VOL. 16, NO. 3, FEBRUARY 2021 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EVALUATION OF THE ELASTICITY MODULE IN SUBBASES MODIFIED WITH HDPE, THROUGH SIMULATED CBR TESTS WITH FEM

Jackson Andres Gil H., Maria Paula Ramos and Carolina Gaviria Puentes
Civil Engineering Program, Faculty of Engineering, Surcolombiana University, Neiva, Huila, Colombia
E-Mail: jackson.gil@usco.edu.co

ABSTRACT

Despite the limitations of the California Bearing Ratio (CBR) test, this test is currently one of the most widely used experimental procedures to define the quality of materials in pavement design. Several investigations have sought to correlate CBR with parameters used in pavement design, but to date there are few investigations aimed at correlating the stiffness of modified sub-bases with High-Density Polyethylene (HDPE), with the value of CBR. The purpose of this article is to correlate the modulus of elasticity (E) of a modified granular subbase with different percentages of HDPE, with the results of CBR tests. To define this correlation, the Finite Element Method (FEM) calibration was carried out in the Plaxis program, simulating the CBR tests carried out on modified subbases. The calibration of the parameters was carried out through a retrospective analysis, where the stress-strain curves obtained in the CBR tests were compared with those determined by the numerical model. Finally, this research performed an analysis of the stress distribution on the sample during the CBR test, and proposes a relationship between the CBR and the elasticity modulus.

Keywords: CBR test, elasticity modulus, finite element method, numerical modeling.

1. INTRODUCTION

Overpopulation and low awareness about the use of natural resources has led the world to an environmental crisis exacerbated by the excessive production of non-biodegradable waste. At a global level, several countries have proposed strategies to encourage recycling of these wastes, seeking to reduce greenhouse gas emissions, save raw materials, and encourage new economic activities [1, 2]. In Colombia, the government has promoted different regulations to encourage the recycling of industrial waste, and in some cities, waste separation programs have been proposed, seeking to protect the environment [3].

On the other hand, the recycling of inorganic waste in different fields of engineering has increased as science advances in the physical and mechanical characterization of materials. In road geotechnics, several authors have characterized waste from different industries, seeking its reuse in the different layers that make up the pavement structure.

Appiah *et al* (2016) investigated the effect of mixing different compositions of high-density polyethylene (HDPE), and Polypropylene (PP) in conventional AC-20 bitumen. During the investigation it was found that the rheological properties of the modified bitumen were better than the properties of the unmodified bitumen; It was observed that the PP polymer generated effects on the homogeneity and compatibility of the compound, where a slight increase in the values of viscosity, softening and penetration stands out, compared to significant changes for the bitumen modified with HDPE [4].

Choudhary *et al* (2012), evaluated how soil properties are modified when adding plastic strips in percentages from 0.25% to 4%, finding that the addition of recycled plastic strips increases the CBR and improves the secant module [5].

Benson and Khire (1994) investigated the behavior of sands reinforced with strips of different lengths of High-Density Polypropylene (HDPE). During the investigation they evaluated how the CBR, the secant modulus, the elasticity modulus, and the shear strength of the modified material were modified. It was found that the evaluated properties increased considerably when using strips with a ratio of 8 (long strips), and when using strips with a ratio of 4 (short strips) the material was weakened [6].

The objective of this research was to determine a relationship between the results of CBR tests on modified subbases with different percentages of recycled plastic, and the elasticity modulus of the modified materials. To meet this objective, a retrospective analysis was performed using the Finite Element Method, where the CBR tests were modeled in the Plaxis 2D program, and it was sought that the stress-strain curves obtained during the CBR tests were similar to those obtained in the Finite Element Method.

2. MATERIALS AND METHODS

Next, Figure-1 shows a diagram of the methodology used to determine the elasticity modulus of a subbase modified with HDPE, from the results of CBR tests modeled with finite elements.

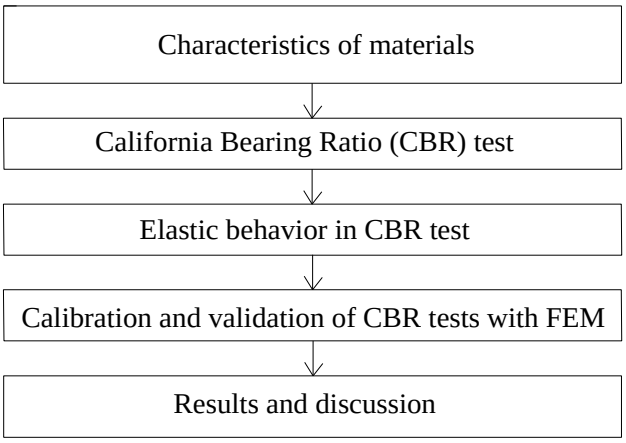

Figure-1. Methodology used to characterize modified subbases.

2.1 Characteristics of Materials

The material tested corresponds to a granular subbase type INVIAS (The National Roads Institute of Colombia) class A, modified by adding different percentages (4%, 8%, 12% and 16%) of High-Density Polyethylene. These additions correspond to a crushed material with a maximum size smaller than 4.75mm, the granulometry is presented in Figure-2 and the characteristics of the subbase used are presented in Table-1. The material was characterized in the laboratory of the Surcolombiana University and Trials were carried out for the physical and mechanical characterization of each of the tested samples.

Table-1. Parameters of the class A subbase measured in the laboratory.

Parameter	Determined Value	Standard Used
Plastic limit	6%	ASTM 4318 - 10
Sand equivalent	47.5%	ASTM D2419 - 19
Angels Machine Wear Resistance	19.3%	ASTM C 131-01
Maximum density Optimal humidity	2.177 g / cm3 7.7%	ASTM D 1557-09
Sulfate resistance (fastness)	2.4%	ASTM C88-99 a

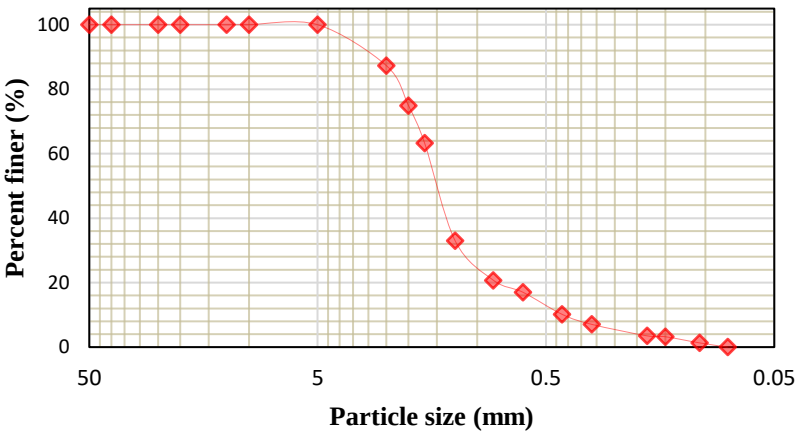

Figure-2. Granulometry of crushed high-density polypropylene.

2.2 California Bearing Ratio (CBR) Test

CBR testing, developed in 1920 by the California Highway Department of the United States of America, is one of the most widely used tests in the world to characterize the behavior of materials involved in pavement design. This test presents great limitations to directly define the parameters required in pavement design, because it does not represent the load conditions to which the structure will be subjected, during its operation. The parameter commonly used in pavement design is the resilient modulus, which represents the ability of the material to recover from cyclical loads, and in turn, it is a function of the elasticity of the material [7-9]. The resilient modulus can be determined in the laboratory with cyclic triaxial tests, representing the load conditions to which the materials are subjected during their usage. Despite the benefits of this test, its implementation in the execution of road projects is normally limited by economic conditions, and by the availability of laboratory equipment [10].

The CBR test consists of compacting a material with the energy level proposed by the ASTM D1883-16 standard, under the optimal moisture content defined by

the modified proctor test. The material is compacted in a standardized mold with a diameter of 152.4 mm and a height of 177.8 mm; Once the material has been compacted, the sample should be submerged for 4 days with a 4.5kg overload to simulate the loads applied by the pavement [11]. Then, the soil sample must be penetrated by a 50.8mm piston at a speed of 1.25mm / min, and the stress-strain curve is obtained until the piston has penetrated 12.5 mm. The value of CBR is determined from the following equation [10, 12],

$$CBR(\%) = \frac{\sigma_{soil}}{\sigma_{standard}} * 100 \quad (1)$$

Where σ_{soil} is the stress required to penetrate the soil 2.5 mm according to the stress-strain curve obtained in the test, and $\sigma_{standard}$ is a stress required to penetrate 2.5 mm a crushed California limestone (the standard stress corresponds to 6900 kPa).

2.3 Elastic Behavior in CBR Tests

Opiyo in 1995 proposed a methodology to determine the elasticity modulus of the material, from the elastic deformations that occur during the CBR test. This proposal considers that the total deformations registered in the upper part of the sample correspond to the sum of the deformations of the conical area and the cylinder area (see Figure-3) [10, 12].

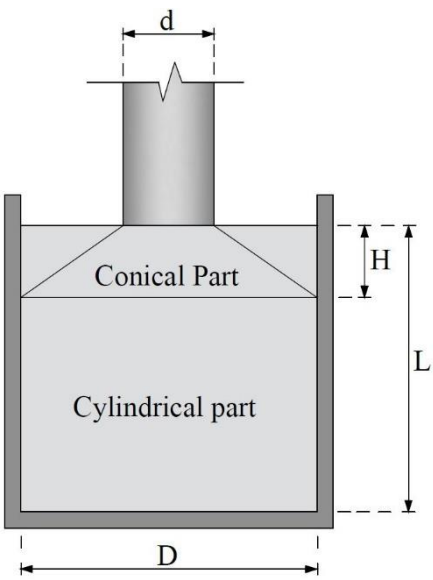

Figure-3. Penetration diagram of a cylindrical punch (modified from Mendoza and Caicedo (2017) [12, 13]).

This approach considers that the forces transmitted by the piston to the sample are distributed conically and then cylindrically. The proposed equation to determine the elasticity modulus according to the aforementioned approach is presented below:

$$E = \frac{qd}{h_e D}\left(H + \frac{d(L-H)}{D}\right) \quad (2)$$

Where E=elasticity modulus of the material tested, q is the stress applied under the punch, L is the height of the cylinder, h_e is the elastic deformation of the punch, H is the height of the conical area, d is the diameter of the punch, and D is the diameter of the cylinder.

In addition, Opiyo (1995), proposed equations to determine the elasticity modulus of the material considering the influence of the soil-mold interaction, from Finite Element Methods. Below, the equations to determine the elasticity modulus are presented in regard to consider, or not, the soil-mold friction [10, 12].

No soil-mold friction

$$E\ (MPa) = \frac{1.797\ (1-\nu^{0.889})q\left(\frac{d}{2}\right)}{{h_e}^{1.098}} \quad (3)$$

Considering the soil-mold friction

$$E\ (MPa) = \frac{1.375\ (1-\nu^{1.286})q\left(\frac{d}{2}\right)}{{h_e}^{1.086}} \quad (4)$$

Where d and h_e must be expressed in millimeters

Penetration tests were initially proposed for the characterization of metals and were later used to characterize materials in road projects. The CBR can be considered as the most used penetration test to define the quality of the materials that make up the pavement structure[10, 12].

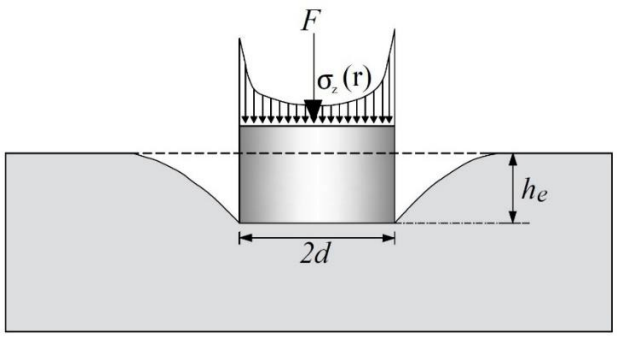

Figure-4. Penetration diagram of a cylindrical punch (taken from Mendoza and Caicedo, 2017 [12]).

Snedon (1965) proposed that the pressure transmitted by a punch to the ground could be defined as a function of penetration and the radius of the punch (see Figure-4) [10, 12]. Next, the equation that relates the stress to the load registered by the punch during the CBR test is presented,

$$P_m = \frac{F}{\pi * a^2} \quad (5)$$

Where F is the load recorded to generate a penetration into the ground and a is the radius of the punch that transmits the load to the ground.

The relationship between the elasticity modulus of the material and the pressure transmitted to the sample is presented below:

$$P_m = \frac{2Eh}{\pi a(1-\upsilon^2)} \quad (6)$$

According to Figure-4, the distribution of stresses under the punch is not uniform, and can be determined from the following relationship,

$$\sigma_z(r) = \frac{P_m}{2\sqrt{1-r^2/a^2}} \quad (7)$$

The deformation of the soil surface for r > a can be defined based on the following equation:

$$u_z(r,0) = \frac{2h}{\pi}\arcsin\left(\frac{a}{r}\right) \quad (8)$$

2.4 Calibration and Validation of CBR Tests with FEM

The numerical analysis of the CBR tests was carried out with the help of the Plaxis 2D finite element program. This program allows to represent the behavior of the soil for various stress-strain conditions through different constitutive models. The calibration of the numerical model was carried out by comparing the stress-strain trajectories generated with FEM, and those obtained in 26 CBR tests carried out on modified sub-bases with different percentages of HDPE. The CBR tests were carried out in the geotechnical laboratory of the Universidad Surcolombiana [14].

For the modeling of the CBR test, the load and geometry conditions to which a soil sample is subjected during the test were considered (see Figure-5), according to the ASTM D1883-16[11] standard. The CBR test was represented by an axisymmetric model, with a triangular mesh of 15 nodes adjusting the density of the mesh. The mold was represented by a plate-type element with restriction of horizontal and vertical movement (see Figure-5).

To represent the soil-mold interaction, an interface was considered according to the recommendations of the Plaxis manual, based on the mechanical and geometric characteristics of the materials.

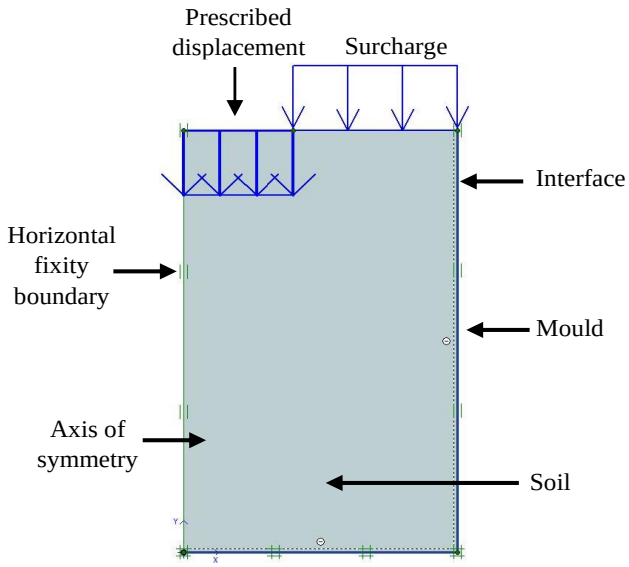

Figure-5. Geometric configuration of the FEM.

The soil was represented with a Mohr-Coulomb (MC) model in a drained condition, and the parameters required by the MC are: angle of internal friction (ϕ), cohesion (c), dilatancy angle (ψ), elasticity modulus (E), poisson's ratio (υ) and unit weight (γ).

3. RESULTS AND DISCUSSIONS

3.1 Stress-Strain Behavior

Caicedo and Mendoza (2019) define that during the execution of a CBR test three zones are delimited with different stress conditions (see Figure-6).

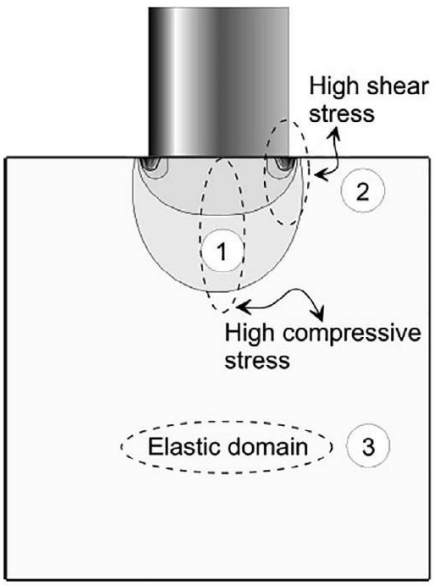

Figure-6. Delimitation of three mechanical behavior domain zones during CBR tests (taken from Mendoza and Caicedo, 2019[10]).

In zone 1, the greatest magnitude of compression stresses are present, and in this zone the material reaches

VOL. 16, NO. 3, FEBRUARY 2021 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

the limit of the elastic domain; zone 2 represents the highest concentration of shear stresses, the parameters that represent this limit are the angle of friction (ø) and cohesion (c) of the material tested; and in zone 3, the soil is in an elastic range and the parameters that represent this domain are the elasticity modulus (E) and the poisson's ratio (υ) [10].

During the simulation of the numerical models, it was found that the modified subbase with the addition of HDPE conforms to that proposed by Mendoza and Caicedo.

In Figures 7 and 8 the distribution of shear and vertical forces found in the numerical model is presented; for the different HDPE addition percentages in the modified sub-bases. According to the results of the modeling, the distribution of the stresses in the subbase adjusts to that proposed by Mendoza and Caicedo 2019, observing a large concentration of stresses around the punch (zone 2) and other areas of the sample subjected to low stresses of compression within the elastic state (elastic tensions zones 1 and 3).

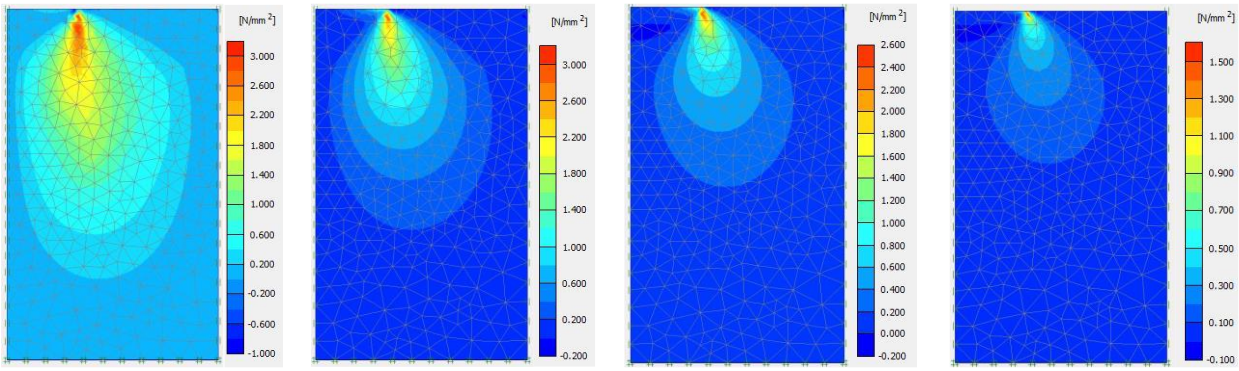

Figure-7. Distribution of shear forces for different percentages of HDPE addition.

The distribution of the shear stresses in the subbase changes as the different percentages of HDPE are varied. That is, as the percentage of HDPE in the subbase sample increases, the area of material involved in the fault decreases. The preceding occurs because the increase in the percentage of HDPE generates a loss of rigidity in the subbase; and in turn, induces a punching shear failure that involves a smaller amount of material

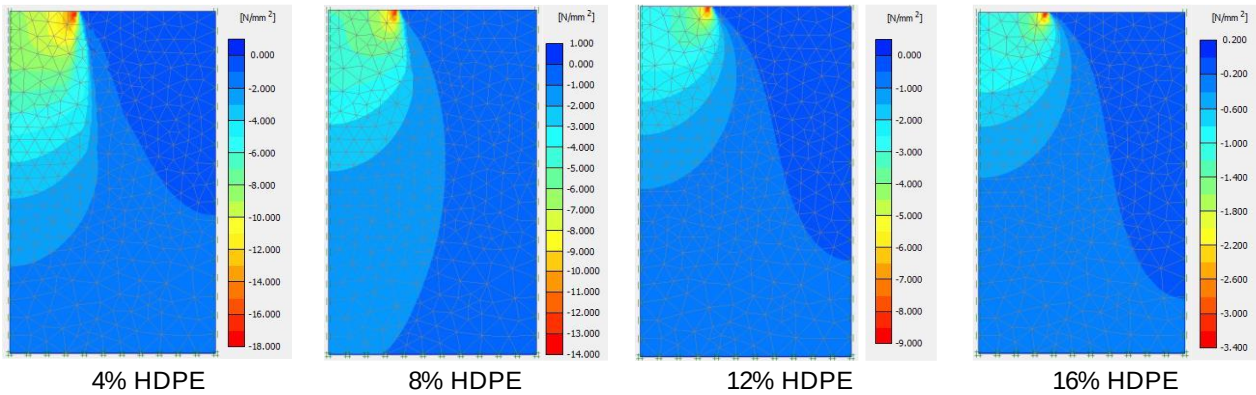

Figure-8. Distribution of vertical forces for different percentages of HDPE addition.

The stress distribution under the punch is not uniform, and there is a greater concentration of vertical and shear stresses on the perimeter of the punch. To verify the distribution of normal stresses on the soil sample, a sensitivity analysis was performed where it was observed how the HDPE % affects the distribution of normal and shear stresses (see Figure-9). The results show that as the HDPE % increases, the vertical forces necessary to generate the 12.5mm displacement decrease. In other words, the laboratory results showed that the subbase that developed the highest stress concentration under the piston was the one with a HDPE % of 4%.

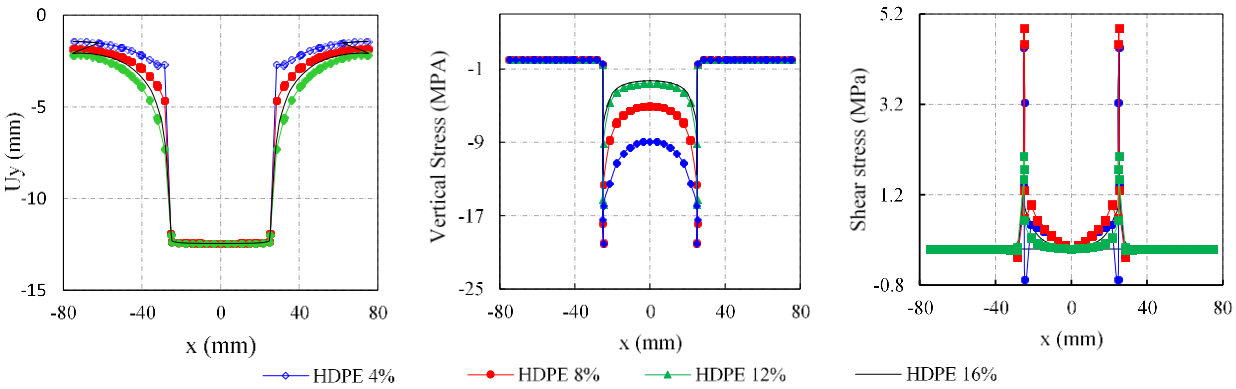

Figure-9. Verification of the effort zones proposed by Mendoza and Caicedo, 2019.

3.2 Relationship between Elasticity Modulus and CBR

Different authors have evaluated the relationship between the elasticity modulus and the results of the CBR test. Some of them have proposed that the CBR depends on the elasticity modulus, and on establishing linear relationships between the two parameters; while other authors consider that the results of the CBR test are a function of additional factors such as: material moisture, liquid limit, permeability, unit weight, compaction energy, and type of behavior (drained or not drained).

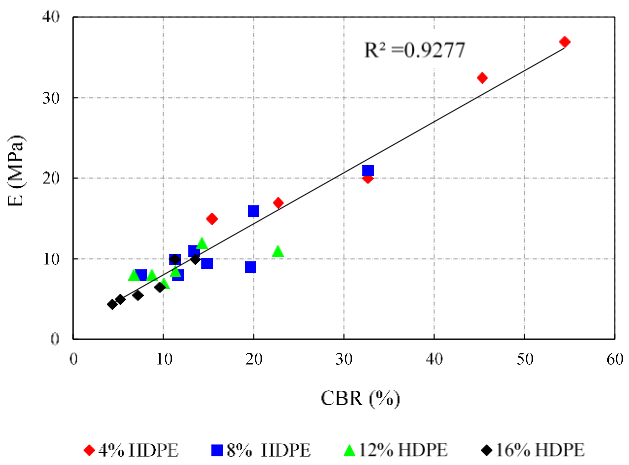

Figure-10. Variation of the modulus of elasticity vs the value of CBR (%) according to different percentages of HDPE.

This research sought to evaluate the variation of the modulus of elasticity as a function of the percentage of addition of HDPE, and it was found that as the percentage of addition of HDPE in the subbase increases, a notable decrease in the modulus of elasticity is generated (see Figure 10). That is, as the percentage of HDPE increases, the subbase loses rigidity. This behavior is deduced, since there was not a good adherence between the HDPE particles and those of the subbase. On the other hand, the low adhesion between the HDPE particles and the subbase generated a loss in the cohesion of the soil sample according to the parameters defined for the calibration of the stress-strain curves in FEM.

4. CONCLUSIONS

The article analyzed the stress-strain behavior of modified subbase samples with HDPE percentages of 4%, 8%, 12% and 16%; comparing the results of CBR tests in the laboratory, with finite element modeling. For the simulation of the CBR tests, an axisymmetric model was used in the Plaxis 2D program and the stress-strain curves of the CBR tests were compared with those obtained by FEM.

The results of the modeling showed that the highest stress concentration occurs in the perimeter of the piston, and that the increase in percentages of HDPE in the sub-base, generates localized punching shear failures under the piston involving less material.

It was observed that the increase in HDPE in the subbase generates a loss of rigidity in the soil. This was evidenced because, as the percentage of HDPE increased, the vertical effort necessary to penetrate 12.5mm into the soil sample decreased.

The results showed a good fit between the modulus of elasticity and the CBR value, but it is recommended to investigate how permeability, compaction, plastic limit and confinement affect; in the CBR value for modified subbases with different percentages of HDPE.

ACKNOWLEDGEMENTS

The authors thank Surcolombiana University, for their collaboration during the development of this study.

REFERENCES

[1] Turku I., *et al*. 2017. Characterization of wood plastic composites manufactured from recycled plastic blends. Composite Structures. 161: 469-476.

[2] Arulrajah A., *et al*. 2017. Recycled plastic granules and demolition wastes as construction materials: Resilient moduli and strength characteristics. Construction and building materials. 147: 639-647.

[3] Jaramillo Henao G. and L. M. Zapata Márquez. 2008. Aprovechamiento de los residuos sólidos orgánicos en Colombia.

[4] Appiah J. K., V. N. Berko-Boateng and T. A. Tagbor. 2017. Use of waste plastic materials for road construction in Ghana. Case studies in construction materials. 6: 1-7.

[5] Choudhary A., J. Jha and K. Gill. 2010. Utilization of plastic wastes for improving the sub-grades in flexible pavements, in Paving materials and pavement analysis. pp. 320-326.

[6] Benson C. H. and M. V. Khire. 1994. Reinforcing sand with strips of reclaimed high-density polyethylene. Journal of Geotechnical Engineering. 120(5): 838-855.

[7] Caicedo B. and C. Mendoza. 2015. Geotechnical behaviour of unpaved roads: understanding the CBR test. From Fundamentals to Applications in Geotechnics. pp. 95-100.

[8] Putri E. E., N. Rao and M. Mannan. 2012. Evaluation of modulus of elasticity and modulus of subgrade reaction of soils using CBR test. Journal of Civil Engineering Research. 2(1): 34-40.

[9] Shaban A. and P. Cosentino. 2017. Characterizing structural performance of unbound pavement materials using miniaturized pressuremeter and California bearing ratio tests. Journal of Testing and Evaluation. 45(3): 818-834.

[10] Mendoza C. and B. Caicedo. 2019. Elastoplastic framework of relationships between CBR and Young's modulus for fine grained materials. Transportation Geotechnics. 21: 100280.

[11] D, A. 2016. Standard test method for California bearing ratio (CBR) of laboratory-compacted soils. ASTM International West Conshohocken, PA.

[12] Mendoza C. and B. Caicedo. 2017. Elastoplastic framework of relationships between CBR and Young's modulus for granular material. Road Materials and Pavement Design. 19(8): 1796-1815.

[13] Magnan J.-P. and M. Ndiaye. 2015. Determination and assessment of deformation moduli of compacted lateritic gravels, using soaked CBR tests. Transportation Geotechnics. 5: 50-58.

[14] Narzary B. K. and K. U. Ahamad. 2018. Estimating elastic modulus of California bearing ratio test sample using finite element model. Construction and Building Materials. 175: 601-609.