International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 14, Number 10 (2021), pp. 1068-1076

Stabilization of granular materials for road construction through the modification of their particle size distribution

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Abstract

The behaviour and performance of the granular layers that are part of the structural packages of the pavements, depends on their physical and mechanical properties. That is why construction standards and regulations establish minimum quality requirements that these materials must meet. However, very often, there are limitations in the quality of the materials available in the sources close to the project area, which leads to serious problems, since this situation tends to make road infrastructure projects more expensive or disturb the viability of road infrastructure. That is why, the improvement or stabilization of the properties of granular materials, results in a viable and indispensable option to obtain materials that meet the requested specifications. For this purpose, other materials can be chosen to incorporate, which mixed in certain proportions together with the original material, generate a product that meets the particle size distribution and other specified properties. In the present work, the results obtained when carrying out a particle size distribution stabilization process are shown, where, after carrying out several analytical tests, the working formulas could be obtained, which establish the proportions in which the Aggregate from the La Cabaña Quarry together with three granular materials from the JOMEVE Company, in order to obtain aggregate mixtures that fully comply with the requirements established by the specifications of the Instituto Nacional de Vías of Colombia, for the construction of granular bases and sub-bases.

Keywords: Granulometric stabilization, Material mix, Granular sub-base, Granular base, Particle size distribution

I. INTRODUCTION

Granular materials are inert solids that are used in road surfaces with or without the addition of active elements and with suitable particle sizes; they are used for the manufacture of resistant artificial products [1]. The types of stone aggregates are classified according to the origin and the technique used for their use, the main ones being: natural aggregates, crushing aggregates, artificial aggregates and marginal aggregates [2]. The most commonly used admixtures in Colombia for civil projects are natural, crushing or a mixture of both [3], the latter providing certain advantages for the case of particle size distribution stabilization of soils, because when crushing the material, it is It can adjust to the particle size curve required by the specification or when combined with a natural material, it can improve its particle size ratios.

The physical-mechanical characteristics of road construction materials categorically condition the quality and performance of the pavement structures of which they are part, for which it should be sought that said materials have the characteristics and qualities that guarantee that the pavement structure is kept in optimal condition throughout its service life. From this it follows, the importance of the study, choice and quality control of these materials, in order to guarantee the good performance of the pavement structure. For these reasons, work contracting companies must supply their projects with granular materials that meet the minimum specifications required by the applicable legal regulations in each case. In a complementary way, if a certain project has materials of optimal qualities or excellent physical and mechanical behaviour, it is possible to reduce the design thicknesses in each of the layers that make up the pavement [4], with all the advantages that this reduction of thickness entails.

Granular materials require a detailed study of their properties in order to determine their application on site. Commonly, it is sought, as far as possible, to use materials available from sources close to the project site, in order to reduce transportation costs and thus, to minimize the total cost of the project. Unfortunately, it is often not possible to find materials in the vicinity of the project area that meet the required construction specifications. This lack of granular materials has led research institutions to carry out processes to achieve optimal granular materials and, at the same time, help mitigate the growing environmental problems that cause the exploitation of these materials [5], being the most common, to apply on said materials, soil improvement techniques in order to optimize their behaviour [6], [7].

With regard to the stabilization of granular materials, this consists in the execution of all the activities necessary for the construction of one or more structural layers of pavement, consisting of materials resulting from the scarification of the existing surface layer or by material of loan, or as it is the case that concerns us, a mixture of two or more materials in order to obtain one that meets the requirements in its size distribution. Additionally, techniques could be applied that generate an increase in mechanical resistance and durability, through certain physical and / or chemical processes, in accordance with the guidelines indicated in the project documents [8].

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The stabilization of materials is a widely used activity, which offers several important advantages, for example, in the environmental field, the use of existing materials along the road corridor, avoids exploiting new banks, also reducing the need for landfills; as well as the elimination of the transport of new materials, which generates the reduction of CO2 emissions and other pollutants and reduces the damage generated by fuels and oils, as well as the collateral impacts (dust, erosion and others) that it causes on the roads and its environment. In the technical field, there is the advantage of being able to take advantage of materials close to the project area, for which, through stabilization techniques, their characteristics can be improved to the desired degree. Regarding the economy, the fact of using materials from sources close to the work, implies a significant reduction in transportation costs. On the other hand, obtaining higher quality bases or pavements allows an economy in the upper layers of the pavement and reduces the total thickness of the excavation compared to other alternatives, in which untreated materials are used [9].

In the present work, the results of a physical stabilization process are presented, by mixing various granular materials, in order to obtain aggregates for Granular Subbase and Base that meet the particle size distribution requirements required in the Specifications for Road Construction of the Instituto Nacional de Vías of Colombia. For this purpose, materials from the La Cabaña Quarry, located in the city of Sincelejo, and other aggregates from the town of Toluviejo, north of Colombia, were used.

II. MATERIALS AND METHODS

For the execution of this work, the following sequence was followed:

- Visual inspection carried out within the existing quarry area, to identify the sectors with the greatest potential for the exploitation of granular materials.
- Obtaining representative samples of the materials found in the different layers of the quarry for their subsequent characterization.
- Carrying out laboratory tests for the classification of soils of the materials from the La Cabaña quarry: particle size distribution, liquid limit and plastic limit.
- Carrying out laboratory tests for soil classification of imported materials with potential of use to carry out physical stabilization: particle size distribution, liquid limit and plastic limit.
- Graphic representation of the particle size distributions obtained for the different materials and testing, in an analytical way, of different combinations in order to determine working formulas.
- Proposal of analytical work formulas, in such a way as to result in granulometric curves that fall within the particle size distribution bands established by the specifications of the Instituto Nacional de Vías, in the case of sub-bases and granular bases.
- Carrying out complementary tests, in accordance with the requirements of the granular base and sub-base specifications, to verify the engineering properties of the combined materials, including resistance through the CBR test.

The methodology used is shown schematically in the Figure 1 and Figure 2 shows the image showing the location of the La Cabaña quarry.

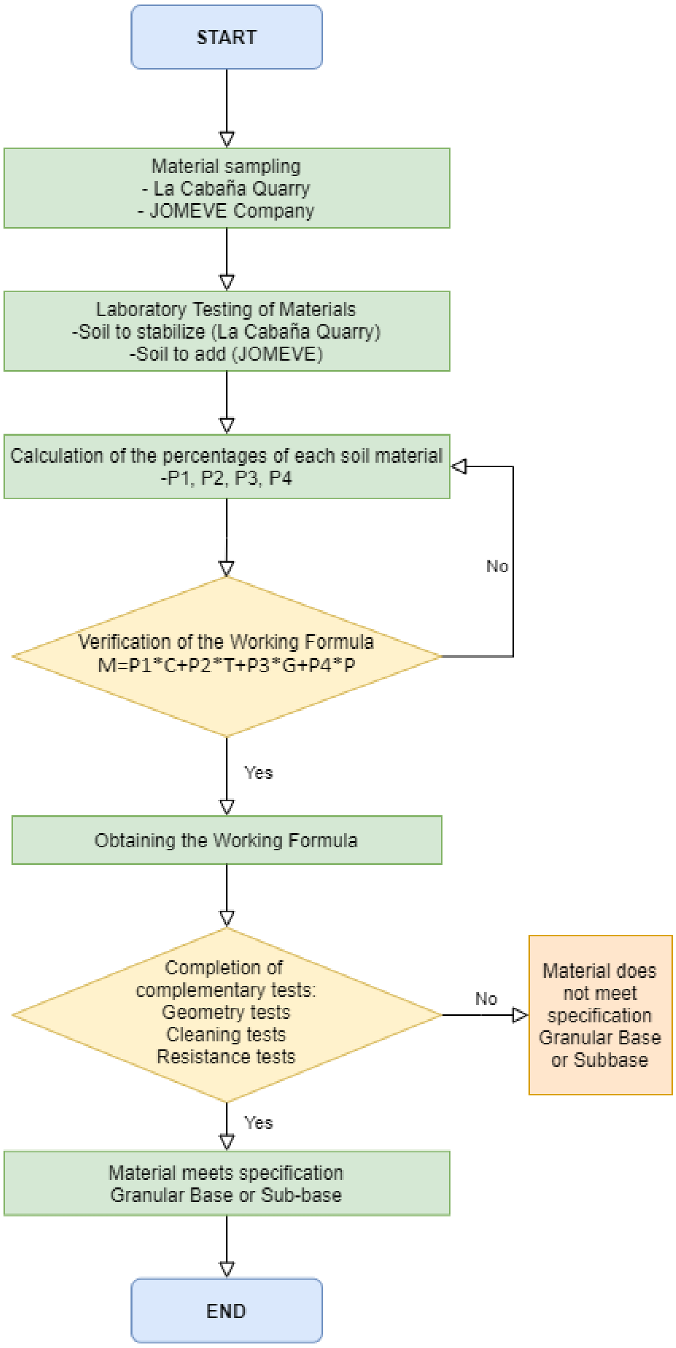

Fig. 1. Sequence of the activities carried out in the development of the work

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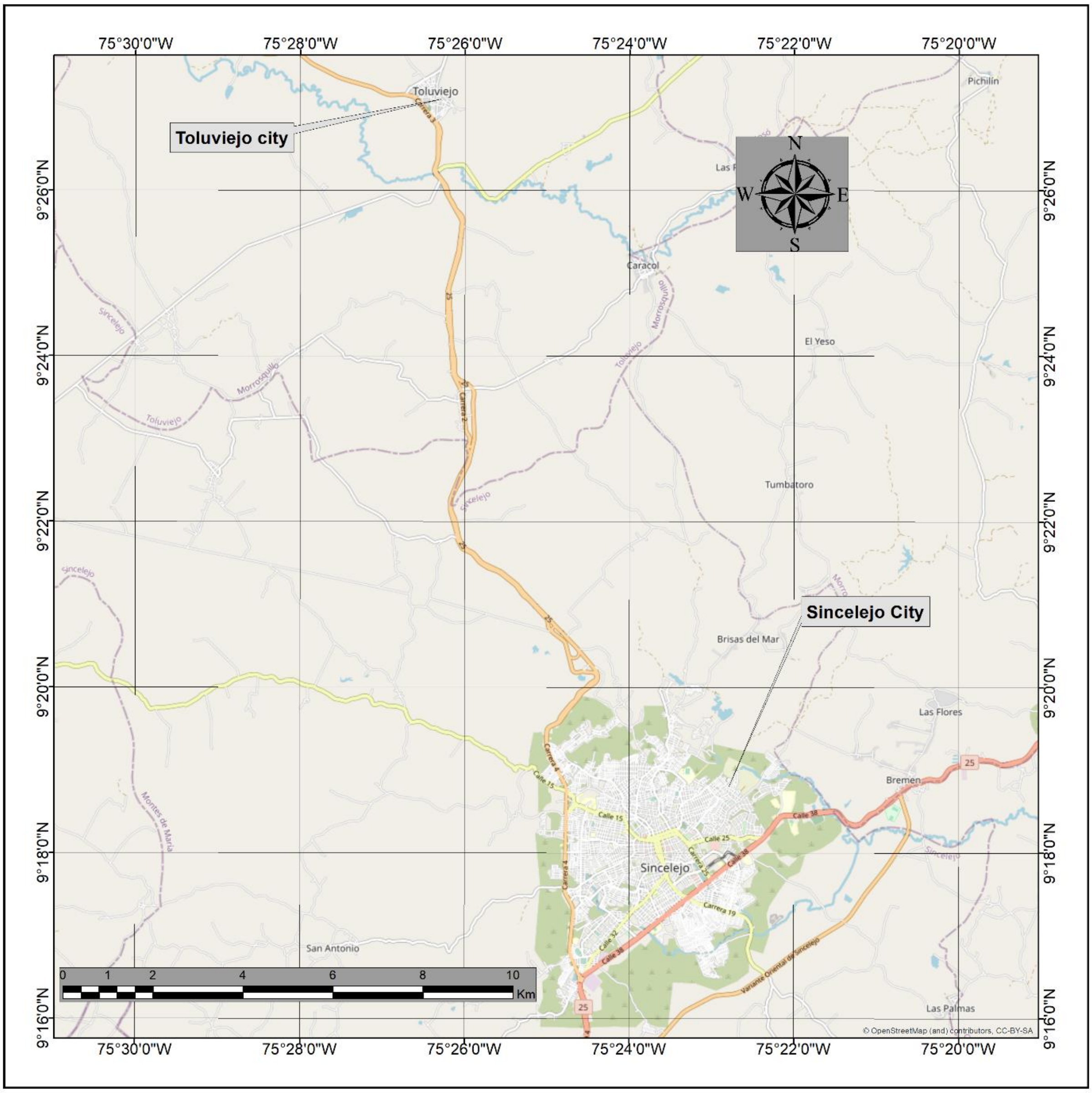

Fig. 2. Location of the municipalities where is localized the quarries

II.I Obtaining Materials

The materials available for the physical stabilization of the granular subbase and obtaining the granular base, are made up of aggregates from the La Cabaña quarry (object of this study), and located near the city of Sincelejo, in the Sierra Flor sector, which has an estimated plant area of 75.28 Ha. On the other hand, there are imported aggregates from the JOMEVE quarry located in the Municipality of Toluviejo. It should be noted that from the quarry located in the town of Toluviejo, three different portions were used: crushed, gravel and dust.

For the materials from the La Cabaña quarry, in the case of accessible sites, samples were extracted from the different observed strata, using manual tools; Meanwhile, in the case of sites located near the steep slopes and difficult to access, they were collected with the help of a backhoe. Subsequently, the samples were transported to the laboratory to carry out the tests required for their characterization. The quarry material the most promising hut to be used as part of the mix for Subbase or granular base, was named Sample P3M E (1-4). Regarding the rest of the materials to be added in the stabilization process, these were collected from the stock disposed in the patio area of the Quarry owned by the JOMEVE Company, located in the town of Toluviejo. Likewise, these were conveniently transported to the laboratory to be tested.

II.II Conducting Laboratory Tests

To carry out the laboratory tests on the different materials collected, the "Test Standards for Highway Materials" of the National Institute of Roads of Colombia were taken as a reference. Table 1 shows the laboratory tests performed.

Table 1. Test for Sub-base and Granular Base materials - INVIAS 2013.

LABORATORY TESTS			GRANULAR MATERIAL	
Test Type	**Test**	**Normative**	**Sub-base**	**Base**
Composition	Granulometría	INV E-213	✓	✓
Hardness	Desgaste en máquina de los ángeles	INV E-218	✓	✓
	Contenido de terrones de arcilla y partículas deleznables en agregados	INV E-211	✓	✓
Durability	Perdidas en el ensayo de solidez por sulfatos	INV E-220	✓	✓
Cleanliness	Límite líquido e índice de plasticidad	INV E-125 INV E-126	✓	✓
	Equivalente de arena	INV E-133	✓	✓
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	Califronia Bearing Ratio (CBR)	INV E – 148	✓	✓

II.III Materials mix

For the preparation of the mixtures of the different aggregates, the methodology set forth and developed in the book Soil Engineering in Land Roads by the engineers Rico and Del Castillo [10] was followed, where it is shown that to achieve this purpose, takes the soil to stabilize and percentages of other available materials are added, in order to produce a material that meets the requirements established in the specifications of current regulations for the construction of granular layers of roads. In summary, the procedure consists in that, to the soil that is desired to improve its physical properties of particle size distribution, it is divided into several fractions and the percentage of material that is included in that fraction is calculated, to later take a known percentage of another material and add it to improve its particle size distribution.

Then, if A, B, C, D ... are percentages that pass through a sieve of a set of soils 1, 2, 3, 4…, respectively and that they want to combine to form a single soil and if a, b, c, d ..., are the percentages in which the aforementioned soils will enter the combination, the percentage of the mixture that will pass through a certain sieve will be given by the equation:

$$P = aA + bB + cC + dD \qquad (Eq. 1)$$

Next, the simplest example of the methodology is presented, for the case of mixing only two materials.

For this purpose, the combination equation is developed as follows:

$$P = aA + bB \qquad (Eq. 2)$$

Where, the percentages of soils 1 and 2 are expressed as follows:

$$a = (p - B) / (A - B) \qquad (Eq. 3)$$

$$b = (p - A) / (A - B) \qquad (Eq. 4)$$

Equations 3 and 4 show the percentages (a, b) in which soils 1 and 2 must be combined, so that the resulting material has the desired P percentage, on the sieve chosen for the calculation.

For the present work, the material from La Cabaña was combined with the other three materials mentioned above (crushed, gravel and dust), with the aim of helping to improve the particle size distribution of the first material. Therefore, taking into account that the mixture will be made up of four materials, the working formula will be obtained from Eq. 5.

$$M = P1 * C + P2 * T + P3 * G + P4 * P \qquad (Eq. 5)$$

Where:

M = amount of mixed material retained for each sieve
P1, P2, P3 and P4 = percentage by weight to be used of each material
C, T, G and P = Percentage of Material that passes through a certain sieve
Where, C = Cabaña Material, T = Crushed, G = Gravel, P = Dust, are the respective materials.

II.IV. Verification of the Physical-Mechanical properties of the Evaluated Material.

In the first instance, the property that is being optimized or improved must be verified, for this case, the particle size distribution, so that once the combinations have been made in a theoretical way, the materials must be combined in the established proportions and verify the new particle size distribution of the mixture. What is expected in this instance is that the new particle size distribution satisfies the regulatory requirements, but because the soil is not totally homogeneous, it may be the case that this requirement is not yet fully met, therefore, They will have to adjust again the percentages in which each material will intervene, until obtaining a new particle size distribution that satisfies the requirements of the specification.

Once an optimal particle size distribution has been obtained, on the resulting mixture of materials, the verification of the other properties required in the specifications should be continued, because the problem of stabilizing the soil mixture arises from two points of view: the particle size distribution of the soil mix and the resulting plasticity in the fines included in the mix. It is these two aspects that will be taken into account for the design of stabilization [11].

Once the mixed material meets all the requirements listed in Table 1, it can be stated that the working formula of the material mixture is viable to be used, either as a Subbase or a granular base, as the case may be.

III. RESULTS

The results obtained during the development of this research are presented below. First, a summary is shown with the characteristics of the material chosen to stabilize, which has been called Sample P3M E (1-4), whose name comes from the place and stratigraphic profile taken from the quarry under study. In Table 2 and in Figures 3 and 4, the properties of said material are shown, where it can be observed that it does not satisfy the requirements for particle size distribution and material resistance (CBR).

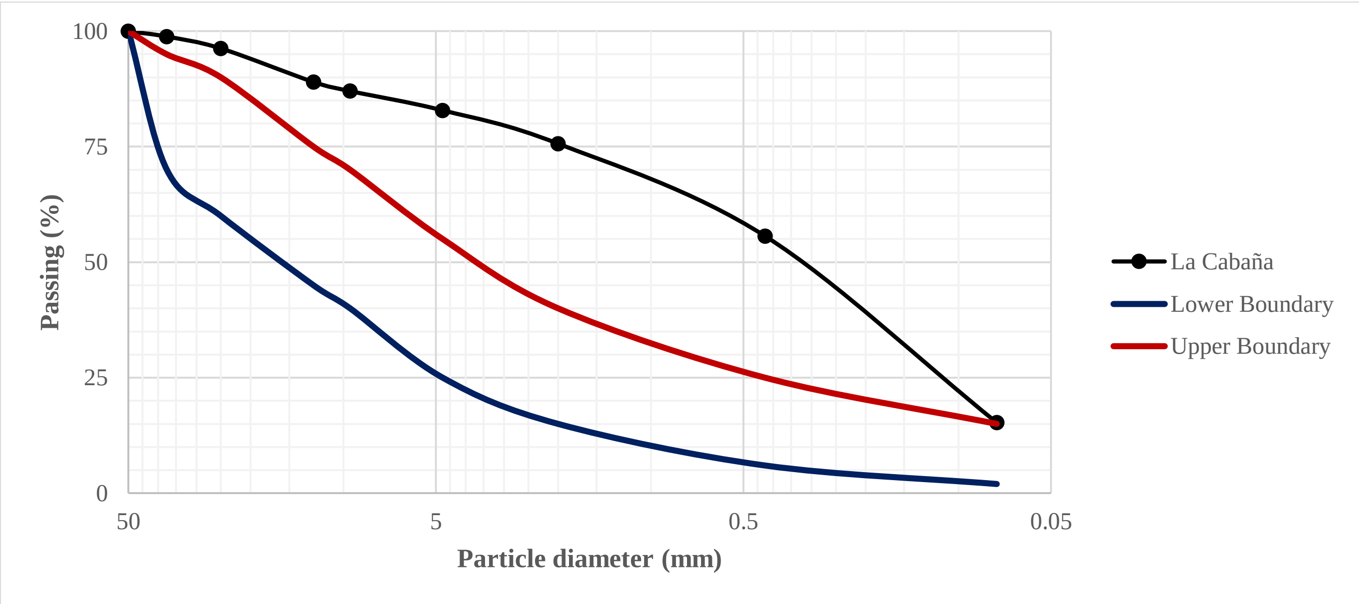

Fig. 3. La Cabaña quarry particle size distribution - sub-base particle size distribution curve

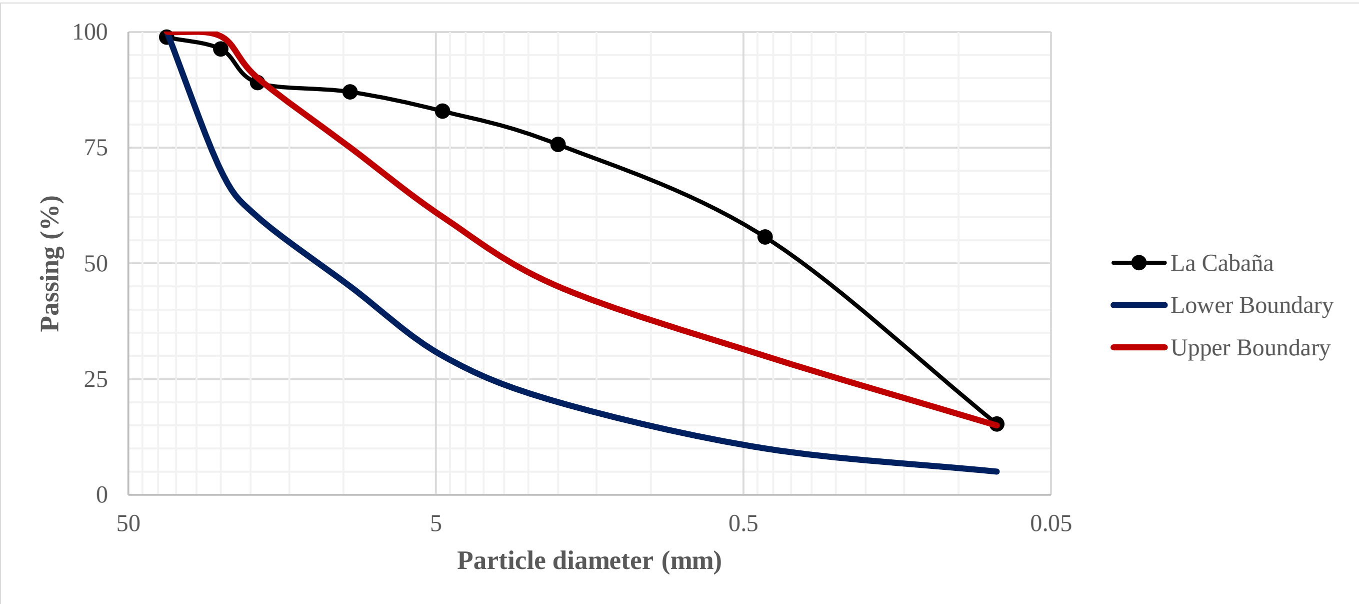

Fig. 4. La Cabaña quarry particle size distribution - base particle size distribution curve

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 14, Number 10 (2021), pp. 1068-1076

As can be seen in Figures 2 and 3, the particle size curve of the material (black colour) is practically entirely outside the bands of the particle size distribution curves required in the specifications 320-13 and 330-13 of the Instituto Nacional de Vías of Colombia, for the granular subbase and base cases, respectively. Due to this situation, the material was stabilized with the other three materials from the JOMEVE Company's materials yard. In Table 3, the particle size distributions of the three materials are shown.

Table 2. Properties of the P3M E sample (1-4)

Laboratory test	Sub-base	Sample P3M E(1-4)		Base	Sample P3M E(1-4)	
COMPOSITION						
Granulometría	Tabla 330-3	Figure 3	NOT COMPLY	Tabla 320-3	Figure 4	NOT COMPLY
HARDNESS						
Desgaste en la Máquina de los Ángeles (Gradación A) - 500 rev	≤ 50	29	COMPLY	≤ 40	28	COMPLY
Desgaste en la Máquina de los Ángeles (Gradación A) - 100 rev	-			≤ 8	7	COMPLY
DURABILITY						
Sulfatos de Magnesio	≤ 18	Fine G.S. =15.0 Coarse G.S. =10.0	COMPLY COMPLY	≤ 18	AG. FINO=13.0 AG. GRUESO=8.1	COMPLY COMPLY
CLEANLINESS						
Limite Liquido (%)	≤ 25	24.1	COMPLY	≤ 25	23.6	COMPLY
Índice de Plasticidad (%)	≤ 6	0.8	COMPLY	≤ 3	0.4	COMPLY
Equivalente de Arena (%)	≥ 25	29	COMPLY	≥ 30	31	COMPLY
Contenido De Terrones De Arcilla y Partículas Deleznables en Agregados	≤ 2	Fine G.S = 1.9 Coarse G.S. =1.1	COMPLY COMPLY	≤ 2	AG. FINO= 1.9 AG. GRUESO= 0.4	COMPLY COMPLY
PARTICLE GEOMETRY						
Índice de aplanamiento y de alargamiento de los agregados para carreteras	-			≤ 35	15.32, 16.72	COMPLY
Porcentaje de caras fracturadas en los agregados	-			≥ 50	91	COMPLY
MATERIAL STRENGTH						
CBR (%)	≥ 30	19	NOT COMPLY	≥ 80	19	NOT COMPLY

Table 3. Particle size distribution of the materials from the JOMEVE Company

Material	Percentage Passing Sieve									
	2"	**1 ½"**	**1"**	**3/4"**	**1/2"**	**3/8"**	**N°4**	**N°10**	**N°40**	**N°200**
Gravel 1 (T)	100	100	64	10	0,6	0,5	0,4	0,3	0,3	0,2
Gravel 2 (G)	100	100	99	96	68	49	8,0	2,3	1,6	0,3
Gravel 3 (P)	100	100	100	100	100	100	99	72	32	2,4

From the materials referred to in table 3, several tests were carried out until the resulting working equations were obtained, both for the base and for the granular sub-base.

For the case of the granular subbase, the working equation was as follows:

$$M = 30\% * C + 25\% * T + 25\% * G + 20\% * P \quad (Eq. 6)$$

Based on the equation Eq. 6, the particle size distribution shown in Figure 5 and the CBR values presented in Figures 6 were obtained. For the case of particle size distribution, the theoretical curve (resulting from the analytical calculation) and the real curve (resulting from the combination of materials in the laboratory), observing a substantial change in each sieve fraction of the granulometric curve of the resulting material, compared to the initial particle size distribution (Figure 3).

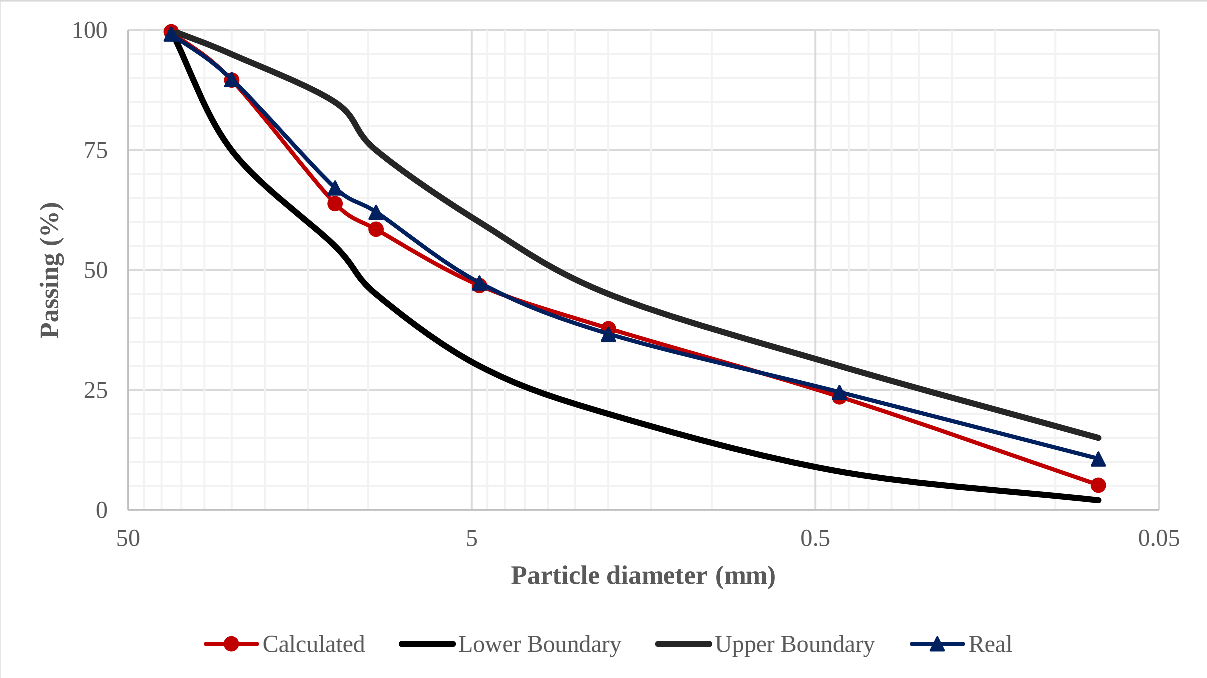

Fig. 5. Real and Calculated Particle Size Distribution with Granular Subbase bands (SBG-38)

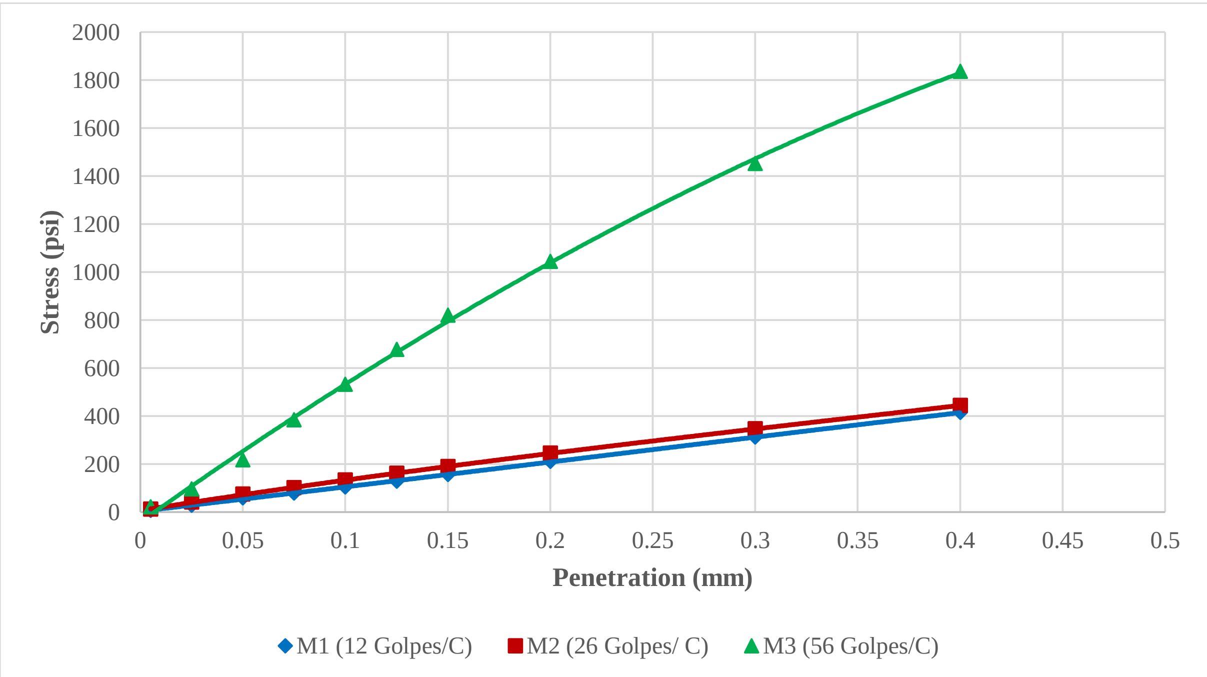

Fig. 6. CBR curves for SBG-38

For the granular base, the materials from the quarry were mixed with the materials from the JOMEVE Company, according to the following expression:

$$M = 45\% * C + 25\% * T + 25\% * G + 5\% * P \quad (Eq.7)$$

The granular materials obtained showed improvements in their granulometric and resistance properties (CBR values), as happened with the granular sub-base material. These changes can be seen in Figures 7 and 8.

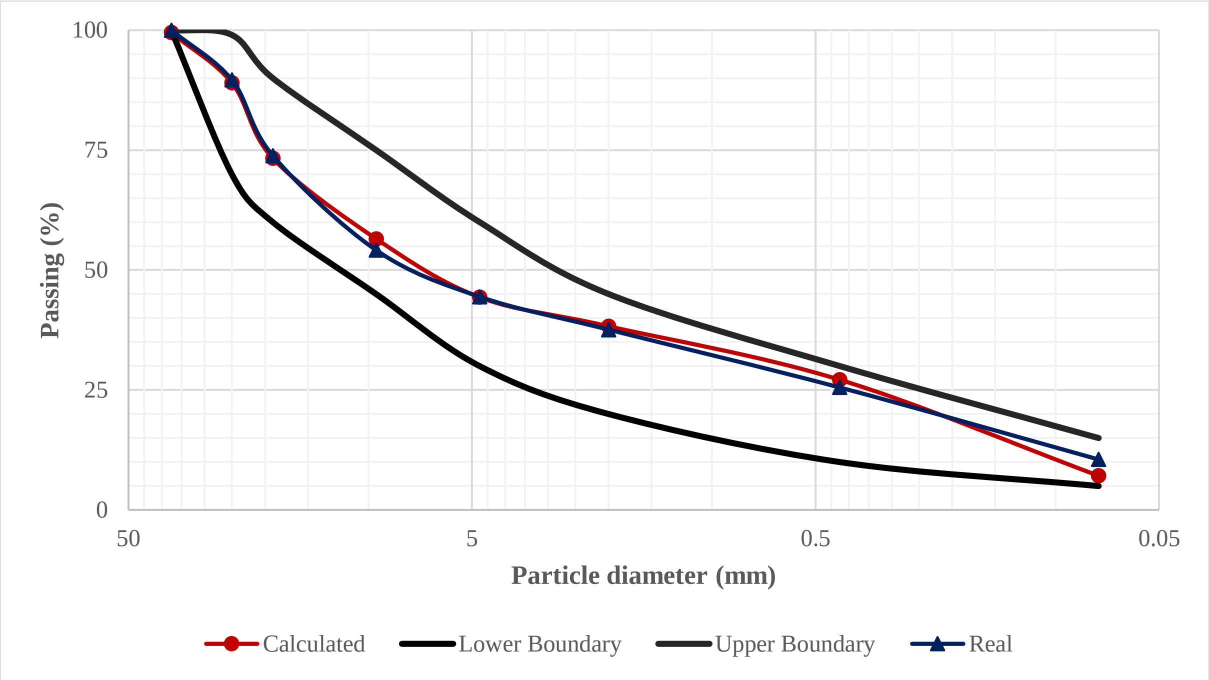

Fig. 7. Real and Calculated Particle Size Distribution with Granular Base bands (BG-38)

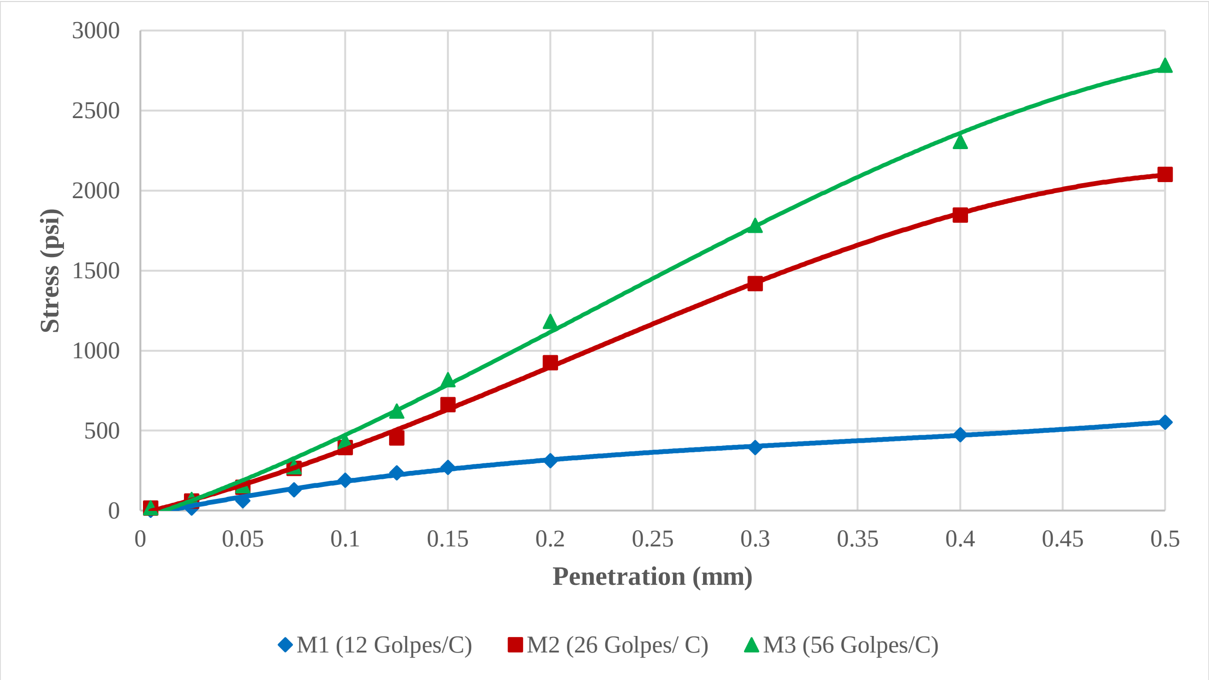

Fig. 8. CBR curves for BG-38

Once all the tests had been carried out, it could be determined that the samples meet all the requirements shown in Table 1 for the two granular materials considered. The additional physical properties remained the same or improved, complying with the regulatory requirements and regarding the particle size distribution and capacity properties that were not met at the beginning, they were fully satisfied, leaving the particle size curves for the granular sub-base and for the granular base as seen in Figures 5 and 7, with CBR values of 82 and 85, respectively.

IV. CONCLUSIONS

Through the present work, it was possible to obtain the working formulas of a particle size stabilization process carried out in a granular material from the La Cabaña quarry located on the outskirts of the city of Sincelejo, which by itself did not meet the established requirements with regard to its size distribution, to be used as a structural layer in a pavement. For this purpose, different proportions of three granular materials were added, from the town of Toluviejo, located in the north of Colombia. This procedure allowed obtaining aggregates for granular base and sub-base suitable for use in pavement structures, in accordance with the requirements established in the General Specifications for Highway Construction of the Instituto Nacional de Vías of Colombia.

ACKNOWLEDGMENTS

The authors thanks the civil engineering of the University of Sucre, Manuel Francisco Betín Pérez for your research work.

REFERENCES

[1] Smith M and Collis L. Áridos Naturales y de Machaqueo para la Construcción. 2ª.Edición. The Geological Society. Edición especial No. 9 sobre Ingeniería Geológica. Colegio Oficial de Geólogos de España. Versión en Español Editada por: L. Suárez y M. Regueiro. 1994.

[2] Padilla A. Análisis de la resistencia a las deformaciones plásticas de mezclas bituminosas densas de la normativa mexicana mediante el ensayo de pista. Universitat Politècnica de Catalunya. 2004. Retrieved from: https://upcommons.upc.edu/handle/2099.1/3334

[3] Rivera J and Pajajoy M. Agregados petreos en Colombia: ¿Una industria que crea valor?. Revista TENDENCIAS. 2018; 19(2).

[4] Guney Y, Aydilek A and Demirkan. Geoenvironmental behavior of foundry sand amended mixtures for highway subbases. Waste Management. Elsevier. 2006;26:932-945. Retrieved from: http://www.scielo.org.co/pdf/tend/v19n2/2539-0554-tend-19-02-00022.pdf

[5] Reyes F and Reyes O. Efecto del Uso de Desperdicio de una siderúrgica en bases y subbases granulares. Revista Ingenoieria de construcción. 2003; 18(3):165–169.

[6] Hsai-Yang F. Foundation Engineering Handbook. 2 Ed. Van Nostrand Reinhold Book, New York, 1991.

[7] Bowles J. Foundation Analysis and Design. 3 ed. McGraw-Hill, 1982.

[8] Alcaldía Mayor de Bogotá. Guía para el diseño y la construcción de capas estructurales de pavimentos estabilizadas mediante procesos químicos. Bogotá. 2005.

[9] Torres A. Propuesta metodológica para la evaluación y mejoramiento, con emulsión asfáltica y/o cemento, de los materiales granulares existentes en las vías terciarias. 2014. Retrieved from: https://repository.unimilitar.edu.co/handle/10654/12229

[10] Rico A, Del Castillo H. La Ingeniería de Suelos en las Vías Terrestres. Vol. 2. Editorial Limusa. México. 1977.

[11] Revollo F and Villalba W. 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.