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Improvement of the geotechnical performance of soil reinforced with ichu fibers (Stipa ichu) in Arboleda II Etapa, district of Carabayllo

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Abstract*– The main objective of this research is to improve the geotechnical behavior of soils through the use of natural ichu fibers (Stipa ichu). It is hypothesized that the addition of ichu fibers will increase the bearing capacity of the soil, improving its compressive and shear strength, which will reduce differential settlements and, consequently, structural failures in buildings located in areas with problematic soils. The research methodology includes laboratory tests, such as the standard Proctor test, compressive and shear strength tests, in order to evaluate the influence of ichu fibers on the mechanical properties of the soil. Likewise, the optimum dosage of fibers will be determined to maximize soil stability and minimize environmental impact in the region. This study is justified not only by the increasing urban expansion into areas with unstable soils, but also by the need to develop sustainable and accessible stabilization methods. The use of natural ichu fibers represents an innovative and environmentally friendly solution that could replace the use of more costly and environmentally damaging conventional stabilizers.

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***Keywords*-- soil stabilization, ichu fibers (Stipa ichu), geotechnical behavior, soil bearing capacity, differential settements.**

I. INTRODUCTION

Urban growth in Peru has experienced uncontrolled expansion, generated mainly by the demand for housing in marginal areas and the increase in informal construction. This phenomenon has been driven by factors such as increased population density, lack of regulation, and the scarcity of land suitable for the development of safe infrastructure. The Peruvian Chamber of Construction (CAPECO) estimates that around 70% of housing in Lima is informal, wich implies that they have been built without complying with structural safety regulations, many of them located in areas with unstable soils or low bearing capacity [1]. This situation represents a significant challenge for civil engineering, where soil stabilization becomes a critical need to ensure the safety of buildings and the lives of their occupants. The use of ichu fibers for soil stabilization presents a significant economic and environmental advantage compared to traditional methods based on chemical stabilizers, such as lime or cement. Studies by Bordoloi, Garg and Sekharan [2] have shown that the incorporation of natural fibers can increase soil strength by 20% to 30%, depending on the dosage and soil type. In addition, ichu, being a plant native to the Andes, is low cost and easily accessible to high Andean communities, making it a sustainable and economically accessible alternative [3].

Demographic expansion: Soil stabilization is a critical aspect of civil engineering, as it ensures the stability and durability of buildings. However, population expansion and increasing urbanization in areas with problematic soils are increasing the need for effective soil stabilization. As the population relocates to less favorable terrain, the lack of adequate stabilization can have serious consequences, such as building collapses, accidents due to differential settlement and the progressive deterioration of buildings. These events not only represent significant economic losses, but also put the lives of the people living in these areas at risk.

Soil instability: Soil instability is a fundamental cause of these collapses, as inadequately stabilized soils cannot safely support the weight of structures. The result can be catastrophic failure of buildings, which in addition to representing a high cost in terms of repair and maintenance, compromises the safety and well-being of the affected communities. Building subsidence, on the other hand, is common in areas where soil settles unevenly, causing cracks, slopes and eventually the total collapse of buildings. Increasing population pressure and urban sprawl into areas with more unstable soil and soil erosion.

II. STATE OF THE ART

The use of conventional techniques for soil improvement such as lime and cement gradually recognized the impact on the environment. Environmental pollution from the construction industry, these techniques cause deterioration of sustainable life and natural environment, since geosynthetics take many years to decompose, as they deteriorate, they generate nanoplastics and microplastics which cause serious alterations to the ecosystem and risks to human health [4].
Strengthening the geotechnical behavior of soil by incorporating natural ichu fibers is essential for several reasons. In addition, natural fibers can improve mechanical properties, where the samples were subjected to various tests, among them are absorption tests, tensile tests, compression, shear, standard compaction, California bearing ratio (CBR), shear tests, unconfined compression. Thus, adding fibers increases strength, prevents shrinkage and limits crack propagation [5].

The application of natural fibers to strengthen the soil can prevent problems such as landslides or subsidence; therefore, microstructure tests were carried out using scanning electron microscopy to analyze the texture and mineralogy of soil samples treated with fibers. In addition, compressibility and shear strength tests were performed to evaluate the impact of the fibers on the mechanical properties of the soil, which contributes to reduce the risks of collapse and accidents, thus ensuring the safety of the inhabitants [6].

In conclusion, the use of ichu fibers to reinforce soil in high Andean regions represents a promising strategy to improve geotechnical behavior. The incorporation of fibers is shown to be effective in improving the failure ductility of the soil, as well as increasing its stability, reducing moisture, improving its strength and slope stability, as well as increasing its durability and compression. Likewise, a modification in the indicators of shear, cohesion and friction angle of soils was observed [7]. Moreover, the use of natural fibers does not contaminate soils, which makes this method an environmentally friendly alternative and requires less energy for its production [8].

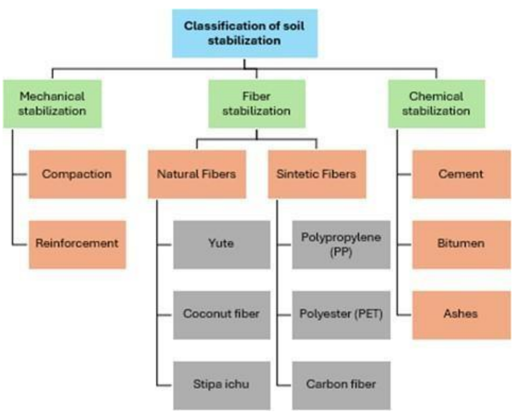


Fig. 1. Classification of soil stabilization

Stipa Ichu Natural Fiber

III. THEORETICAL FRAME

The physical and mechanical properties of soils allow determining the optimum percentage for mixing natural fibers, thus improving their compaction. By means of standard Proctor test it is possible to establish the chemical composition of natural fibers and compaction details in soil samples [9].

A. Standard Proctor Test

The standard Proctor compaction test are tests performed on the soil with the objective of determining the technical properties of the soil, they are performed with different samples, in this case the combined samples between soil and natural fibers, to find the properties of these samples such as optimum moisture content (%) and maximum dry density (g/cc) [10]. With the standard Proctor compaction test, the chemical composition of the natural fibers and also the compaction properties of the soil samples are determined [11].

B. Compressive strength

This mechanical property indicates the ability of the soil to withstand applied loads without having to undergo significant plastic deformation. In the context of soil stabilization, this property is essential to ensure the durability and stability of various structures. Adequate compressive strength helps prevent structural failure and minimize differential settlement, which can compromise the integrity of structures [12]. Unconfined compressive strength reflects the strength properties of natural fiber in soils, with significant improvements observed with increasing fiber content [13].

C. Soil stabilization

Soil stabilization is the method used to improve soil properties by mixing with other materials, improving the shear strength of soils, thus increasing their bearing capacity [14]. The process to stabilize the soil is performed by two methods, being the first method, mechanical stabilization and the second method, chemical stabilization, where the reinforcement of soils with fibers in this case natural increases the shear strength, bearing in mind that it is very abundant and is more cost effective [15]. Soil compaction increases its density by redirecting free air voids.

D. Natural fibers

Natural fibers are fibrous materials obtained from natural sources. These fibers when used as stabilizers for soils increase their mechanical properties, solving settlement and load bearing capacity failures, natural fibers have lower cost compared to other synthetic stabilizers, they are also biodegradable thus avoiding environmental pollution [16]. The use of natural fibers to reinforce soils has much acceptance as they are sustainable materials that can replace synthetic fibers manufactured from petroleum [17], they distribute the stresses applied to the soil more uniformly, reducing the stress concentration and, therefore, the possibility of crack formation and failures, this effect is known as "dispersed matrix reinforcement" [18].

IV. Experimental Part

This chapter demonstrates the procedures for particle size, plastic limit - liquid limit, modified proctor and unconfined compression tests.

- Granulometry: Determine soil particle size distribution.

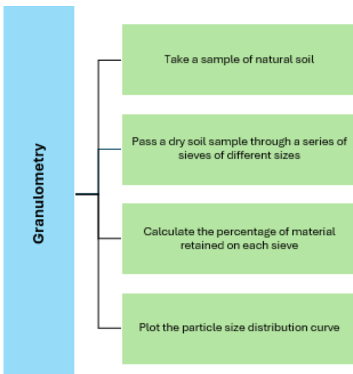


Fig. 2. Granulometry procedure

Granulometric Analysis of Soils by Sieving

- Liquid Limit: To evaluate soil plasticity and determine its behavior under different moisture conditions.

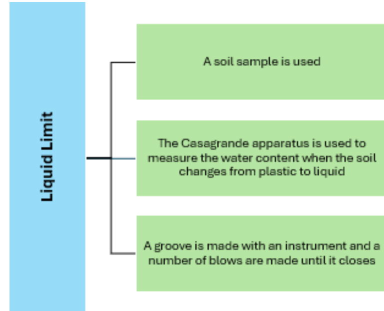


Fig. 3. Liquid Limit

Determination of Liquid Limit of Soils

- Plastic Limit: It determines the water content at which the soil changes from a plastic to a semisolid state.

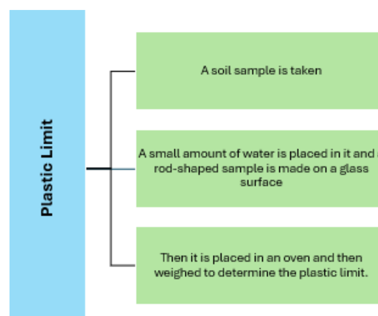


Fig. 4. Plastic Limit

Determination of the Plastic Limit

- Modified Proctor: Determine the optimum ratio between water content and maximum density that a soil can achieve by compaction.

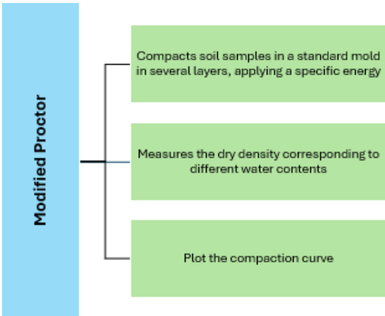


Fig. 5. Modified Proctor

Soil Compaction with Modified Proctor

- Unconfined Compression: Determine the unconfined strength (without lateral support) of the cohesive soil.

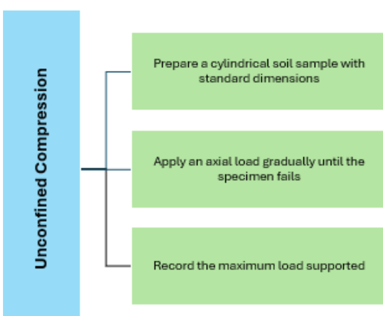


Fig. 6. Unconfined Compression

fiber length measurement

Soil Sample Mixture with Ichu

Unconfined Compression Test with Universal Press

V. RESULTS

Subsequently, the weights are measured to the soil samples for each sieve with the use of a balance with a sensitivity of 0.1% according to what is indicated in the MTC 107 Standard [19].

A. Granulometry

Grain size tests were carried out using sieves according to the MTC standard, in which it was observed that the sample is not fine-grained.

TABLE I
SOIL PARTICLE SIZE ANALYSIS BY SIEVING

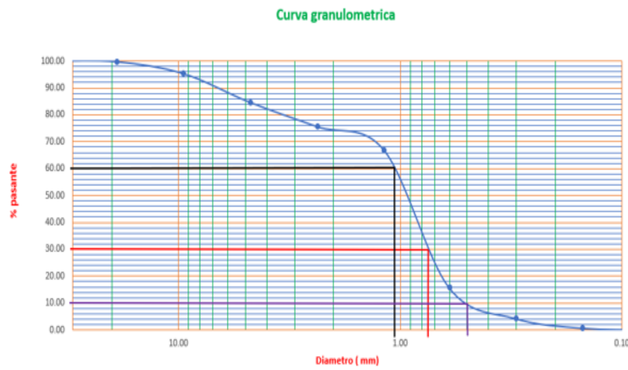
ANALISIS GRANULOMETRICO DE SUELOS POR TAMIZADO					
Tamises	Abertura (mm)	Peso Retenido (g)	% Retenido	%Retenido acumulado	% Mas Fino (%pasa)
1.-1/2"	37.50	0	0.00	0.00	100.00
3/4.	19.00	8	0.27	0.27	99.73
3/8.	9.50	132	4.41	4.67	95.33
N° 4	4.75	320	10.68	15.35	84.65
N° 8	2.360	271	9.05	24.40	75.60
N° 16	1.180	261	8.71	33.11	66.89
N° 30	0.600	1532	51.13	84.25	15.75
N° 50	0.300	344	11.48	95.73	4.27
N° 100	0.150	106	3.54	99.27	0.73
N° 200	0.075	20	0.67	99.93	0.07
Fondo		2	0.07	100.00	0.00
Total		2996			

After performing the calculations, the granulometric curve was determined to find the D10, D30 and D60 and the curvature coefficient and uniformity coefficient were also determined. A well graded or graded soil has a uniformity coefficient greater than 4 for gravels, 6 for sands and a gradation coefficient between 1 and 3 for gravels and sands. Also, a soil may have a combination of two or more uniformly graded fractions. According to the established calculations, for a greater definition of the granulometry, it was obtained that Cu= 2.29 and Cc= 1.31, so it can be inferred that it corresponds to a well graded material.

TABLE II
TABLE OF GRANULOMETRIC CURVE RESULTS

D10	0.496
D30	0.858
D60	1.136
Cc	1.31
Cu	2.29

TABLE III
GRANULOMETRIC CURVE



B. Liquid and Plastic Limit

The liquid limit and plastic limit were determined by laboratory tests, in which the liquid limit was found to have 25% moisture content with three tests of 20, 25 and 30 blows in each test.

TABLE IV
RESULTS OF LIQUID LIMIT

DESCRIPCIÓN	UNIDAD	ENSAYO N° 1	2	3
Peso de tara	W1 (gr)	32.00	32.00	32.00
Peso de tara + suelo húmedo	W2 (gr)	52.00	52.00	52.00
Peso de tara + suelo seco	W3 (gr)	49.00	48.00	48.00
Peso de agua	W4 (gr)	3.00	4.00	4.00
Contenido de humedad	w%	17.65%	25.00%	25.00%
N° de golpes	N	20.00	25.00	30.00

The plastic limit was determined by laboratory tests, which is 20%, and was calculated with the data of tare, wet soil, water weight and dry soil weight.

TABLE V
RESULTS OF PLASTIC LIMIT

DESCRIPCIÓN	UNIDAD	ENSAYO N° 1
Peso de tara	W1 (gr)	31.00
Peso de tara + suelo húmedo	W2 (gr)	37.00
Peso de tara + suelo seco	W3 (gr)	36.00
Peso de agua	(gr)	1.00
PL=(W2-W3)*100/(W3-W1)	PL%	20.00%

C. Modified Proctor

First, the data obtained for the test such as mold height, diameter, volume, mold weight and sample weight were determined. Then, the volumetric weight was calculated.

TABLE VI
MODIFIED PROCTOR DATA

Datos	Espécimen 01	Espécimen 02	Espécimen 03
Altura del molde (cm)	11.69	11.69	11.69
Diámetro del molde (cm)	10.08	10.08	10.08
Volumen del molde (cm3)	932.774	932.774	932.879
peso del molde (gr)	4204	4204	4204
Peso molde + muestra (gr)	6023	6179	5972
Peso de la muestra (gr)	1819	1975	1768
Peso volumétrico húmedo (gr/cm3)	1.95	2.12	1.90

Finally, the calculations of the modified proctor were made in which the moisture content of the three specimens was determined, which was between 8% and 12%.

TABLE VII
MODIFIED PROCTOR RESULTS

DESCRIPCIÓN	MUESTRA 1	MUESTRA 2	MUESTRA 3
PESO DEL SUELO HÚMEDO COMPACTADO+MOLDE (gr)	6023	6179	5972
PESO DEL MOLDE (gr)	4204	4204	4204
PESO DEL SUELO HÚMEDO COMPACTADO (gr)	1819	1975	1768
PESO VOLUMÉTRICO HÚMEDO (gr/cm3)	1.95	2.12	1.90
TARA N°	1	2	3
PESO DEL SUELO HÚMEDO +TARA (gr)	195	237	283
PESO DEL SUELO SECO + TARA (gr)	182	221	268
PESO DE LA TARA (gr)	37	91	91
PESO DEL AGUA (gr)	13	16	15
PESO DEL SUELO SECO (gr)	145	130	177
CONTENIDO DE AGUA (%)	9%	12%	8%
PESO VOLUMÉTRICO SECO (gr/cm3)	1.95	2.11	1.89

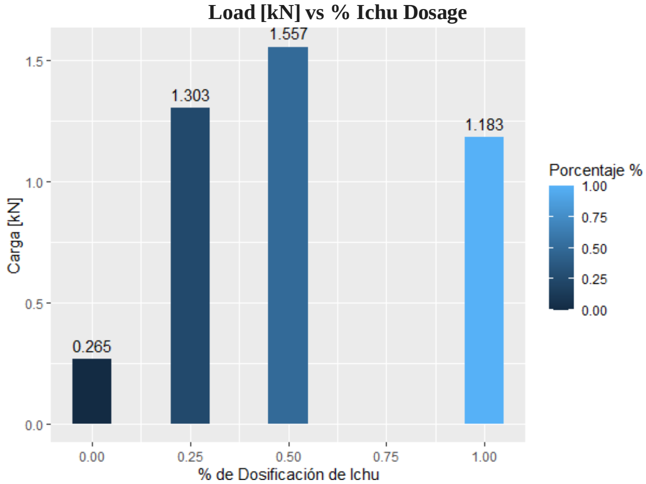
D. Unconfined pressure

The maximum load in the unconfined compression test is at a dosage of 0.5% ichu.

TABLE VIII
UNCONFINED COMPRESSION RESULTS

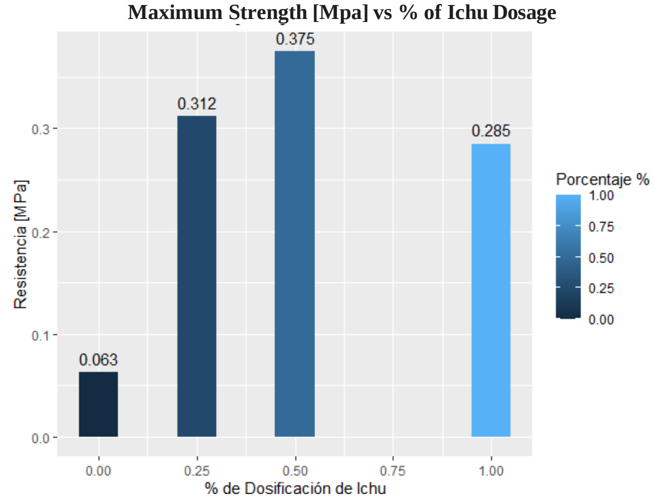
Descripción	% de ichu			
	0	0.25	0.5	1
Carga Máxima (KN)	0.265	1.303	1.557	1.183
Resistencia Máxima (MPa)	0.063	0.312	0.375	0.285
Deflexión Axial (mm)	0.819	1.129	0.146	0.065

Load [kN] vs % Ichu Dosage



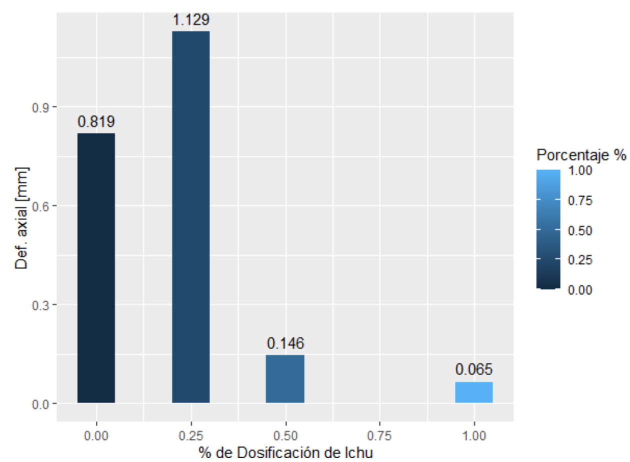
In dosing with 0.5% ichu, a maximum load of 1,557 kN has been obtained

Maximum Strength [Mpa] vs % of Ichu Dosage



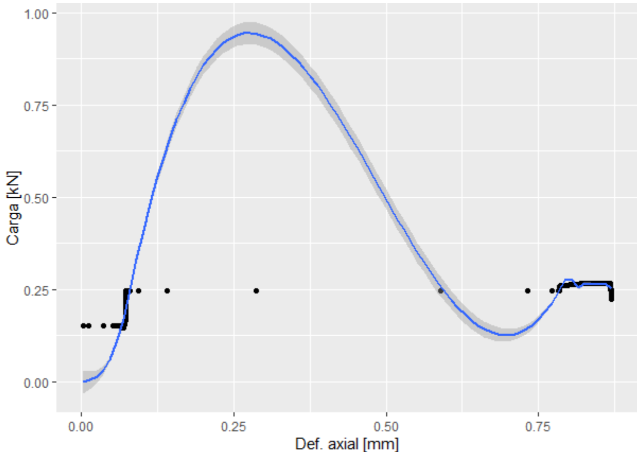
In dosage with 0.5% ichu, the maximum resistance of 0.375Mpa has been obtained.

Axial Deformation vs % Ichu Dosage

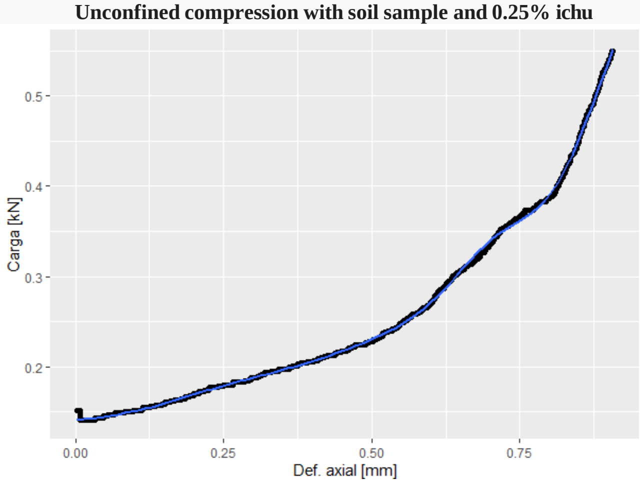


In dosing with 0.5% ichu, an axial deformation of 0.146mm has been obtained.

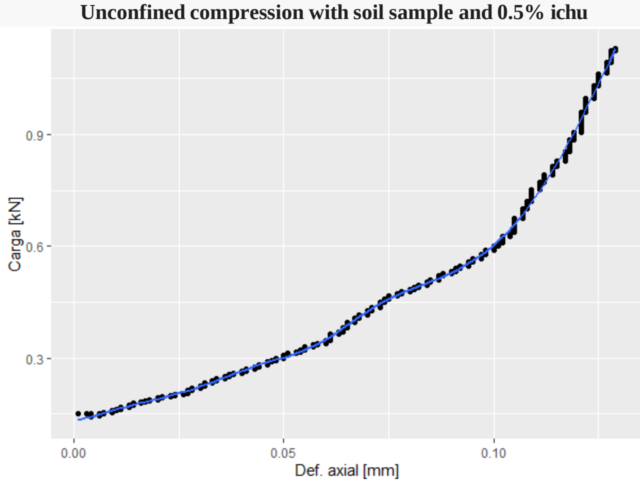
Unconfined compression of soil sample



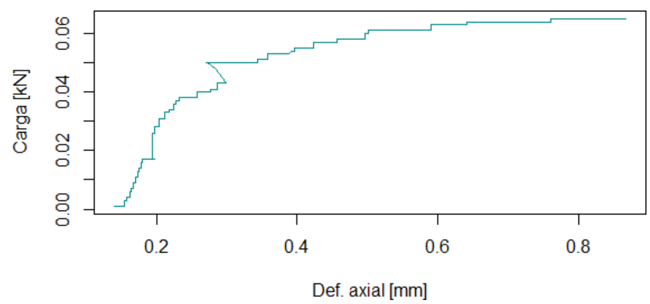
Unconfined compression with soil sample and 0.25% ichu



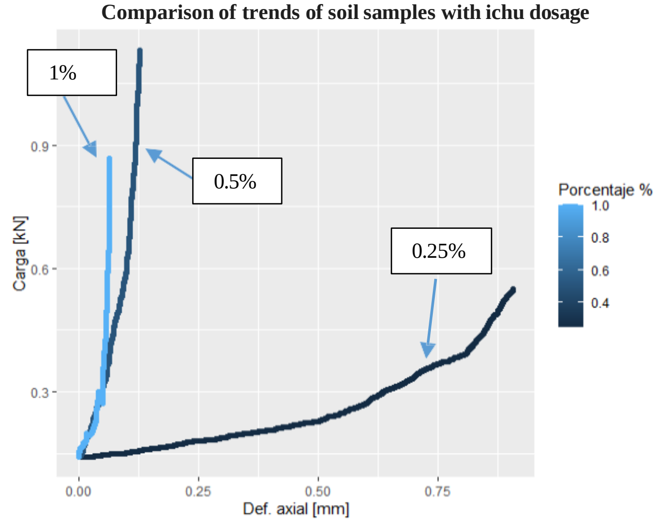
Unconfined compression with soil sample and 0.5% ichu



Unconfined compression with soil sample and 1.0% ichu

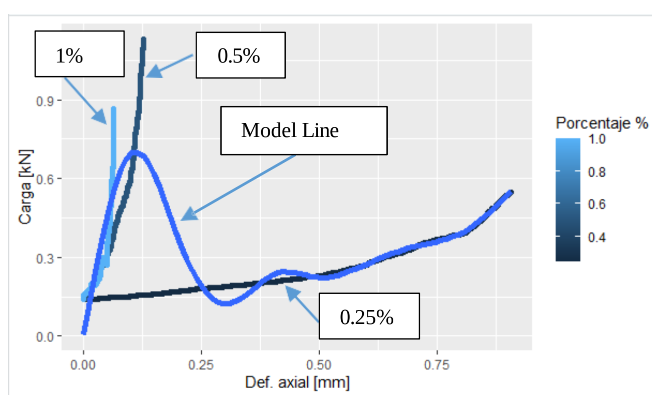


Comparison of trends of soil samples with ichu dosage



In this graph it can be seen that the maximum load is obtained with a dosage of soil with 0.5% ichu.

Trend line of soil sample compression with ichu dosing



In the model line it is observed that its maximum level is intersecting with the load line in kN of the 0.5% ichu dosage, demonstrating that this percentage of icho is the recommended one for soil stabilization.

Conclusions

• For the results of the modified Proctor, method A was used according to what is indicated in MTC E 115 (Ministry of Transport and Communications, 2016).

The optimal density of the soil was determined to be approximately 1.90 gr/cm3.

• The unconfined compression tests on soil samples alone and combined with ichu fiber were carried out in accordance with the provisions of MTC E 121 115 (Ministry of Transport and Communications, 2016).

The maximum load obtained was 1.557 kN with an axial deflection of 0.146mm.

• The optimal dosage obtained was with 0.5% of ichu with respect to the weight of the soil sample, with the ichu being 40 mm long and 0.5% of water with respect to the weight of the soil sample, where the maximum load of 1,557 kN.

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