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Comparative for obtaining the optimum dosage of the soil-cement in clays of high and low plasticity

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Abstract. Dosage is a technique to modify and improve the conditions of the soil-cement that comply with the conditions of the “Instituto Nacional de Vías” standard and in the same way, is economic to be implemented in different types of clay. The clay was classified depending on its plasticity (high plasticity and low plasticity) and the behavior at loads; making laboratory tests of modified proctor, compaction and CBR% for the clays with 4% of soil cement; at the same time, the results of CBR% of soil cement of 4% with natural soils, of 6% of cement and 1 were compared. In this way, was made a proposal of the elaboration of each type of soil-cement with its respective percentage, concluding that the clay of high plasticity can be used for subgrade and the one of low plasticity has a weak bearing capacity.

1. Introduction

Concrete is a material used in construction because it is versatile and reliable, despite the fact that over time its production and the properties of the final product have changed, developing new products, technologies and environmental issues, always in search of less expensive cements [1]. It is used in the development of roads, being inseparable from the influence of the capacity of the land to maintain the continuity of all activities that occur in each product of construction. This is due to channeling the load from the superior structure to the inferior structure, for this reason, it is ideal that the load capacity of certain soils can support the load on them [2].

Road construction is currently required with high flexural strength concrete that need little time to reach the expected strength $f_r' = 45 \text{ kg/cm}^2$, therefore, high strength concrete is required a high-quality concrete [3]. A cement floor with too much softness makes it weak in strength, highly deformable; on the other hand, the morphology, tissue and level of cementation, contribute to the microstructure that further characterizes a sensitive or soft soil condition [4].

The property of a material that allows it to be repeatedly deformed without breaking when it acts by sufficient force to cause deformation and that allows it to retain its shape after the applied force has been removed [5]. Clay is a type of soil that is stabilized due to its wet plastic and cohesive properties, which is necessary to repair those properties and increase bearing capacity [6]. The stabilization process can be carried out by increasing the density of the soil, adding inactive materials to increase cohesion, substances that can cause chemical and physical changes, lower the phreatic layer and replace the poor soil [7].

This article presents a comparison and analysis according to the percentages of cement added to the clay, finding the optimal dosage of the soil-cement based on its stability and cost, contributing to the search for the percentage of soil-cement that can improve the stabilization and durability of clay type soils, since the vast majority of the problems that arise in road structures is due to the low bearing



capacity that the materials have, Colombia is one of the countries in Latin America that has great delays in the presentation of transport infrastructure services, due to infrastructure adaptation, geographical restrictions, insufficient and poor maintenance of road infrastructure, little investment and vulnerability due to geological and climatic reasons [8]; Therefore, this type of research provides the identification of the optimal dosage of soil-cement for the improvement of tertiary roads in the country, from the classification of the types of clay.

2. Methodology

The research project focuses on urban roads is that they are suitable to use the optimal dosage of clays; performing laboratory tests such as the modified Proctor where a wet mixture is used with 4% below the optimum moisture content, prepared in an extension collar of 101.6 mm in diameter in five layers (height 125 mm) that are compacted by 25 blows; the extension collar is removed and weighed with the wet soil (kg). A sample according to INV E-141 [9] is taken for weighing and drying in an oven at $110\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ ($230\text{ }^{\circ}\text{F} \pm 9\text{ }^{\circ}\text{F}$) for a minimum of 12 hours, determining the water content. The California Bearing Ratio% (CBR%) test is carried out with a mass of 6.8 kg with the moisture content determined in a mold to the base plate, a spacer disc inside the mold and a thick filter paper, after its compaction, the mold is dismantled and reassembled inverted, but without spacer disc and with the filter paper in the middle, to determine the mass of the mold with the compacted specimen; this procedure is carried out for clays of high and low plasticity with 4% cement [10]. Subsequently, a comparison was made between the percentages of CBR% for clays of high plasticity in natural soils, soil cement of 4% and soil cement of 1.2% [11]; in the clays of low plasticity the comparison of CBR% was made between the natural soil, soil cement of 4%, of 6% and 1.2% [12]; depending on these results of CBR% the adequate dosage of soil-cement is obtained that fulfills the standard INVIAS E-141 [9] and with the lowest costs of elaboration in the two types of clay: high plasticity and low plasticity.

3. Result and discussion

3.1. Laboratory tests for high plasticity clay with 4% cement

Table 1 shows the maximum density of the modified Proctor of 1950 gr/cm^3 and an optimum humidity of 10.00% in the second test and with mold 1, while Table 2 adjusted to nine types of mold, obtaining 3 ideal densities, considering that the best option is the first one, since it demonstrated a 30.27% of CBR to the resistance to the shear stress of a soil.

Table 1. Proctor modified with 4% cement for high plasticity.

Test	1	2	3
Mold #	1	1	1
Water quantity	90	180	270
Mold weight + wet floor (gr)	5620	5790	5790
Mold weight (gr)	3760	3760	3760
Wet soil weight (gr)	1860	2025	2030
Humidity	7.031	10.007	13.538
Dry soil weight (gr)	1737.81	1840.79	1787.95
Volume (cm^3)	944	944	944
Dry density (gr/cm^3)	1.841	1.950	1.894

- CBR for humidity 10.365% and density $121.999\text{ lb/ft}^3 \rightarrow 30.27\%$
- CBR for humidity 10.375% and density $115.289\text{ lb/ft}^3 \rightarrow 19.21\%$
- CBR for humidity 10.615% and density $109.984\text{ lb/ft}^3 \rightarrow 13.39\%$

Table 2. Compaction in the laboratory at 4% of cement in high plasticity.

Reference	Mold								
	13/56	53/56	4/56	53-49/26	6/26	15/26	5/12	6-10/12	10/12
Mold w+ floor (gr)	11500	14298	13250	12200	13250	13680	13200	13625	12950
Mold w (gr)	6860	9290	8227	7780	8517	9041	9000	9100	8523
Number of strokes	55	55	55	26	26	26	12	12	12
Water quantity	174	348	522	174	348	522	174	348	522
Wet ground weight (gr)	4640	5008	5023	4420	4733	4639	4200	4525	4427
Humidity %	7.037	10.365	13.778	7.170	10.375	13.820	7.125	10.615	134.762
Dry soil weight (gr)	4334.96	4537.66	4414.73	4124.28	4288.10	4075.73	3920.65	4090.78	3901.26
Dry soil weight (lb)	9.557	10.004	9.733	9.093	9.454	8.985	8.644	9.019	86.008
Mold volume (ft ³)	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082
Dry density (lb/ft ³)	116.549	121.999	118.693	110.884	115.289	109.579	105.410	109.984	104.888
Dry density (gr/cm ³)	1.865	1.952	1.899	1.774	1.845	1.753	1.687	1.760	1.678

3.2. Laboratory tests for low plasticity clay with 4% cement

In Table 3, the optimum humidity found in the 3 samples tested to obtain the maximum density of the modified Proctor is 11.033% with a maximum density of 1927 gr/cm³; and according to Table 4, to obtain the ideal CBR according to humidity and density, conditions were found that can be considered to have the best resistance to the shear stress of a soil compared to the nine samples:

Table 3. Proctor modified to 4% cement for low plasticity.

Test	1	2	3
Mold #	1	1	1
Water quantity	90	210	330
Mold weight + wet floor (gr)	5542	578	5734
Mold weight (gr)	3760	3760	3760
Wet soil weight (gr)	1782	2020	1974
Humidity	7.150	11.033	15.326
Dry soil weight (gr)	1663.09	1819.27	1711.68
Volume (cm ³)	944	944	944
Dry density (gr/cm ³)	1.762	1.927	1.813

Table 4. Compaction in the laboratory at 4% cement in low plasticity.

Reference	2	13	10	49	4	15	5	9	23
Mold w+ floor (gr)	13.00	11.82	13.45	11.92	12.87	13.67	12.82	12.82	13.52
Mold w (gr)	8.58	6.85	8.54	7.78	8.25	9.02	8.95	8.53	9.20
Number of strokes	55	55	55	26	26	26	12	12	12
Water quantity	174	290	580	174		580	174	290	580
Wet ground weight (gr)	4.42	4.97	4.91	4.14	4.62	4.65	3.87	4.29	4.32
Humidity %	7.146	11.053	15.453	7.425	11.341	15.544	7.692	11.513	15.517
Dry soil weight (gr)	4125.21	4475.18	4252.83	3853.86	4149.41	4024.45	3593.58	3847.08	3739.71
Dry soil weight (lb)	9.095	9.866	9.376	8.496	9.148	8.872	7.923	8.481	8.245
Mold volume (ft ³)	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082
Dry density (lb/ft ³)	110.909	120.319	114.341	103.614	111.560	108.200	96.616	103.432	100.545
Dry density (gr/cm ³)	1.775	1.925	1.829	1.658	1.785	1.731	1.546	1.655	1.609

- CBR for humidity 11.053 % and density 120.319 lb/ft³ → 9.17%
- CBR for humidity 11.340 % and density 111.560 lb/ft³ → 6.11%
- CBR for humidity 11.510 % and density 103.432 lb/ft³ → 4.54%

3.3. Comparison of the different tests carried out in the laboratory on high and low plasticity clays with 4% cement

Tables 5 and 6 show the results of liquid limit (LL), plastic limit (PL), plasticity index (PI), CBR% and density; it can be observed that clays tend to behave differently when mixing soil-cement, since high plasticity clays obtain a 396% increase compared to low plasticity clays, which show a 279% increase. In addition, the difference between the percentage increase is 117%, while the limits in any of the clays studied do not have an increase when mixing with cement, such as plasticity values. The results of maximum density for the clays of low plasticity with the mixture of soil-cement in 4%, presented a small increase, in turn, present the highest CBR% between the two, while the clay of high plasticity with mixture of soil-cement of 4% decreased, instead they have a greater CBR in comparison of the other element of study.

Table 5. Comparison of tests in clays of high plasticity.

High plasticity clays (HC)					
Tests	LL	PL	PI	CBR (%)	Density (lb/Ft ³)
4% Cement	58.40	21.49	36.91	30.27	121.99
Natural	57.20	22.96	34.24	6.10	122.45

Table 6. Comparison of tests on low plasticity clays.

Low plasticity clays (LC)					
Tests	LL	PL	PI	CBR (%)	Density (lb/Ft ³)
4% Cement	27.70	16.04	11.66	9.17	120.31
Natural	27.00	15.97	11.03	2.41	117.38

3.4. Mix design for high plasticity clays

Table 7 shows the results of the mix design for high plasticity clays [8,10]; the bearing capacity in which 1.2% was used with respect to the 4% of cement was not found to be a considerable increase, therefore, it is more resistant to cutting a soil under humid conditions and with controlled density for high plasticity clays.

Table 7. Mixture design for high plasticity clays.

Investigation	#1		#2	
Material	Natural soil	Cement soil 4%	Natural soil	Cement soil 1.2%
CBR %	6.10	30.27	8.17	28.03

A 4% increase in soil-cement clay is shown compared to natural soil 0% cement with 496%, while for research #2, the natural soil of 0% is 8.17 and there is a 343% increase, represented in Figure 1.

The mix design of the high plasticity clay is given according to the requirement for which you want to classify, since, these clays can be classified with 4% cement in a use as a sub-base which can be beneficial for urban roads, according to Table 8.

Table 8. Soil qualitative classification [13].

CBR	Soil qualitative classification	Application
2-5	Very poor	Sub-flush
5-8	Poor	Sub-flush
8-20	Average - good	Sub-flush
20-30	Excellent	Sub-flush
30-60	Good	Sub-base
60-80	Good	Base
80-100	Excellent	Base

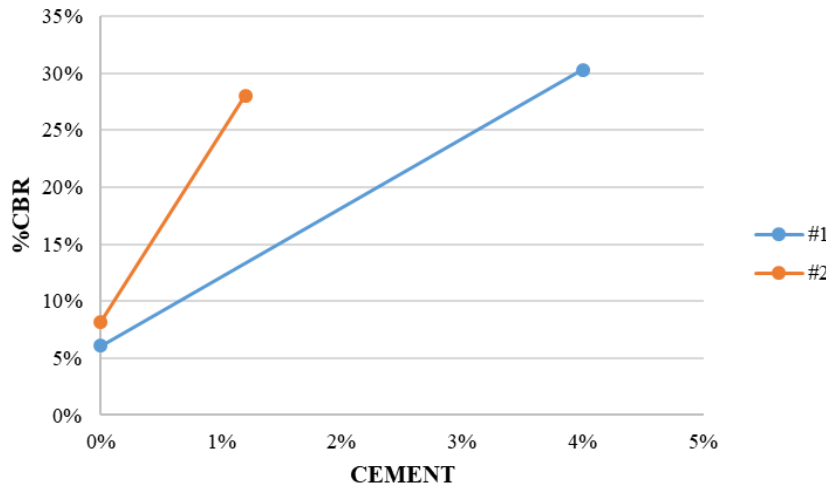


Figure 1. CBR values, high plasticity.

3.5. Mix design for low plasticity clays

According to Table 9, the results for the mix design of low plasticity clay [8,10,11] are observed, which are in the requirement for which we want to classify, since, the observed behavior of low plasticity clays with cement is not as gratifying as with high plasticity clays, but with 4% cement its qualitative classification is good for subgrade improvements.

Table 9. Mixture design for low plasticity clays.

Investigation	#1		#3		
Material	Natural soil	Soil cement 4%	Natural soil	Soil cement 1.2%	Soil cement 6%
CBR %	2.41	9.17	3.50	3.80	18.50

In the two investigations an increase of CBR% was found, for the first case, the increase in soil cement of 4% was of 379%; in the second case, for soil cement 1.2% of 108% and being the highest of all the 6% with 528%, as represented in Figure 2.

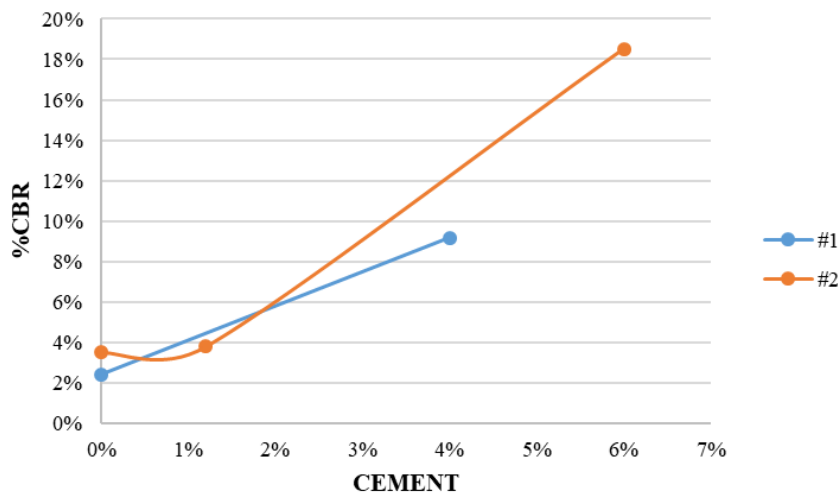


Figure 2. CBR values, low plasticity.

3.6. Comparative budget

Performing the analysis of the comparison of the costs between each of the investigations, it was observed that clays of high plasticity at the time of their stabilization are more economic than clays of low plasticity, since, as the clays of high plasticity reach big CBR with low percentages of cement, as observed in Table 10.

Table 10. Comparative budget.

Investigations	#1		#2		#3
Type of clay	High plasticity clay	Low plasticity clay	High plasticity clay	Low plasticity clay	
Material	Soil cement 4%	Soil cement 4%	Soil cement 1.2%	Soil cement 1.2%	Soil cement 6%
Quantity of cement per m ³ (gr)	78000	74800	22320	19680	98400
Quantity of cement per m ³ (kg)	78.00	74.80	22.32	19.68	98.40
Cost bale cement per 50 kg (8.36)	\$ 12.35	\$ 12.51	\$ 3.53	\$ 3.12	\$ 15.60

4. Conclusions

With clay of high plasticity in its natural state and 4% cement, when compared with a percentage of 1.2% cement, it was demonstrated that it is not necessary to improve it with cement for its use as a subgrade, but in the case that it has been used as a grade for tertiary roads, 1.2% cement guarantees its behavior, due to the fact that it can reach a CBR of 28% to 30%. In the case of clay of low plasticity in its natural state and with 4% cement, it was compared with clays that have a percentage of cement between 1.2% and 6%, having similar characteristics but underlining that to be used as a subgrade, it is necessary to improve it with cement, since its bearing capacity is between 2% and 4%, giving it a very bad qualitative classification, but when making an improvement with 4% cement its classification would increase these indicators and it would be apt.

Also, studying the comparison of costs between each one of the investigations it is analyzed that the amount of cement for the clays of high plasticity is greater than for the clays of low plasticity using the same dosage, this is due to the fact that the clays of high plasticity obtained a greater density with respect to the clays of low plasticity. In the analysis of the comparison of the costs between each one of the investigations it was observed that the clays of high plasticity at the time of their stabilization are more economic than the clays of low plasticity, since, the clays of high plasticity reach big CBR with low percentages of cement.

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