SPANISH VERSION

Stabilization of soils through the use of oily sludge
Estabilización de suelos mediante el uso de lodos aceitoso

J. Alarcón [1]*, M. Jiménez *, R. Benítez *

* Universidad Pedagógica y Tecnológica de Colombia – Tunja, COLOMBIA

Fecha de Recepción: 17/07/2019
Fecha de Aceptación: 05/01/2020
PAG 5-20

Abstract

This study of soil stabilization emerges as an alternative in road construction to replace the conventional materials used in the granular layers and/or to improve the subgrade of the pavement structures, while taking advantage of the waste from oil extraction, in an attempt to mitigate the negative impacts on the environment. Soils from the Tunja region were used. A granular material and a clayey subgrade soil were characterized and later mixed with different percentages of oily sludge. Different tests were conducted to determine the properties and analyze the possible behavior in the field with each mixture, among them the CBR and resilient modules. It was determined that with the addition of 6% sludge the best results are obtained referring to improving the properties of resistance and plasticity of the granular material and 4% for the subgrade, with curing periods of 26 days.

Keywords: *Soil stabilization, oily sludge, resilient modulus, subgrade, plasticity*

Resumen

El estudio de estabilización de suelos surge como alternativa en la construcción de vías para reemplazar los materiales convencionales usados en las capas granulares y/o mejorar la subrasante de las estructuras del pavimento, a la vez que se aprovechan los residuos de la extracción del petróleo, buscando mitigar los impactos negativos al medio ambiente. Se emplearon suelos de la región de Tunja; un material granular y un suelo arcilloso de subrasante los cuales fueron caracterizados y posteriormente mezclados con diferentes porcentajes de lodo aceitoso, a cada mezcla se le realizó diferentes ensayos para determinar las propiedades y analizar el posible comportamiento en campo, entre ellos el CBR y módulos resilientes. Se determinó que con la adición del 6% de lodo se consiguen los mejores resultados referentes a mejorar las propiedades de resistencia y plasticidad del material granular y 4% para la subrasante, con periodos de curado de 26 días.

Palabras clave: Estabilización de suelos, lodo aceitoso, módulo resiliente, subrasante, plasticidad

1. Introduction

In a developing country like Colombia, where the main means of transport is by road, the need for road infrastructure is increasing, demanding quality materials, which are often difficult to obtain. In this situation, constructive alternatives arise, including soil stabilization with various stabilizing agents such as asphalt, cement, lime and oils, which improve the engineering properties of soils and make them suitable for use in the different layers of the pavement.

This study analyzed the feasibility of using oily sludge as a stabilizing agent for granular materials and subgrade soils, seeking to improve strength and plasticity properties and take advantage of the waste from oil extraction, to mitigate the negative environmental impacts generated by these substances. For this purpose, the materials to be stabilized and the stabilizing agent were characterized, and mixtures were made by adding different percentages of oily sludge to the materials mentioned above. Strength, plasticity and water stability tests were carried out on each mixture in order to determine the possible behavior of the new material and the optimum percentage of sludge to be used.

[1] **Corresponding author:**
Universidad Pedagógica y Tecnológica de Colombia – Tunja, COLOMBIA
E-mail: joserodrigo.alarcon@uptc.edu.co

2. Methodology

The methodology used consists of four main stages.

2.1 Literature review

At this stage, an exhaustive review of the state of the art was carried out regarding the different methods and soil stabilization agents and the oily sludge from the extraction of the crude oil, and the type of stabilization to be used in the investigation was defined.

2.2 Characterization of materials

Granular material, subgrade and oily sludge were collected with their respective physical, chemical and mechanical characterization.

2.3 Stabilizations

The mixtures of granular material and subgrade with different percentages of oily sludge as a stabilizing agent were made and characterization tests were carried out on each mixture.

2.4 Analysis of results

In this stage, the technical, economic and constructive feasibility analysis of stabilizing soils with oily sludge and its recommended percentage for granular material and subgrade was carried out.

3.Theorical framework

Oil field operations include underground or surface management of formation waters associated with hydrocarbon production. To mitigate the environmental impact caused by these conditions, Ecopetrol has decided to implement in the Acacias station area, an efficient sludge management system, through a combined procedure of oil separation and subsequent dewatering of the obtained sludge, to reduce the volumes transported, and at the same time, to recover part of the oil that is lost with this material (Tecca, 2014) page 3.

3.1 Oily sludge

"It is possible to deduce that similar conflicts and environmental impacts caused by the development of oil activity have been observed in the foothills of the plains" (Vargas and León, 2016), page 19.

Currently, the sludge generated in the Apiay area is treated with Bioremediation, an efficient environmental practice for the type of generated waste since it allows the reduction or removal of potentially hazardous waste present in soils, sludge, surface water, groundwater and wastewater, as well as gases. (Garzón et al., 2017), page 4.

In recent years, the volume of oily sludge has increased significantly. This has led to the implementation of different projects to provide an alternative disposal or use of this material, thus mitigating the environmental impact produced at the storage site. "One of the methods of handling oily sludge is its reuse in road surfacing" (Méndez et al., 2013), page 12.

3.2 Soil stabilization

Soil stabilization tends to improve physical, mechanical and strength properties, with a permanent effect on time. The design of stabilization with additives includes classifying the soil, determining the type and amount of stabilizer and the procedure for carrying out the stabilization. The design method depends on the intended use of the stabilized soil. It is difficult to establish material stabilization patterns, especially when a wide variety of pavement design methods is available. (Bada, 2016), page 16.

It is necessary to understand the stabilization mechanisms of non-traditional products, while clearly defining the objective of stabilization to make the right choice of the product to be used. Many variables can be involved in this process such as the type of soil or existing material, route characteristics, climate and others. (Ulate, 2017), page 4.

The pavement designer must—when no suitable materials are available for the construction of the pavement layers—decide on the most suitable type of stabilization treatment to make them apt for the construction of the layers. The same applies to weak subgrades. The solution is to treat the soil with additives, that is to say, to subject them to certain manipulation or treatment so that their best qualities can be used, thus obtaining a stable soil, capable of resisting the effects of traffic and the most severe climate conditions.

Today in Colombia, it is common to use chemical stabilization of soils, either with lime, cement, polymers or chemical additives (Chavarro and Molina, 2015) page 101. The main advantages of chemical stabilization are that the setting time and the curing time can be controlled. However, chemical stabilization is generally more expensive than other types of stabilization and can cause environmental risks. (Olaya, 2018), page 59.

Each soil stabilization technique has particular specifications and different tests to measure the effectiveness of stabilization by measuring compressive strength, plasticity indexes, etc. (Álvarez, 2015), page 16.

4. Results and Discussion

4.1 Characterization of granular material

The granulometric curve resembles a stabilized base course A-25, as shown in (Figure 1).

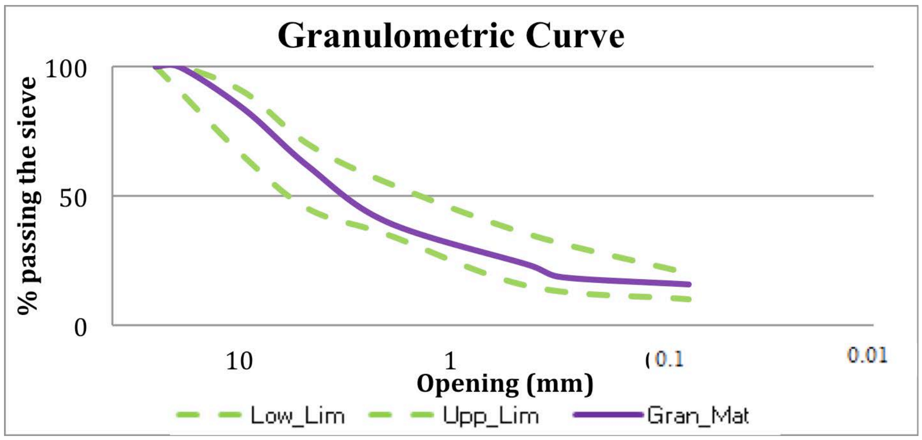

Figure 1. *Granulometric curve of granular material and stabilized base course A-25. Source: provided by the authors*

According to the Unified Soil Classification System (USCS), the material is composed of 15.8% fines, 45.7% sand and 38.5% gravel and is classified as silt, and according to the American Association of State Highway and Transportation Officials (AASHTO) is classified as A-2-4. (Figure 2) shows the compaction curve of the Modified Proctor Test.

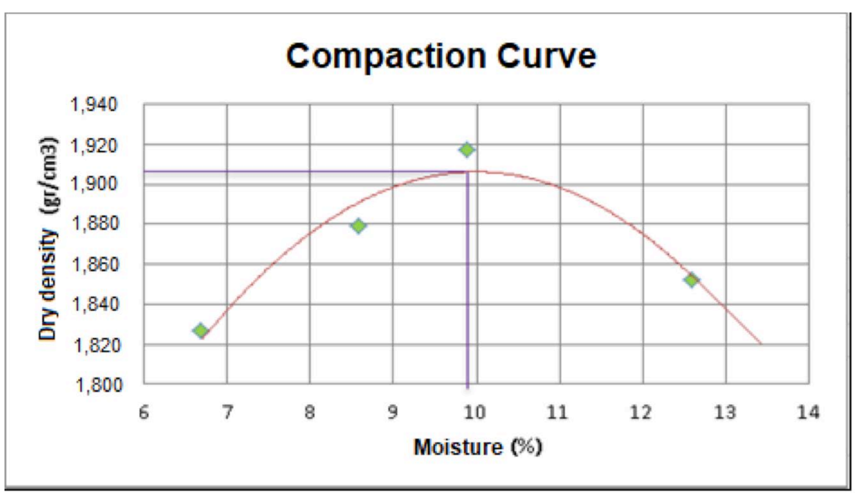

Figure 2. *Compaction curve of the granular material. Source: provided by the authors*

The void ratio is 0.318, i.e. a relatively compact soil with low water absorption and a porosity of 0.24 indicating that the soil has a low capacity to absorb water.

The granular material has an average CBR of 30% to 90% of dry density, with a maximum expansion of 0.44%, which is low and probably does not cause major problems in the pavement structure. Other tests conducted on the granular material are shown in (Table 1).

By analyzing the results of the characterization tests of the granular material as a whole, according to the General Specifications for Road Construction (INVIAS, 2013), the aggregate complies with the A-25 standard, except for the content of clay lumps and friable particles, which is above the maximum percentage allowed. Plasticity is 8%, slightly high given the presence of clayey material determined in the granulometry of the material.

Table 1. *Results of granular material characterization tests*

Test	***INV Standard***	***Requirement***	***Result***	***Compliance***
Abrasion in Los Angeles machine (%)	*218*	*50 maximum*	*40*	*Yes*
Solidity in magnesium sulfate (%)	*220*	*18 maximum*	*4.7*	*Yes*
Liquid limit (%)	*125*	*40 maximum*	*35*	*Yes*
Plastic limit (%)	*125*	*…*	*27*	*…*
Plasticity index (%)	*125-126*	*4 to 9*	*8*	*Yes*
Content of clay lumps and friable particles (%)	*211*	*2 maximum*	*5.4*	*No*
CBR (%): associated with 90% of the maximum dry density and subjected to 4 days of immersion	*148*	*≥ 15*	*30*	*Yes*

Source: provided by the authors

4.2 Characterization of subgrade material

The plasticity index is 17%, slightly high for a subgrade floor. According to the USCS, the material was determined to be sand with the presence of clays or silts or clayey sand (SM). According to AASHTO, it is A-2-6-soil.

Modified Proctor compaction test, type A. It is obtained 1.92 gr/cm3 of maximum dry density and 12% optimum moisture of compaction.

Capillary action test. (Figure 3) shows the progress of the test, in which it can be seen that the greatest increase in slope occurs in the first 80 minutes with 40%, from then onwards the increase is 10% for each of the intervals adopted for the test until reaching an elevation in the whole of the test specimen 6 hours after the beginning of the test.

Capillary absorption test. The addition of chemical products to the subgrade soil is an interesting solution to study, making use of the initial conditions of the land to increase strength, with the respective densification of the structure and the implications this would have on the delay in water absorption by the pavement layers as a whole (Díez et al., 2015) P.2. (Figure 4) shows the weight increase per unit area of the specimen, with the largest increase over a time interval of 1 hour.

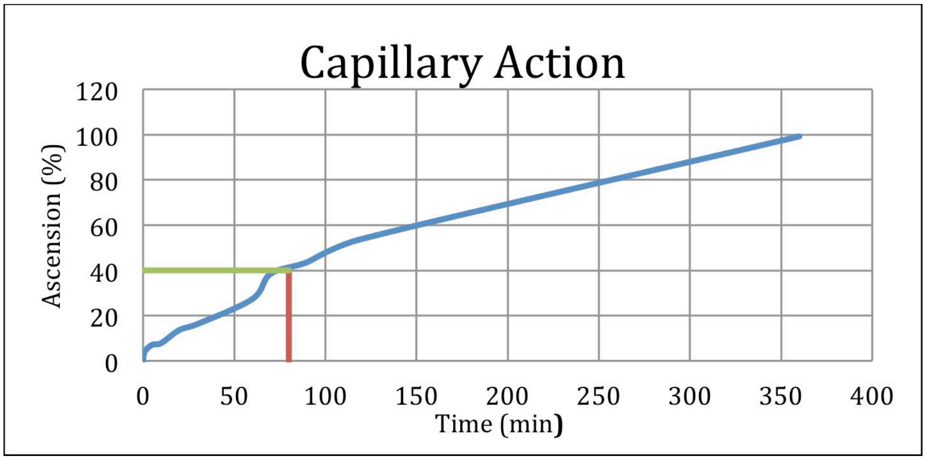

Figure 3. *Capillary action curve for subgrade material. Source: provided by the authors*

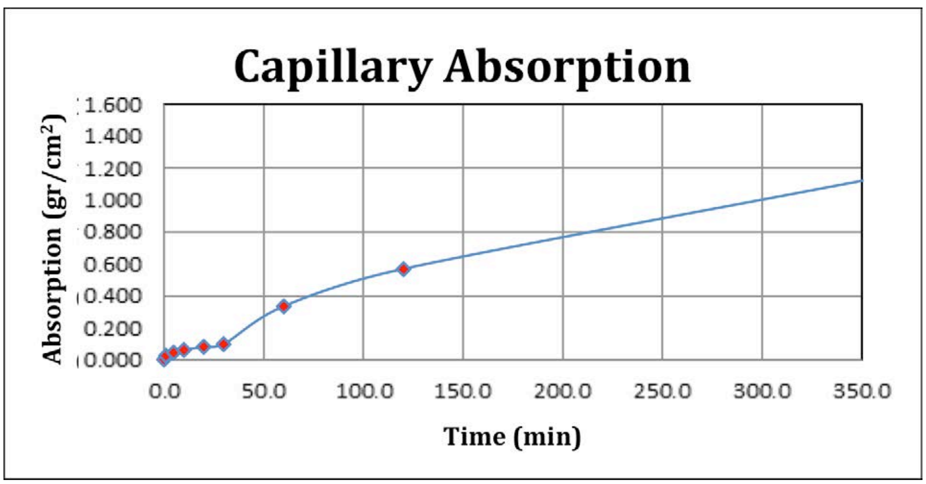

Figure 4. *Capillary absorption curve of subgrade material. Source: provided by the authors*

Due to the high absorption potential of the subgrade material, the disintegration of the briquette occurred rapidly, the collapse occurred within 6 hours of the beginning of the test, as shown in (Figura 5).

Figure 5. *Briquettes after the capillary absorption test. Source: provided by the authors*

Water stability. After the immersion, immediately there was a great loss of material. After 30 minutes of immersion, there is a loss of material to a greater extent as it can be observed in (Figure 6). After 8 hours of testing, the total collapse of the specimen occurs.

Figure 6. *Water stability test after 30 minutes. Source: provided by the authors*

4.3 Characterization of stabilizing agent – oily sludge

The chemical composition of the oily sludge was determined using the X-ray fluorescence test. The spectrum obtained is shown in (Figure 7).

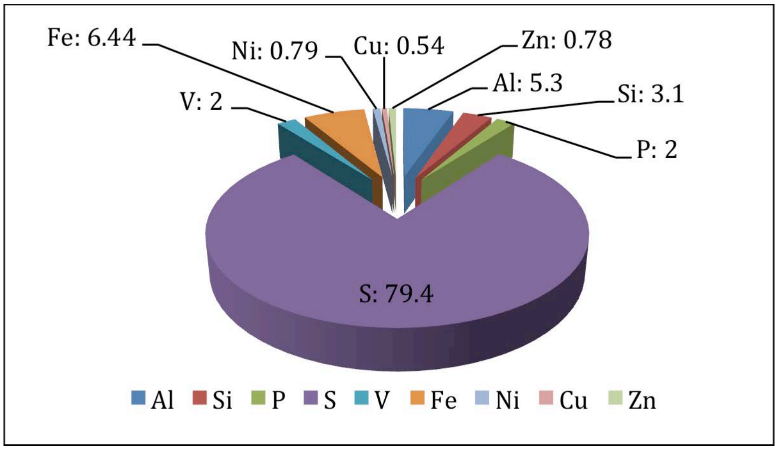

Figure 7. *Chemical composition spectrum of the oily sludge. Source: provided by the authors*

According to the relative density of the sludge under study, its API gravity is 10, which, according to the classification established for crudes by (Peralta et al., 2017) page 8, it is an extra-heavy crude oil.

4.4 Stabilization process

In the absence of a standard procedure for oily sludge stabilization and following the general trend in stabilizations, it was decided to produce mixtures with the addition of different percentages of oily sludge to identify the best behavior or performance trend of the stabilized material through the measurement of certain physical and strength characteristics.

On the La Primavera - Puerto Carreño road, the strength and durability properties of clay soils with low plasticity were evaluated by adding sodium silicate. Samples were compacted in the laboratory and cured under controlled environmental conditions of relative humidity and temperature, representative of the area under study. Different percentages of sodium silicate were used, for ages of 0, 7 and 14 days to select the optimal percentage of salts, which would allow obtaining the highest strengths in compression tests and the lowest losses in dilution and durability test (Caballero, 2017) page 9.

(Figure 8) shows the experimental design used for the processes of dosing, preparation, curing and testing of mixtures of granular material and subgrade with oily sludge.

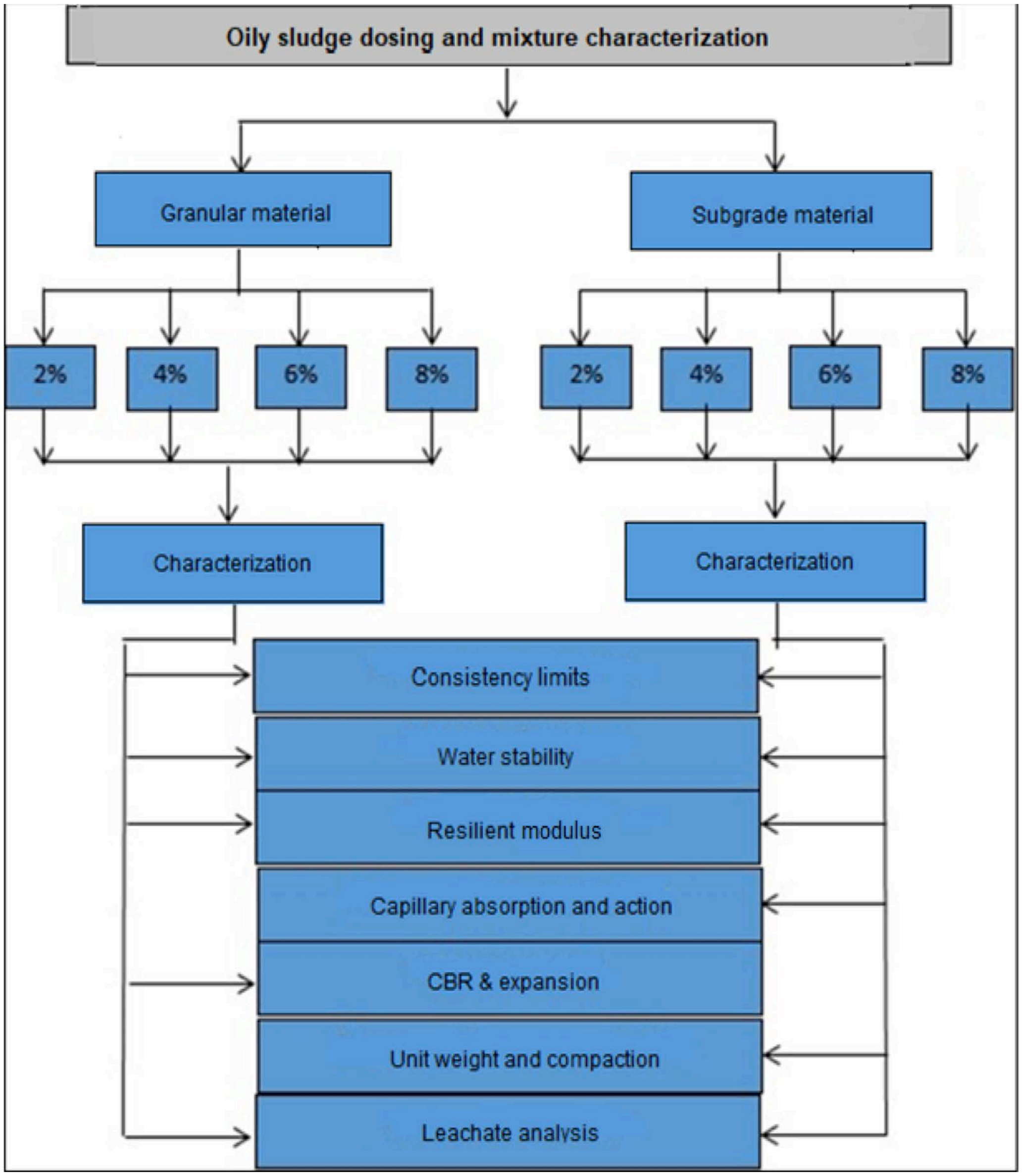

Figure 8. *Experimental design of the research. Source: provided by the authors*

4.4.1 Results of granular material stabilization

The CBR of the mixture was determined for 2%, 4%, 6% and 8% oily sludge and for curing for 4 days in immersion, dry curing for 14 days and curing for 14 days with 7 days in immersion and 7 days of dry curing.

The general trend suggests that the greatest increase in the CBR of the stabilized material, for untreated material (30%), occurs with the addition of 4% sludge and a 14-day dry curing period (52%). In addition, untreated material increases its CBR with 4% sludge, regardless of the curing period, in all cases, as shown in (Figure 9).

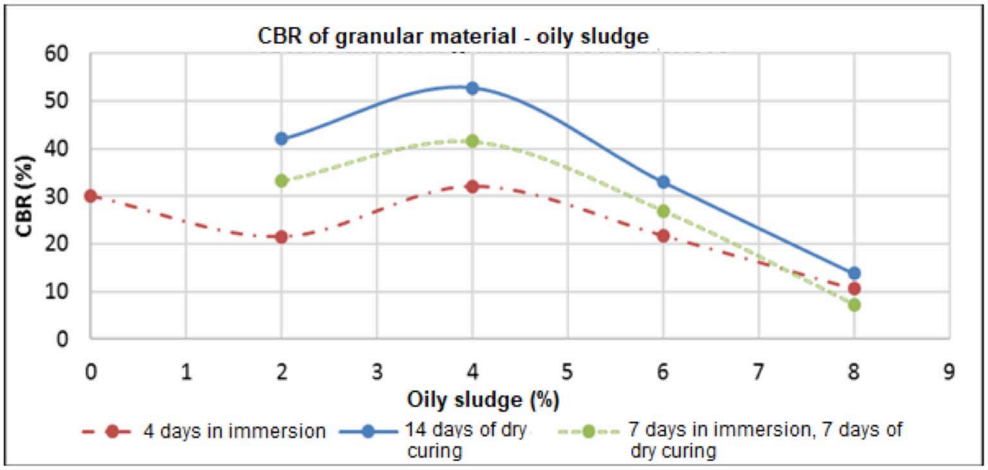

Figure 9. *CBR of granular material - oily sludge. Source: provided by the authors*

The expansion to the CBR samples was determined; concluding that all expansion measurements for the stabilized samples are less than the expansion of the untreated material, i.e., the sludge added to the material decreases the effect of water on the granular material. (Figure 10) shows the extent of the reduction in the expansion values.

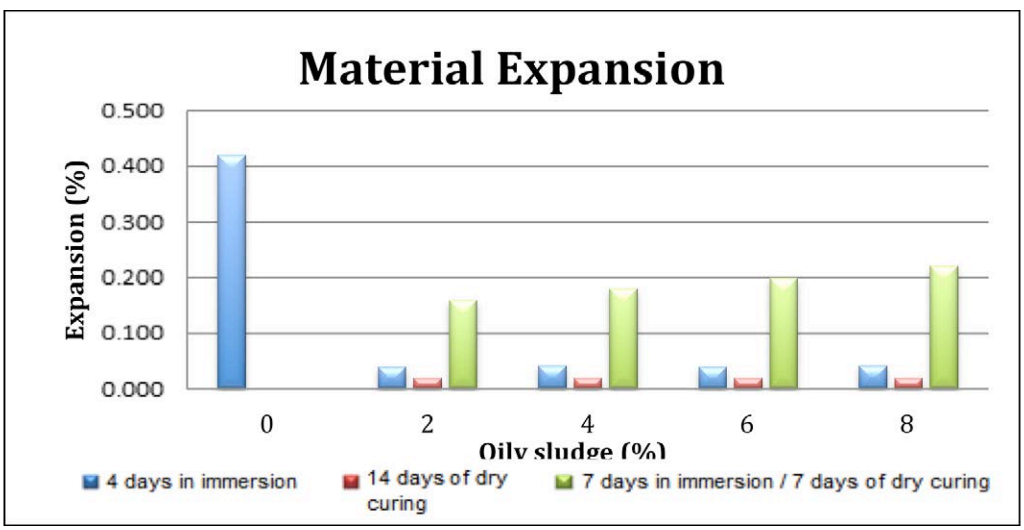

Figure 10. *Material expansion. Source: provided by the authors*

The water stability was carried out to the briquettes of the CBR test for the unstabilized and stabilized samples. (Figure 11) shows aspects of test performance, the unstabilized briquette presented a slight loss of material after 5 minutes, at 11 hours it disintegrated by 60%. After 24 hours, it failed by more than 90% and it was destroyed on the fifth day. The stabilized specimens did not show any variation at any time.

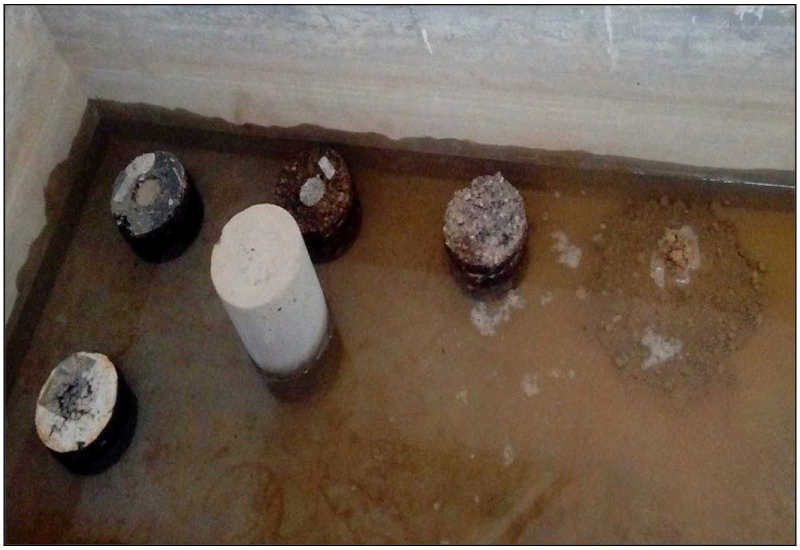

Figure 11. *Water stability after 24 hours of testing. Source: provided by the authors*

The addition of oily sludge to the granular material decreases its plasticity from 8% to N.P. from 6% sludge. With 4% sludge, it decreases to 7%; that is to say, the favorable effect in this property in the granular material occurs with the addition of sludge above 6%.

The low sensitivity to the presence of water produced by the oily sludge on the granular soil is very useful, taking into account that the behavior of compacted soils depends on their maximum dry density and water content. In low plasticity soils, changes in moisture produce collapse deformations when wet, this deformation increases in poorly compacted soils because they are partially saturated and can change their volumetric stability (Chávezet al., 2016), page 1.

4.4.2 Subgrade stabilization results

The unit weights of the mixtures decrease as the percentage of oily sludge increases since the unit weight of the oily sludge is lower than the unit weight of the subgrade.

The plasticity index decreases as the sludge is added to the subgrade material up to 6%. With 8%, the effect of the sludge is zero and the material has the same plasticity as the untreated material. The addition of sludge to the subgrade does not greatly affect the optimum moisture content and maximum dry density.

The capillary action in the stabilized specimens was zero; the opposite occurred in the original subgrade specimens. The oily sludge improves the impermeability of the subgrade by delaying the ascension of the water towards the interior of the specimen; it reduces the loss of material generated by the water and the decrease in strength.

In the water stability test, it was found that after 5 minutes of immersion no change occurred in the specimens; after 20 days of immersion, in the briquettes with 2% and 4% of sludge, a certain degree of saturation was observed without collapse or loosening of material, while in the briquettes with 6% and 8% of sludge no change occurred.

In the study of the subgrade for pavements, its support capacity is very important. Therefore, it is necessary to take into account the sensitivity of the soil to moisture, both in terms of strength and possible variations in volume, once changes in volume lead to damage to the structures that are supported on it. For this reason, when a pavement is built on this type of soil, care must be taken to prevent variations in soil humidity, in which case waterproofing of the structure must be considered (Hernández et al., 2016), page 8, this can be achieved by adding oily sludge to the subgrade of approximately 6% by weight.

4.4.3 Analysis of leachate in mixtures

It was carried out to evaluate the environmental problems that can be generated by the use of stabilized mixtures with oily sludge when exposed to rain and its runoff. Leachate characteristics are highly variable and depend on the interaction of many factors, such as waste composition and age, oxygen availability and moisture, rainfall rate, site hydrology, compaction, sampling procedures and the interaction between leachates and the environment (Arrechea et al., 2015), page 7.

The specimens of the stabilized mixtures were subjected to saturation for 15 days. Then, the water was sampled for X-ray fluorescence analysis. The results are shown in (Table 2).

Table 2. *Water components before and after 15 days of immersion*

Component	Al	Si	P	S	V	Fe	Ni	Cu
Components of the water sample before the immersion of specimens								
Content	3	0	2	91.3	1	0.9	0.8	0
Unit (%)	%	%	%	%	%	%	%	%
Components of the water sample after immersion of specimens of granular material - sludge								
Content	2	0.6	2	91.9	1	0.9	0.7	0.3
Unit (%)	%	%	%	%	%	%	%	%
Components of the water sample after immersion of specimens of subgrade - sludge								
Content	3	0.6	2	91.2	1	1	0.9	0
Unit (%)	%	%	%	%	%	%	%	%

Source: provided by the authors

For the mixture containing sludge - granular material, it was found that traces of elements such as silicon (Si), sulfur (S) and copper (Cu) remain in the water; whereas for the mixture containing subgrade - sludge, the content of silicon (Si), iron (Fe) and nickel (Ni) increases, although in very low proportions.

4.4.4 Dynamic characterization

Current pavement design methodologies consider the resilient modulus as a fundamental property to characterize the materials. These are used both for the design of the asphalt mixture for the pavement and for the design of the layer thickness of the asphalt pavement (Corona, 2017), page 67.

Triaxial testing is one of the most widely used methods to determine the resilient modules of granular materials and subgrade soils. The test simulates the most realistic conditions of the stress states to which materials are subjected in the layers of flexible pavement structures when exposed to moving loads over the useful life of the materials. "The mechanical behavior of coarse granular soils of alluvial origin was studied through a direct consolidated drained shear test and large-scale triaxial compression test" (Nanclares, 2018), page 7.

To determine the resilient modulus, specimens of each material (subgrade and granular) were made with 0%, 2%, 4%, 6% and 8% of oily sludge. They were left in a curing chamber, as shown in (Figure 12). The curing period was 7, 20 and 26 days. The test was carried out in the Nottingham Asphalt Tester (NAT) servo-pneumatic machine. Figure 13 shows the result obtained for the subgrade.

Figure 12. *Chamber for curing specimens. Source: provided by the authors*

The resilient modules were found for particular stress conditions, and the traditional pavement structure shown in (Figure 14) was proposed for this purpose.

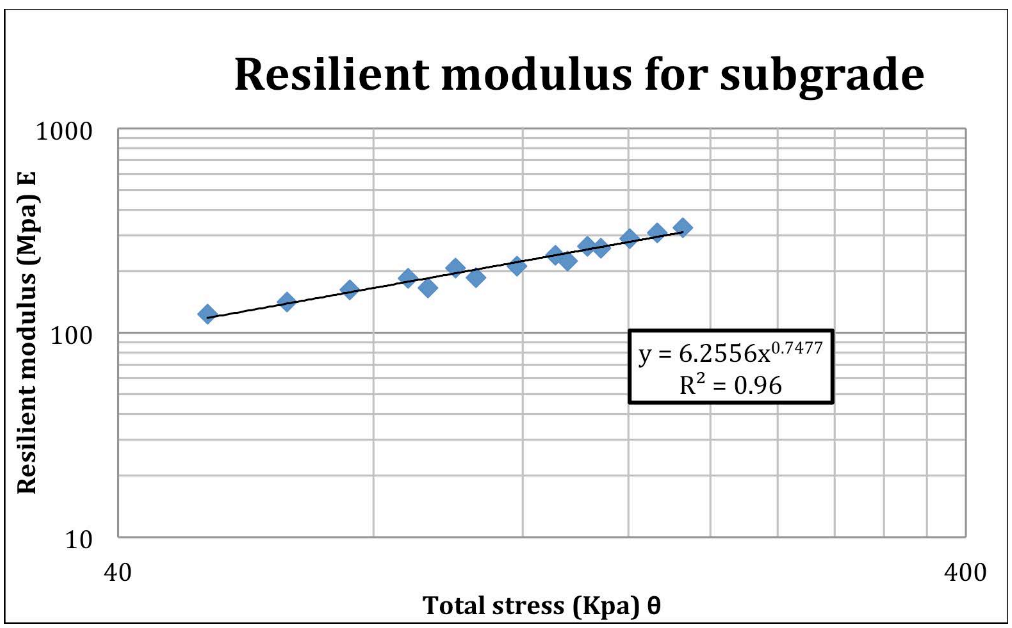

Figure 13. *Resilient modulus of untreated subgrade and 7 days of curing. Source: provided by the authors*

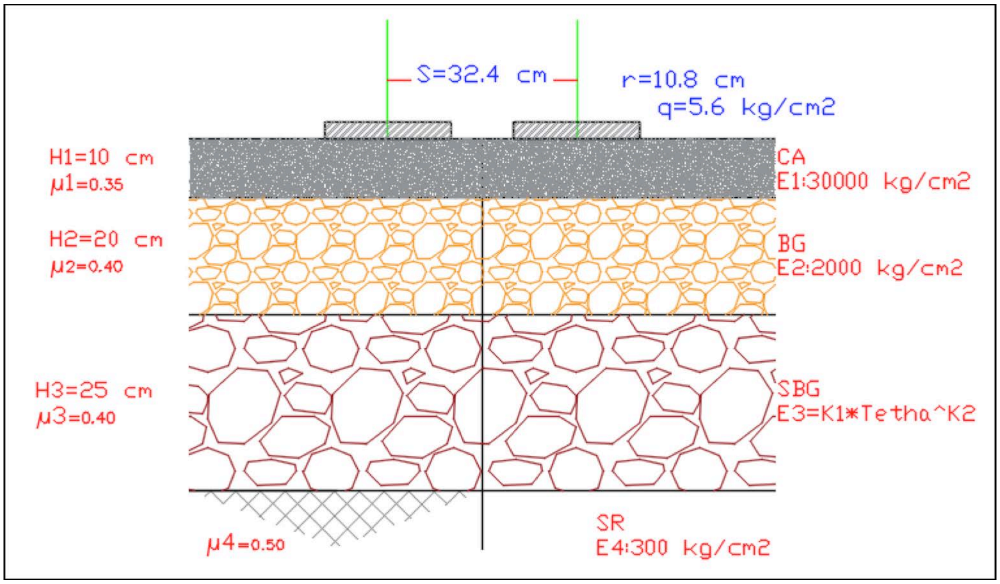

Figure 14. *Structural model of flexible pavement. Source: provided by the authors*

The stress values for the proposed pavement structure were recorded and, taking into account the models obtained from the triaxial test, the resilient modulus was determined. These results are shown in (Figura 15) and (Figure 16).

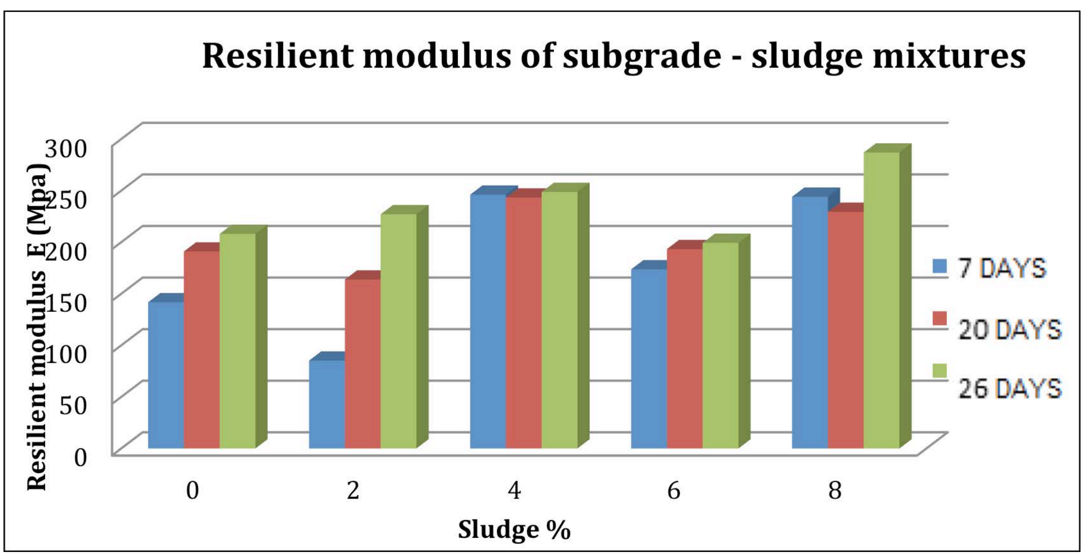

Figure 15. *Resilient modulus of subgrade - sludge mixtures. Source: provided by the authors*

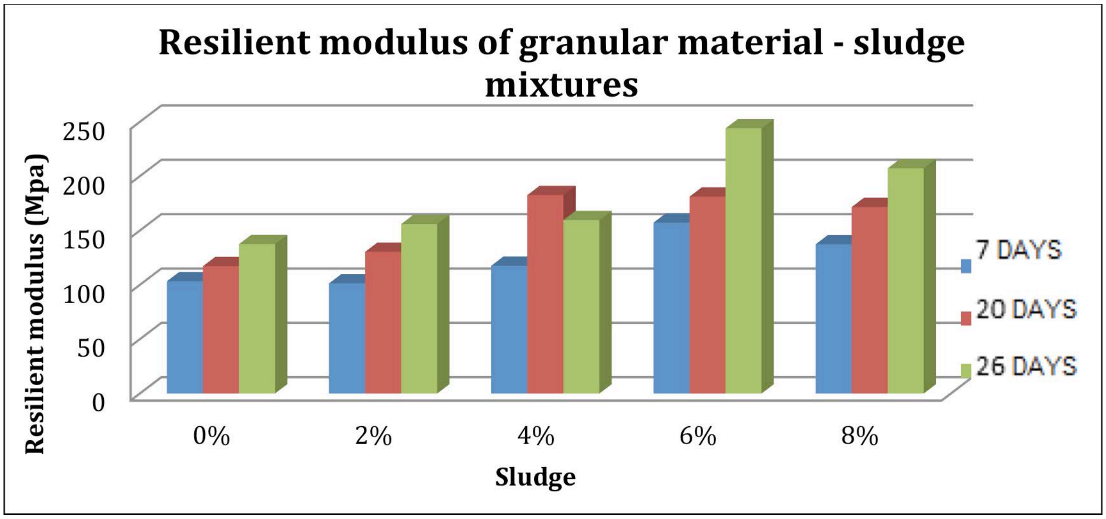

Figure 16. *Resilient modulus of granular material - sludge mixtures. Source: provided by the authors*

The resilient modulus of the subgrade has an irregular behavior with respect to the percentage of sludge and curing period. The best results are obtained with 8% sludge and 26-day curing. Similar data are obtained with 4% sludge for the different curing periods. In the case of granular material, the highest modulus values are obtained with 6% sludge and 26-day curing. In both cases, the addition of sludge to the original materials produces a positive effect on their strength.

5. Economic analysis

To analyze the economic feasibility of stabilizing subgrade or granular material with the addition of oily sludge, the costs of the original and stabilized material were determined as an integral part of one of the layers of a flexible pavement structure, which was initially designed with conventional materials for given design traffic. The resulting structure is shown in (Figure 17).

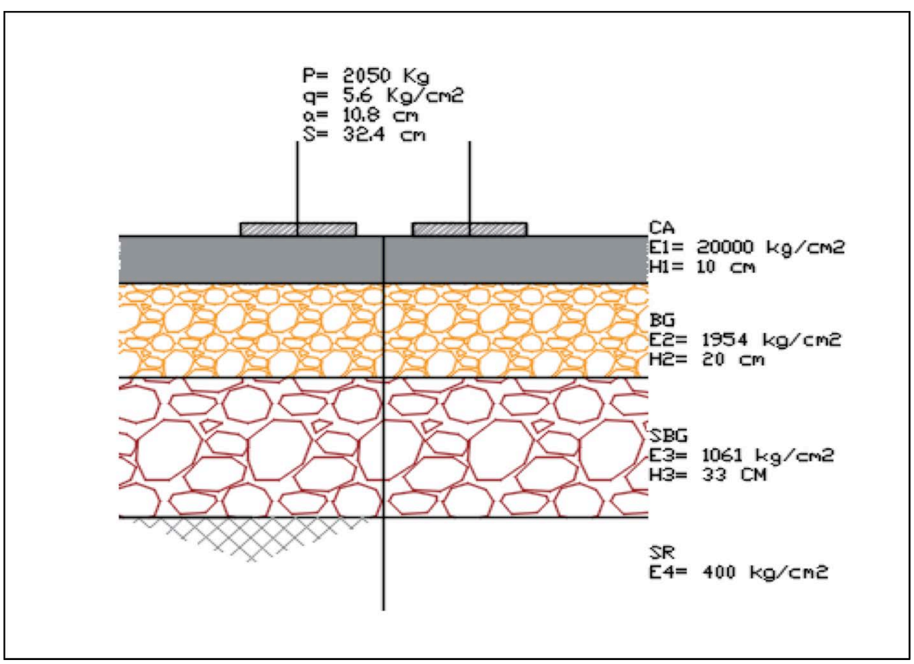

Figure 17. *Pavement structure with conventional granular material. Source: provided by the authors*

At the same time, a flexible pavement structure similar to the previous one was designed, but the granular sub-base layer was replaced by a layer of granular material stabilized with 6% oily sludge. This structure was dimensioned in such a way that the service values were similar to the pavement structure initially planned. The new structure is shown in (Figure 18).

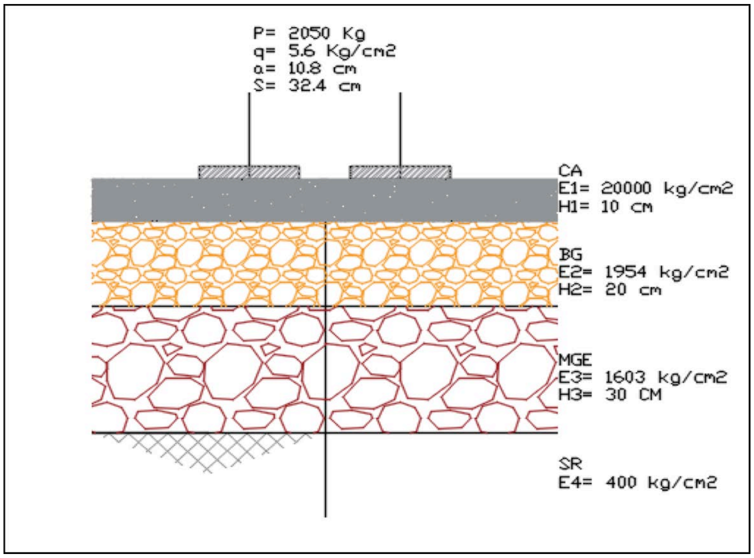

Figure 18. *Pavement structure with stabilized granular material. Source: provided by the authors*

As noted, the flexible pavement structure using the granular material stabilized with 6% oily sludge reduces its thickness by 5cm from the granular sub-base of the conventional structure.

The unit price values obtained are \$90,046/m^3 and \$79,170/m^3 for conventional sub-base material and granular material stabilized with 6% oily sludge, respectively.

Although this is not an absolute result, it does show a trend to reduce costs and is an invitation to continue research on the subject and, obviously, to implement testing sections that cast more light on aspects not covered in this study, including the analysis of the behavior of these two layers over time.

6. Conclusions

The optimal percentage of oily sludge recommended to stabilize the granular material, stabilized base course type, is 6%, which increases the resilient modulus by approximately 40% in relation to the resilient modulus of the untreated granular material, with a 7-day curing period.

4% oily sludge is recommended to treat the subgrade, with which an increase in strength of approximately 37% compared to the natural subgrade is achieved.

Given the results of the CBR and resilient modulus tests and taking into account the conditions under which the specimens were tested, the importance of curing the mixtures to gain strength over time is noted.

The oily sludge generates a positive effect on the subgrade, making it less susceptible to the action of water, more waterproof, increasing its water stability when subjected to saturation, which guarantees the preservation of the strength properties of the material under the most critical conditions.

It is important to mention the reduction of plasticity achieved in the granular material - oily sludge mixture, when going from 8% to 0%, that is, with the addition of a 6% stabilizing agent, a non-plastic mixture is produced.

According to the chemical analysis conducted on the water to check the action of the leachates generated by the mixtures stabilized with oily sludge, it was found that the threat of polluting water sources, in a possible implementation of the mixture, is minimal since no traces of the components of the oily sludge were quantified in the chemical test reports.

From the economic analysis of the possible implementation of the stabilized granular material, as a layer of a flexible pavement structure, two fundamental advantages were found. On the one hand, the thicknesses of the structure are reduced, and on the other, the construction costs per m^3 are reduced, taking into account the replacement of the conventional granular sub-base by a layer of granular material stabilized with 6% oily sludge.

The results of the stabilization of granular material and subgrade with oily sludge, in the laboratory, were satisfactory for its use in roads. It would be advisable to construct instrumented test sections to monitor and verify the behavior of stabilized mixtures in service when they are an integral part of a pavement structure.

7. References

Álvarez, M. (2015). Estabilización química de suelos en proyectos de infraestructura vial en Antioquia. (tesis de maestría). Escuela de Ingeniería de Antioquia, Envigado, Colombia.

Arrechea, A.; López, M.; Espinosa, M. y Orestes, Ll. (2015). Propuesta para tratamiento de lixiviados en un vertedero de residuos sólidos urbanos. Ingeniería Hidráulica y Ambiental, 36 (2).

Bada, D. (2016). Aplicación del aditivo químico Conaid para atenuar la plasticidad del material granular del tramo de la carretera tauca – bambas (km73 + 514 – km132 + 537) de la ruta nacional pe – 3na. (tesis de maestría). Universidad Privada Antenor Orrego, Trujillo, Perú.

Caballero, O. (2017). Estabilización química con silicato de sodio del material de préstamo de la vía La Primavera – Bonanza – La Venturosa en el departamento del Vichada. (tesis de maestría). Universidad Nacional de Colombia, Bogotá, Colombia.

Chavarro, W. y Molina, C. 2015). Evaluación de alternativas de pavimentación para vías de bajos volúmenes de tránsito. (tesis de especialización). Universidad Católica de Colombia, Bogotá, Colombia.

Chávez, C.; Espinosa, J.; Alarcón, J. y Arreygue, J. (2016). Colapso por humedecimiento en los terraplenes de la autopista Páztcuaro-Uruapan. Ingeniería Investigación y Tecnología, 17 (2), 201-210.

Corona, C. (2017). Determinación de módulo de rigidez y caracterización de módulo dinámico de mezcla Superpave. (tesis de pregrado). Universidad Técnica Federico Santa María, Valparaíso, Chile.

Díez, L.; Montes, O. y Caicedo, B. (2015). Estabilización de subrasantes con productos químicos. Universidad de los Andes, Bogotá, Colombia. Recuperado de https://www.researchgate.net/publication/238782419_Estabilizacion_de_Subrasantes.

Garzón, J.; Rodríguez, J. y Hernández, C. (2017). Aporte de la biorremediación para solucionar problemas de contaminación y su relación con el desarrollo sostenible. Universidad y Salud, 19(2), 309-318. doi: http://dx.doi.org/10.22267/rus.171902.93.

Hernández, J.; Mejía, D. y Zelaya, C. (2016). Propuesta de estabilización de suelos arcillosos para su aplicación en pavimentos rígidos en la facultad multidisciplinaria oriental de la universidad de el salvador. (tesis de pregrado). Universidad de el Salvador, San Miguel, El Salvador.

INVías. (2013). Especificaciones generales de construcción de carreteras. Bogotá, Colombia.

INVías. (2013). Normas de ensayo de materiales para carreteras. Bogotá, Colombia.

Méndez, R.; Gómez, P.; Ledesma, J. y Ceniceros, C. (2013). Manejo integral de los recortes de perforación de la industria petrolera en Tabasco. Revista Iberoamericana de las Ciencias Biológicas y Agropecuarias, 2(4). Recuperado de https://es.scribd.com/document/337666457/manejo-integral-de-los-recortes-de-perforacion-docx.

Nanclares, F. (2018). Comportamiento mecánico de suelos grueso granulares de origen aluvial. (tesis de doctorado). Universidad Nacional de Colombia, Bogotá, Colombia.

Olaya, A. (2018). Aplicación de agente químico como estabilizador de suelos arcillosos para la construcción de vías. (Tesis de pregrado). Universidad Nacional Abierta y a Distancia – UNAD, Bucaramanga, Colombia.

Peralta, A.; Blanco, J.; Reina, J. y Mantilla, L. (2017). Transporte de crudo pesado por oleoducto usando el método de dilución: Un enfoque práctico para modelar la caída de presión y la precipitación de asfaltenos. Fuentes: El reventón energético, 15 (2), 7-17. doi: https://doi.org/10.18273/revfue.v15n2-2017001.

Tecca. Compañía operadora del agua. (2014). Planta mejoramiento de lodos. Proyecto tricanter generalidades. Bogotá.

Ulate, A. (2017). Estabilización de suelos y materiales granulares en caminos de bajo volumen de tránsito, empleando productos no tradicionales. PITRA-LanammeUCR, 8(2).

Vargas, Y. y León, N. (2016). Exploración y explotación de petróleo: enfoque geográfico de los efectos ambientales en el piedemonte llanero. Perspectiva Geográfica, 21(2), 199-224. doi: http://dx.doi.org/10.19053/01233769.5795.