Visual diagnosis of roads and slope stability design in the Potosí sector – Ciudad Bolívar

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Abstract: The main idea of this social project comes from the need and the study of a community in vulnerable conditions. Although they have a complete network of public services, this is not the same regarding a consistent road infrastructure. This document mentions some aspects where the design of slope stability structures is critical. Through these studies, the community will have the technical tools, which is the basis for management and process before the corresponding entities, as well as the verification, acceptance and consequent construction of the designs made. The intervention points of the project are on selected routes of the Potosí Sector, Jerusalem locality of Ciudad Bolívar, where a visual diagnosis of roads, topography, georeferencing, in-situ tests, laboratory tests and subsequent tests were carried out.

I. Introduction

With this document, a study and design of stabilization of slopes, in sites that were considered critical to evaluate, is presented to the community of Potosi. Studies and designs that were carried out throughout the year 2017 in the development of the Professional Practice and systematization as a requirement to get the title of Civil Engineer at the University Minuto de Dios.

In response to the need of a forgotten community with a delayed infrastructure and development, it is necessary to ensure the presence of an institution with a social character, to intervene through different fields of knowledge. UNIMINUTO is present in its attempt to set solid basis where the state is not present. here arises the need of an in-depth study of the roads of the sector which due to their topographical conditions, a large number of them do not have pavement structure, this is due to the fact that some of them require stabilization of slopes (reason why, repeatedly, it is not prioritized the construction of roads in the sector). Considering this problem, the project to generate the designs of stabilization of slopes is created, for some of the critical points found. It started with of the visual diagnosis of roads of the sector and all the preliminaries to the designs of stability (Topography, Georeferencing, in-situ probes and laboratory analysis). To subsequently make the design of slope stability, using retaining walls as stabilizing element.

Constant complaints on the part of the community were stated, since, by the poor condition of the roads trash trucks, ambulances, private vehicles and loading cars (essential for transport of food and medicines) cannot approach to several areas of the sector which implies a rudimentary transport, however, is an even bigger problem, for the elderly, children and people in a condition of disability or reduced mobility. Due to the refusal of the entity responsible for providing the sector with the construction of roads (mostly by the difficult topographical conditions), it was agreed with the community, to provide a study related to slope stability, giving a technical argument at the time of application for the construction of steep slopes, that will stabilize later construction of roads.

II. Material and Methods

2.1 Laboratory tests

The laboratory tests that were conducted, were carried out according to the parameters of the rules INVIAS and they were the following:

•Description and identification of soils (manual and visual procedure) [1]
•Standard penetration test (SPT) and sampling of soils with split pipe [2]
•Determination in the laboratory of water content (moisture) of soil, rock and soil-aggregate mixtures samples [3]
•Determination of particle sizes of Soils [4]
•Determination of liquid limit of Soils [5]
•Plastic limit and plasticity of soils index [6]
•immersion method of water with paraffin for unified weights [7]

The test of direct cutting for undisturbed samples (from where physical characteristics of the soil such as mechanical cohesion and the angle of internal friction, are obtained) was not carried out due to the fact that the samples were altered when extracted, and a triaxial test was not possible by the size of the soil particles that have been removed. For this reason, the values of cohesion and internal friction angle were obtained from the method of correlations for resistance in tests SPT, created by the engineer Alvaro Jaime González García, a professor at the National University of Colombia. [8]

2.2 Preliminary, standard penetration test SPT.

According to the Design Manual for Foundations [9], it is necessary to perform a preliminary analysis when making a standard penetration test (SPT). These criteria are fundamental for the test to yield the results that are required depending on the structure, its location, the section of the structure and its height.

Among these criteria it is important to note that (according to AASHTO, 1996 [10]) the depth of drilling for a containment structure must be between 0.75 and 1.5 times the height of the wall, below the foundation level. Depending on the conditions of the terrain, it is drilled until the fulfillment of this parameter or the rejection point (more than 50 consecutive blows in an extracted sample). For the frequency and separation of perforations (defined by FHWA, 2006 [11]), at least 2 perforations are recommended per wall, for very long walls, the separation between perforations should not exceed 60m; for walls less than 6m high, the perforations must be spaced to a maximum of 25m.

Retaining walls and their operation

These walls provide constant lateral support to vertical or almost vertical slopes of the ground. Also, in some cases, construction works require soil excavations where vertical or near-vertical faces can be generated, for example, the basements of buildings in developed areas, construction of tracks in dense topographies or underground transport facilities to shallow (cut and type of construction cover). The vertical faces of the cuts must be protected by temporary containment systems to avoid failure, among the containment systems, one of the most used, are the retaining walls. [12]
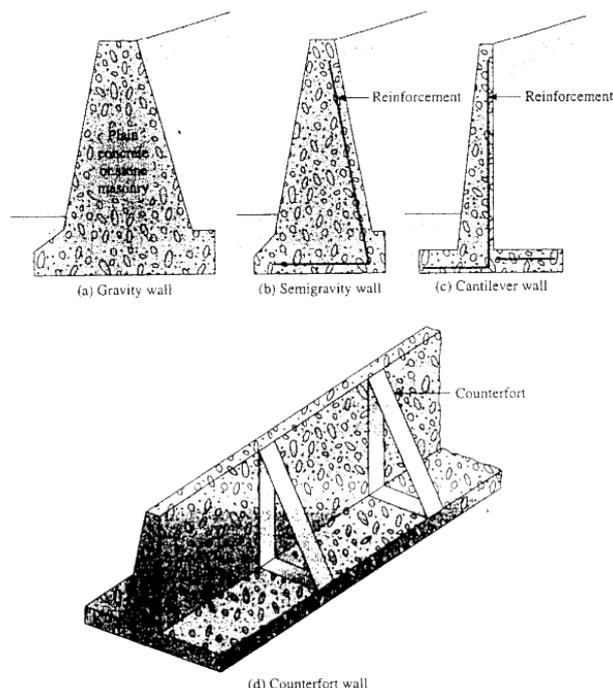
Types of Containment Walls

Fig. 1. Types of Containment Walls. [12]

The gravity walls: they are built with concrete or cyclopean masonry. They depend on their own weight and any ground support on the structure for stability. This type of construction is not recommended for high walls, it can represent high costs. In many cases, the steel can be used for the construction of gravity walls, minimizing in this way the size of wall sections. Such walls are generally known as semi-gravity walls.

Reinforced walls: they are made of reinforced concrete consisting of a thin spur and a base slab. This type of wall is economical up to a height of around 8m. Fig. 1 shows a reinforced retaining wall under the wall under construction, and when compared with the other types of wall, the decrease in cross section is evident, which makes it economically and spatially viable.

Buttress walls: they are similar to reinforced walls. However, at regular intervals they have thin slabs of vertical concrete known as abutments, which join the wall and the base slab. The purpose of the abutments is to reduce the shear stress and the bending moments. [1]
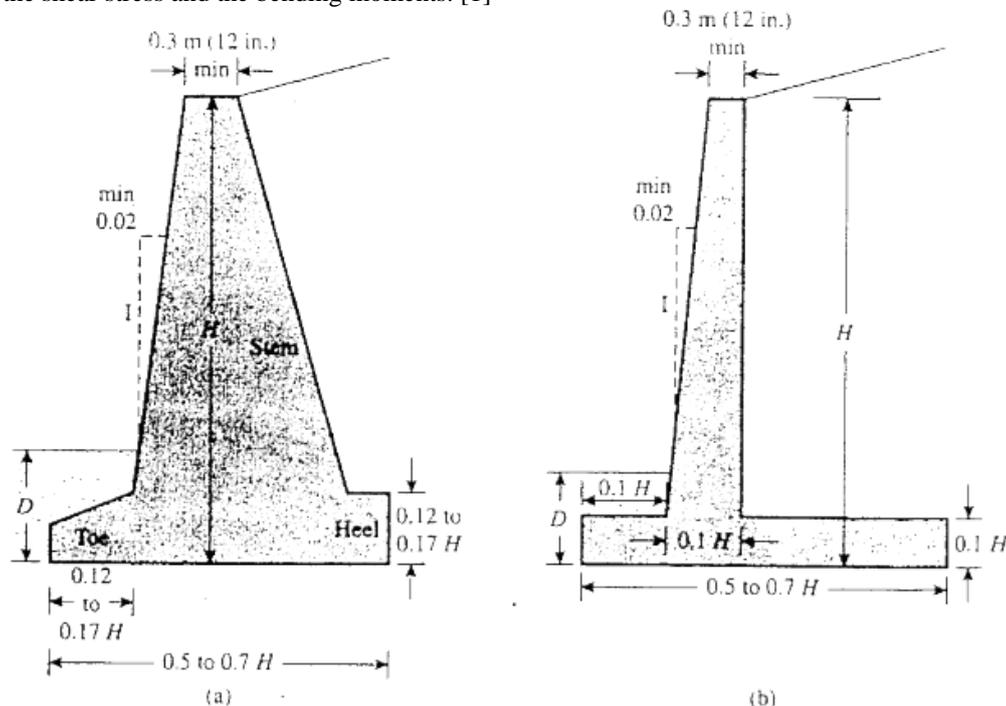

Fig. 2: Approximate dimensions of the various retaining wall components for the initial stability controls: (a) gravity wall, (b) cantilevered wall [12]

For the case of this document, we chose cantilevered or reinforced wall designs.

2.3 SPT test and the correlations obtained for the parameters of the Mohr-Coulomb model.
It consists of counting the number of strokes (N) that are needed to penetrate a soil stratum, with a sample-taking (split spoon) of approximately 45 to 60 cm in length at different depths. The sample-taking is hit, with a free-falling club of 140lb. (33.5Kg) and a drop height of 30in. (76.2cm.) The energy produced by the impact of the cylinder in free fall on the base, provides the necessary thrust to the sample-take to penetrate the ground. This test is carried out in deposits of sandy soil and soft clay; It is not recommended in deposits of gravel, rock or consolidated clay, due to the damage that the drilling equipment could suffer when coming into contact with very hard materials. [13]

The equipment to be used are the following:

- 140lb cylinder, with a drop height of 30in.
- Drilling rods and arms
- Sampler or split pipe with the following dimensions: length: 50cm, outside diameter: 51mm, inner diameter: 35mm
- Total weight: 16lb
- Load tripod
- Flexometer
- Sealant paraffin
- Plastic covers
- ID cards.

This test must be carried out up to 50 strokes, since, after this limit, introducing the drilling equipment within the stratum can cause damage to it. When we have this case, it is said that there is REJECTION (very good rock or soil). [13]

Calculations. The following are the equations to be used: The value of N (number of strokes necessary to drive a 45 cm long sampling in a soil stratum is determined, as mentioned above, by adding the values of N1 + N2 + N3, so:

Where:

  N1: Number of strokes necessary to drive the sample-taking 15 cm.
  N2: Number of strokes necessary to drive the sample-taking another 15 cm.
  N3: Number of strokes necessary to drive the sample-taking another 15 cm.
 From the N of the SPT test the penetration resistance and the admissible pressure can be determined.

$$Rp = N * 4 \qquad (1)$$

Where:

Rp: resistance to penetration
  N: number of hits

Where:

$$\sigma_{adm} = \frac{N}{10} \qquad (2)$$

σadm: admissible load
N: number of hits

Another parameter that can be determined from the N obtained and the subsequent classification of the soil, is the degree of compactness in case of sandy soils and the consistency in case of clay soils, this through Table 1 that relates the mentioned values and that serve as a basis of analysis to the correlations for resistance in SPT trials. [8]

Table 1: Value list for resistance parameters. [10]

COMPACTNESS (Granular Soil)	Degree of compactness	N (S. P. T.)	Static penetration resistance	□
Very loose	< 0,2	< 4	< 20	< 30
Loose	0,2 - 0,4	4 - 10	20 - 40	30 - 35
Compact	0,4 - 0,6	10 - 30	40 - 120	35 - 40
Dense	0,6 - 0, 8	30 - 50	120 - 200	40 - 45
Very dense	> 0,8	> 50	> 200	> 45

2.4 Attractive forces between particles.
When the edges and surfaces of the particles are charged oppositely, there is attraction due to the interactions between the double layers of the opposite sign. It is observed that the fine particles of the soil adhere when they are dry. The electrostatic attraction between surfaces with different potentials has been suggested as a cause. When the gap between the surfaces of parallel particles separated by the distance d in the potentials v1 and v2 is conductive, there is an attractive force per unit area, or tensile strength, given by:

$$F = \frac{4.4 * 10^{-6}(V_1 - V_2)^2}{d^2} N/m^2 \qquad (3)$$

Where f is the tensile strength, d is in micrometers, and v1 and v2 are in millivolts. This force depends on the particle size and becomes significant (greater than 7kN / m² or 1psi) for separation distances less than 2.5nm. [14]

In the SPT correlation calculations, the minimum cohesion values suggested by the electrostatic attraction were taken, since in some cases, the formulation showed cohesion values of 0KN / m², which in real conditions does not happen, due to the effects of electrostatic attractions.This section presents the phase-wise description of the developed risk-impact assessment methodology.

III.   Location

The Potosí neighborhood is located in location 19 of Ciudad Bolivar, UPZ 70 Jerusalem. Bordered on the north by Zanjón de la Muralla and Caracolí neighborhood, east by Las Brisas neighborhood, west by Zanjón del Ahorcado and rural area of Ciudad Bolívar and south by the Arborizadora Alta neighborhood.

The use of land is residential and commercial stratum 1, it is evident within the neighborhood public transport service, cargo and private.

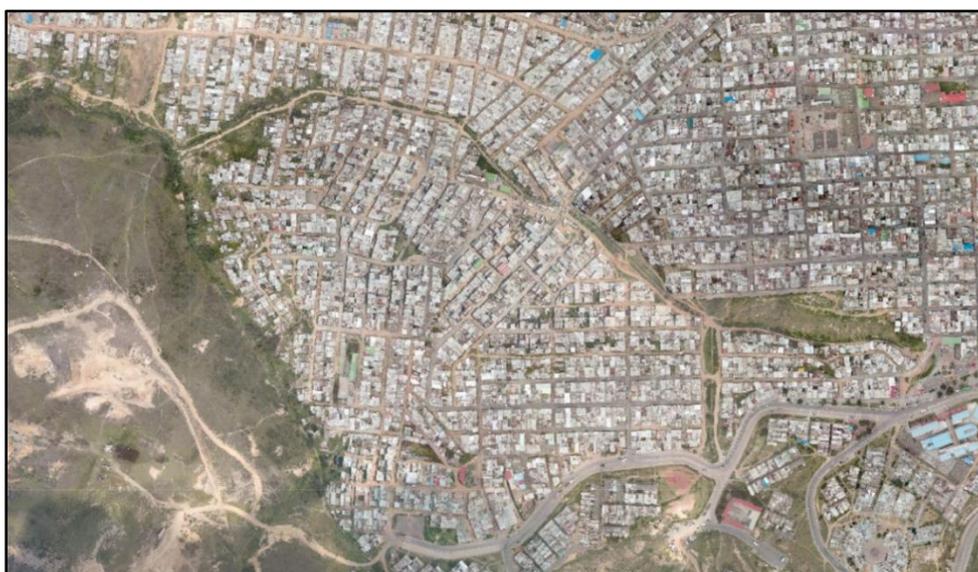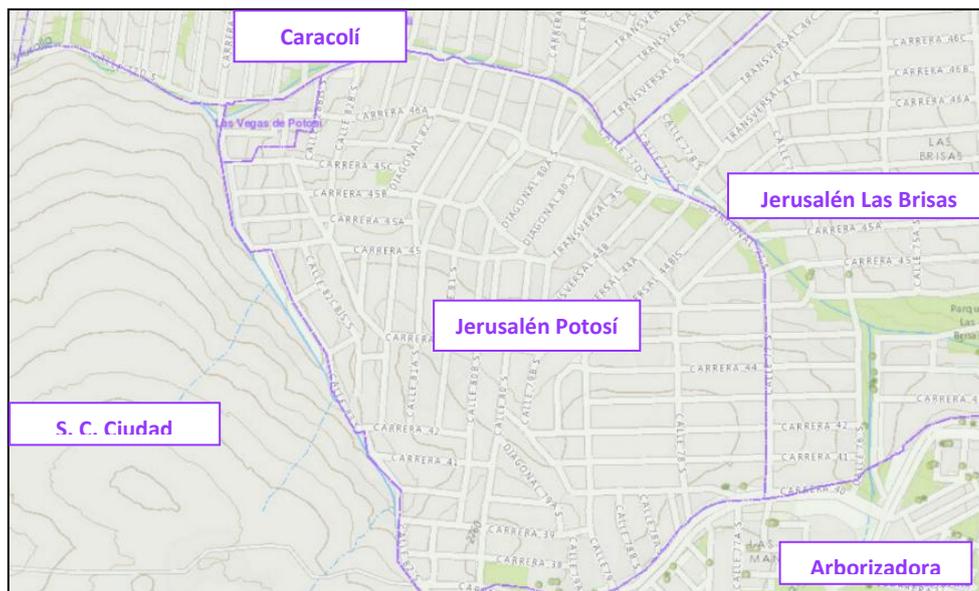**Fig. 3: Neighborhood distribution of the Potosí Sector, Ciudad Bolívar [15]**

Fig. 4: Satellite photography of the Potosí Sector, Ciudad Bolívar. [16]

IV. Geology

4.1 Regional Geology

In the central zone of the Eastern mountain range is the Sabana de Bogotá, from which rocks sprout from the superior Cretaceous to the Quaternary, which are evidence of sedimentation conditions. In the formations La Frontera, Chipaque, Conejo and Simijaca are the oldest rocks; this sedimentation occurred in marine environments with the deposit of approximately 1,200m of sequence. The sedimentation conditions change from the Campanian and it is deposited in distal zones, the sedimentation continues with the Formation of Plaeners in the Superior Campanian.

The sedimentation of fluvial origin in the Paleogene and the Neogene in the origin of the formations Regadera, Cacho, Bogotá and part of Tilatá. The Miocene is a time of active tectonics, folding, faulting and uplift of the Eastern mountain range that affected the formations before depositing and possibly formed the basin of the current Sabana de Bogotá.

The area of the Sabana de Bogota is an area that has a great diversity of resources that allow the supply for itself and some close areas, in minerals such as gravel, clays, sands and coal, depending on the development of a plan proper ordering. There are areas with salt diapirism, generally located in the core of the anticlines, such as those observed in Nemocón, Zipaquirá and possibly between the sector of Sesquilé and La Calera. [17]

4.2 Local Geology

Thanks to geological and soil studies, Ciudad Bolivar can be divided into eleven zones, from which the following stand out: One located to the north, corresponding to a relatively flat sector, with slight inclinations surrounded by the neighborhoods of Candelaria la Nueva, San Francisco and Abraham Lincoln. This corrected area of the Tunjuelito river is composed of expansive clays, which make the land unstable, threatening the current housing, the non-continuation of the urbanization process is warned.

Due to the fillings caused by the old exploitations of material in the sector, the area delimited by the artillery school (Tunjuelito), the neighborhood Mexico to the north and, neighborhood the Cortijo to the south, whose soils are mainly composed of sandy-silty gravels, the area is at risk due to the instability of the land in the attempt to urbanize. From the neighborhood Rincón and in a south to north way, passing by the areas of the Volador, the Canteras of Peña Colorada and the Tanque, located in an intermediate point of CiudadBolívar (Sierra Morena) sloping soils vary from 20 ° at 40 ° formed by sandy layers classified as high risk soils. Towards the west of neighborhood Los Alpes, the Colombian Institute of Geology and Mining INGEOMINAS recommends urbanizing in sectors with smoother slopes (15 to 30 °).In the village of Quiba the land is made up of hard sandstones, with gentle inclinations that do not exceed 20°; what does not allow the presence of geotechnical risks, making the area suitable for urbanization. [17]

V. Visual Diagnosis of Roads

A visual diagnosis of all the road sections evidenced in the sector was made. While walking, important information for the analysis of the actual condition of the roads was collected, such information was related to the type of pavement, the condition of the pavement and if it had coverage of public services.

From this diagnosis a book was generated and given to the community. The document includes an elaborate data sheet (see Fig. 3) that contains the technical data collected from each of the road sections. A total of two hundred and eighteen (218) cards were made with the data of each section found in the sector. Also, for the sections of paved roads, a diagnosis of pathologies present in the pavement was made, both for rigid and flexible pavement, taking as reference the guidelines of the Visual Inspection of Flexible Floors manual [18] and the INVIAS Visual Inspection of Rigid Pavement [19]. (Although some sections of the roads were paved, they were not necessarily in good condition). From the diagnosis was generated a plan that contains the information of the type of pavement of each section of the roads of the entire area that includes the neighborhoods of Potosí, Las Brisas and Jerusalem in Ciudad Bolívar.

It was also made a parallel between the information generated, and that one provided by the IDU on its web site. When comparing the diagnosis that was made with the information provided by the digital platforms, numerous inconsistencies were evidenced, since in the diagnosis that was made, unpaved roads were found, but in the IDU report they appear paved or finished.

Information from the different public services providers was collected and it was found that the neighborhood has a full coverage of essential public services. (Drinking water and sewage system, energy and natural gas). The study carried out in this diagnosis allowed to find the critical points where it was considered necessary to have technical studies for slope stability. Although there are several interventions to be made, six (6) critical points were prioritized.

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Fig. 1: Example sheet of the Visual Diagnosis of Roads. Source: Own creation

5.1 Charts and percentages of the diagnosis.

From the study carried out it can be established that more than 50% of the roads do not have a pavement structure (affirmed or mill). This represents a potential risk for the inhabitants of the sector considering that due to the difficult topographic conditions, the displacement is very difficult for anyone, but it is even more difficult for people with disabilities, elderly people, pregnant women and children. The displacement of people would be even more dangerous depending on how optimal are the weather conditions. The results of the study carried out are the following:

Table 2: Total sections according to types of pavements. Source: Own creation.

PAVEMENTS	SECTIONS
AFFIRMED	112
FLEXIBLE	24
MILLING	52
RIGID	29
STONE	1
TOTAL	**218**

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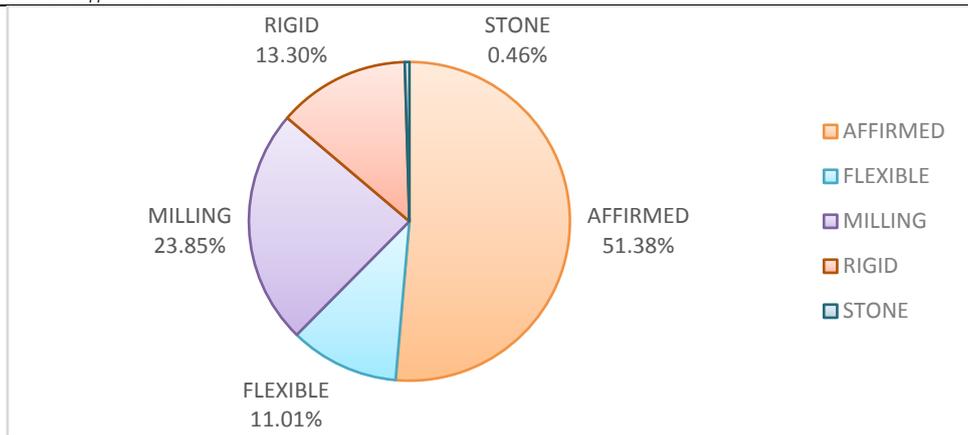*www.ijlrhss.com || PP. 85-103*

Fig. 2 : Total percentage of sections according to types of pavements.Source: Own creation.

Chart 1: Total meters according to types of pavements. Source: Own creation

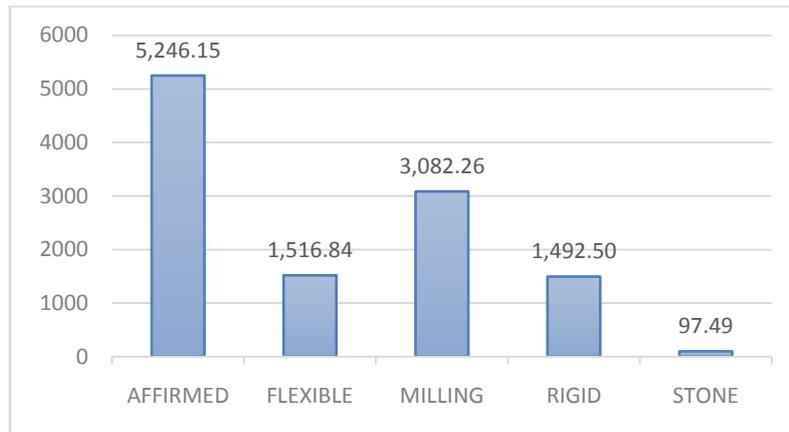| PAVEMENTS	SECTIONS
AFFIRMED	5246.15
FLEXIBLE	1516.84
MILLING	3072.26
RIGID	1492.5
STONE	97.49
TOTAL	**11425.24**

Fig. 3 : Total meters according to types of pavements.Source: Own creation
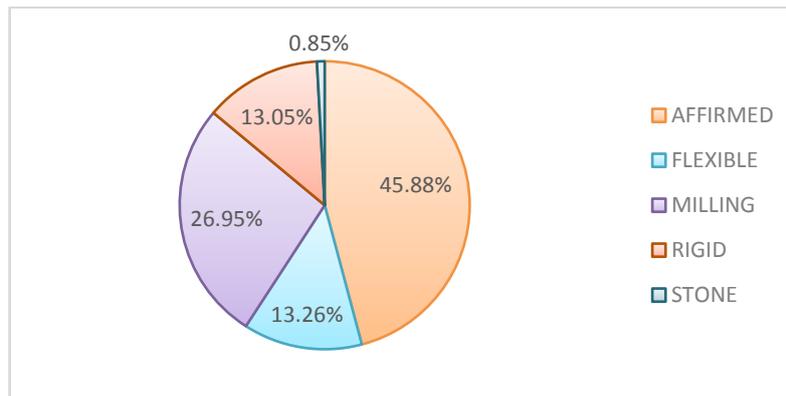

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Fig. 4: Total percentage according to length obtained from the different types of pavements Source: Own creation.

VI. Topography

The topography was performed with Topcon Total Station GTS 120N, where more than one thousand (1000) points were taken in the places where a slope stability study was required, the georeferencing was done with an Ashtech Promark GPS Antenna (see attached report). A total of 6 sections were analyzed as it is shown below.

Slope 1 – KR 44 between CL 76 SUR and CL 78 SUR

Fig. 9: Slope 1 Source: Own creation.

Slope 2 – KR 43 between CL 77 SUR and CL 78 SUR

Fig. 10: Slope 2 Source: Own creation.

Slope 3 – CL 82C SUR between KR 45 and KR 45B

Fig. 11: Slope 3 Source: Own creation.

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Slope 4 – KR 46A between DG 82A SUR and CL 72B SUR

Fig. 12: Slope 4 Source: own creation

Slope 5 – CL 81 SUR between KR 38 and KR 39

Fig. 13: Slope 5 Source: own creation

Slope 6 – KR 40 between CL 77 SUR and CL 78 SUR

Fig. 14: Slope 6 Source: own creation

Topographic plans were made with their respective transversal cuts for each slope, the cross section is taken at the critical point of the slope, that is, the point where the height and the slope are greater; This is due to

the fact that it is at these points that it is necessary to carry out soil explorations and design models. A general map of the location of the intervention points of the six (6) slopes is also generated.

VII. Exploration Y Labs

7.1 Exploration

For the in-situ soil explorations, SPT perforations were made, two (2) per slope: one in the top and the other in the base of the slope. Considering that there were 6 slopes to be evaluated, twelve (12) explorations were made in total. The penetration was until reaching the point of rejection (more than 50 strokes) or up to the maximum height of each slope.
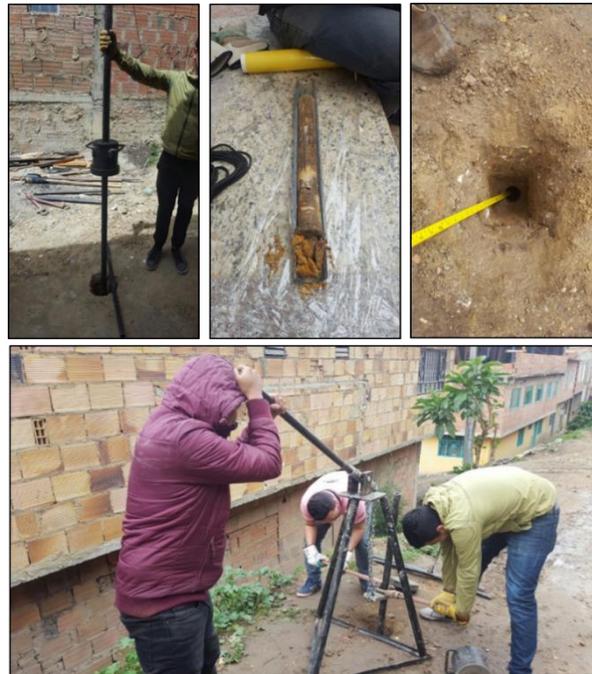

Fig. 15: Soil exploration in-situ. Source: own creation.

7.2 Labs

Fig. 16: Laboratory tests. Own source

The laboratory tests were carried out with the samples obtained from the SPT, where they were tested for granulometry by sieving, natural humidity, limits of Atterberg, unit weight by paraffin and soil classification. Direct cutting tests were not performed due to the fact that under ideal conditions, the samples have to be

extracted from the soil, in an unaltered way, and the SPT (standard penetration test) extracts only undisturbed samples.

The undisturbed samples are extracted with triaxial tests, but granular and rocky soils were found, such samples would not fit in the test cylinder. This is why the calculation of friction angle and soil cohesion were calculated with the SPT hits correlation procedure, designed by Engineer Álvaro J. González García, professor at National University.

VIII.   Analysis of Stability

In total, six (6) slopes were studied, however, only the analysis, results and designs of only one (1) slope would be shown, this, considering that the process was the same for all the slopes. It is important to mention that Slope 1 does not require containment structure, this is because the slope by itself meets the safety factor in both the static and the dynamic case according to NSR - 10, title H. And for the slope 5, no intervention was developed, since rocky bodies were evident in the whole surface of the slope, the analysis in rocks is different from the analysis of the soil. To obtain their physical-mechanical properties, it was necessary the RQD (Rock Quality Designatión) test that is developed by geologists with different equipment that it was not possible to have for the exploration, compared to the SPT equipment that was used for the other explorations and which was completely available.

Table 4: Stratigraphic profile - Slope 2 Source: Own creation.

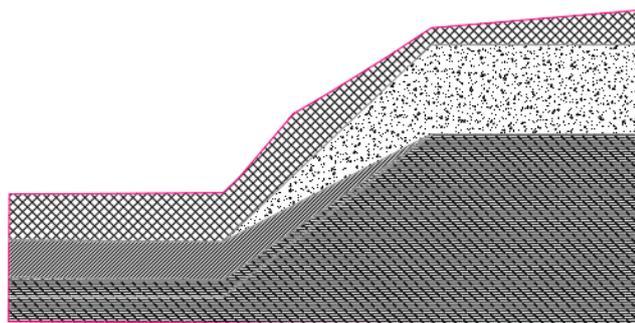| Stratigraphic profile Slope 2	
Layer	**Material**
CP	Poorly graded sand with the presence of silt
1	Sand poorly graded coffee with traces of rust
2	Poorly graded orange sand
3	Poorly graded sand with low plasticity slime

Fig. 17: Stratigraphic profile - Slope 2. Source: own creation

8.1 Static Case

According to the NSR-10 standard, the minimum safety factor for slope stability is 1.5. The selected slopes are modeled below, in case that the slope has a safety factor less than 1.5, it is necessary to carry out a stabilization design for that slope. All the analysis models were developed by the software Slide 6.0 which is ideal for the analysis of slope stability and, all the data, with which the analyzes were fed, were obtained in the calculations of the laboratory tests and the correlations of the SPT test.The analyzes were developed with overloads of 50kN / m² that simulate the efforts on the top of the slope, which the ground would have to support for vehicular traffic and machinery.
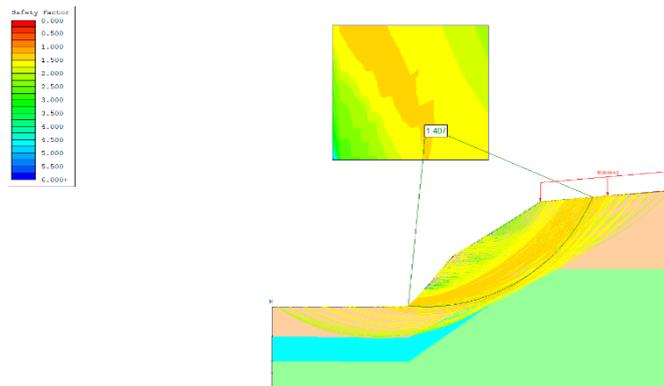
Slope 2

Fig. 18: Static Analysis – Slope 2. Source: own creation
FS=1.407 DOES NOT MEET, requires stabilization design.

8.2 Dynamic Case

For the dynamic case, what must be taken into consideration is the possible effects of an earthquake on the structure. For this case as for the static case, the standard sets a minimum-security factor for the slope, however, and unlike the static case, this Security Factor is 1.05. All the models of analysis were developed using the software Slide 6.0, ideal for the analysis of slope stability. All the data that contributed to the analyzes were obtained in the calculations of the laboratory tests and the correlations of the SPT test. However, for the dynamic case, it has to be considered the factor of spectral acceleration (acceleration that is necessary to load the model). This factor was obtained from the seismic microzoning of Bogotá (for this specific case) from where a coefficient of horizontal seismic force of 0.16 was obtained and a vertical one of 0.016. This applies only to Zone 5 (see Bogota seismic microzoning). The analyzes were carried out with overloads of 50kN / m² which simulate the efforts in the top of the slope, which would have to support the ground for vehicular and machinery traffic.

For zone 5:

$Am=Aa$
$Am=0.2$
Horizontal force $=Aa*0.8=0.2*0.8=0.16$
Vertical force=10% Horizontal force$=0.1*0.16=0.016$

CONDITION	BUILDING	STATIC	SISM	STATIO SEUDO
GLIDE	1.6	1.6	DESIGN	1.05
VOLCAMIENTO: THE ONE THAT RESULTS MORE CRITICISM OF RESISTANT MOMENT / MOMENT ACTUATING EXCENTRICITY IN THE SENSE OF THE MOMENT (e / B).	> 3.00	> 3.00	DESIGN	> 2.00
EXCENTRICITY IN THE SENSE OF THE MOMENT (e / B).	< 1/6	< 1/6	DESIGN	< 1/4
BEARING CAPACITY	EQUAL TO THOSE IN TABLE H.4.1			
INTRINSIC STABILITY POTTERY MATERIALS (reinforced or not)	EQUAL TO THOSE IN TABLE H.2.1			
INTRINSIC STABILITY MANUFACTURED MATERIALS	ACCORDING TO MATERIAL (CONCRETE-TITLE C; WOOD-TITLE G; ETC.)			
GENERAL STABILITY OF THE SYSTEM:				
PERMANENT OR LONG-LASTING (> 6 months)	1.2	1.5	DESIGN	1.05
TEMPORARY OR SHORT-TERM (<6 months)	1.2	1.3	50% OF DESIGN	1
Adjacent slopes (zone of influence> 2.5H)	1.2	1.5	DESIGN	1.05

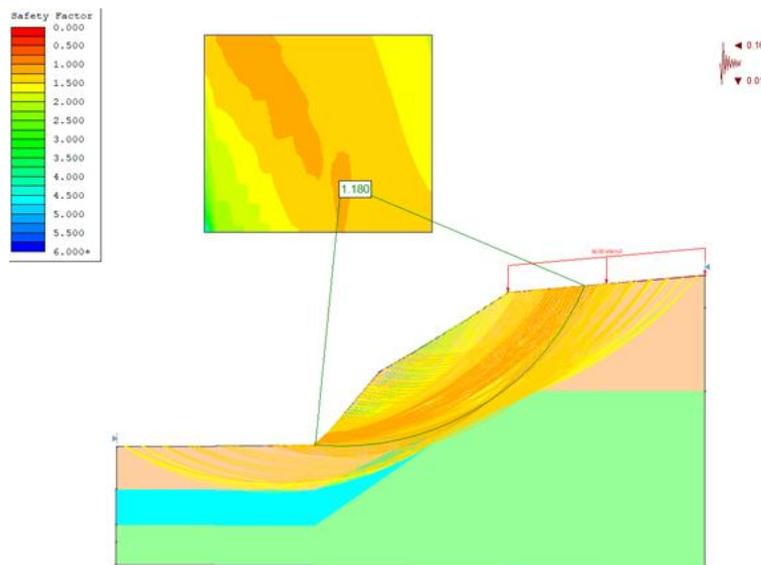**Fig. 19: Minimal indirect security factors. [20]**

Slope 2

Fig. 20: Dynamic Analysis Source: own creation

FS=1.180 MEETS, but it requires stabilization design since it does not meet the safety factor for the static case. (It is necessary that the safety factor meets the static and dynamic case)

IX. Design of Stability

For the design of stability, cantilever walls were made on all the slopes. They were designed at the midpoint between the base and the top of each slope, in this way, the stabilization structure is optimized, because by constructive methods, it is difficult to extract very large volumes of earth. Also, it does not require large amounts of filler, which can get to change the physic-mechanical characteristics of the soil to be stabilized. To make these designs, it is necessary to consider four (4) important aspects, which the structure has to meet according to the NSR-10. These four aspects are:

•Slip safety factor, it must be equal or higher than 1.5
•Safety factor due to overturning, it must be higher than or equal to 2 for pseudostatic design.
•Safety factor for carrying capacity, must be higher than or equal to 3.0.
•General safety factor for the structure, it must be higher than or equal to 1.5 for the static case and 1.05 for the dynamic case.

Slope 2
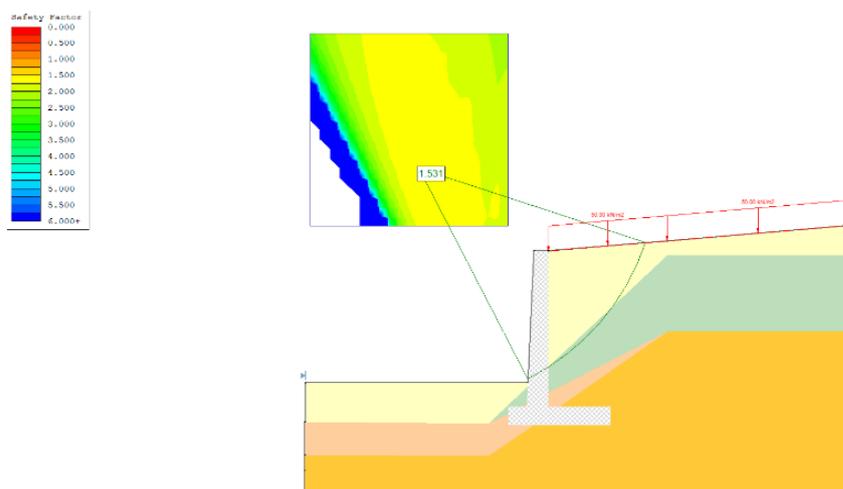**Static case with containment structure**

Fig. 21: Static Analysis with containment structure. Source: own creation

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FS=1.531 MEETS

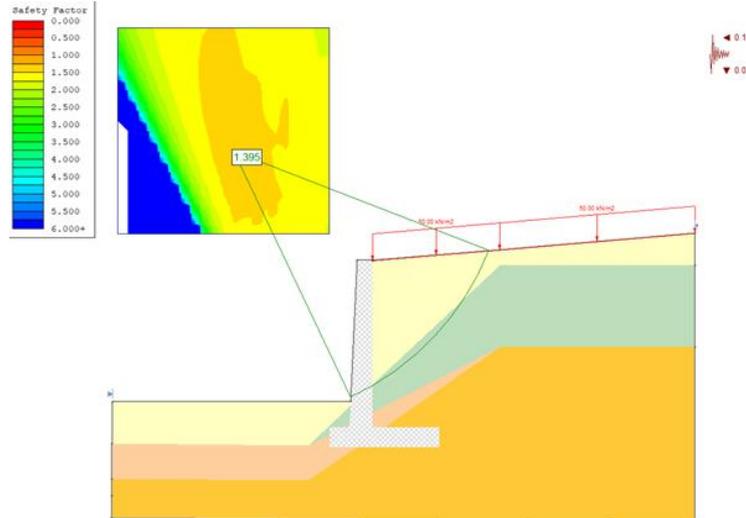**Dynamic case with containment structure**

Fig. 5: Dynamic Analysis with containment structure. Source: own creation

FS=1.395 MEETS

Calculation
Table2: Calculations of safety factors of the structure. Source:own creation

Slope 2 Design Containment Structure				
OVERTURNING				
INITIAL DATA				
γ_1	17.49 kN/m³		α	6.00 °
φ'_1	34.81 °		γ concreto	23.50 kN/m³
c'_1	0.00 kN/m²		γ peso ideal	18.00 kN/m³
CALCULATIONS			$K_a = cos\alpha \dfrac{cos\alpha - \sqrt{cos^2\alpha - cos^2\phi'}}{cos\alpha + \sqrt{cos^2\alpha - cos^2\phi'}}$	
H'	4.940 m			
K_a	0.277			
P_a	59.115 kN/m		P_h	58.791 kN/m
P_v	6.179 kN/m		ΣM_o	96.810 kN(m/m)
RESISTANT MOMENT				
SECTION	AREA (m²)	WEIGHT / STRENGTH	ARM (m)	MOMENT (kN(m/m))
1	1.72	40.42	0.80	32.34
2	0.48	11.28	0.63	7.11
3	1.40	32.90	1.40	46.06
4	7.31	131.58	2.40	315.79
5	0.12	2.16	2.13	4.60
	Pv	6.18	6.18	38.19
	ΣV	224.52	ΣM_R	444.08
FS (OVERTURNING)	4.5872	MEET	$FS = \dfrac{\Sigma M_R}{\Sigma M_0}$	
GLIDE				
INITIAL DATA				
γ_2	17.77 kN/m³		c'_2	0.99 kN/m²
φ'_2	37.00 °		D	1.00 m
CALCULATIONS			$P_P = \dfrac{1}{2}\gamma_2 D_1^2 K_P + 2c'_2 D_1\sqrt{K_P}$	
K_P	4.02			
Pp	39.71 kN/m			
FS (GLIDE)	2.4742	MEET	$FS = \dfrac{(\Sigma V)tan\delta' + Bc'_a + P_P}{P_a cos\alpha}$	
CARRYING CAPACITY				
INITIAL DATA				
B	2.80 m		φ'_2	37.00 °
N_c	55.63		N_y	66.19
N_q	42.92		PARAMETERS ACCORDING TO THE MEYERHOF TABLE	
CALCULATIONS				
e	-0.147	e < B/6	$B/6$	0.47
q_{max}	54.97		F_{yd}	1.00
q	17.77		$\psi°$	14.67
B'	3.09		F_{ci}	0.70
F_{qd}	1.08		F_{yi}	0.00
F_{cd}	1.08		q_u	617.16
FS (BEARING CAPACITY)	11.2269	MEET	$FS = \dfrac{q_u}{q_{max}}$	

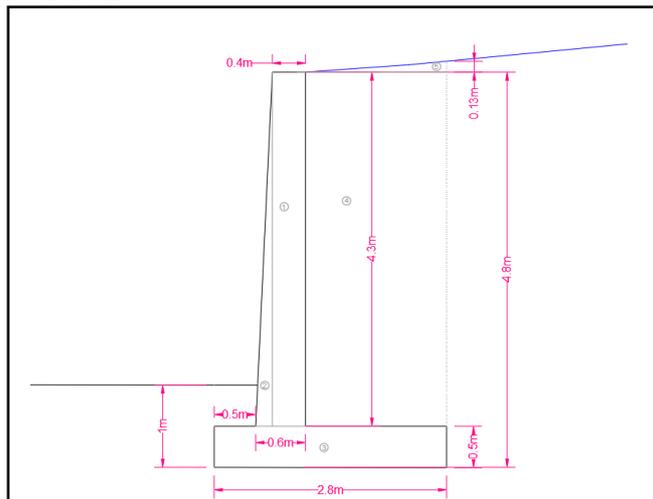**Pre-sizing of containment structure**

Fig. 6: Pre-sizing of containment structure - Slope 2. Source: Own creation

9.1 Summary chart and pre-sizing

In Table 6, the information obtained in the other evaluated slopes will be detailed, from where the same process of the Slope 2 was carried out. Stability analysis, stability design and calculations of safety factors for its subsequent development were developed. Pre-sizing and values obtained from the safety factors were the following:

Table 6: Summary table of the safety factors.

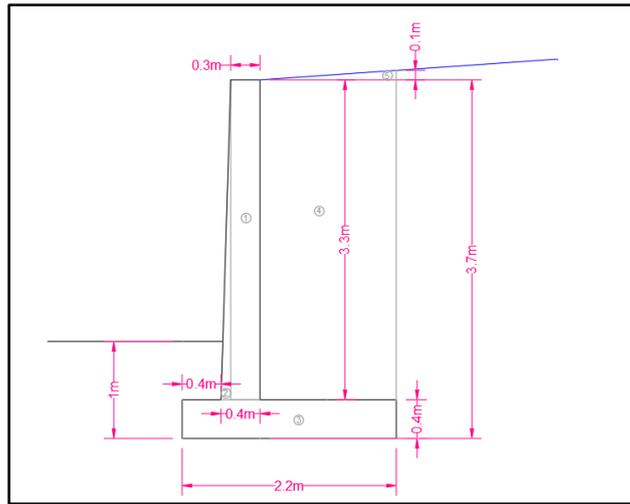|	Slope 1	Slope 3	Slope 4	Slope 6
ANALYSIS OF STABILITY				
Static Case	1,515	1,251	1,265	1,469
Dynamic Case	1,325	1,086	1,145	0,787
DESIGN OF STABILITY				
Static Case	Does not require stabilization	1,526	1,917	2,076
Dynamic Case		1,405	1,786	1,934
SAFETY FACTORS OF THE STRUCTURE				
Overturning	Does not require stabilization	4,3640	4,5064	2,5772
Slip		2,4645	6,5801	4,5872
Carrying Capacity		8,8588	23,8943	11,6518

Pre-sizing of containment structure

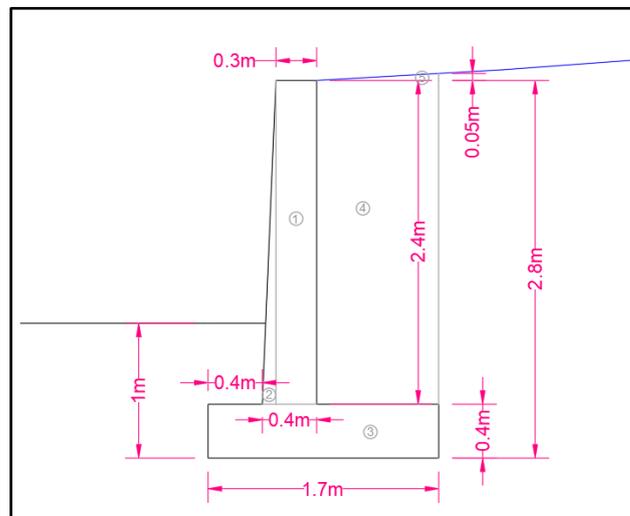**Fig. 7: Pre-sizing of containment structure - Slope 3. Source: Own creation**

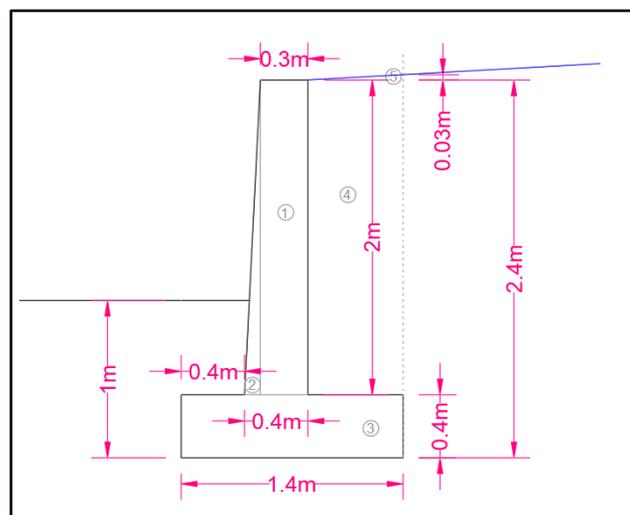**Fig. 8: Pre-sizing of containment structure - Slope 4. Source: Own creation**

Fig. 9: Pre-sizing of containment structure - Slope 6. Source: Own creation

X. Conclusions

This diagnosis contains information collected during the second half of 2016, for this reason, at the moment of reading this paper it is probably that the condition of the roads and information centers may be subject of changes, repairs or even deterioration.   From this study it can be established that more than 50% of the roads do not have a pavement structure (affirmed or mill). This represents a potential risk for the inhabitants of the sector considering that due to the difficult topographic conditions, the displacement is very difficult for anyone, but it is even more difficult for people with disabilities, elderly people, pregnant women and children. The displacement of people would be even more dangerous depending on how optimal are the weather conditions.

It is important to note that even if a track of the road is paved, it is not necessarily in a good condition. For this reason, it was also carried out a visual diagnosis of the pathologies of the flexible and rigid pavement, which were obtained from the visual diagnosis of pathways. From this study we can say that there are some roads in which, due to the time and the use, it starts to be difficult to go by in both vehicle and walking.

The topography carried out allowed us to find the neuralgic points where it was necessary to have penetration of soils (always looking for the place where the slope had greater height); and the georeferencing locates the planimetry in the real space where it is necessary to work.

Through tests carried out in the laboratories of CorporaciónUniversitaria Minuto de Dios, it is reaffirmed that the soil of Potosí can be classified as colluvium, since it is a deposit of soils by mass movements and presents fine and granular mixed material. This represents a stable soil, however, considering the appearance of building constructions, continuous deposits of rubble in the whole sector and cuts of slopes without considering natural rest angles, the soil loses a considerable consistency.

With the calculations obtained through the in-situ SPT test and the software models, it was possible to corroborate that the slopes are able to support their own weight (reason why there are no landslides). However, when evaluating it with normal overloads such as vehicular traffic, dynamic effects such as seismic movement or housing a dead load, most of the slopes in these situations would collapse.

It is evident that the slopes that were studied in the neighborhood of Jerusalem in the area of Potosí of Ciudad Bolivar, a large part, require a slope stability design (the design suggested and developed in this document, is done through cantilevered retaining walls). Due to unstable soils, the current condition of the roads represents a risk for the community, if it is not stabilized first it is impossible to build pavement structures. However, from this study it is known that the Slope 1 is stable by itself and even in the middle of overloads or dynamic effects, it does not require stabilization structure

The slopes mentioned here, do not necessarily refer to all the points where it is necessary to stabilize, they are only part of some of the routes that were prioritized, however, there were more points where it is necessary to study slope stability as well. For future studies it is recommended to carry out tests for rocks, requiring a trained geologist to obtain the physical-mechanical characteristics of rocky soils through different methods. This, considering that in some points of the rout we took, the soil was made up of rock, and at that time we did not have access to equipment needed to develop such trials.

Two (2) documents were given to the community, they can be used for both consultation and technical support, when the community desires to request to the corresponding entities the construction, maintenance or rehabilitation of the roads. The first document is addressed to the General Diagnosis of Roads, and the second one refers to the slope stability designs.

XI. References

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