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Study of the physical and mechanical behavior of an asphalt-stabilized subgrade of the Rocafuerte - Tosagua road in the province of Manabí

Estudio del comportamiento físico y mecánico de una sub-rasante estabilizada con asfalto de la vía Rocafuerte – Tosagua de la provincia de Manabí

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Abstract

Within the province of Manabí we have different types of soils, among which clays are predominant, that is why before building any civil work, studies should be carried out where we can know the properties of the soil, in order to achieve its improvement through its stabilization. In this article we study the characteristics of a subgrade in its natural state and stabilize it with asphalt to determine the physical-mechanical behavior of the soil and thus establish differences between them after stabilization. This research has a quantitative experimental methodology that comprises three stages, the first one is the extraction of a sample along the Rocafuerte - Tosagua road, where differential changes were observed in the pavement structure with the presence of cracks of more than 10 centimeters of opening. In the second stage, the soil samples were tested in the soil laboratory under ASTM standards, including: moisture test (ASTM D2216), Atterberg Limits (ASTM D4318), Fine Series Granulometry (ASTM D422), Proctor test (ASTM D 1557-78) and CBR bearing capacity (ASTM D-1883). The tests were carried out both for the natural soil sample and for the sample stabilized with asphalt, in percentages of 3%, 6%, 9%, 12% and 15%, and finally, in the third stage, comparisons were made between the physical and mechanical characteristics of the subgrade in its natural state and that stabilized with asphalt,

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demonstrating that with the addition of asphalt a considerable increase in the maximum dry density and CBR was obtained in the samples.

Key words: Soil characteristics, clays, soil stabilization, bearing capacity, asphalt.

Resumen

Dentro de la provincia de Manabí tenemos diferentes tipos de suelos entre las que predominan son las arcillas, es por eso que antes de construir alguna obra civil se deben realizar estudios en donde podamos saber las propiedades del suelo, con el fin de poder lograr su mejoramiento atreves de estabilización del mismo. En el presente artículo se estudian las características de una subrasante en estado natural y estabilizarla con asfalto para determinar el comportamiento físico – mecánico del suelo y así establecer diferencias entre ellas luego de su estabilización. Esta investigación tiene una metodología experimental cuantitativa que comprende en tres etapas, la primera es la extracción de muestra a lo largo de la vía Rocafuerte – Tosagua, donde se observó cambios diferencial en la estructura de pavimento con presencia de grietas más de 10 centímetros de abertura. En la segunda etapa, la muestra de suelo fueron realizadas en el laboratorio de suelo bajo normas ASTM entre estos tenemos: ensayo de humedad (ASTM D2216), Límites de Atterberg (ASTM D4318), Granulometría de serie fina (ASTM D422), ensayo de Proctor (ASTM D 1557-78) y capacidad Portante CBR (ASTM D-1883). Los ensayos fueron realizados tanto para la muestra de suelo natural como para la muestra estabilizada con asfalto, en porcentaje de 3%, 6%, 9%, 12% y 15% y finalmente en la tercera etapa se obtienen las comparaciones entre las características físicas y mecánicas de la subrasante en estado natural y la estabilizada con asfalto, demostrando que con la adición del asfalto se obtiene aumento considerable en la densidad máxima seca y el CBR en las muestras.

Palabras claves: Características del suelo, Arcillas, estabilización del suelo, capacidad Portante, Asfalto.

Introduction

Roads are an important source that is closely related to the development and sustainability of a town, city, country, etc., due to this it is strictly necessary that the materials used in the manufacture of roads are of high resistance, durability and good quality. A road that is in a state of deterioration can have consequences of considerable gravity for the society, among which we can point out the lack of development of the communities or localities, notable problems of mobilization, traffic accidents, among other problems. (Corradine & Espitia, 2015).

A parameter that must be highly considered is the presence of expansive clays in the soil where the road project in question will be developed. The mechanisms experienced by expansive clays are the result of a variation in the moisture content of the soil that alters the internal stress equilibrium in the soil. Generally, the incidence of the behavior of materials with expansive characteristics is not taken into account even though it is a fundamental cause of damage experienced in road structures. (Chicaiza & Oña , 2018).

The subgrade is the initial layer of a pavement structure made up of soils in their natural state or in certain cases with some improvement process, such as the so-called mechanical stabilization, which is the application of loads to reduce the voids between particles of the soil structure with the purpose of increasing its bearing capacity. The quality of this layer influences the thickness of the pavements, even in the case of third order roads, the wearing course is the same, so it is important that it has a good quality to avoid problems with traffic due to deformations that may occur on the road. The most representative properties that are analyzed in a subgrade include drainage, resistance, ease and preservation of compaction and volumetric stabilization. (Alzate, 2019).

There are several methods to stabilize a soil with the presence of expansive clays, some authors; (Sanchez, 2014) y (López-Lara, 2010) mention physical procedures consisting of soil mixtures and use of geotextiles; mechanical methods such as compaction, vibro flotation and preloading; and chemical methods consist of stabilization with lime, portland cement, asphalt products, chlorides and polymers.

The purpose of this project is to study the physical and mechanical behavior of a subgrade stabilized with asphalt on the Rocafuerte - Tosagua road in the province of Manabí, which presents deformation problems that can be attributed mainly to the swelling of the clays, this being the predominant material in this area.

Types of clays

Clays are commonly constituted by three groups of clay minerals, montmorillonites, kaolinites and illites; being the montmorillonites the cause of the expansion in the clay, while kaolinites and illites are collapsible, due to this to achieve stabilization of clays it is a priority to first reduce the expansion caused by the montmorillonites (Jiménez & Zamora, 2017).

According to the qualification work of (Castro, 2017) titled "Stabilization of clayey soils with rice husk ash for subgrade improvement", the characteristics of the crystalline forms are the most influential factor on the physical properties of clays, then, the main minerals that constitute clays are presented in detail: Kaolinites Stable clay because of possessing an inexpandable structure; formed by indefinite superposition of aluminous and silicic lamellae. The union of the particles is very strong and therefore opposes the entry of water between them, thus avoiding the effects of swelling when saturated. Illite presents some internal friction; formed by indefinite superposition of an aluminous layer between two silicic ones. Its internal constitution is formed by lumps of material that cause a reduction of the area exposed to water, thus limiting its property to expand. Montmorillonites have a similar structure to illites, but the union of their particles is much weaker, resulting unstable in the presence of water; the water molecules enter easily, which causes an increase in the volume of the crystals, thus causing the expansion of the soil.

The expansion capacity of clay is the cause of serious construction problems because it can absorb a large amount of water and retain it, which causes an increase in the volume of the material and also a drastic reduction in volume when the retained water dries up, which leads to a non-uniform increase in volume, generating settlements that can severely damage the structure of the pavement. (Quezada, 2017). In addition, in the province of Manabí in the city of Calceta, an analysis of the clays was also carried out, where cohesive soils such as low plasticity clays of medium to very compact compact compactness and for non-cohesive soils such as sands, silty sands with loose to dense compactness with the presence of recent deposits with liquefaction susceptibility, in addition, the volumetric changes of the soil were also studied, qualifying it as a low expansive soil. (Zambrano-Rendón, V. A., Ortiz-Hernández, E. H., & Alcívar-Moreira, W. S, 2021). Also in the city of Portoviejo, which is 50 km from Calceta, the expansive behavior was analyzed without any stabilization component and the result was high to very high, affecting the surface of the structure with presence of deformations. (Hernández, E. H. O., Moncayo, E. H. O., Sánchez, L. K. M., & de Calderero, R. P, 2017).

The important characteristics of clays lie in their properties, according to (Castro, 2017) classifies them as follows: Plasticity, is the main characteristic of clay type soils, it originates as a consequence of the presence of water itself which forms a kind of envelope around the lamellar particles causing a lubricating effect; this property is closely related to the lamellar morphology and particle size, this property can be measured using the Atterberg limits. The main characteristics of montmorillonites are hydration and dehydration of the interlamellar space, the swelling of the material originates when water enters and the lamellae separate causing electrostatic repulsive forces between the lamellae, thus favoring the swelling process by dispersing some lamellae from others. Thixotropy can be defined as the loss of resistance when kneaded and the recovery of the same in the course of time, this type of thixotropic clays can become liquid at the moment of being kneaded, however, when they are left to rest they recover their cohesion. This phenomenon is present when the water content in the soil is close to its liquid limit.

Currently, problems are being presented in pavement structures due to deformations, where it was necessary to evaluate CBR parameters both in the field and in the laboratory. (Vera, C. A. M., Delgado, J. R. G., Hernández, E. H. O., & Vínces, J. J. G., 2020).. After obtaining the design CBR value, the subgrade category to which the sector or section corresponds will be classified as shown in Table 1.

Table 1. *Subgrade Category.*

Subgrade category	CBR
Inadequate subgrade	CBR < 3% CBR < 3% CBR < 3% CBR < 3% CBR < 3% CBR < 3%
Poor subgrade	3% ≤ CBR < 6%.
Regular subgrade	6% ≤ CBR < 10%
Good subgrade	10% ≤ CBR < 20%.
Very good subgrade	20% ≤ CBR < 30%.
Excellent subgrade	CBR ≥ 30%.

On occasions when the subgrade is not in optimal conditions to form a pavement structure, either because of low strength or some other problem, it is necessary to implement a method of improvement or stabilization of this layer that allows achieving the parameters required in the design. According to the general specifications for the construction of roads and bridges, stabilization is a treatment applied to the pavement layer. (Ministry of Public Works and Communications, 2002).stabilization is a treatment applied to soils through the addition of a binder, be it lime, cement, asphalt or chemical products, in order to improve their mechanical characteristics and thus obtain a soil capable of withstanding the stresses caused by traffic loads and resisting the action of atmospheric agents, while maintaining uniformity. Generally, this type of procedure is used precisely to improve the subgrade and thus reduce the thickness of the layers above it (sub-base and base) or also for the construction of a base layer sufficiently capable of supporting a wearing course immediately above it. (Cuadros, 2017). According to (Demera, M. L. A., Romero, C. M. D., Hernández, E. H. O., & Gutiérrez, D. A. D., 2020). The term "pavement" refers to the fact that at present there is no single terminology to designate the different layers that make up a rigid, flexible and articulated pavement.

According to the different studies of the master's work "Stabilization of Macas Clayey Soils with CBR Values lower than 5% and Liquid Limits higher than 100%, to be used as Subgrade in Roads". (Castillo, 2017) mechanical soil stabilization methods comprise three groups which are: Physical methods, Mechanical methods, Chemical methods. Stabilization carried out using chemical methods is aimed at varying the properties of the soil by adding special chemical substances. The purpose of applying a chemical stabilizer is to give the treated soil properties aimed at improving its behavior during the construction or service period. In certain cases it is preferable to carry out the stabilization process using some asphalt type material. The use of these types of products, including cutback asphalts, asphalt emulsions and asphalt cements, is somewhat restricted to granular or coarse-particle soils. In the case of clayey materials, stabilization can be difficult because of the lumps that are characteristic of these types of soils. (Almeida & Sanchez, 2011)..

Stabilization with the use of asphalt products is subject to two purposes:

- Reduction of water absorption in the material, with the use of a slight amount of asphalt.
- Increase in the strength of a material with the use of a considerable amount of asphalt.

The inclusion of asphalt in the mix increases the shear strength and on the other hand decreases the susceptibility to damage due to the presence of moisture, as a result of the dispersion of the asphalt among the finer particles of the aggregate. When asphalt emulsions are used, they are conveniently dispersed among the finer particles, but not only in them, but also some coarse particles are partially coated. However, when asphalt of the foamed type is used, it does disperse only among the fine particles, producing what are known as "spot welds" between the mastic of the asphalt droplets and the fine particles of the aggregate. (Asphalt Institute, 2001). In addition, modifications are also made with additives in the conventional asphalt, which makes a great contribution to improve all its physical-mechanical properties to extend its useful life once practiced in the road field, since it works in an ideal way to have roads in better conditions and satisfy the needs of road users. (Ortiz Hernández, E. H., & Macías Sánchez, L. K., 2018).

According to the guide "Design guide for asphalt-stabilized materials", granular materials that are stabilized with asphalt differ from other materials in the following ways (Ulloa Calderón & Múnera Miranda, 2020). granular materials that are stabilized with asphalt differ from other materials by the following elements: The behavior is very similar to that of granular materials that are not stabilized, however, a considerable increase in cohesion is notable, with the angle of internal friction remaining practically constant, which is evident with the increase in the mechanical capacity of the material. In addition, greater resistance to damage caused by humidity is also achieved, as well as greater durability and resistance to bending due to the viscoelastic properties of the asphalt.

The properties of the soil that make up the subgrade are the most determining parameters when designing a pavement structure, whether it is rigid, flexible or paved. To determine the physical and mechanical characteristics of the material that makes up the subgrade, it is necessary to take samples along the entire length of the road, taking a minimum depth of 1.5m, to be subsequently taken to the laboratory and carry out the corresponding tests. (Cuadros, 2017)

Materials and methods

The methodology applied is quantitative experimental, where numerical values corresponding to each laboratory test were obtained and with them it was possible to determine the physical and mechanical characteristics of the sample to determine its behavior.

The research work was carried out in three stages: The first was the work done in the field taking soil samples on the Rocafuerte - Tosagua road, three calicatas were made in the most critical places, where the deterioration of the road could be appreciated as illustrated in the (Figure 1). The second stage was the laboratory work, which included tests such as natural moisture, Atterberg limits, granulometry, Proctor and CBR, the latter two were done for both natural soil and soil stabilized with asphalt, in percentages of 3%, 6%, 9%, 12% and 15%. The laboratory tests were performed in accordance with ASTM (American Society for Testing and Materials) standards. The third stage consisted of calculating and interpreting the results of the laboratory tests to determine the physical-mechanical properties of the asphalt-stabilized subgrade.

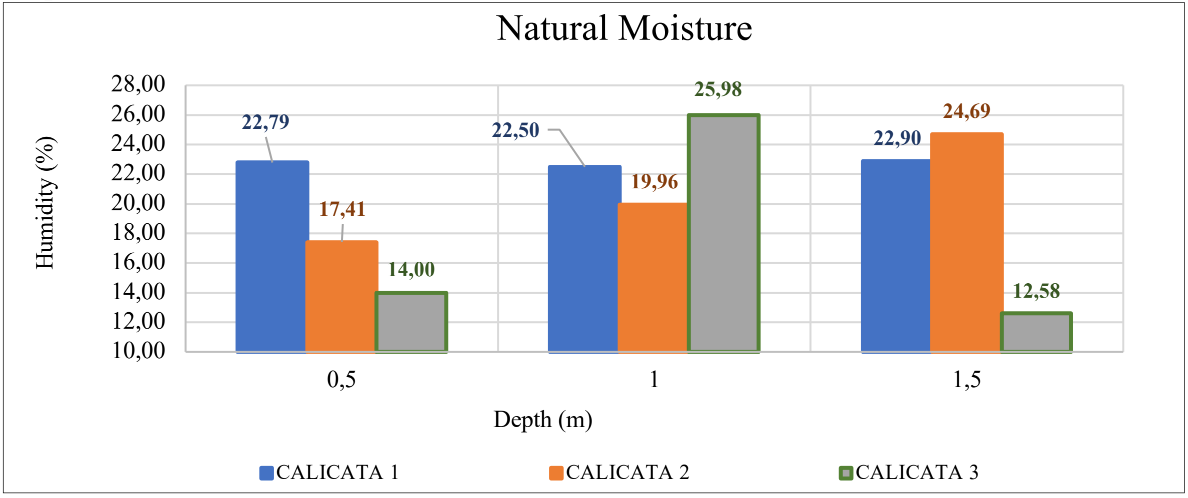
Result

The following are the results of laboratory soil mechanics tests such as: moisture, liquid limit, plastic limit, granulometry, Proctor and CBR for subsequent stabilization with asphalt in percentages of 3%, 6%, 9%, 12% and 15%.

NATURAL MOISTURE TEST

This physical property of the soil is very useful in civil construction and is obtained in a simple way, since the behavior and resistance of soils in construction are governed by the amount of water they contain. The moisture content of a soil is the ratio of the quotient of the weight of the solid particles and the weight of the water it holds, expressed in terms of percentages. (Bedoya Peña, E. R., & Molina Real, A. E., 2010).. The results are illustrated below in bar graphs.

Graph 1 Natural moisture (ASTM D2216)

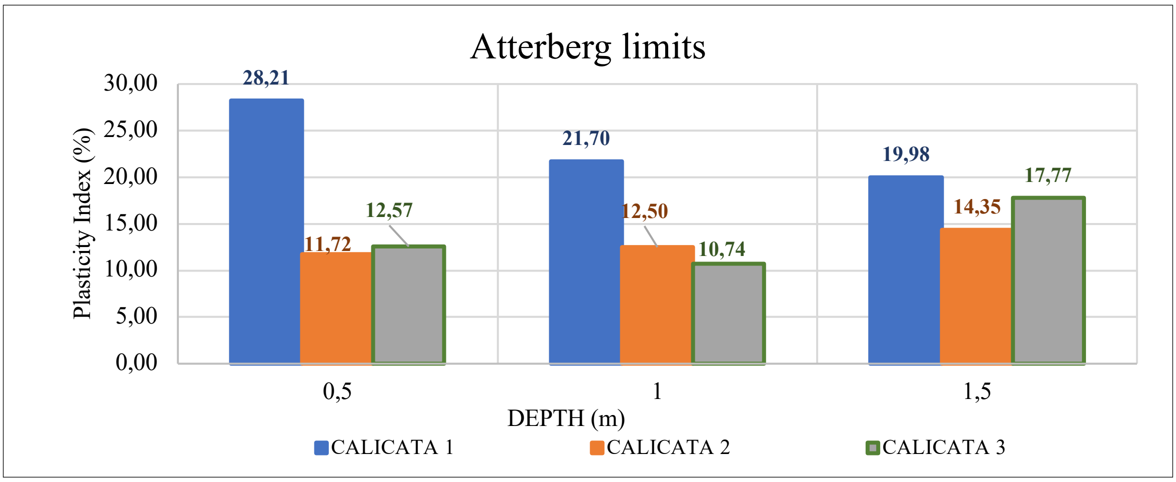


Graph 1 shows the percentages of natural moisture of the soil sample in its natural state, values between 12.58% and 25.98% are observed, which could clearly indicate that it is a soil sample that is moderately moistened and even contains a considerable amount of moisture, since being a clay soil sample, it tends to present an expansive behavior.

ATTEBERG LIMIT TEST

For the determination of the liquid limit, it was obtained following the following standard. (ASTM D 4318-00)For this, a soil sample is taken to which water is added, it is mixed and placed in the Casagrande cup, a groove is made in the center of the sample and the crank is turned to perform the process of lifting the cup and letting it fall from a height of approximately 10 mm with a frequency of one stroke per second. It is continued until the groove of the sample closes in an approximate length of 13 mm, this should be achieved after 25 blows with the cup. (CANDELARIA, J., BERNAL, M., FLORES, O., GUZMAN, A., & HERNANDEZ, S, 2018). The water content, in percent, in the soil specimen when the groove is closed at 25 blows, as indicated above, is defined as the liquid limit. (CANDELARIA, J., BERNAL, M., FLORES, O., GUZMÁN, A., & HERNÁNDEZ, S, 2018). The results are illustrated below by bar graphs.

Graph 2 Plasticity index**.**

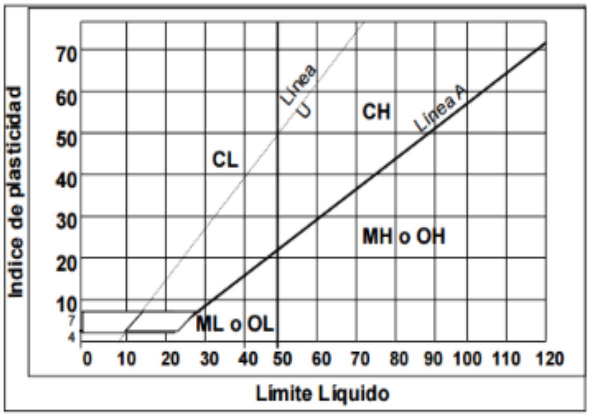


Once the liquid and plastic limits have been calculated, the plasticity index [PI] can be determined, which is defined as. (CANDELARIA, J., BERNAL, M., FLORES, O., GUZMÁN, A., & HERNÁNDEZ, S, 2018).:

IP = wL - wP (1)

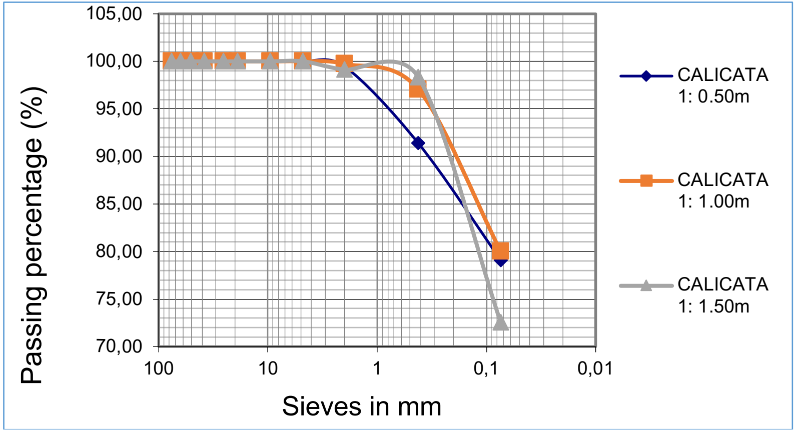
Graph 2 shows the plasticity indexes of each test pit in the state of natural soil, and as can be observed, the values of plasticity index, for each test pit is in a range of values between 10.74% and 28.21%, which could be considered as a medium plasticity for the case of test pit 1, and even low as is the case of test pit 2 and 3; and it is precisely because in the area prevails pavement damage with the presence of settlement in the pavement structure. When referring to WL and IP (Casagrande, 1932)proposed the plasticity chart, in which the liquid limit is plotted on the abscissa axis and the plasticity index on the ordinate axis, as illustrated in Figure 2. (CANDELARIA, J., BERNAL, M., FLORES, O., GUZMÁN, A., & HERNÁNDEZ, S, 2018) Within the plasticity chart we distinguish line A, which is the division between silty (ML and MH) and clayey (CL and CH) soils, while line U is approximately the upper limit of the ratio of the plasticity index with respect to the plastic limit for any soil found by Casagrande. (Das, B. M., 2001)..

Graph 3 Plasticity chart proposed by Arthur Casagrande in 1932**.**



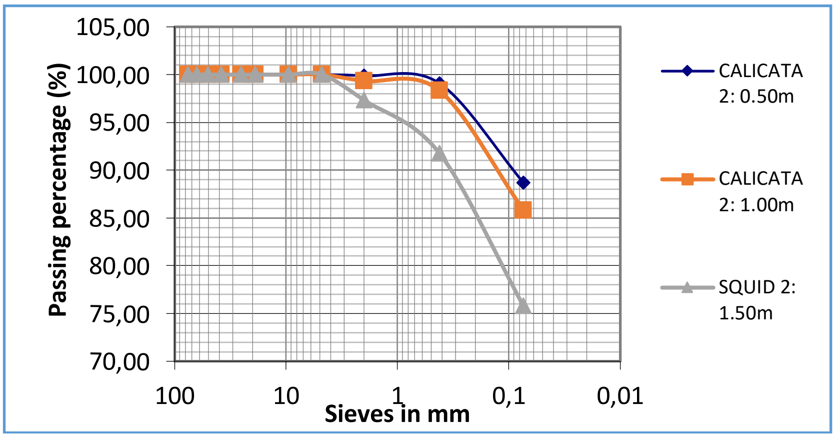
FINE SERIES PARTICLE SIZE TEST

Graph 4 Grain size analysis of test pit 1 ***(***ASTM D422).

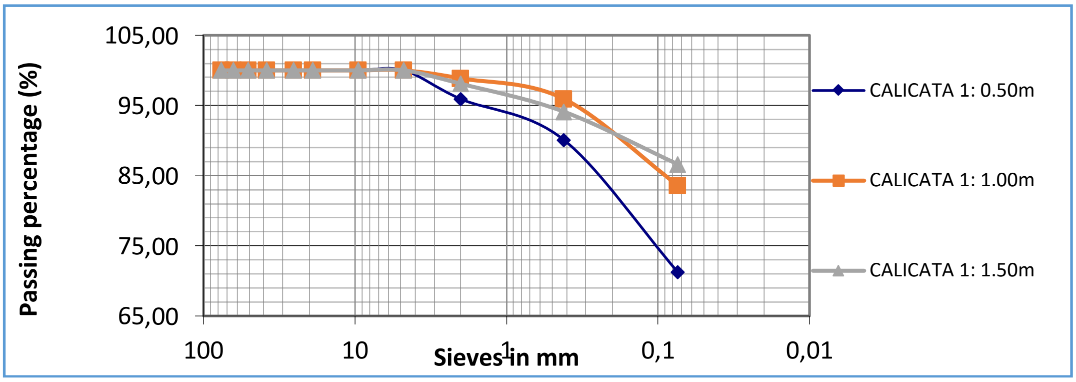


After performing the fine granulometry according to the standard (ASTM D422) of the natural soil, the percentages passing each of the sieves of the fine material are illustrated. Graph 3 shows the results of test pit 1, Graph 4 shows the results of test pit 2 and Graph 5 shows the results of test pit 3.

Granulometric analysis (ASTM D422) of test pit 2.



Graph 5. Fine grain size series (ASTM D422) of test pit 3.

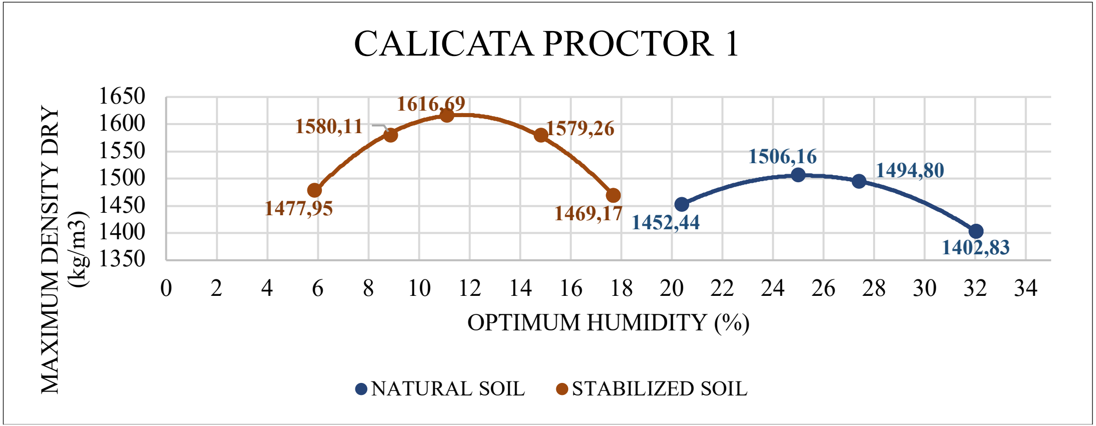


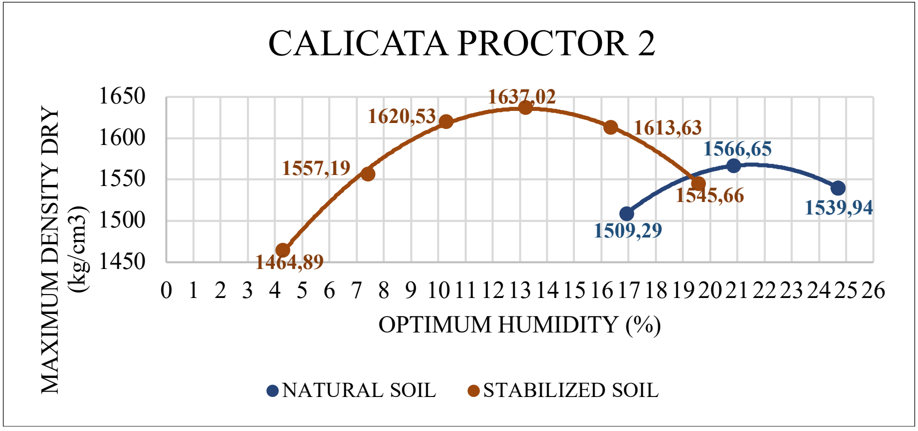
PROCTOR TEST

From this test, the maximum dry density and optimum soil moisture are determined, its importance lies in increasing the resistance and the reduction of voids in the soil, in addition to reducing the deformations that may occur in the soil. That is why in the study methodology the soil density was evaluated in a 500 m section in the Rocafuerte Tosagua El Junco sector, obtaining very similar results between the three test pits as shown in graph 6,7,8 in natural state. In addition, the Proctor tests stabilized with Asphalt have a slight increase in density and a decrease in optimum soil moisture as shown in the Proctor test graphs. In Graph 6 belonging to test pit 1, a maximum dry density of the stabilized soil of 1616 kg/m3 is observed, which is greater than that of the soil in its natural state, which is 1506 kg/m3, while the values of optimum moisture decrease, this is due to the fact that when stabilized with asphalt, this material becomes more compact and does not allow the material to become wet.

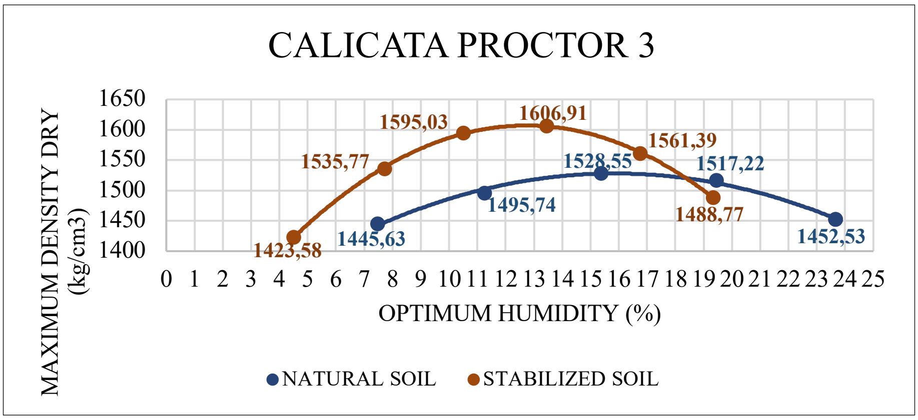
In Graph 7 corresponding to test pit 2, the same behavior is observed, a maximum dry density of the stabilized soil of 1637 kg/m^3 , this is higher than that of the soil in its natural state, which is 1567 kg/m^3 , while the values of optimum humidity decrease, when stabilized with asphalt, this material becomes more compact and does not allow the material to become wet. Graph 8 corresponding to test pit 3 shows the same behavior with asphalt stabilization, a maximum dry density of the stabilized soil of 1607 kg/m^3 , which is greater than that of the soil in its natural state, which is 1529 kg/m^3 , while the values of optimum moisture decrease when stabilized with asphalt, this material becomes more compact and does not allow the material to become wet.

Graph 6 Determination of the Soil Moisture-Density Ratio of test pit 1.





Graph 7. Determination of the Soil Moisture-Density Ratio of test pit 2.

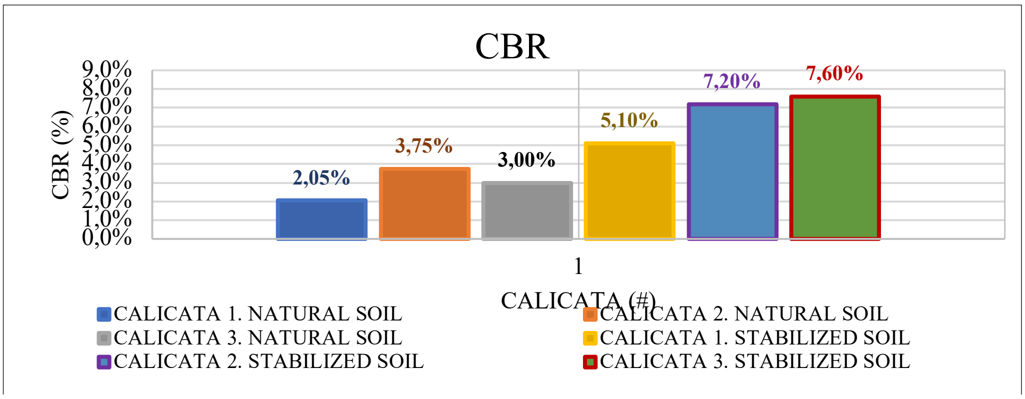


Determination of the Soil Moisture-Density Ratio of test pit 3.

CBR TESTING

As can be seen in Graph 9 of the CBR test, it shows the values for the soil stabilized with asphalt, which provides greater bearing capacity than the natural soil because the stabilized soil reaches a higher maximum dry density, generating a substantial increase in the bearing capacity of the soil. Subsequently qualifying the stabilized subgrade and the natural subgrade from a poor to fair subgrade.

Graph 8 Determination of the bearing capacity (CBR) of the soil.



Conclusions

The ideal percentage of asphalt to stabilize the natural soil is approximately 12%, determined by the Proctor test graph. When comparing the physical and mechanical characteristics of the soil, it is shown that with stabilization using the optimum percentage, its maximum dry density improves, providing a decrease in natural moisture, making the soil more compact and consequently decreasing sponging.

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