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Research Article

Effects of Vegetation and Soil Type on the Stability of the Marankiari Road Slope, Chanchamayo

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ARTICLE INFO	ABSTRACT

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The research article presents the results of a study aimed at understanding the effect of vegetation and soil type on the stability of road slopes in the province of Chanchamayo. The data and methods section includes tables showing in detail the analyses carried out in the Soil Mechanics laboratory for slope stability purposes, as well as graphs showing the safety factors and percentage increase in the safety factor considering vegetation independently to see their effects on each type of soil. In the results it was observed that both vegetation and soil type have a significant influence, profile 3 is already considered unstable in the analysis due to the type of soil alone, but if we apply vegetation such as Tillandsias in pseudostatic conditions the safety factor in relation to the initial value of soils increases by 16.36% while in static conditions the safety factor does not increase significantly since it is the most critical profile unlike profile 1 in which in static and pseudostatic conditions with Albizia carbonaria vegetation the percentage increases by 8.35% and 11.14%; and in profile 2 with Ochroma vegetation pyramidale in static and pseudostatic conditions the percentage increase was 16.39% and 19.23%.

Keywords: slope, stability, limit equilibrium, safety.

1. INTRODUCTION

In terms of land routes worldwide, the factors that contribute to landslides on slopes are surface water, lack of cross drainage, also deforestation of the slope, and the decrease in vegetation cover on the slopes increases the probability of landslides of soil masses. Since in 1999 due to intense prolonged rainfall generated the slope slide in the city of Taziutlán, Mexico causing the loss of 110 people (Munive García & Domínguez Morales, 2023). In Latin America various studies were carried out about the stability of the slope located on highways, a clear example is the study carried out in the department of Chontales, Nicaragua that had as its main objective to analyze the instability of the road slope on highway Nic.7, resulting in a very unstable slope, with safety factor values that are below 0.5. It should be noted that, despite applying the rearrangement method to make geometric changes to the slope, the safety factor tended to be even more unstable, mention Prado et al. (2020), thus demonstrating that in Latin America there are still problems with slope stability on land roads.

To address the issue at a national level, landslides are caused mostly by the instability of a slope caused by heavy rainfall or also by seismic activity. In Peru, it is estimated that 5 million people live in areas vulnerable to landslides since it affects the physical infrastructure and the life of the population (Gómez, 2020).

On the other hand, the relationship between the depth of the roots and the depth of the landslides is the indicator of the contribution of the vegetation in the stability, which when the mechanical aspects of the vegetation are considered, the safety factor increases up to 25% (Emadi, et al, 2021). Due to this, this research project entitled Effects of vegetation and soil type on the stability of the road slope, Marankiari, Chanchamayo, in its development theories are reviewed: limit equilibrium method, static analysis, pseudostatic analysis , parts of a slope, mechanical properties , physical properties , cohesion , filtration, characteristics of the plants, which are related to the variables, vegetation,

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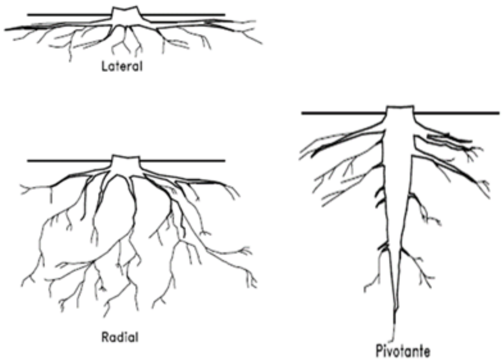
soil type and slope stability. The objective is to determine the effects of vegetation and soil type on the stability of the road slope, Marankiari, Chanchamayo. The importance of the research lies in the recurrence of landslides in winter, which block vehicular traffic, also harming the population that lives in this place, causing damage due to landslides.

To analyze analyse the effect, it is important to know how deep the roots are, which is usually no more than five metres in trees, no more than two metres in shrubs and 30 centimetres in grasses (Diaz, 1998, pág. 283). The following image shows the types of roots.

Figure 1 Types of roots



Reference .(Diaz, 1998, pág. 283)

The roots that are most effective in stabilizing are the taproots. They reach a greater depth compared to vertical or radial roots. He also (Diaz, 1998, pág. 284)states that in most roots the elongation is greater than the depth, unlike taproots, which have a greater depth than their elongation, and therefore the anchoring in the soil is superficial.

According to studies carried out by Emadi et al., (2021, pág. 13)they mention that an increase in the depth of the roots has a positive effect, improving the safety factor of the slope.

2. DATA AND METHODS

2.1. Place of study

The study site was developed in the community of Marankiari, located in the district of Perene, province of Chanchamayo, a mountainous area with diverse vegetation ideal for studying the influence of vegetation and soil type on the stability of road slopes.

The research level aims to describe the effects of soil type and vegetation on slope stability, and is therefore of the applied type because it uses the theoretical knowledge will be considered in a non-experimental design, because no variable will be altered.

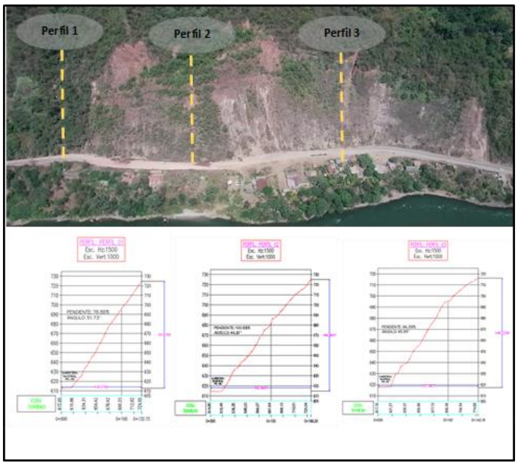
Our population is composed of the cut slopes located on the central road PE 5S belonging to the Perene – Pichanaki section (44.5 km) and the sample by the cut slopes in the Marankiari sector within the progressive km 16+626 to km 16+926 comprising approximately 300 meters of road length.

2.2. Biotechnical stability of the road slope in Marankiari

Biotechnical stability is the method that studies the stability of a slope considering vegetation as a stabilizing agent. This vegetation can be considered native or sown vegetation, taking into account that there is a variety of species such as grasses, shrubs and trees Vallarino et. al (2021, pág. 2). Soils that present both granular and cohesive resistance demonstrate that it is of useful importance to start a slope treatment, however, when there are only granular soils, those that have greater resistance to friction, sliding studies are relatively simple, which are very rare (Smith, 2014, pág. 404).

For the study, a photogrammetric study was carried out for the visual recognition of the native vegetation present on the slope, thus considering three predominant vegetation types: Tillandsias , Ochroma Pyramidale and Albizia Carbonaria.

Figure 2 Slope profiles.



Note. It is observed that in profiles 1, 2 and 3 they include heights with values of 167.6793 m, 165.3697 m and 148.2299 m, slopes of 78.88%, 100.68% and 96.59%; and angles of 51.73 °, 44.81 ° and 45.99 °. The profiles include slopes that are within the range of rugged terrain since according to the Geometric Design Highway Manual it mentions that rugged terrain includes slopes from 51% to 100% (Ministerio de Transporte de Comunicaciones, 2018, pág. 14). The three profiles present detachment of soil mass from the body to the base of the slope, thus being considered rotational failure.

Figure 3 Tillandsias

Note. Native vegetation Tillandsias commonly known as the Orchid family. This vegetation has a type of lateral root that can grow up to 0.2 meters with a life span of 2 years. The Tillandsias are located both in the lower and upper part of the slope within the sections of profile 1 (km 16+626 to km 16+718) and profile 3 (km 16+817 to km 16+926).

Figure 4 Ohrima pyramidal

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Note: Native vegetation Ochroma pyramidale commonly called Huampo Negro. This vegetation has a type of radial root that can grow up to 30 meters with a life span of 7 years. The Ochroma pyramidale pyramidale is located in the three profiles of the study, but is mainly found in the section of profile 2 (km 16+718 to km 16+817).

Figure 5 Albizia carbonaria

Note. Native vegetation Albizia Carbonaria commonly called Albizia . This vegetation has a type of taproot that can grow up to 25 metres with a life span of 30 years. Albizia Carbonaria is located mainly in the lower and central part within the sections of profile 2 (km 16+718 to km 16+817) and profile 3 (km 16+817 to km 16+926).

The method for calculating the safety factor will be the limit equilibrium through the Simplified Bishop, Simplified Janbu and Spencer. The use of this technique has been used over the years as explained by the following authors Abramson et. al (2001), (Craig, 2004), (Cheng & Lau, 2014)and (Smith, 2014). Technique that expresses the slope in slices of dough to obtain the desired results.

2.3. Analysis of the study

There are three fundamental characteristics for calculating the stability of a slope: the unit weight Y (kg/m ^{3}), the cohesion C (KPa) and the angle of internal friction ø (°) Osínski et. al (2014, pág. 2).

Laboratory tests were carried out according to the following standards ASTM C 128 (Specific weight) and ASTM D 3080 (Direct shear test).

The study of the main characteristics of the soil was carried out, it was classified both in SUCS and ASSHTO, which is explained in the following table:

Table 1
Soil type

Profile	Pits	SUCS	AASHTO	Description
1	C-01	GP-GC	A-2-6(0)	Poorly graded gravel with clay and sand
2	C-04	SW-SC	A-2-6(0)	Well graded sand with clay and gravel
3	C-07	GW-GC	A-2-6(0)	Well graded gravel with clay and sand

For the SUCS classification, the symbols were identified according to their classification by granulometry, according to (Das, 2015, pág. 85)the GP-GC group greater than or equal to 15% of sand are considered poorly graded gravel with sand, for the SW-SC group greater than or equal to 15% of gravel are considered well graded sand with clay and gravel and; for the GW-GC group greater than or equal to 15% of sand are considered well graded gravel with clay and sand. It should be noted that it (Das, 2015, pág. 84)also mentions that the percentage of gravel is that which is retained by sieve No. 4 and the percentage of sand is the difference between the percentages retained between sieve No. 200 and No. 4.

To determine the safety factors, the specific weight values were determined considering only the soils:

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Table 2 Data to obtain the FS considering only soils.

Progressive	Profile	Type of soil	Specific weight (gr/cm3)	Cohesion (kPa)	Friction angle (°)
km 16+626 to km 16+718	1	Poorly graded gravel with clay and sand	11.17	7.051	41
km 16+718 to km 16+817	2	Well graded sand with clay and gravel	15.00	10.679	39
km 16+817 to km 16+926	3	Well graded gravel with clay and sand	18.79	13.837	36

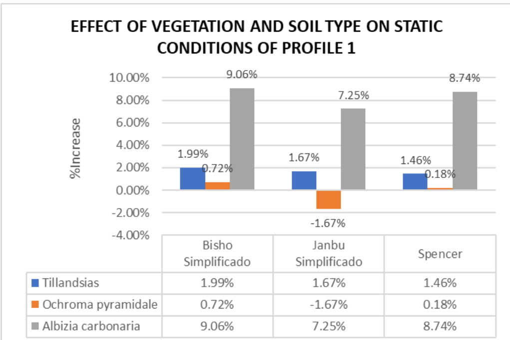
Now, considering the vegetation we proceed to obtain the following results:

Table 3 Data to obtain the FS considering only soils.

DIRECT CUT						
Progressive	Profile	Description	Type of vegetation	Specific weight (gr/cm3)	Cohesion (kPa)	Friction angle (°)
km 16+626 to km 16+718	1	Poorly graded gravel with clay and sand	Tillandsias	11.17	12.56	40
			Ochroma pyramidal	11.17	49.88	34
			Albizia carbonaria	11.17	35.52	38
km 16+718 to km 16+817	2	Well graded sand with clay and gravel	Tillandsias	15.00	5.24	40
			Ochroma pyramidal	15.00	38.74	37
			Albizia carbonaria	15.00	37.20	32
km 16+817 to km 16+926	3	Well graded gravel with clay and sand	Tillandsias	18.79	19.34	34
			Ochroma pyramidal	18.79	44.18	29
			Albizia carbonaria	18.79	34.51	31

Now that we have the values necessary to calculate the safety factors, we will proceed to learn the FS in static and pseudostatic conditions, which will better detail the effect of increasing the safety factor of each vegetation in the different profiles.

Figure 6 Effect of vegetation and soil type on static conditions of profile 1



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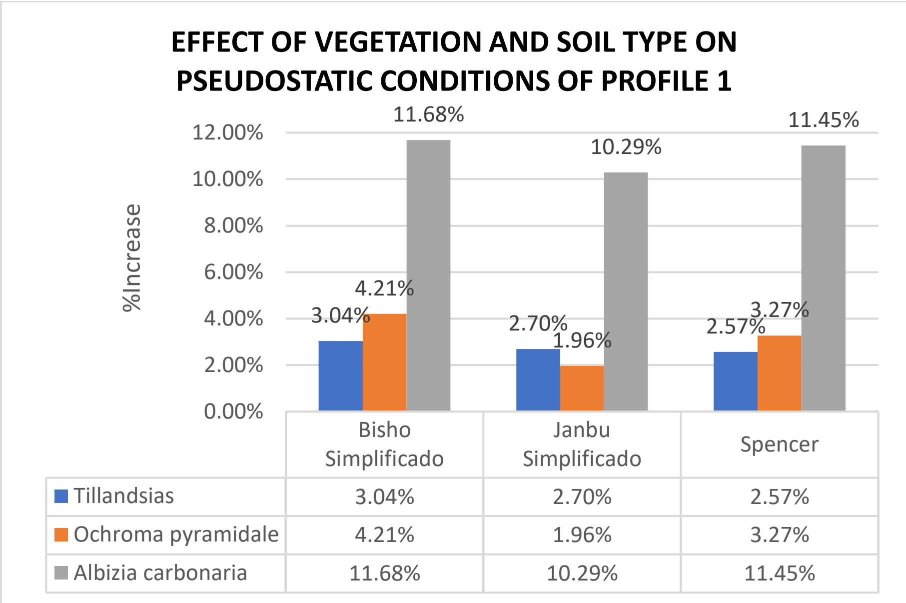
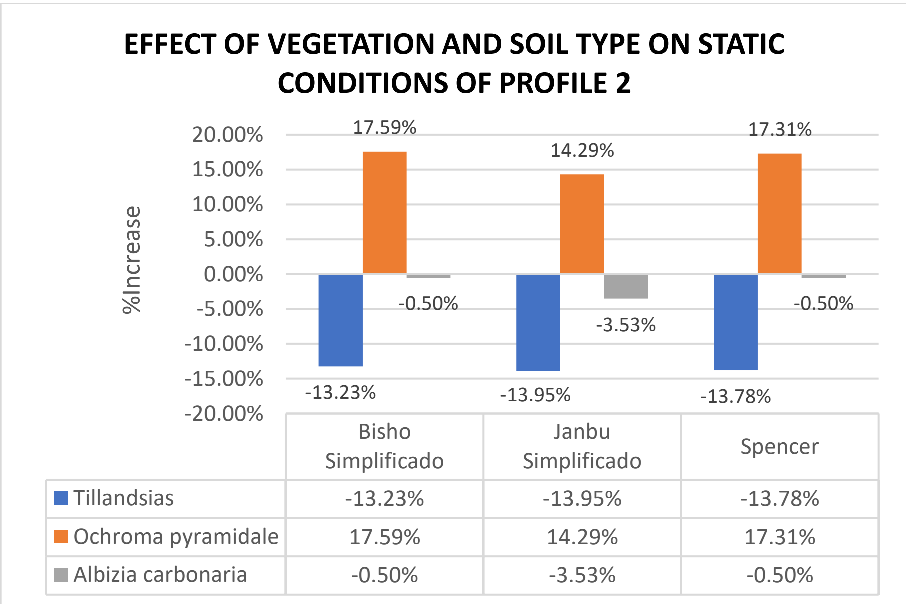
Note. Represents the increase or decrease of the safety factor of profile 1 under static conditions, knowing that it is a poorly graded gravel soil with clay and sand according to the SUCS classification.

Figure 7
Effect of vegetation and soil type on pseudostatic conditions of profile 1



Note. Represents the increase or decrease of the safety factor of profile 1 under pseudostatic conditions, knowing that it is a poorly graded gravel soil with clay and sand according to the SUCS classification.

Figure 8 Effect of vegetation and soil type on static conditions of profile 2



Note. Represents the increase or decrease of the safety factor of profile 2 under static conditions, knowing that it is a well-graded sandy soil with clay and sand according to the SUCS classification.

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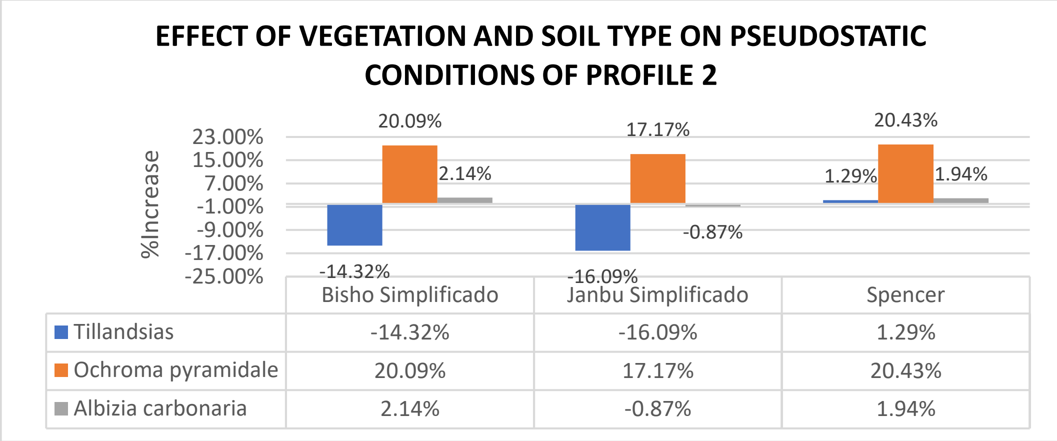
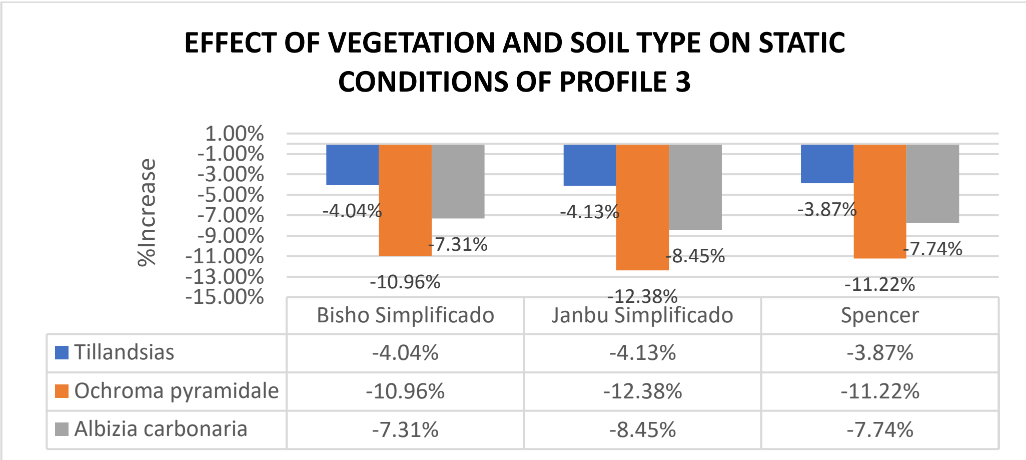
Figure 9 Effect of vegetation and soil type on pseudostatic conditions of profile 2



	Bisho Simplificado	Janbu Simplificado	Spencer
Tillandsias	-14.32%	-16.09%	1.29%
Ochroma pyramidale	20.09%	17.17%	20.43%
Albizia carbonaria	2.14%	-0.87%	1.94%

Note. Represents the increase or decrease in the safety factor of profile 2 under pseudostatic conditions, knowing that it is a well-graded sandy soil with clay and sand according to the SUCS classification.

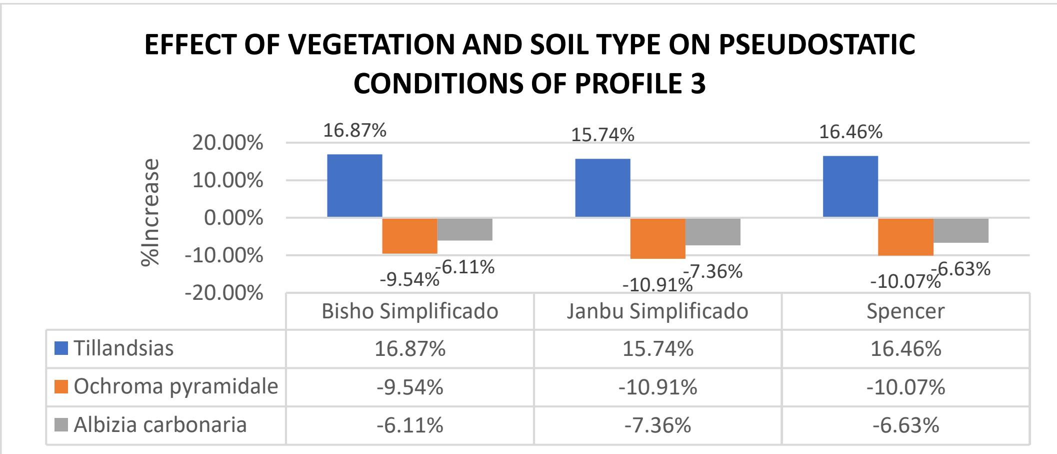
Figure 10 Effect of vegetation and soil type on static conditions of profile 3



	Bisho Simplificado	Janbu Simplificado	Spencer
Tillandsias	-4.04%	-4.13%	-3.87%
Ochroma pyramidale	-10.96%	-12.38%	-11.22%
Albizia carbonaria	-7.31%	-8.45%	-7.74%

Note. Represents the increase or decrease of the safety factor of profile 3 under static conditions, knowing that it is a well-graded gravel soil with clay and sand according to the SUCS classification.

Figure 11 Effect of vegetation and soil type on pseudostatic conditions of profile 3



	Bisho Simplificado	Janbu Simplificado	Spencer
Tillandsias	16.87%	15.74%	16.46%
Ochroma pyramidale	-9.54%	-10.91%	-10.07%
Albizia carbonaria	-6.11%	-7.36%	-6.63%

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Note. Represents the increase or decrease of the safety factor of profile 3 under pseudostatic conditions, knowing that it is a well-graded gravel soil with clay and sand according to the SUCS classification.

3. RESEARCH RESULTS

3.1. Results of the estimation of the effect of vegetation and soil type on the road slope safety factor

Based on the results of the tests carried out in the soil laboratory, the three profiles of the road slope are modelled, taking into consideration the variety of vegetation and types of soil characteristic of each profile.

Under static conditions

The following table shows the safety factors according to the Simplified Bishop, Simplified Janbu and Spencer methods.

Table 4 Safety factor under static conditions

	PROFILE	Method	Simplified Bisho	Janbu Simplified	Spencer
Safety factor in static condition	Profile 1 (km 16+626 to km 16+718)	A-2-6 (0)	0.552	0.538	0.549
		Tillandsias	0.563	0.547	0.557
		Ochroma pyramidal	0.556	0.529	0.550
		Albizia carbonaria	0.602	0.577	0.597
	Profile 2 (km 16+718 to km 16+817)	A-2-6 (0)	0.597	0.595	0.595
		Tillandsias	0.518	0.512	0.513
		Ochroma pyramidal	0.702	0.680	0.698
		Albizia carbonaria	0.594	0.574	0.592
	Profile 3 (km 16+817 to km 16+926)	A-2-6(0)	0.520	0.509	0.517
		Tillandsias	0.499	0.488	0.497
		Ochroma pyramidal	0.463	0.446	0.459
		Albizia carbonaria	0.482	0.466	0.477

Table 4 shows the FS values, where in profile 1 it can be observed that the values increase with the presence of vegetation. In profile 2, however, with the presence of Tillandsias the values decrease, although with the other two types of vegetation they increase favorably. In profile 3 there is a decrease taking into account the vegetation, thus the presence of vegetation in this profile is unfavorable.

Pseudostatic condition

The slope under study, being located in the district of Perene, is in zone 2, for which its maximum acceleration would be 0.25, so the effective horizontal acceleration would be 50% with a value of 0.125 and the vertical acceleration would

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be two thirds of the effective horizontal acceleration with a value of 0.083 according to (Reglamento Nacional de Edificaciones, 2020, pág. 34).

Table 5 Safety factor under pseudostatic conditions

	PROFILE	Method	Simplified Bisho	Janbu Simplified	Spencer
Safety factor in pseudostatic condition	Profile 1 (km 16+626 to km 16+718)	A-2-6 (0)	0.428	0.408	0.428
		Tillandsias	0.441	0.419	0.439
		Ochroma pyramidal	0.446	0.416	0.442
		Albizia carbonaria	0.478	0.450	0.477
	Profile 2 (km 16+718 to km 16+817)	A-2-6 (0)	0.468	0.460	0.465
		Tillandsias	0.401	0.386	0.471
		Ochroma pyramidal	0.562	0.539	0.560
		Albizia carbonaria	0.478	0.456	0.474
	Profile 3 (km 16+817 to km 16+926)	A-2-6(0)	0.429	0.394	0.407
		Tillandsias	0.478	0.456	0.474
		Ochroma pyramidal	0.370	0.351	0.366
		Albizia carbonaria	0.384	0.365	0.380

In table 5, taking into account this pseudostatic condition in profile 1, the presence of vegetation with respect to the soil type, there is an increase in the values of the safety factor. In profile 2, with respect to the soil type of this profile, there is no increase in the values considering Tillandsias and Albizia Carbonaria , but in the case of Ochroma Pyramidale if there is an increase in the values. In profile 3 with respect to the type of soil in this profile, the presence of vegetation causes a decrease in the safety factor, making vegetation unfavourable in this profile. That is to say, in some profiles, depending on the type of soil they have, there is a favourable increase, while in others there is no increase but rather a decrease in the values.

3.2. Results of the evaluation of the effect of vegetation and soil type on the type of road slope failure

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According to the visual evaluation and taking into account the profiles already mentioned, the types of failure are detailed in the following table.

Table 6 Type of road slope failure

Profiles	Progressive	Escarpment depth (m)	Failure surface	Type of fault
Profile 1	km 16+626 to km 16+718	2.30	Superficial	Rotational
Profile 2	km 16+718 to km 16+817	1.00	Superficial	Rotational
Profile 3	km 16+817 to km 16+926	0.5	Superficial	Rotational

Table 6 shows the visual recognition of the type of fault, with the three profiles being of the rotational sliding fault type with a scarp that varies from 0.5 m to 2.30 m, resulting in the section km16+626 to km 16+718 belonging to profile 1 with the greatest sliding material.

3.3. Results of the determination of the effect of vegetation and soil type on the stability of the road slope

The determination is according to the CE.020 standard, which mentions that the minimum value for the slope to be stable is 1.5 in static condition and 1.25 in pseudostatic condition.

Static condition

Table 7 Slope stability considering vegetation and soil type under static conditions

Stability considering vegetation and soil type under static conditions					
		METHOD			
Profiles	Vegetation	Simplified Bisho	Janbu Simplified	Spencer	Standard CE.020
Profile 1	Tillandsias	0.563	0.547	0.557	Unstable
	Ochroma pyramidal	0.556	0.529	0.550	
	Albizia carbonaria	0.602	0.577	0.597	
Profile 2	Tillandsias	0.518	0.512	0.513	Unstable
	Ochroma pyramidal	0.702	0.680	0.698	
	Albizia carbonaria	0.594	0.574	0.592	
Profile 3	Tillandsias	0.499	0.488	0.497	Unstable
	Ochroma pyramidal	0.463	0.446	0.459	
	Albizia carbonaria	0.482	0.466	0.477	

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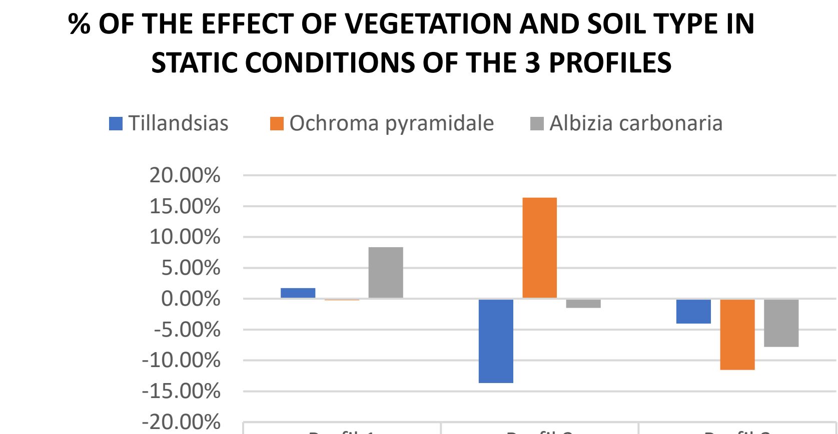
Table 7 shows the level of stability of the road slope considering the type of vegetation in static conditions, in relation to the safety factor and as established in the CE.020 standard where it is determined that profile 3 has greater instability since it has the following safety factors: simplified Bishop 0.463, simplified Janbu 0.446 and Spencer 0.459 considering that it has the type of vegetation Ochroma pyramidale . All three profiles are unstable under static conditions.

Effect of vegetation and soil type on road slope stability

The following graph shows the percentage increase or decrease in the safety factor which determines the stability of the slope considering the presence of vegetation.

Figure 12 Percentage variation of the effect of vegetation and soil type on the safety factor



	Perfil 1	Perfil 2	Perfil 3
Tillandsias	1.71%	-13.65%	-4.01%
Ochroma pyramidale	-0.26%	16.39%	-11.52%
Albizia carbonaria	8.35%	-1.51%	-7.83%

In Figure 12, profile 1 resulted in an increase in FS under static conditions, considering Tillandsias vegetation at 1.71% and Albizia carbonaria with a percentage of 8.35%, these two species influencing positively in this profile. While Ochroma pyramidale decreased by -0.26%.

In profile 2 it resulted in an increase in FS under static conditions, where Ochroma vegetation is considered. pyramidale by 16.39% which has a positive influence. While Tillandsias decrease by -13.65% negatively influencing the profile, and Albizia carbonaria vegetation decreases the FS by -1.51%.

In profile 3 it is the most unstable section in static conditions by the Simplified Bishop, Simplified Janbu and Spencer method; it resulted in the decrease of the FS in the three vegetations, being thus -4.01% Tillandsias , -11.52% Ochroma pyramidale and -7.83% Albizia carbonaria, showing that under static conditions the three vegetation types do not positively influence the FS.

Pseudostatic condition

Table 8 Slope stability considering vegetation and soil type under pseudostatic conditions

Stability considering vegetation and soil type under pseudostatic conditions					
PROFILES	VEGETATION	METHOD			Standard CE.020
		Simplified Bisho	Janbu Simplified	Spencer	
Profile 1	Tillandsias	0.441	0.419	0.439	Unstable

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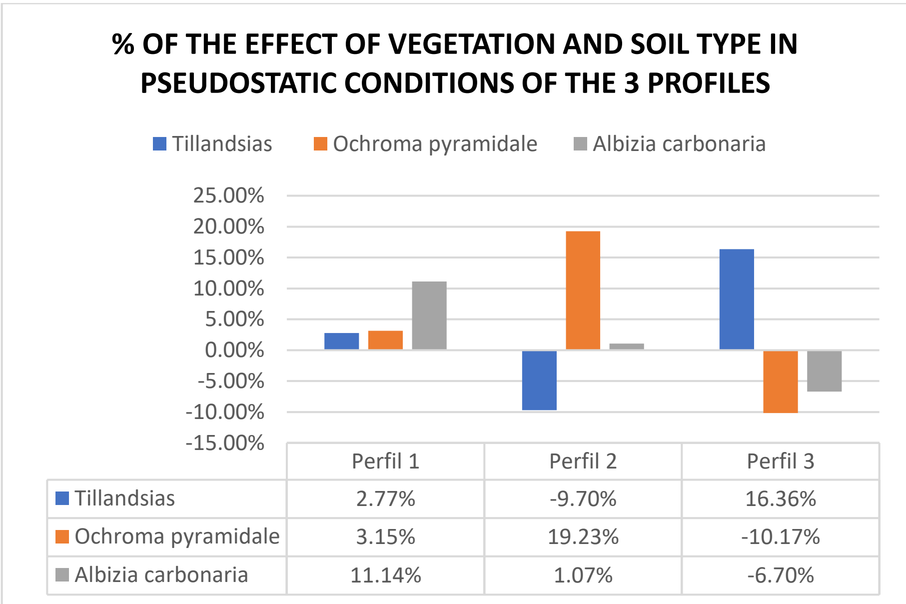
	Ochroma pyramidal	0.446	0.416	0.442	
	Albizia carbonaria	0.478	0.450	0.477	
Profile 2	Tillandsias	0.401	0.386	0.471	Unstable
	Ochroma pyramidal	0.562	0.539	0.560	
	Albizia carbonaria	0.478	0.456	0.474	
Profile 3	Tillandsias	0.478	0.456	0.474	Unstable
	Ochroma pyramidal	0.370	0.351	0.366	
	Albizia carbonaria	0.384	0.365	0.380	

Table 8 shows the level of stability of the road slope considering the type of vegetation in pseudostatic conditions in relation to the safety factor and the CE.020 standard, therefore it is determined that profile 3 has greater instability since it has the following safety factors: simplified Bishop 0.370, simplified Janbu 0.351 and Spencer 0.366 considering that it has the type of vegetation Ochroma Pyramidale . All three profiles are unstable under pseudostatic conditions since their safety factor values are less than 1.25.

Effect of vegetation and soil type on road slope stability

Figure 13 Percentage variation of the effect of vegetation and soil type on the safety factor



In profile 13 it resulted in an increase in FS in pseudostatic conditions , considering the following vegetation: Tillandsias 2.77%, Ochroma pyramidale 3.15% and Albizia carbonaria 11.14%, with Albizia carbonaria having a greater positive influence on the slope.

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In profile 2 there is an increase in FS under pseudostatic conditions considering the Ochroma vegetation pyramidale by 19.23% and to a lesser extent, but positively Albizia carbonaria by 1.07%, and yet Tillandsias generate a decrease in FS by - 9.70%.

In profile 3, the section considered the most unstable in pseudostatic conditions , the Tillandsias vegetation has a positive influence by increasing the FS by 16.36%. While the two remaining vegetations show a decrease in the FS, the most critical of which is Ochroma. pyramidale with -10.17%, then Albizia carbonaria -6.70%, thus showing that under static conditions the three do not positively influence the FS, however, under pseudostatic conditions the Tillandsias do have a positive influence compared to the two remaining vegetations.

4. CONCLUSION

The safety factors in the three profiles were unstable both in static and pseudostatic conditions. Despite this, there was an increase in the safety factor in the vegetation and the soil type in each profile, so that in profile 1, when only the soil type was considered, the values obtained in static conditions were simplified Bishop 0.552, Jambu 0.538 and Spencer 0.549 and in pseudostatic conditions they were simplified Bishop 0.428, Jambu 0.408 and Spencer 0.428. With the Albizia carbonaria vegetation obtaining in static conditions simplified Bishop 0.602, Jambu 0.577 and Spencer 0.597 and in pseudostatic conditions simplified Bishop 0.478, Jambu 0.450 and Spencer 0.477. In profile 2, since only the soil type was considered, the values obtained under static conditions were simplified Bishop 0.597, Jambu 0.595 and Spencer 0.595 and under pseudostatic conditions they were simplified Bishop 0.468, Jambu 0.460 and Spencer 0.465 and with the Ochroma vegetation Pyramidale in static conditions were simplified Bishop 0.702, Jambu 0.680 and Spencer 0.698 and pseudostatic simplified Bishop 0.562, Jambu 0.539 and Spencer 0.560. Finally in profile 3 as the most unstable since only with the type of soil its values obtained in static conditions were simplified Bishop 0.520, Jambu 0.509 and Spencer 0.517 and in pseudostatic conditions were simplified Bishop 0.409, Jambu 0.394 and Spencer 0.407. And when considering the Tillandsias the following safety factors result with static conditions were simplified Bishop 0.499, Jambu 0.539 and Spencer 0.560. 0.488 and Spencer 0.497 and under pseudostatic conditions were simplified Bishop 0.478, Jambu 0.456 and Spencer 0.474.

Regarding the type of failure of the road slope, it presents scarps that have been displaced from 0.5 meters to 2.3 meters, forming rotational faults in the entire section between Km 16+626 and Km 16+926 due to the different characteristics of the soil and the climate.

Having the results of the safety factors, it was found that the Albizia carbonaria vegetation has a positive effect on profile 1, increasing by 8.35% in static conditions and 11.14% in pseudostatic conditions. The Ochroma vegetation pyramidale presents a positive effect in profile 2 increasing by 16.39% and 19.23% in pseudostatic conditions, as for profile 3 the three types of vegetation do not generate an increase in the safety factor in static conditions however in pseudostatic condition Tillandsia generates an increase of 16.36%. Therefore, the vegetation will depend on the type of soil to obtain an increase in the safety factor and at the same time it is appreciated that there is a greater increase in pseudostatic conditions.

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