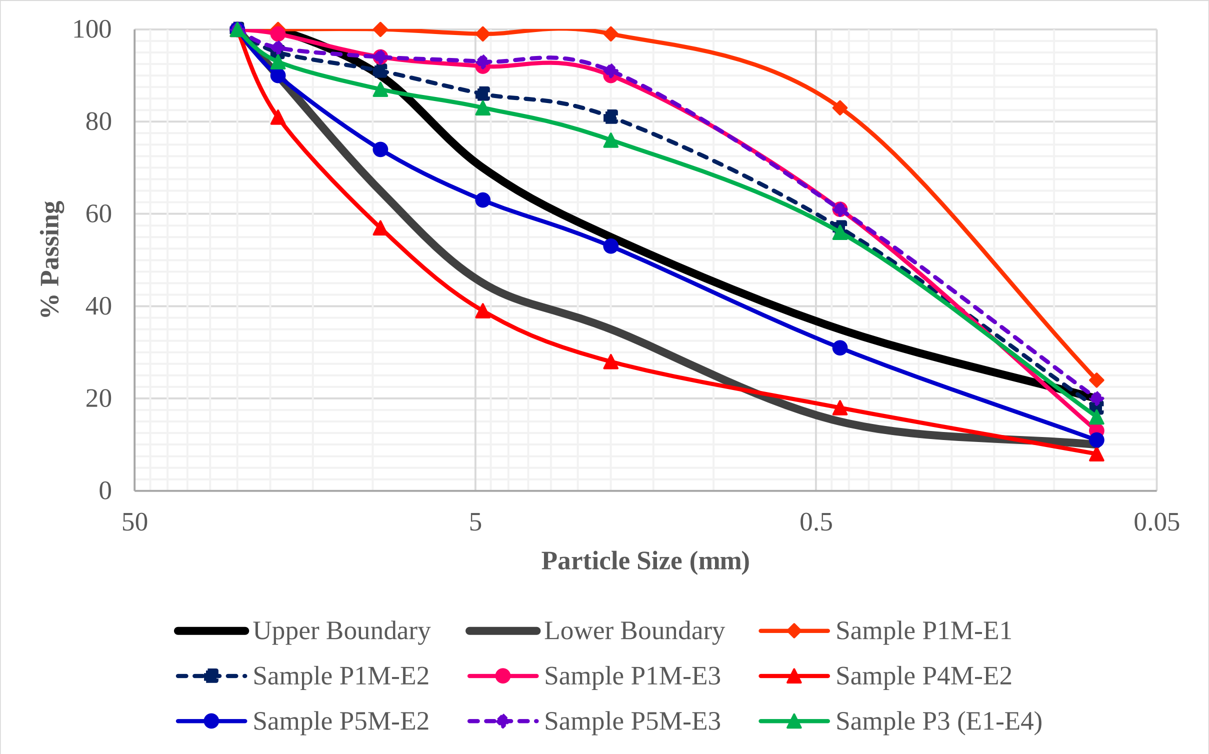

Fig. 5. Soil particle size distribution and specifications for Affirmed A-25

On the other hand, in Figures 6 and 7, the same soil particle size distributions are presented, but in this case, they are compared with the particle size bands established by Specification INV 320-13, for the case of the granular sub-base material.

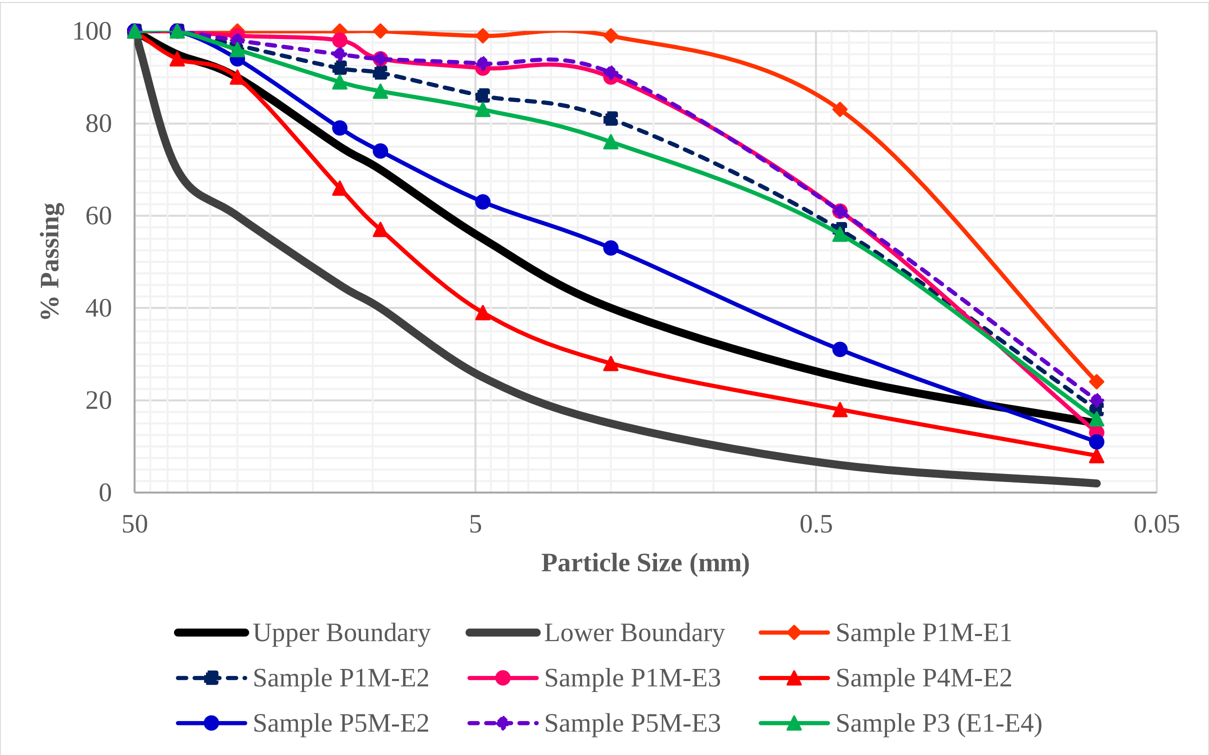

Fig. 6. Soil particle size distribution and specifications for SBG-50

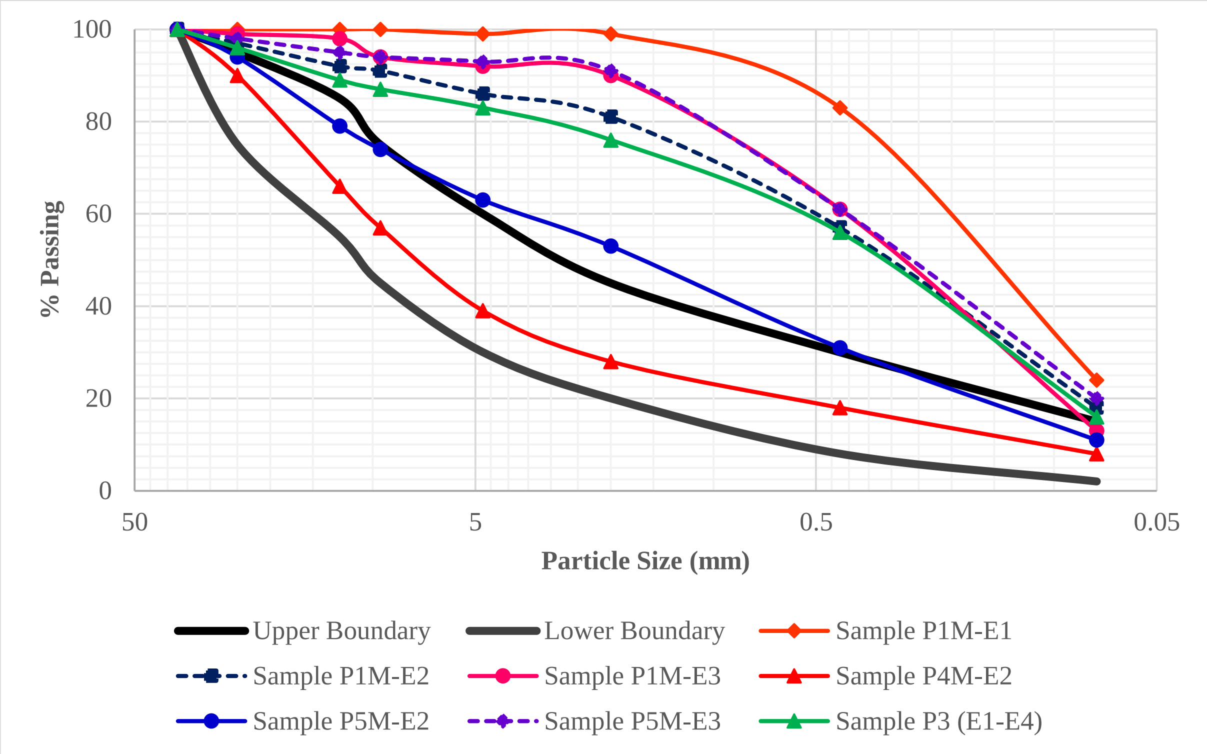

Fig. 7. Soil particle size distribution and specifications for SBG-38

As can be seen in Figures 3 to 6, most of the samples tested have a particle size distribution that does not conform to bands established by the Instituto Nacional de Vías, in order to be used as affirmed or sub-base granular layers. Of the seven materials tested, only two met for granular sub-base and for affirmed (Sample P4M-E2, Sample P5M-E2), respectively. It can also be observed that of the other five types of materials found, Sample P3M (E1-E4), is the one with the closest soil particle size distribution to that required by the regulations. In view of these results, Tables 3 and 4 are presented, where the results obtained in the tests are compared with the reference values established in the corresponding specifications.

Table 3. Comparison of Sample P3M (E1-E4) results with the sub-base specification

Laboratory test	Normative INV	Sub-base	Sample P3M- E (1-4)	
COMPOSITION				
Granulometría	E - 213	Tabla 320.1	Figure 3,4,5 y 6	NOT COMPLY
CLEANLINESS				
Limite Liquido (%)	E - 125	≤ 40	0	COMPLY
Índice de Plasticidad (%)	E - 126	≤ 6	0	COMPLY
Equivalente de Arena (%)	E-133	≥ 25	25	COMPLY
MATERIAL STRENGTH				
CBR (%)	E - 148	≥ 30	19	NOT COMPLY

It can be seen that the material called Sample P3M (E1-E4) does not meet the specification of granular sub-base (INV 320-13), because in addition to not having a satisfactory particle size distribution, it does not meet the minimum values CBR required. Therefore, it is not considered a suitable material to be used as a granular sub-base.

In a complementary manner, the characterization of the material corresponding to Sample P3M (E1-E4) was carried out, to compare it with the specification of Terraplenes (INV 202-13). For this purpose, Table 4 presents the results obtained. According to these results, it can be established that the evaluated material meets all the requirements to be used as a material for forming road embankments.

On the other hand, Table 5 presents the results of the composition, hardness, durability, cleanliness and resistance tests for the materials corresponding to Sample P4M-E2 and Sample P5M-E2. It can be seen that these meet all the requirements to be used as granular sub-base material in road infrastructure works.

Table 4. Comparison of results of Sample P3M (E1-E4) with the specification of Embankments

CHARACTERISTIC	NORMATIVE INV	"SUELOS SELECCIONADOS"	"SUELOS ADECUADOS"	"SUELOS TOLERABLES"	Sample P3M –E (1-4)	
Parts of the embankment to which they apply		All	All	Foundation and Core	Results	Compliance
Tamaño máximo, mm	E- 123	75	100	150	50	COMPLY
Porcentaje que pasa el tamiz de 2 mm	E- 123	80	80	-	76	COMPLY
Porcentaje que pasa el tamiz de 75 µm	E- 123	25	35	35	15	COMPLY
Contenido de materia orgánica, máximo	E- 121	0	1	1	0	COMPLY
Límite líquido, máximo (%)	E- 125	30	40	40	0	COMPLY
Índice de plasticidad, máximo (%)	E- 126	10	15	-	0	COMPLY
CBR de laboratorio, mínimo (%)	E- 148	10	5	3	19	COMPLY

Table 5. Comparison of Sample P4M-E2 and Sample P5M-E2 results with the sub-base specification

Laboratory test	Normative INV	Sub-base	Sample P4M-E2		Sample P5M-E2	
COMPOSITION						
Granulometría	E - 213	Tabla 320.1	Figures 6 and 7	COMPLY	Figure 5	CUMPLE
HARDNESS						
Desgaste en la Máquina de los Ángeles (Gradación A)	E - 218	≤ 50	21	COMPLY	26	COMPLY
Contenido De Terrones De Arcilla y Partículas Deleznables en Agregados	E-211	≤ 2	Fine G.S= 1.8 Coarse G.S.=1.0	COMPLY COMPLY	Fine G.S = 1.2 Coarse G.S.=1.1	COMPLY COMPLY
DURABILITY						
Evaluación en el ensayo de solidez en Sulfatos	-	-				
Sulfatos de Magnesio	E-220	≤ 18	Fine G.S=15.9 Coarse G.S.=7.2	COMPLY COMPLY	Fine G.S =14.7 AG. Coarse G.S.=8.6	COMPLY COMPLY
CLEANLINESS						
Limite Liquido (%)	E - 125	≤ 40	0	COMPLY	0	COMPLY
Índice de Plasticidad (%)	E - 126	≤ 6	0	COMPLY	0	COMPLY
Equivalente de Arena (%)	E-133	≥ 25	31	COMPLY	30	COMPLY
MATERIAL STRENGTH						
CBR (%)	E - 148	≥ 30	35	COMPLY	32	COMPLY

IV. CONCLUSIONS

Through the present investigation, it was possible to determine the possibility offered by the materials of the La Cabaña Quarry, located on the outskirts of the city of Sincelejo, of being used as granular materials in pavement construction projects. According to the results obtained in the tests carried out on the samples taken from the different strata present throughout a sector in operation, it was found that granular materials have a high potential for use in the construction of selected landfills and granular sub-bases; and by being combined within certain proportions, according to the representative physical-mechanical characteristics of each stratum and with crushed materials from other sources, it is possible to obtain granular bases with adequate characteristics, in accordance with the requirements established in the Specifications General Construction of Roads of the National Institute of Highways of Colombia.

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REFERENCES

[1] Escobar F, Sumba D and Tapia A. Caracterización de la explotación de materiales para la construcción en el sector oeste de la ciudad de Guayaquil. Facultad de Ingeniería en Ciencias de la Tierra. Escuela Superior Politécnica del Litoral. Tesina De Seminario De Graduación. 2009.

[2] Ramírez M. Sostenibilidad de la explotación de materiales de construcción en el Valle de Aburrá. Universidad Nacional de Colombia. Tesis de Maestría. Medellín. 2009.

[3] Basabe F and Bejarano M. Estudio del impacto generado sobre la cadena de valor a partir del diseño de una propuesta para la gestión del mantenimiento preventivo en la cantera salitre Blanco de Aguilar Construcciones S.A. Trabajo de grado para optar al título de Ingeniero Industrial. Pontificia Universidad Javeriana. Bogotá. 2009.

[4] Contreras M, Orjuela J. Probabilidad de producir concretos de mediana y alta resistencia con agregados de las formaciones geológicas de Toluviejo y San Cayetano. Facultad de Ingeniería. Trabajo de grado para obtener el título de Ingeniero Civil. Universidad de Sucre. Sincelejo. 2009

[5] Revollo F, Villalba W and Zabala F. Estabilización de dos materiales a usar como base y subbase de vías, mediante la modificación de su granulometría. Facultad de Ingeniería. Trabajo de grado para obtener el título de Ingeniero Agrícola. Universidad de Sucre. Sincelejo. 2000.

[6] Gobernación de Sucre. Características Geográficas. Instituto Geográfico Agustín Codazzi. Sucre. 2003.

[7] Clavijo J and Barrera R. Planchas 44 - 52 / Sincelejo y Sahagún - Memoria Explicativa. Instituto de Investigación e Información Geocientífica, minero-Ambiental y Nuclear INGEOMINAS. 2001.