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SLOPE STABILIZATION AND CONTAINMENT STUDY

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ABSTRACT
Accidents caused by the instability of slopes on the sides of highways are a reality in our country, as it has regions with a subtropical climate and mountainous reliefs. This disorder is responsible for economic, environmental and societal damage. In view of this problem, this work aimed to analyze a slope located on the banks of the MG – 425 Highway that connects the city of Caratinga to the city of Entre Folhas. Therefore, this work proposed slope containment techniques to ensure its safety and stability.

Keywords: Slope stability. Revegetation. Retaluding. Drainage.

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INTRODUCTION

It is common knowledge that the state of Minas Gerais has the largest road network in Brazil, with approximately 270,000 kilometers of federal, state and municipal roads. Being influenced by the subtropical climate and mountainous geoforms, where intense rains cause erosion and gravitational movements, which can often bring economic, environmental and life damage.

Slopes are sloping surfaces composed of earthy, rocky or mixed masses, and can be classified as natural or artificial. Natural slopes are those formed by the geological action or weathering of rocks. These slopes are constantly subject to problems of instability, since gravitational forces act continuously, contributing to the triggering of mass movements.

There are also those who use an essentially physical-mechanical approach to classify the phenomenon, among other perspectives (GERSCOVICH, 2012) and (GUIDICINI; NIEBLE, 2013). Anyone who circulates on the roads of our region, at some point, has come across stretches affected by landslides, mass or solid landslides, or even by various types of erosion. In view of this, the study of slope stabilization processes and containment techniques becomes essential, considering the serious consequences that landslides can cause. The occurrence of these events tends to increase, due to the intensification of urbanization and the development of areas susceptible to landslides, the continuous deforestation of these regions and the increase in precipitation rates caused by climate change (DYMISKI, 2016). The recovery costs of these highways generate large amounts of money annually for the public coffers, and around 150 million reais are spent every year on highway recovery (DNIT, 2017). It is becoming more difficult to ignore the disorderly growth that is taking place in Caratinga MG, both in urbanization and in deforestation for agricultural crops and cattle. On the MG-425 highway, also known as the old alcohol highway, stretches with soil slips can be found, requiring slope stabilization actions. As a result, different types of interventions will be analyzed with the objective of restoring the balance of the slope, taking into account the data obtained in the investigations of
field, laboratory tests, as well as the recommended methods for the execution of the work and its subsequent maintenance.

According to Santos, Oliveira and Martins (2021), an in-depth understanding of the geological characteristics of the region is essential, achieved through studies of pedogeomorphology. In this way, it allows the adoption of customized solutions for different types of slope containment systems. According to Santos et al. (2022), the movement of mass and slopes of roads, as there is no procedure for monitoring and/or technological control of these land masses, may cause inconvenience to those who frequent and travel through these places, given that any physical change alters their stability, causing breakage and fall.

Santa et al. (2022) propose an effective solution for the stabilization of slopes and slopes: the construction of gabions with retaining walls. This approach proves particularly advantageous for excavated streets, roads, and canals due to its low cost and reduced environmental impact. These structures emerge as promising solutions to mitigate the incidence of landslides, a challenge faced in practically all regions of Brazil. By adopting this technique, it is possible not only to strengthen vulnerable structures, but also to promote the resilience of communities and the environment in the face of adverse events. Study slope stability, according to (ZAMBIAZZI; ALEXANDRE NIENOV, 2023), is of fundamental importance in the field of civil engineering, since studies can significantly reduce the risk of damage resulting from the collapse of structures. Such a study plays a fundamental role in preventing potential adverse impacts, which, if they occur, could lead to substantial losses and even serious accidents in civil construction.

Salomão and Laure (2023) state that the stability analysis of a slope must have an in-depth knowledge of the phenomena that can lead to critical circumstances, and it is essential to measure the conditions related to stability, knowing that it is not evident and/or plausible, they also highlight that the movement of slopes in urban areas has resulted in tragedies and serious incidents, especially due to the irregular construction in massifs of unstable soils. The implementation of these approaches not only aims to prevent significant material losses but also to save lives and preserve the environment. For Silva et al. (2023) morphological parameters are crucial in incorporated investigations of vulnerability of terrains to low translational landslides.

According to Araújo et al. (2023), the adoption of digital technologies are tools that offer an innovative and efficient approach to geotechnical risk analysis, allowing for a more accurate and comprehensive assessment of terrain conditions, acting in the prevention, mapping, and monitoring of possible landslides on natural slopes.

The use of these tools emerges as an indispensable strategy in the sustainable management of the natural environment and in reducing the impacts of disasters related to

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landslides. As a result, different types of interventions will be studied to establish the balance of the slope, taking into account the data from field research, laboratory tests and how the execution of the work and its maintenance should take place.

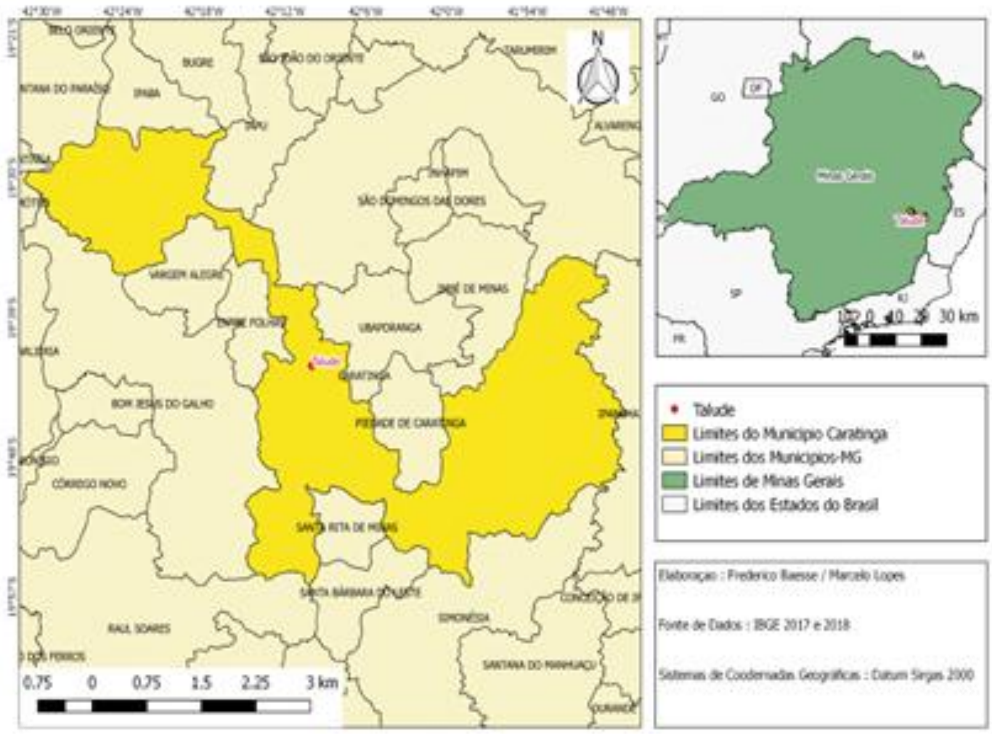
METHODOLOGY

METHODOLOGY

Location of the study area

For the present work, a slope located on the MG-425 highway Latitude 19°42'0.64" S and Longitude 42°9'59" W, a highway that connects Caratinga to the city of Entre Folhas, was studied.

Figure 1 - Location of the slope in Caratinga-MG



Source: Adapted by Authors

Image of the slope taken from the site seen in Figure 01 towards Entre Folhas to Caratinga-MG

Figure 02 - Image of the slope between Folhas and Caratinga-MG

Source: Authors

METHODOLOGY

Types of studies conducted

Laboratory tests for the mechanical characterization of soils are essential components in geotechnical engineering. More in-depth studies on the stress-deformation behavior of soils allow a more precise and rational dimensioning of the works to be executed. For this, we use the Granulometry test, the Liquidity Limit test and the Plasticity Limit test."

Particle Size Test

The particle size test is used to determine the distribution of soil constituent particles in different classes and sizes. It allows you to quantify the percentage by weight of each particle size range.

The main objective of this test is to obtain the granulometric curve of the soil. From this curve, it is possible to estimate the percentages (in relation to the total dry weight) of each granulometric fraction of the soil. The granulometry test is fundamental, as it provides essential information about the type of soil on which works and interventions will be carried out, thus contributing to the safety of workers and future users (ABNT/NBR 7217, 2003)."

Moraes et al. (2021) demonstrated that particle size analysis is an effective tool to determine the dimensions of soil grains on a surface. This study reveals the feasibility of using appropriate methods for such analysis.

Eli and Tsuchiya (2023) highlight that particle size analysis can be conducted through two main methods: sedimentation in liquid medium and sieving. These approaches allow the determination of the proportion of clay and silt, in addition to the separation of materials such as sand and boulders, characterizing their granulometries as coarse, medium and fine.

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Witiuk and Guimarães (2023) emphasize that soil classification systems play a key role as predictive tools to understand the mechanical and physical behavior of the materials studied. These systems make it possible to analyze relevant parameters, making it possible to obtain significant results without the need for excessive investments of resources."

The main equipment and utensils used to perform the Granulometry Test were: Sieve set, scale, porcelain capsule (mortar), pestle.

To carry out this test, 3 soil samples were collected at different points of the slope. Through these samples it was possible to make the classification, being one sample of Horizon Cr and the other samples were classified as Horizon B.

With the sampling soil, weighing began, having: Sample 01: 2.018 KG; Sample 02: 1,030 KG; Sample 03: 1,172 KG. After weighing, the samples were deranged and homogenized. This process was performed using mortar and pestle.

The samples were transferred to a sequence of sieves which had openings of 2.00 mm, 0.84 mm, 0.42 mm, 0.149 mm and 0.074 mm, as shown in Figure 03.

Figure 03 - Porcelain sieves and mortar

Source: Authors

Table 01 shows the normal series sieves in black and the intermediate series in red.

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Table 01 - Sieves Normal Series / Intermediate Series

Number	Aperture (mm)	Number	Aperture (mm)
	76,20	18	1,00
	50,80	20	0,84
1.1/2”	38,10	25	0,71
	25,40	30	0,59
3/4"	19,00	35	0,50
1/2"	12,70	40	0,42
3/8”	9,50	45	0,35
4 or 3/16"	4,76	50	0,297
5	4,00	60	0,250
6	3,36	70	0,210
7	2,83	80	0,177
8	2,38	100	0,149
10	2,00	120	0,125
12	1,68	140	0,105
14	1,41	200	0,074
16	1,19	270	0,037

Source: NBR 5734 of 08/1997

Limits of soil fractions Table 02 by grain size according to ABNT (PINTO, 2000).

Table 02 - Soil fractions

Fraction	Limits
Matacão	From 25 cm to 1m
Stone	From 7.6 cm to 25 cm
Brita	From 4.8 mm to 7.6 cm
Coarse Sand	From 1.2 mm to 4.8 mm
Medium Sand	From 0.3 mm to 4.8 mm
Fine Sand	From 0.05 mm to 0.3 mm
Silt	From 0.005 mm to 0.05 mm
Clay	Less than 0.005 mm

Source: ABNT (PINTO, 2000)

METHODOLOGY

Liquidity Limit (LL)

This test allows you to determine the moisture content of the soil, which is related to the amount of water that binds the particles. When applied to fine or cohesive soils, soil consistency is directly linked to the moisture content present, i.e., the amount of water contained in the soil.

Ribeiro and Souza (2018) argue that Atterberg's limits are intrinsically linked to the liquidity limit, plasticity, and soil contraction, and that moisture values are determinant in distinguishing between different states of soil consistency.

Following the test standard established in the NBR 6459/1984 standard, the following are used to calculate the Liquidity Limit: Casagrande Device; Chisel; Scale with a

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capacity of 200g; Greenhouse capable of maintaining a temperature of 105º to 110º; Porcelain Capsule (Mortar); Aluminum capsule; Metal Spatula; Distilled water; Peseta and soil sieved in pear tree 0.425 mm (nº40).

In the standardized process, the Casagrande appliance is used, with which blows are applied by letting the shell of the appliance fall from a standard height until the groove closes in an agreed extension. (ABNT / NBR 6459, 1984).

To perform the Liquid Limit Test, it is first necessary to adjust the Casa Grande device, Figure 04 so that the contact of the shell with the base (Ebonite) is 1 centimeter from the base.

Figure 04 - Large Home Appliance and Flexible Spatulas

Source: Authors

After calibrating the device, approximately 200 g of soil was placed in the porcelain capsule (mortar) that passed through the No. 40 sieve. Then, according to Figure 05, adding water in a small amount with the help of the peseta and with a metal spatula, a homogeneous mixture of the sample was made.

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Figure 05 - Preparation of the material in the mortar

Source: Authors

As soon as the ideal point of the mixture was reached, the material was transferred to the shell of the Casa Grande device, so that two thirds of the shell is occupied by the soil, and then with the chisel, a groove was made in the middle of the sample, dividing it into two parts, as shown in Figure 06.

Figure 06 - Test on the Casa Grande appliance

Source: Authors

Then, the application of the blows began, carried out with turns on the crank at a rate of two revolutions per second. The strokes are interrupted when the groove closes along 1.3 centimeters, and the number of strokes necessary for the groove to be closed is recorded.

Subsequently, a small sample of the soil is taken exactly at the point where the groove closes and placed in an aluminum capsule, which is weighed before being taken to a greenhouse with a temperature between 105ºC and 110ºC. The sample remains in the greenhouse for 24 hours, and after this period, the humidity is checked.

The rest of the sample, which remains in the shell, is transferred to a porcelain capsule (mortar), to which water is added. The mixture is carried out again to start a new test.

METHODOLOGY

Plasticity Limit (LP)

The Plasticity Limit (LP) is defined as the moisture content at which the soil ceases to be plastic, becoming brittle. It represents the transition moisture between the plastic and semi-solid states of the soil. In the laboratory, the LP is determined by measuring the moisture content at which a 3 mm diameter soil cylinder begins to show cracks.

According to (ABNT NBR 7250/1982), the plasticity limit is described as the property of fine soils, which, within wide humidity limits, are capable of undergoing large permanent deformations without rupture, cracking or appreciable variation (ABNT/NBR 7180, 2016). The moisture content is determined when a cylinder of soil, shaped with the palm of the hand by means of regular back-and-forth movements on a frosted glass plate, begins to crack when it reaches the standard dimensions of 3 mm in diameter and 10 cm in length.

Bicalho et al. (2017) point out that plasticity plays a crucial role in the behavior of the clay-water system, resulting in deformation under the action of finite forces. When these forces are removed or reduced, the concept of plasticity emerges, widely applied in engineering and science.

To perform the Plasticity Limit Test, the following are used: Ground Glass Plate, with about 30 centimeters on a side; Cylindrical Jig, with 3 mm diameter and 100 mm length; Greenhouse; Porcelain Capsules; Aluminum Capsule; Metal Spatula; Pisseta; Distilled water; Balance;

To perform this test, it was necessary to add a quantity of soil to the porcelain capsule (mortar) that passed through sieve No. 40 and with the help of the piste, a small amount of water was added and the material was made into a homogeneous paste. Then, a portion of the sample was shaped and transformed into a small ball, which was rolled with the hands on the ground glass plate until it acquired the shape of a cylinder.

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The samples should reach a diameter of 10 millimeters and a length of 10 centimeters, as illustrated in Figure 07. If they do not reach these dimensions, they must be returned to the porcelain capsule, where more water is added and the mixture is carried out again until the sample becomes homogeneous."

Figure 07 - Plasticity Limit Test

Source: Authors

When the samples reach the measurements of the template, they are divided into similar pieces, which are placed in an aluminum capsule. The capsule with the pieces is then weighed and quickly taken to an oven with a temperature between 105ºC and 110ºC.

RESULTS AND DISCUSSION

Most soil classification systems divide solid particles based on their dimensions, grouping them into the categories: scrub, stone, gravel, silt, clay, and sand, the latter being subdivided into coarse, medium, and fine sand. Through the granulometry test, it is possible to determine the granulometric distribution of the soil, representing it graphically through the granulometric curve, which allows the identification of its physical characteristics.

The objective of the test was to determine the particle size composition of the soil grains, classifying them as coarse or small. The procedure followed the standards of NBR 7181/2016, which describe the method of particle size analysis by sieving, allowing the determination of the dimensions of the particles present in the sample.

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Sample 01 was initially weighed, registering 2.014 kg. After weighing, the deburring process was started using mortar and pestle, with the objective of making the material as homogeneous as possible. Then, the sample was submitted to sieving, and the weight of material retained in each sieve was recorded: Sieve 2.00 mm = 74 g; Sieve 0.84 mm = 240 g; Sieve 0.42 mm = 268 g; Sieve 0.149 mm = 990 g; Sieve 0.079 mm = 296 g; Bottom = 146 g.

Based on the weights obtained in each sieve, the corresponding percentages were calculated, and the results are presented in Table 01, which details the sieve used, its opening and the retained mass."

Table 01. Sample 1

Sieve (mesh)	Aperture (mm)	Retained mass (g)	% retained simple	% retained Accumulated	% pass-through Accumulated
8	2,83	0	0,00	0,00	100,00
10	2,00	74	3,67	3,67	96,33
20	0,84	240	11,92	15,59	84,41
40	0,42	268	13,31	28,90	71,10
100	0,149	990	49,16	78,05	21,95
200	0,074	296	14,70	92,75	7,25
FUND		146	7,25	100,00	0,00
TOTAL		2014	100,00	-	-

Source: Authors

Sample 02 was weighed, registering 1.024 kg. After weighing, the deburring process was started using mortar and pestle, with the objective of homogenizing the material. Then, the sample was submitted to sieving, and the weight of the material retained in each sieve was recorded.

The data obtained for the type of sieve and the weight of the retained samples are presented as follows: Sieve 2.00 mm = 48 g; Sieve 0.84 mm = 206 g; Sieve 0.42 mm = 240 g; Sieve 0.149 mm = 416 g; Sieve 0.079 mm = 92 g; Bottom = 22 g. The results obtained are detailed in Table 02."

Table 02. Sample 2

Sieve (mesh)	Aperture (mm)	Retained mass (g)	% retained simple	% retained Accumulated	% pass-through Accumulated
8	2,83	0	0,00	0,00	100,00
10	2,00	48	4,69	4,69	95,31
20	0,84	206	20,12	24,80	75,20
40	0,42	240	23,44	48,24	51,76
100	0,149	416	40,63	88,87	11,13
200	0,074	92	8,98	97,85	2,15

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FUND	22	2,15	100,00	0,00
TOTAL	1024	100,00	-	-

Source: Authors

Sample 03 was placed on the scale and the weight of 1.112 kg was measured. After weighing, the unraveling process began, using the mortar and pestle, trying to make the material as homogeneous as possible. After this process, the sample was taken to the sieve, where the sample was weighed and retained in each sieve. The type of sieve and the weight of the retained samples are listed below: Sieve 2.00 mm = 18 g; Sieve 0.84 mm= 270 g; Sieve 0.42 mm= 276 g; Sieve 0.149 mm= 444 g; Sieve 0.079 mm= 80 g; Bottom = 24 g.

Results obtained from the percentages performed in each sieve, Table 03 sample 3, showing the type of sieve and its opening, the mass of retained material and the percentages referring to each sample.

Table 03. Sample 3

Sieve	Aperture	Retained mass	% retained	% retained	% pass-through
(mesh)	(mm)	(g)	simple	Accumulated	Accumulated
8	2,83	0	0,00	0,00	100,00
10	2,00	74	3,67	3,67	96,33
20	0,84	240	11,92	15,59	84,41
40	0,42	268	13,31	28,90	71,10
100	0,149	990	49,16	78,05	21,95
200	0,074	296	14,70	92,75	0,00
FUND		146	7,25	100,00	0,00
TOTAL		2014	100,00	-	-

Source: Authors

LIQUIDITY LIMIT (LL) TEST

To perform the Liquidity Limit Test, it was initially necessary to adjust the Casa Grande apparatus (Figure 07, page...), so that the shell was one centimeter away from the Ebonite base. The test was conducted in accordance with the guidelines of NBR 6459/84, which describes the method for determining the liquidity limit of soils. For sample preparation, NBR 6457/2016 was followed, which establishes the procedures for the preparation of samples for compaction and characterization tests.

In the field, three samples of the slope under analysis were collected. After sample preparation, the material retained in the 0.149 mm sieve was used. The material was placed in the mortar and, gradually, a specific amount of distilled water was added until a homogeneous paste was obtained. Using a spatula, this paste was transferred to the shell of the Casa Grande device, trying to reach an approximate thickness of 10 mm. Next, a groove was made in the paste using a chisel, and the crank movement began to count the blows, until the two parts of the groove joined.

After this procedure, a small sample of dough was collected at the point where the parts joined, which was placed in aluminum capsules and taken to an oven previously heated to temperatures between 105ºC and 110ºC. The rest of the dough was returned to the porcelain mortar, and more distilled water was added. Mixing was performed for 3 minutes and repeated four times, performing the complete testing process for each sample.

For each sample, five Liquidity Limit tests were performed, and the procedure was repeated with the three samples collected from the slope. In Sample 1, the tests were performed five times, and the values obtained are shown in Table 4.

Table 04. Liquidity test Sample 1

LIQUIDITY LIMIT TEST - NBR 6459/1984						
Operator:	**José Geraldo/ Kleber Ramon**	**04/11/2019**		**Sample:**		**1**
CAPSULE NUMBER		1	2	3	4	5
CAPSULE + WET SOIL (g)		16,7	13,5	17,20	21,20	20,00
CAPSULE + DRY SOIL (g)		14,10	11,70	14,30	16,60	15,60
CAPSULE (g)		6,1	5,2	6,40	5,5	5,70
WATER (g)		2,60	1,80	2,90	4,60	4,40
DRY SOIL (g)		8,00	6,50	7,90	11,10	9,90
MOISTURE (%)		32,5	27,7	36,7	41,4	44,4
NUMBER OF BLOWS		37	30	26	24	19

Source: Authors

Based on the results presented in Table 4, a graph was prepared that allowed the determination of the moisture content corresponding to 25 blows. According to (NBR 6459/84), the Liquidity Limit of the soil is defined by the moisture content at which the union of the parts occurs after 25 strokes. From the analysis of Graph 4, it was observed that the Liquidity Limit of the soil was 38%.

In Sample 2, the test

Table 05. Liquidity test Sample 2

LIQUIDITY LIMIT TEST - NBR 6459/1984						
Operator:	**José Geraldo/Kleber Ramon**	**04/11/2019**		**Sample:**		**2**
CAPSULE NUMBER		1	2	3	4	5
CAPSULE + WET SOIL (g)		17,3	20	21,80	22,50	22,00
CAPSULE + DRY SOIL (g)		13,20	14,10	14,90	15,20	14,90
CAPSULE (g)		5,7	5,4	5,20	5,6	5,70

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WATER (g)	4,10	5,90	6,90	7,30	7,10
DRY SOIL (g)	7,50	8,70	9,70	9,60	9,20
MOISTURE (%)	54,7	67,8	71,1	76,0	77,2
NUMBER OF BLOWS	37	27	20	18	17

Source: Authors

In Sample 3, the test was also performed five times, and the values are shown in Table 06.

Table 06. Liquidity test Sample 3

LIQUIDITY LIMIT TEST - NBR 6459/1984					
Operator:	**José Geraldo/Kleber Ramon**	**04/11/2019**		**Sample:**	**3**
CAPSULE NUMBER	1	2	3	4	5
CAPSULE + WET SOIL (g)	20,4	15,5	16,70	19,50	18,00
CAPSULE + DRY SOIL (g)	15,20	11,30	12,10	13,10	12,20
CAPSULE (g)	4	3,3	4,10	3,6	3,90
WATER (g)	5,20	4,20	4,60	6,40	5,80
DRY SOIL (g)	11,20	8,00	8,00	9,50	8,30
MOISTURE (%)	46,4	52,5	57,5	67,4	69,9
NUMBER OF BLOWS	36	30	25	19	15

Source: Authors

PLASTICITY LIMIT (LP) TEST

The Plasticity Limit (LP) is defined as the lowest moisture content at which it is possible to mold a cylinder of 3 mm in diameter, using the palm of the hand to roll the soil. LP marks the transition between the semi-plastic and plastic states and is expressed in percentage terms of moisture. The test was conducted according to the procedures established by NBR 7180/2016, with three tests performed for each sample.

To perform the test, the sample was initially placed in the mortar, where distilled water was added. The mixture was homogenized with a metal spatula until it reached a uniform consistency. Then, a small portion of the mixture, approximately 10 g, was used to form the cylinder. The material was rolled on a glass plate, applying enough pressure with the palm of the hand to obtain a cylinder with a diameter of 3 mm and a length of 10 cm, according to the established template. After the cylinder was broken, the material was transferred to an aluminum capsule, weighing the sample, which was then taken to the oven. The drying process lasted 24 hours, with the temperature controlled between 105ºC and 110ºC. The procedure was repeated two more times using the same sample.

In the case of Sample 1, it was not possible to determine the Plasticity Limit, since the sample did not present plastic characteristics. For Sample 2, the results obtained are presented in Table 07.

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Table 07. Plasticity Limit Sample 2

N° CAPSULES	1	2	3
CAPSULE + WET SOIL (g)	7,80	7,80	7,1
CAPSULE + DRY SOIL (g)	7,2	7,3	6,50
CAPSULE WEIGHT (g)	6,00	6,1	5,4
WATER MASS (g)	0,60	0,50	0,60
DRY SOIL MASS (g)	1,20	1,20	1,10
MOISTURE (%)	50,00	41,67	54,55
PROCEDURE FOR OBTAINING THE PLASTICITY LIMIT			
AVERAGE PARTIAL HUMIDITY	48,74		
AVERAGE CHANGE (+5%)	51,17		
AVERAGE CHANGE (-5%)	46,30		
NEW MEDIUM HUMIDITY	48,74		
PLASTICITY LIMIT (nearest integer) %	49		

Source: Authors

In Sample 3, the results were expressed in Table 08.

Table 08. Plasticity Limit Sample 3

N° CAPSULES	1	2	3
CAPSULE + WET SOIL (g)	6,10	5,40	5,8
CAPSULE + DRY SOIL (g)	5,4	4,9	5,20
CAPSULE WEIGHT (g)	3,90	3,7	3,8
WATER MASS (g)	0,70	0,50	0,60
DRY SOIL MASS (g)	1,50	1,20	1,40
MOISTURE (%)	46,67	41,67	42,86
PROCEDURE FOR OBTAINING THE PLASTICITY LIMIT			
AVERAGE PARTIAL HUMIDITY	43,73		
AVERAGE CHANGE (+5%)	45,92		
AVERAGE CHANGE (-5%)	41,54		
NEW MEDIUM HUMIDITY	43,73		
PLASTICITY LIMIT (nearest integer) %	44		

Source: Authors

DETERMINATION OF THE PLASTICITY INDEX (PI)

For Sample 1, the PI, soil 1 did not show LP, being considered a non-plastic soil, Sample 2, the PI of the soil was 17, being considered a highly plastic soil and Sample 3 PI was 13 being considered a medium plastic soil.

RETRODESIGN

The straightening process aims to reduce the height and angle of friction of the slope by means of cutting or filling. Although it is the most cost-effective solution to achieve slope stability, this procedure is not always effective, since decreasing height reduces normal stress, which in turn can decrease frictional force.

As for the physical characteristics of the slope studied, the results obtained indicate that the predominant soil is classified as cohesive dry clay. Based on this classification, the specific weight of the soil is 1.92 g/cm³, and the friction angle can vary between 10º and 20º, while the cohesion is approximately 1.50 kg/cm². These typical values of cohesion and friction angle can be seen in Table 9.

Table 09 - Typical values of cohesion and friction angle

COHESIVE	CLAY	Material	Specific Weight g/cm³	Friction Angle Degree		Material	Cohesion Kg/cm²
		Wet	1,92	Hard Clay	10-20	Hard Clay	1,50

Source: Authors

SLOPE REVEGETATION

Revegetation plays a crucial role in the protection of slopes, since vegetation cover reduces the impact of rain on the soil, dissipates the energy of surface runoff and contributes to the improvement of soil structure. Based on the environmental characteristics of the site, such as climate, relief, temperature, air humidity, radiation, soil type and rainfall, it was possible to identify the most suitable plant species for slope stabilization.

One of the most suitable plant combinations for the slope is the association of legumes with grasses. Legumes, in particular, have deep roots, an important factor for slope stabilization. In addition, these plants have the ability to fix nitrogen in the soil, promoting its enrichment. Grasses, on the other hand, have shallower roots, usually reaching about one meter deep. They stand out for their good photosynthetic performance and high efficiency in seed production and dispersal, fundamental factors in the recovery of degraded areas.

Among the most appropriate legumes for the studied slope are alfalfa, pigeon pea and jack bean. Jackbean, although slow-growing, thrives well in soils of low fertility, is resistant to high temperatures and drought. Alfalfa, on the other hand, adapts easily to temperate, tropical and subtropical climates, being the legume more adaptable to neutral or alkaline soils. In addition, it is drought-resistant due to its deep roots and tolerates temperature drops. Pigeon pea has a deep root system, one of the most important factors for slope stabilization. This plant grows in poor soils with low pH and propagates by seeds.

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In addition to these legumes, Brachiaria decumbens can be included in the revegetation of the slope. This grass adapts easily to areas with a tropical climate and high temperatures, resists in soils of low fertility, grows well in summer and provides good soil cover, complementing the effectiveness of the root system of legumes.

CONCLUSION

As established in the main objective of this study, methods of stabilization and containment of the slope located on the MG-425 highway (Latitude 19°42'0.64" S and Longitude 42°9'59" W), which connects the cities of Caratinga and Entre Folhas, were investigated through research and laboratory tests.

The results obtained in the granulometry test allowed the division of soil particles into groups based on their dimensions, identifying that most of the soil is composed of hard clay. The Liquidity Limit test, used to determine the soil moisture content, indicated values ranging between 57% and 66%. As for the Plasticity Limit and Plasticity Index test, the results revealed that the soil is moderately plastic to highly plastic.

Regarding the physical characteristics of the slope, it was possible to classify the predominant soil as cohesive dry clay, with a specific weight of 1.92 g/cm³. In addition, the soil presented a friction angle between 10º and 20º and a cohesion of 1.50 kg/cm², fundamental data for the evaluation of stability and stabilization methods proposed for the area.

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