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Stabilised Base with Soil-Cement for Unpaved Roads "Ruta Del Cacao" (Guayas, Ecuador)

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Abstract - Soil-cement has been a constructive method that has contributed to the stabilization of roads, where the soil is mixed with cement, providing an improvement in the physical and mechanical characteristics of the roads, and can be applied to any type of soil. It is necessary to consider that due to the experience of projects executed using this method, it has been possible to work more efficiently during their evolution, both in equipment and in construction procedures. The soil-cement structure supports a greater load, since the stress is distributed over a larger area, thus avoiding greater vertical deformation in the subgrade, which provides a longer useful life. The cement dosage required for the stabilization of this study depends on the material in situ, for which the soil is classified using the AASHTO methodology, it is depending on the soil characteristic, the required cement range is obtained. This study seeks to obtain the least amount of cement necessary to carry out an adequate design considering the traffic, environmental conditions and price. To achieve cement optimization, tests are carried out with a lower dosage and a dosage within the range stipulated by the PCA Design Methodology for soil-cement mixtures (ACI, 1997). After comparing the results of the tests, design and budget, a dosage of 6% of cement by required weight is chosen, which yields a resistance to simple compression strength greater than 24.5 kg / cm2, a road structure made up of the subgrade, the improvement material found on site of 15 cm and the soil stabilized with cement of 25 cm. Due to the fact that this project is carried out with the material in situ, it is friendly to the environment since it avoids the exploitation and transport of materials from other sources.
***Keywords*:** Soil-cement, subgrade, dosage, stabilization

1. Introduction

The objective of this paper is known how to improve the physical and mechanical characteristics of the material of an IV road, using different types of cement dosages. The soil is the oldest construction material used by the first engineers, simple structures were made up to large cities, which regardless of the hundreds of years can still be appreciated. The application of cement soil began to be studied in the decade from 1910 to 1920, where in England from the year 1917, Eng. H.E. Brooke Bradley developed a mixture of cement with clay soils, specifically for road construction in Salisbury Plain - Wiltshire, England.

Guayas is affected by the rainy season, these roads present a real inconvenience, the erosion of these makes vehicular traffic difficult and they need constant maintenance, therefore, we seek to use a methodology that guarantee the useful life of the road, without the need to place a flexible or rigid pavement tread layer, as well as an effective, environmentally friendly and sustainable design, especially in the aforementioned period, where these roads are highly visible affected by the formation of bumps.

2. Location and Information

The present study is located in the southwestern part of the country, it has a length of 3.48 km. This road corresponds to an IV order due to its low TPDA, in the first kilometre and a half of the road, there is a stone material of Ballast shale, while in the remaining kilometres there is a stone material of Pebbled.

The "Ruta del cacao" is affected by erosion caused by precipitation during rainy season, because it is a fourth-order road, so it does not have great waterproofing. To develop this project, it is very important to carry out inspections and pits, in order to know the type of material that is in the "Ruta del Cacao", in which samples of the undisturbed natural earth and other stone materials present in said route [1, 2]. The samples obtained on site will be subjected to laboratory tests to obtain the classification of the material, and then present a proposal for “Soil-cement stabilization”.

3. Advantage of Soil-Cement Constructions

The main advantages offered by soil cement stabilization are as:

- Greater durability due to the fact that pavement structures are obtained with a higher bearing capacity and resistant to atmospheric agents than other pavement materials of similar or higher cost.
- Stabilized aggregate bases reduce the risk of road erosion.
- Reduction in the thickness of the base in the pavements and reduction of manufacturing costs.
- Lower environmental impact, since it uses the road's own soil as long as they comply with the technical specifications.
- Less in costs of transportation of material.
- Savings in investment in secondary roads and local roads.
- Minimum consumption of resources, considerably reducing the carbon footprint of these construction processes.

4. Characteristics of Stone Materials

Generally, all soils can be stabilized with cement, but the amount of cement necessary to achieve the required physical properties depends mainly on the characteristics of the soil to be used, in order to these proceeds to a soil analysis as follow [3]:

1. Take significant soil samples.
2. Determine the physical and mechanical characteristics of the soil, through laboratory tests.
3. Choose the correct dosage of cement and carry out the soil-cement tests.
4. Verify that the mixture achieves the expected simple compressive strength with the lowest possible dosage of cement.
5. Obtain the resilience modules of the layers that make up the road structure from the results of laboratory tests.
6. Use the rational method and together with the Alize program to design the road structure.

4.1 AASHTO classification (ASSHTO M 145)

It is frequently used for the classification of road layers. Groups A-1, A-2 and A-3 soils are granular soil materials, the 35% or less of the particles pass through the 200 sieve [4]. For groups A-4, A-5 soils, A-6 and A-7 are fine soil materials where more than 35% pass through sieve number 200. For the evaluation of the quality of a soil as a material for the subgrade of roads, a number called group index is also incorporated (IG) Eq. (1):

$$IG = (F-35)\ [0.2 + 0.005\ (LL-40)] + 0.01\ (F\ 15)\ (IP-10) \qquad (1)$$

the group indices of granular soils are generally between 0 and 4; those corresponding to silty soils between 8 and 12 and those of clay soils between 11 and 20 or more. In this study, it was found that the shale ballast material has a throughput of 20.62% in the number 4 sieve, 6.20% in the sieve number 40 and 0.15% on sieve number 200, a liquid limit of 22.86% and a plastic index of 8.19%. Therefore, this granular material is an A-2-4. On the other hand, the rolled edge has a through-pass of 27.97% on sieve number 4, 13.09% on sieve number 40 and 6.80% on sieve number 200, a liquid limit of 22.93% and a plastic index of 7.21%. Therefore, this granular material is an A-2-4. It is also necessary to take into account the annual average daily traffic (TPDA), which is the volume of traffic during a period of time divided by the number of days in the period (365 days) [12]. The design period, which is the time in years, where the road will work without any problem supporting the loads exerted by the accumulation of vehicular traffic [5, 6]. Once this period has passed, the road will need maintenance to keep it in optimal condition. The equivalence factor, which is the factor load equivalency, you can evaluate the damage that the different simple axes generate in the pavement.

4.2 Laboratory tests for classification of stone materials

- Granulometry (ASTM D433-63)
- Atterberg limits (ASTM D4318-10)
- CBR (ASTM D1883 - 16)
- Modified proctor (ASTM D1557)
- Los Angeles abrasion (ASTM C -131)

Table 1 shows the results of the laboratory tests carried out in the ESPOL geotechnical laboratory.

Table 1 Soil properties

	W [%]	Max density [kg/m3]	CBR [%]	WL	WP	IP	Abrasion test [%]
Lastre Lutita	7.8	2050	41.9	23	12	8	22.54
Stone River	8.8	2024	48.9	23	17	6	21.84
Subgrade	12.4	1565	5.9	35	25	10	-

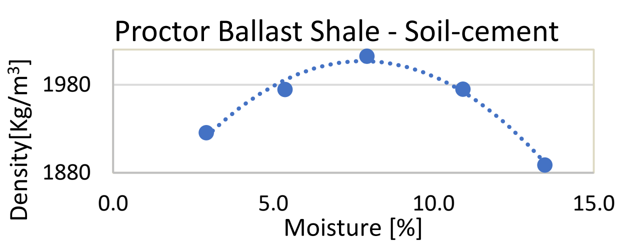
5. Road Structure Design

After the Ballast Shale and Pebbled soils were classified, the soil and cement were mixed based on Table 2 where it gives us the Typical Range of the weight of cement required per "%".

The classification of both materials according to the AASHTO methodology is an A-2-4, the typical range of cement required by weight is between 5 to 9% of the weight of the sample [7 -10].

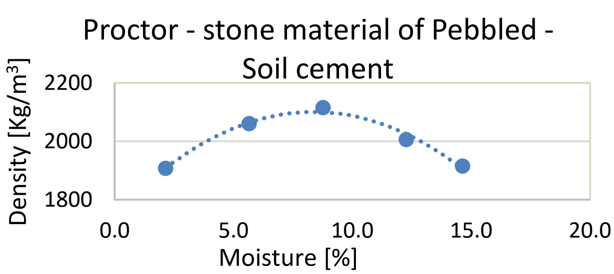
5.1 Modified proctor test (soil -cement)

Two different dosages were used for both materials, these samples were tested by means of the modified Proctor test to know the optimal humidity that is needed to compact the cement-based specimens.



W (%) optimum	Density max [kg/m^3]
8	2010

Figure 1: Graphic Proctor Ballast Shale - Soil Cement



W (%) optimum	Density max [kg/m^3]
8.8	2115

Figure 2: Graphic Pebbled - Soil Cement

Figure 3: Soil stabilized with cement in Isabela Island Galápagos (Holcim, 2020)

5.2 Simple compression strength

For the preparation of the specimens, the ASTM C1435 / C1435M - 08 standard was used, with dimensions 300x150mm following the steps shown below.

- Clean the mould or cylinder.
- Tighten the nuts.
- Grease the walls of the specimens

5.3 Steps for test preparation

- Sift the sample through the 1 ½” sieve.
- Weigh 26 Kg of the sample for the preparation of the specimens.
- Weigh the correct amount of cement needed for the test. Place the sample and the cement in the mixer.
- Put the water little by little through the holes of the mixer, verifying the correct mixing until reaching the optimum humidity obtained by means of the modified Proctor test.
- Check the mixing until a homogeneous sample is obtained.
- Place the sample in the cylinder to be compacted by means of the Hammer Vibrating hammer, about 20 seconds.
- Place the sample in 5 layers, each layer is rodded to obtain a correct compaction.
- Strip the form the next day, wetting and sealing with plastic material to avoid moisture loss.
- Specimen breakage at an age of 7 days.

6. Results

As a minimum simple compression strength parameter, the MOP - 001- F 2002 (República del Ecuador Ministerio de Obras Públicas y Comunicaciones, 2002) 404-6 was used as a reference in which it indicates that the minimum resistance of compression tests should be 18 kg / m^2 for soil-cement and 24.45 kg / cm^2 for gravel-cement structure. The results of SCS shown in Table 2. The traffic study, a count of light vehicles, buses and trucks that travel through the "Ruta del Cacao" was carried out. An ESAL of 277000 was obtained and show in Table 3.

Table 2: Results of Simple Compression Strength

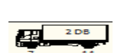
VEHICLE TYPE	ROAD USER CLASSIFICATION	No. AXIE	CLASSIFICATION MTOP	PICTURE	TPD	EQUIVALENT SINGLE AXIE LOAD	ANNUAL GROWTH RATE	GROWTH FACTOR	DESIGN ACCUMULATED TRAFFIC	ESAL ACCUMULATED IN DESIGN
LIGHT VEHICLES	Vehicles	2 AXIE			30	0.0001	1.5	4.09	22397.70	2.24
	Van	2 AXIE			35	0.0001	1.5	4.09	26130.65	2.61
BUS	Bus 2 axie	2 AXIE	BUS 2 EJES		10	1.08	1	4.06	7410.23	8003.05
TRUCKS	Truck 2 axie	2 AXIE	2DB		97	3.73	1.2	4.07	72094.81	268913.63
					172				128033.38	**2.77E+05**

Table 3. ESAL

Cement [%]	Stone material	Elaboration date	Final date	Age (Days)	Weight (Kg)	Density (kg/m3)	Diametre (mm)	Strength (KN)	Compressive strength (MPA)	Average Compressive strength (kg/cm2)
4	Ballast shale	25/11/2020	2/12/2020	7	11.046 10.922	2082.47 2057.45	150.04 150.1	43.85 35.71	2.49 2.02	22.53
6	Ballast shale	17/11/2020	24/11/2020	7	11.097 10.987	2105.54 2078.54	149.56 149.78	49.73 50.19	2.81 2.8	28.09

7. Design Of The Thickness

Using the ALIZE Software, deformations and stresses are verified by calculating the ESAL. These were the alternatives evaluated:

- Using a 4% cement dosage, a thickness of 35cm and a track width of 6.06m.

Table 3: Results of Simple Compression Strength 4%

Acting stress	Allowable stress
0.335 flex traction stress [MPa]	0.467 flex traction stress [MPa]
267.4 vertical stress [millionths	1221 vertical stress [millionths]

- Using a 6% cement dosage, a thickness of 25 cm and a track width of 6.06 m.

Table 4: Results of Simple Compression Strength 6%

Acting stress	Allowable stress
0.536 flex traction stress [MPa]	0.728 flex traction stress [MPa]
368.4 vertical stress [millionths]	1221 vertical stress [millionths]

8. Quantity of Cement Necessary for the Construction Process of the Road

To evaluate the alternative using a 4% cement it was required to obtain the kg / m^3 of cement necessary for the construction process for this alternative, first, the highest optimal volumetric weight is taken from the Proctor-improved compaction tests for the different types of stone material existing on the road (2049.83kg / m^3) to multiply it by the volume to be stabilized. V = 3480 * 6.06 * 0.35 = 7381.08 m^3 to obtain the weight of the material to stabilize.

$$W = \gamma * V$$

$$W = 2050 kg/m^3 * 7381.08 m^3$$

$$W = 15131214\ kg$$

Second, the resistance between the two different materials on the road is increased by a safety coefficient of 30% and projecting this increase in simple compression strength graph (Figure 2), the final cement dosage percentage is obtained and show in the Table 5.

To evaluate the alternative using a 6% cement it was required to obtain the kg / m^3 of cement necessary for the construction process for this alternative, first, the highest optimal volumetric weight is taken from the Proctor-improved compaction tests for the different types of stone material existing on the road (2049.83kg / m^3) to multiply it by the volume to be stabilized V=3480*6.06*0.25 =5272.2m^3 to obtain the weight of the material to stabilize Eq. (2).

$$W = \gamma * V \qquad (2)$$

$$W = 2050kg/m^3 * 5272.2m^3$$

$$W = 10808010\ kg$$

Second, the resistance between the two different materials on the road is increased by a safety coefficient of 30% and projecting this increase in simple compression strength graph (Figure 3), the final cement dosage percentage is obtained and show in the Table 6.

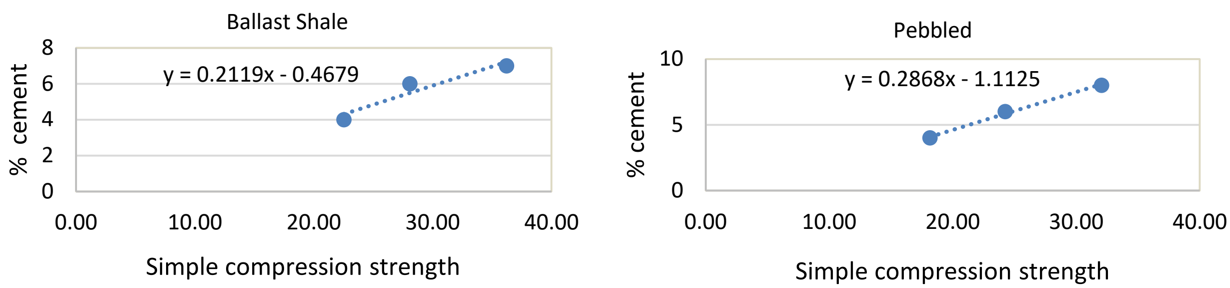


Figure 4 (a) Simple Compression Strength vs % Cement; Ballast Shale; (b) Simple Compression Strength vs % Cement; Pebbled

Table 5: Cement for the construction to 4% Cement

4% Cement Ballast Shale		
Simple compression strength	22.53	kg/cm^2
Safety Coefficient 30%	29.289	kg/cm^2
Cement necessary for the construction Process	**5.74**	**%**
Pebbled		
Simple compression strength	18.16	kg/cm^2
Safety Coefficient 30%	23.608	kg/cm^2
Cement necessary for the construction Process	5.66	%

Table 6 Cement for the construction to 6% Cement

6 % Cement Ballast Shale		
Simple compression strength	28.09	kg/cm^2
Safety Coefficient 30%	36.517	kg/cm^2
Cement necessary for the construction Process	7.27	%
Pebbled		
Simple compression strength	24.22	kg/cm^2
Safety Coefficient 30%	31.486	kg/cm^2
Cement necessary for the construction Process	**7.92**	**%**

9 Conclusions

The design of a road with a better performance of its physical and mechanical properties was obtained through a 6% dosage of cement with respect to the weight of the material to be stabilized and a road structure of 15 cm material for improvement and 25cm of gravel-soil stabilized with cement.

When comparing the price between the 4% and 6% dosage, it is concluded that the 6% dosage is cheaper and has better mechanical properties such as permeability. The chosen alternative is a stabilized soil with 6% cement by weight of the material to be stabilized.

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