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PERFORMANCE EVALUATION OF GRANULAR SUB-BASE BY MAPS OF RESISTANCE USING GRAPHER™. CASE STUDY: IBAGUE, COLOMBIA

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ABSTRACT

In this study, we evaluated the performance of the granular sub-base materials of the “La Caima” and “Martínez” quarries located in Ibagué, Colombia, using resistance maps validated with the traditional data of optimum moisture content, maximum dry unit weight and CBR. From the results of resistance maps made for the two quarries using the Grapher software we concluded that the maximum value of CBR could be obtained with moisture values lower than the optimum moisture content. We conclude that a moisture value lower than the optimum moisture content (obtained from the Proctor test) produces higher values of CBR, for example, in the “La Caima” and “Martínez” quarries a higher CBR value is obtained when the optimum moisture content is reduced by 0.5%. In first case, CBR value increases 31.61% and the second case 24.46%. The results obtained from the two case studies indicate that the development of resistance maps is the most appropriate methodology to achieve a better compaction control of the granular sub-base materials.

Keywords: compaction, proctor, moisture, density, CBR, resistance maps, performance.

1. INTRODUCTION

Ibagué city in Colombia is recovering the road network in recent years using a periodic maintenance called "Bacheo". This technique consists in the localized repair of the bituminous pavements to guarantee the uniformity of the surface and to repair the damages that appear in some points of the road [1].

Sometimes these "Bacheos" instead of improving the road generate in the short-term deteriorations of cracking and permanent deformation becoming a structural damage instead of a solution when they are built with limited quality protocols [2].

One of the factors of deterioration is the lack of control in the compaction of geomaterials [2] and for this reason this study presents the results of a performance evaluation of granular subbase of SBG-38 of two main quarries that provide granular material of Subbase to build roads in Ibagué city, Colombia. Performance is estimated based on CBR, moisture content, dry unit weight and saturation.

2. METHODS

2.1 Study cases

The granular sub - bases of the “La Caima” and “Martínez” quarries were studied. These quarries provide the sub-base material for road construction in Ibague city located in Colombia. These granular sub-bases are of type SBG 38 (see Figures 1 and 2) according to the construction specifications for roads of INVIAS 2013 [3] [4].

INVIAS is the technical entity responsible for issuing specifications, regulations, guides and manuals for the design, construction and rehabilitation of road infrastructure in Colombia. On the other hand, the granular sub-base material of “La Caima” quarry is non-plastic and the granular sub-base material of the “Martinez” quarry has clay material and low plasticity.

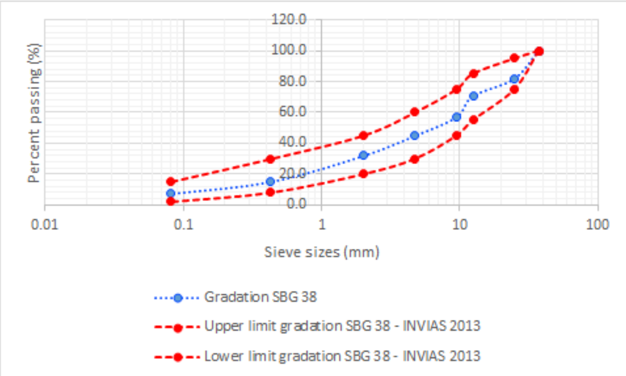

Figure-1. Gradation of granular sub-base SBG 38. “La Caima quarry”.

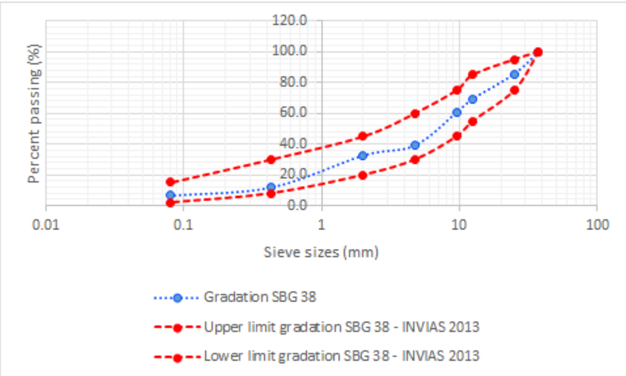

Figure-2. Gradation of granular sub-base SBG 38. “Martinezquarry”.

The quarry “La Caima” is located at 4 ° 36'02.58 “N, 74°56'28.28”W, elevation 352 m. The quarry

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“Martinez” is located at 4 ° 17'07.12 “N, 75 ° 13'03.54”W, elevation 987 m.

Figure-3. Ubication of “La Caima” quarry.

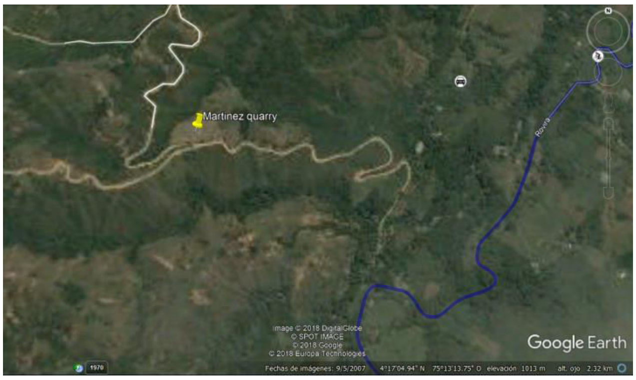

Figure-4. Ubication of “Martinez” quarry.

2.2Modified Proctor test and CBR

2.2.1 Modified Proctor test

Modified Proctor is a test method that determines moisture ratios and dry unit weight in soils under the considerations of the Colombian specification INV E-142-2013 and the American standard ASTM D 1557-2009. Modified Proctor test uses a sample built of soil five layers placed inside a mold. The soil is molded by striking each layer with a 44.48 N (10 lb) hammer that falls from a height of 457.2 mm (18 in), producing an approximate compaction energy of 2700 kN-m/m^3 (56,000 lbf-ft/ft^3). The soil is compacted with different moisture contents and each layer of soil is hit with 25 or 56 blows, at the end, dry unit weight is determined. The procedure is executed with an enough number of molding moistures to graph a curve that relates moisture content and dry unit weights. This curve is called the compaction curve and its vertex represents the optimum moisture and the maximum dry unit weight [4] [5].

The modified Proctor test is considered a recipe because it is easy to understand and execute. However, this test has a limitation since it doesn’t represent the mechanical performance of the soil [6].

2.2.2 CBR

The CBR called California Bearing Ratio is a penetration test that uses a standard piston (3 in^2). This piston penetrates the soil at a standard speed of 0.05 in/min. A unit load is recorded at different depths of penetration, typically 0.1 and 0.2 inches. The CBR value is calculated by dividing the registered unit load and the standard unit load that is required to penetrate a high-quality crushed stone material (1000 and 1500 psi for 0.1 inches and 0.2 inches, respectively).In CBR test, a sample of soaked soil is made. The immersion in water is done during 96 hours to simulate the soil worst condition (saturated) used in the pavements design [4] [7] [8] [9].

The CBR is characterized by being a mechanical test but not a performance test because it must be executed from soil samples made with the optimum moisture from the modified Proctor test [6]. The CBR test is developed according to the considerations of the Colombian specification INV E-148-2013 and the American standard ASTM D 1883-2007.

2.3 Resistance maps: performance method

The resistance maps come from the RAMCODES technology. This technique focuses on the analysis of the performance of geomaterials according to moisture content, dry unit weight and CBR. Resistance maps require a previous factorial experiment. The factorial test entries are: *i)* 15 points of CBR (minimum amount), *ii)* three energies of the Proctor test (56, 25 and 12 hits per layer), *iii)* range of moisture content and dry unit weight. The range of moisture content depends on the optimum moisture content [10] [11] [12] [13] [14] [15].

After the factorial experiment, the resistance maps are modeled from a multivariate plotter such as the Grapher [16] or Origin. In this study Grapher software was used for its usefulness in multivariate analysis. Resistance maps are usually accompanied by soil saturations. When this is done, a multivariate analysis is proposed to establish detailed studies of physical and mechanical behavior. The saturations are functions of dry unit weight, moisture content[17], specific gravity of soil solids [18]and unit weight of water[19] [20].

2.3.1 Grapher scientific graphing package

Grapher is a full-featured scientific graphing package, allowing the user to import data in many formats, create and combine a wide variety of 2 and 3-D plot types, and customize the plots in infinite detail.

Grapher modeler is a graphical program. Grapher was useful for generating resistance maps with linear interpolation. Grapher graphic modeler consists of nine interfaces (see figure 5) that perform different functions: 1) File, 2) Home, 3) Page Layout, 4) Draw, 5) Graphs, 6) View, 7) Arrange, 8) Developer, 9) Plot Menu [16]. The typical steps in the procedure for calculating a graphic problem with Grapher are: i) input of, moisture, content, dry unit weight and CBR, ii) Graphs contour surface, contour XY Data Map and axis properties.

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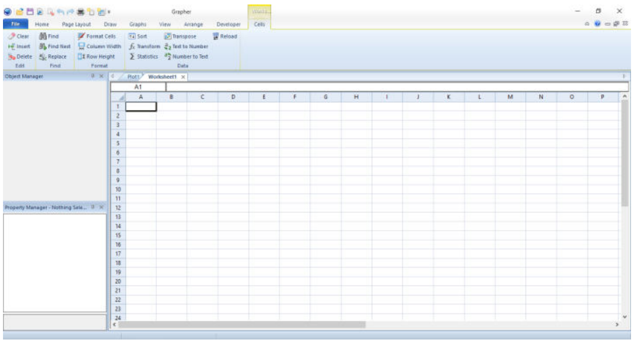

Figure-5. Grapher interface.

3. RESULTS AND DISCUSSIONS

3.1 Modified Proctor and CBR results

Figures 6 and 8 show the results of the modified Proctor test including the saturation curves of "La Caima" quarry and "Martínez" quarry, respectively. The optimum moisture weight in "La Caima" quarry was 6.9% and the maximum dry unit weight was 20.44 kN/m3. In "Martinez" quarry the optimum moisture weight was 7.5% and the maximum dry unit weight was 20.037 kN /m^3.

Figures 7 and 9 show the results of CBR with dry unit weight in "La Caima" quarry and "Martínez" quarry, respectively. Each CBR sample is made with the optimum moisture weight from the modified Proctor test. The CBR in "La Caima" quarry was 33.39% and the maximum dry unit weight was 20.44 kN/m^3. The CBR in "Martinez" quarry was 7.5% and the maximum dry unit weight was 20,037 kN /m^3.

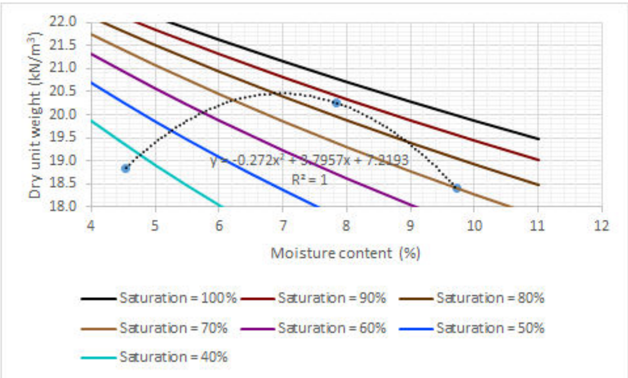

Figure-6. Proctor modified results including saturation curves. "La Caima" quarry.

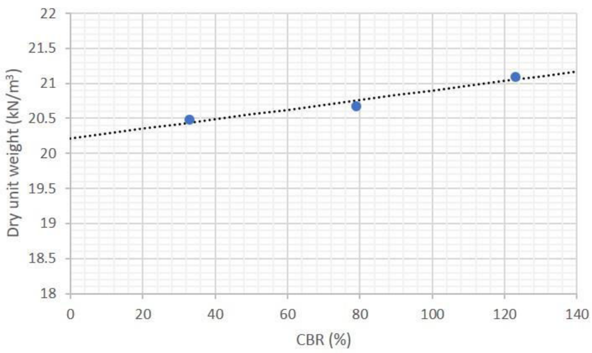

Figure-7. CBR results - optimum moisture contents. "La Caima" quarry.

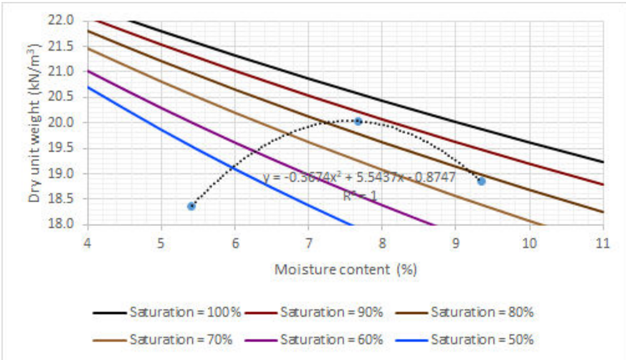

Figure-8. Proctor modified results including saturation curves. "Martinez"quarry.

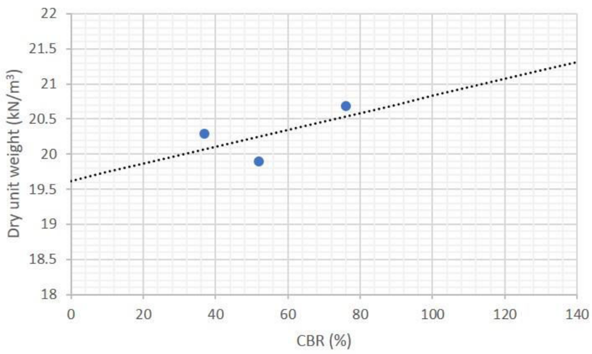

Figure-9. CBR results - optimum moisture contents. "Martinez" quarry.

3.2 Resistance maps validation

Table-1 presents the results of the validation of the resistance maps with the Grapher graphing modeler. The reference value of CBR is that obtained in the laboratory with the optimum moisture content.

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Table-1. Validation ofresults- Resistance maps.

Quarry	CBR		Variation [%]
	Laboratory	Resistance Maps	
La Caima	33.39%	33.39%	0%
Martinez	34.54%	34.54%	0%

In Table-1 we observe that the results of CBR found by Grapher and in the laboratory with optimum moisture content are equal. This situation demonstrates that the decisions made in modeling with Grapher modeler to estimate the performance of the granular sub-bases SBG-38 in both quarries were adequate. In figures 10 and 11 the results of the graphic models with Grapher are presented in "La Caima" quarry and "Martinez" quarry.

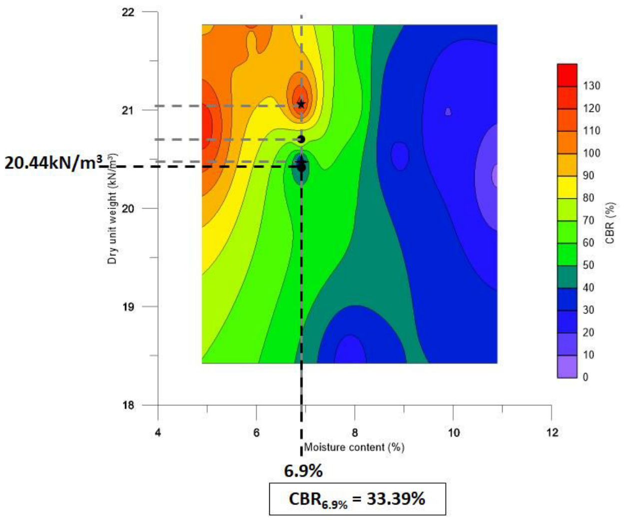

Figure-10. Validation of resistance maps. Sub-base granular SBG 38, "La Caima"quarry.

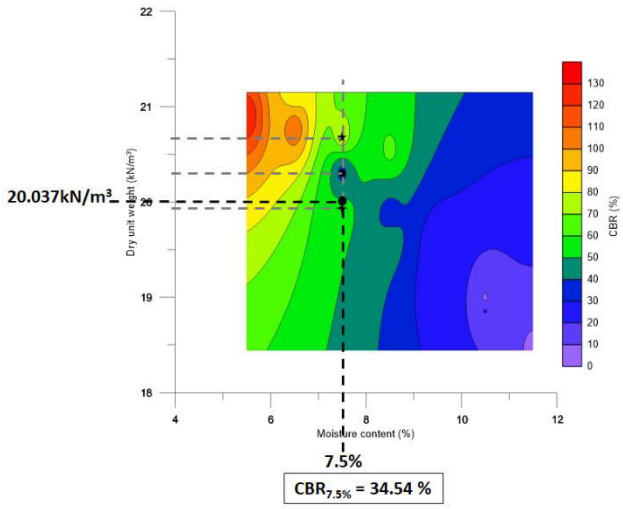

Figure-11. Validation of resistance maps. Sub-base granular SBG 38, "Martinez" quarry.

3.3 Resistance maps

Table-2 shows the results of CBR when optimum moisture content is reduced by -0.5%. The increments of CBR indicated in percentage were 94.67% and 70.82% for "La Caima" quarry and "Martínez" quarry, respectively.

Table-2. Comparison of CBR results for the two quarries. Optimum moisture content against Optimum moisture content -0.5%.

Quarry	CBR		Variation [%]
	Laboratory- Optimum moisture content	Resistance Maps- Optimum moisture content - 0.5%	
La Caima	33.39%	65%	94.67%
Martinez	34.54%	59%	70.82%

Figures 12, 13 and 14 present the results of the resistance maps of "La Caima" quarry. Figures 12 and 13 show the transformation from 2D to 3D. The variables in the horizontal plane are the moisture content and dry unit weight, the variable in elevation is the CBR.

Figure-13 shows the mechanical and physical surface performance of the SBG-38 granular sub-base. Significant increases in resistance were observed for CBR values between 90% and 130% with dry unit weight from 20 to 21.86 kN /m^3 and moisture content from 5% to 6.5%.

Figure-14 expands the study because the saturation variable is added in the resistance maps. This represents a more detailed study of the mechanical and physical behavior of the SBG-38 granular sub-base. In Figure-14 we also observe that the CBR values are accompanied by saturations of 50% and 100% and dry unit weight and moisture content found in Figure-13.

In the resistance maps of "La Caima" quarry we realize that a smaller amount of water can produce higher values of CBR. This situation contradicts the results of optimum moisture weight determined from the modified Proctor test.

The optimum moisture weight obtained from the modified Proctor test for the granular sub-base SBG-38 of "La Caima" quarry is 6.9% and the CBR is 33.39%. This CBR value is less than 65% that is obtained from the resistance maps when the optimum humidity is reduced by 0.5% (6.4%) and saturations from 70 to 80%.

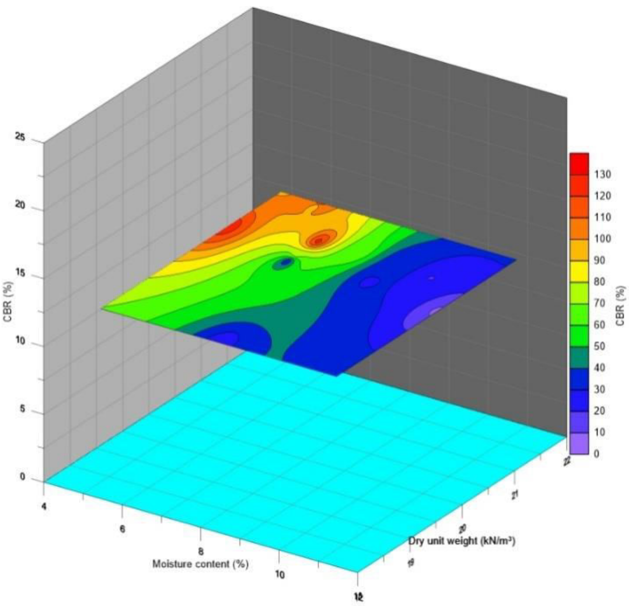

Figure-12. Resistance maps of sub-base granular SBG-38. “La Caima”quarry.

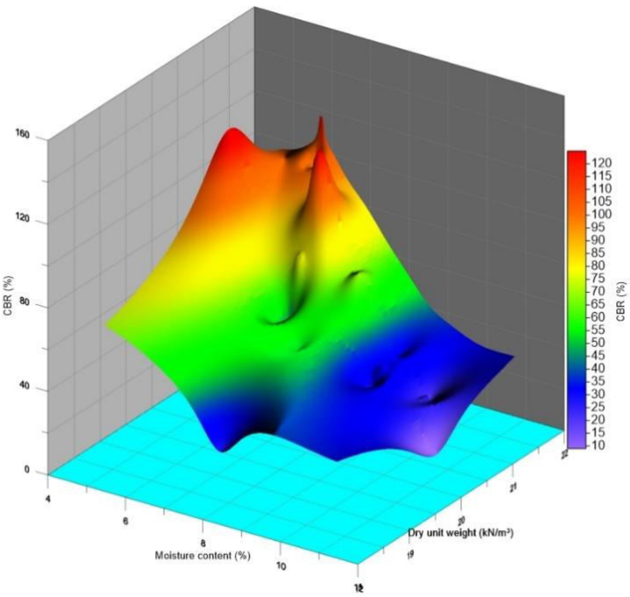

Figure-13. 3D resistance maps of sub-base granular SBG-38. “La Caima”quarry.

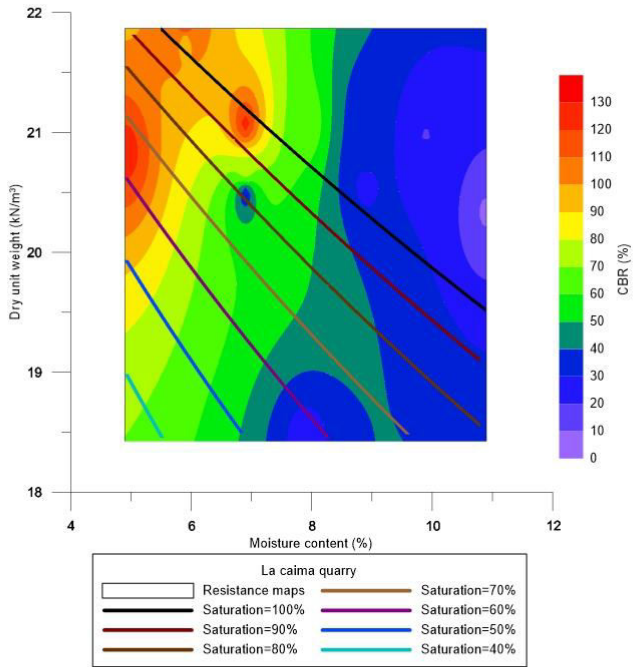

Figure-14. Resistance maps including saturation curves of sub-base granular SBG-38. “La Caima”quarry.

Figures 15, 16 and 17 present the results of the resistance maps of “Martínez” quarry. Figures 15 and 16 show the transformation from 2D to 3D. The variables in the horizontal plane are the moisture content and dry unit weight, the variable in elevation is the CBR.

Figure-16 shows the mechanical and physical surface performance of the SBG-38 granular sub-base. Significant increases in resistance were observed for CBR values between 90% and 130% with dry unit weight from 20.30 to 21.15kN/m^3 and moisture content from 4.7% to 6.7%.

Figure-17 expands the study because the saturation variable is added in the resistance maps. This represents a more detailed study of the mechanical and physical behavior of the SBG-38 granular sub-base. In Figure-17 we also observe that the CBR values are accompanied by saturations of 60% and 100% and dry unit weight and moisture content found in Figure-16.

As in “La Caima” quarry in the resistance maps of "Martínez" quarry we realize that a smaller amount of water can produce higher values of CBR. This situation contradicts the results of optimum moisture weight determined from the modified Proctor test.

The optimum moisture weight obtained from the modified Proctor test for the granular sub-base SBG-38 of "Martínez" quarry is 7.5% and the CBR is 34.54%. This CBR value is less than 59% that is obtained from the resistance maps when the optimum humidity is reduced by 0.5% (7%) and saturations from 70 to 80%.

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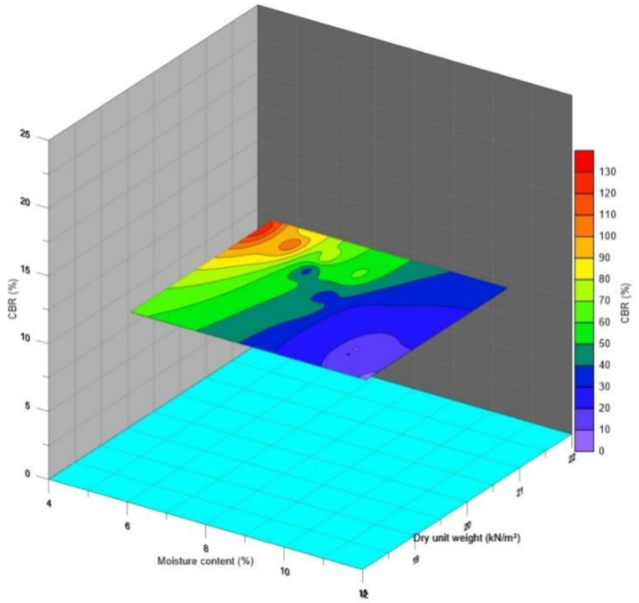

Figure-15. Resistance maps of sub-base granular SBG-38. "Martínez" quarry.

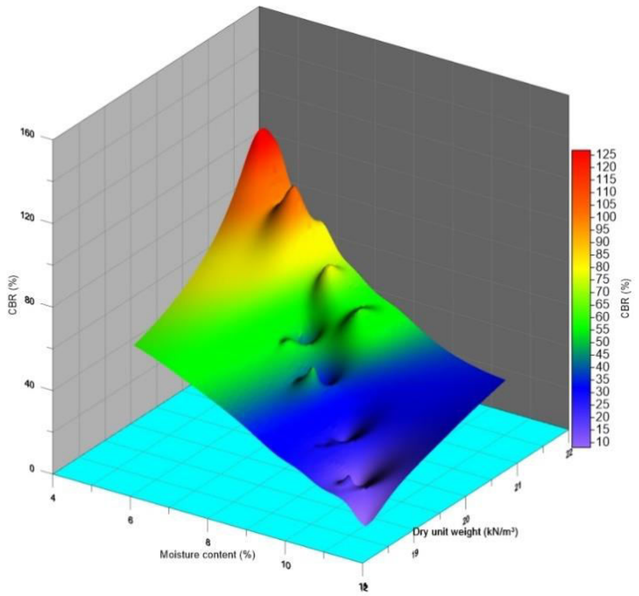

Figure-16. 3D resistance maps of sub-base granular SBG-38. "Martínez" quarry.

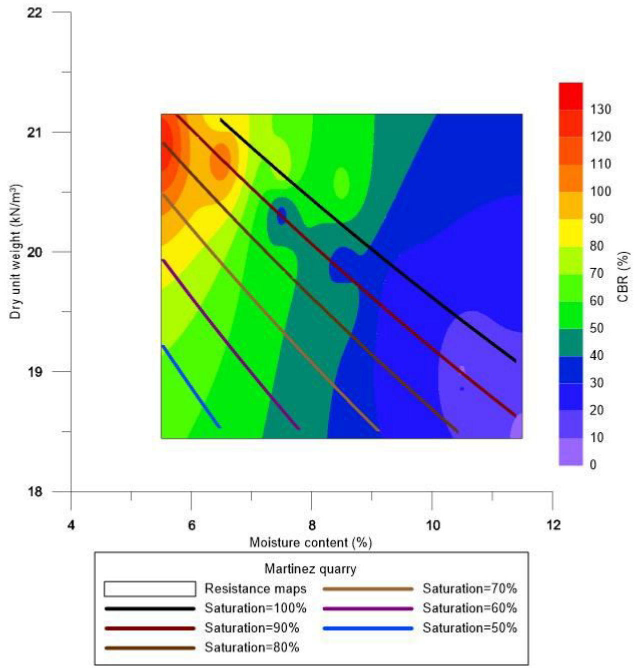

Figure-17. Resistance maps including saturation curves of sub-base granular SBG-38. "Martínez" quarry.

4. CONCLUSIONS

- The performance of the sub-base granular materials of the "La Caima" and "Martínez" quarries located in Ibagué, Colombia, using resistance maps were validated with the traditional data of optimum moisture content, maximum dry unit weight and CBR.
- The maximum value of CBR could be obtained with moisture values lower than the optimum moisture content.
- A moisture value lower than the optimum moisture content (obtained from the Proctor test) produces higher values of CBR.
- The results obtained from the two case studies indicate that the development of resistance maps is the most appropriate methodology to achieve a better compaction control of the granular sub-base materials.
- The resistance maps demonstrate the need to control compaction by performance.
- Variation in values of CBR when optimal moisture is reduced using resistance maps demonstrates the need to evaluate the compaction control protocols of granular materials used to build roads in Ibagué city, Colombia.
- Probably one of the factors reducing the resistance of the granular sub-base of Martínez quarry is the presence of clay material with low plasticity.

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