

Determination of Soil Infiltration Values with In Situ Tests and Direct Moisture and Precipitation Measurements

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Abstract Rain events are the cause of many landslides that occur on slopes causing a loss of strength by decreasing the effective tension. In this article, it performs the geo-mechanical characterization of a soil slope located in Colombia which has been defined as a zone of instability, where there is instrumentation consisting of a volumetric soil moisture meter and a pluviometric station. With this information, we intend to determine the times of saturation and evacuation of rainwater in the mentioned soil considering too the frequency of events. In that sense, an experimental calibration of moisture meter installed on the site is done, and the Water Retention Characteristic Curve is constructed to determine the variation of the effective efforts as soil moisture and permeability of the material and the relationship is a determined index empty as soil structure to know its maximum saturation level. The main results showed an increase in the correlation of soil moisture as depth increases, on the other hand, the permeability coefficient obtained was low, which is typical of soils with low permeability, a situation that was also evidenced in the differences of the suction curves obtained; additionally it was found that at greater depths more accumulated precipitation is required to reach saturation moisture, which corresponds to the infiltration process in the soils, the void ratio found and the mentioned permeability coefficient.

Keywords Geotechnical Characterization, Geotechnical Instrumentation, Disaster Prevention, Landslides

1. Introduction

The water content in the soil plays an important role in its mechanical and hydraulic behavior; understanding the effects suffered by the material due to the variation of its moisture content is a priority when analyzing the factors causing landslides in any region [1]. For this case study located in Medellín-Colombia, the historical analysis of vulnerability to mass movements has conceived this area as one of those with the highest landslide threat in the city [2][3] and generates the constant concern of the surrounding community, the consequences can compromise with the patrimonial goods to human lives. As one of the main strategies for irrigation management, the area has been monitoring various hydrometeorological variables to generate early warnings of natural events [3-5]. In this sense, the site has soil moisture sensors and precipitation records provided by a pluviometry network. Based on the information provided by the equipment installed in the area and geotechnical laboratory tests carried out, the objective is to determine the index

properties of the material, hydraulic properties such as permeability and mechanical properties such as the variation of suction at different moisture contents. This will allow defining risk thresholds for the early warning system in the studied area, and will have a starting point for future investigations in other sites.

The project arose from the need to alert in a timely manner the occurrence of extreme hydrometeorological events, in order to take preventive actions to reduce the impact generated by the imminent threat situation.

2. Materials and Methods

The study area is in the hillside sector of northwestern Medellín-Colombia. This area is framed geologically between formations that have little extension and are characterized by presenting different stages of fracturing and weathering, on these base rocks there are some deposits of slope type flow of mud and debris and full anthropic exhibiting slopes that vary from gentle to steep. [6]

The change in morphology is directly associated with the environmental agents that incur in the material's alteration; both erosion and mass movements are the two processes that generate sudden changes in the natural states of the slopes, especially in areas of debris flow or anthropic fills, endangering the stability of these slopes stability [5][7].

Altered and unaltered samples were taken to perform the physical and mechanical characterization of the material. Samples were taken at one meter depth, in order to determine the variation of the properties with respect to depth, thus establishing a comparison and analysis of the results.

Physical characterization tests consisted of voids index, permeability, consistency limits, specific gravity and mesh granulometry on the altered samples, as shown in as shown in Table 1 [8-12].

Table 1. Physical characterization results

e	Gs	LL (%)	IP (%)
1.20	2.62	58	20
%Fine	USC	K (cm/sg)	
66	MH	2.15e-10	

The permeability values are too low corresponding to soils of high plasticity, which agrees with the unified classification [1][13].

The debris flows are the predominant materials in the area under study, and superficially they have a high content of organic matter [2][3], which due to its higher level of oxidation has a higher level of water absorption providing greater plasticity at lower water levels [14]. Remember that the analysis is carried at a depth considered superficial (1 m), according to the classification, and it obtained the soil that is classified as fine silty soil with high plasticity

before an intermediate liquid limit as a consequence of the organic material [15]. These are indications of a material with poor resistance thus increasing its probability of slippage [16].

Mechanical characterization tests were carried out such as, direct shear and suction test with filter paper in mixed trajectory as shown below [17][18].

In Figure 1, the results of the direct shear made in non-drained conditions are shown, which show weakening for resistance properties due to the absence of apparent cohesion of the material.

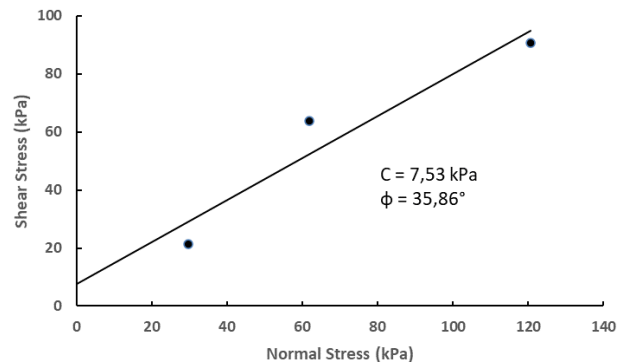


Figure 1. Direct Shear Results

The suction test was executed by the mixed trajectory filter paper method with the aim of determining the matric and total suction of the sample. This test consists of using test bodies with a diameter of 50 mm and a height of approximately 20 mm, in which the humidity is distributed from the minimum to the maximum starting from the natural moisture content, which is achieved by letting the bodies dry or moisten with distilled water. Then the filter paper is placed and the humidity is allowed to balance for a minimum of fifteen days. After this time, the moisture of the paper associated with a matric suction value is determined, which is the same as that of the sample. As the suction value is determined through a calibration curve, this method is known as indirect. Subsequently, the humidity of the test bodies is determined and the characteristic curve or water retention curve of the soil (moisture content ad vs. suction) is plotted, as shown in Figure 2.

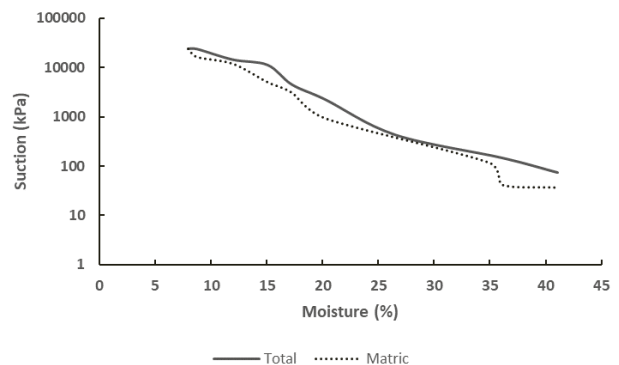


Figure 2. Soil Water Characteristic Curve

As observed for humidity close to saturation moisture, the soil has high suctions, which is probably because the soil studied has a clay structure, knowing that these have tubular structures [19].

3. Results and Discussion

A series of site monitoring data composed of volumetric soil moisture and precipitation values were used.

Different rainfall events were identified from the data series, from which cumulative rainfall versus volumetric site moisture data were taken for each depth, specifically 30 cm, 70 cm and 100 cm. It should be noted that the change in moisture is not instantaneous but depends on the time of water infiltration into the soil voids [20]. The methodology used consisted of identifying rainfall events in the data series, from which time versus accumulated precipitation and time versus humidity curves were plotted for each point. The onset of rainfall was taken as time zero.

From the visual interpretation of these graphs, and under the hypothesis of a positive correlation between moisture content and accumulated precipitation, the points where the moisture curve has a similar behavior to the accumulated precipitation are determined.

During the visual inspection, different rainfall events where no change in the trend of the moisture curves could be appreciated were discarded. For the analysis, accumulated precipitation from 3, 9 and up to 15 days before the events studied were considered together with the single accumulated precipitation of each event. Different factors were identified, such as humidity at the beginning of the event and peak humidity reached during the event, and the accumulated precipitation in which a visible increase in humidity measurements is no longer obtained [1][21].

Due to the variation of the humidity sensor between consecutive measurements, the humidity at the beginning of the event was determined as the average of the 10 data recorded before the beginning of the event, and the humidity at the top as the average of the 10 data recorded where a tendency of humidity not to increase was identified. The lag times of rainfall events are longer with the increasing depth.

The humidity vs. accumulated precipitation data are plotted to determine the degree of correlation between

them.

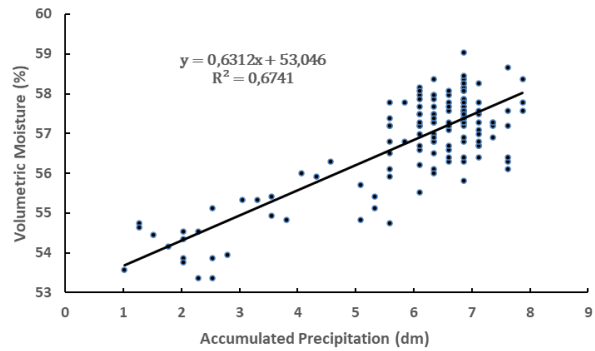


Figure 3. Volumetric Moisture vs. Accumulated precipitation (30 cm Depth)

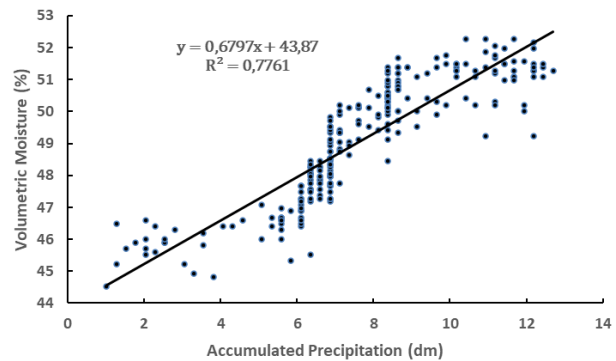


Figure 4. Volumetric Moisture vs. Accumulated precipitation (70 cm Depth)

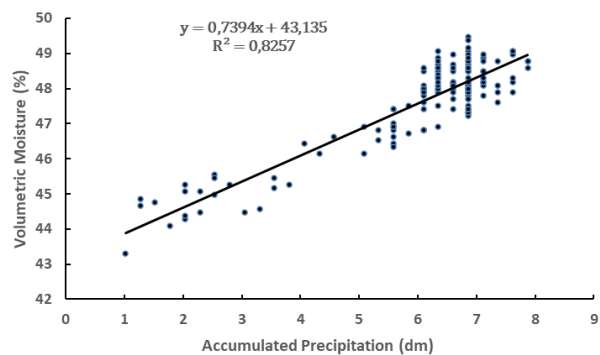


Figure 5. Volumetric Moisture vs. Accumulated precipitation (100 cm Depth)

From the graphs it can be observed that for different depths the volumetric moisture content has a linear trend vs. the accumulated precipitation. The moisture that is showed as an outcome of monitoring the sensor is volumetric as already mentioned, therefore an expression is established that determines the gravimetric humidity which is more used in geotechnical engineering, and this was done by calibrating the sensor [1][14].

To perform the aforementioned calibration of the sensor, samples were taken in situ to perform natural moisture tests in the laboratory according to the procedure of the ASTM-D2479 standard and taking into account the different installation depths of the sensors (30 cm, 70 cm and 100 cm); these values were plotted with the volumetric moisture values measured by the sensor on the same day and time of extraction of the sample, then a polynomic adjustment was made. The adjustment is shown in the Figure 6.

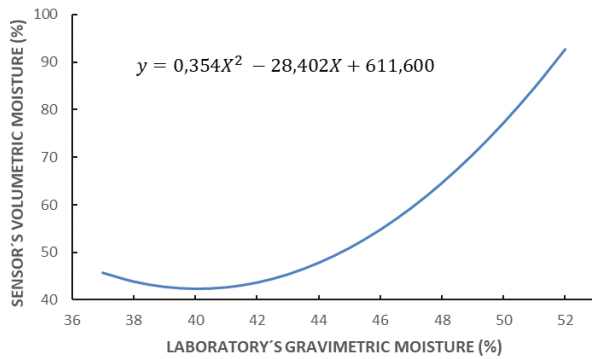


Figure 6. Polynomic adjustment for sensor calibration

The data adjustment was performed with the Python Polyfit function obtaining a Pearson correlation $r = 0.991233$.

Taking into account the void ratio of the material, the specific gravity and the polynomial adjustment made, both volumetric and gravimetric saturation moisture values were found. See Table 2.

Table 2. Saturation Moisture

Saturation gravimetric Moisture	Saturation volumetric Moisture
45,80%	53,99%

Table 3. Physical characterization results

DEPTH (m)	R-Squared	Acc precipitation 100% saturation(dm)
30	0,6741	1,49
70	0,7761	14,89
100	0,8257	14,68

Figures 3 to 5 show the correlation coefficient between moisture content and accumulated precipitation, and the

Table 3 shows these correlation values and the precipitation value required to bring the soil to its saturation moisture.

It is observed that at greater depths there is a greater increase in the correlation of the polynomial adjustments made, which responds to the variation that the surface moisture may have due to being more exposed to climatic effects. The saturation moisture at greater depths requires higher values of accumulated precipitation, due to the transit of water in the voids in the unsaturated soil, which depends on permeability, soil type and void ratio [22].

For more specific considerations, measurements should be made on other soil types, with different permeabilities and rainfall variations.

4. Conclusions

The lag times found at each depth differ greatly between both events, reaching differences greater than 200 minutes, so for a generalization of the infiltration process at the site other factors must be analyzed, such as precipitation and soil moisture conditions before, during and after the event.

When analyzing the information, different aspects were identified in which it should be noted that at 1 m depth the material differs in terms of natural moisture content and saturation moisture, this could indicate that at this depth the material is denser, at the same time it should be emphasized that the material corresponds to a flow of slope and debris, so we talk about a heterogeneous material [6].

The values of Resistance parameters correspond to the parameters of a medium strength material [23].

As for the accumulated precipitation, it is not possible to reach a generalization for each sensor since both events yielded values with considerable differences for each sensor in the cases analyzed. In both events it is noted that the difference in precipitation between the sensor of 30 cm and 1 m deep is around 1-2 dm, and could be an indication of the amount of rain needed to saturate this part of the profile, however, the precipitation found in the sensor at 70 cm depth is higher than that corresponding to 1 m deep, opening the possibility that the infiltration in the profile is not vertical.

Similarly, the frequency of measurement of the equipment can cause two rainfall events with different precipitation rates over time, to yield accumulated precipitation values for infiltration with a high inequality.

The presence of rock balls in the studied profile can influence the infiltration processes of the site and make them asymmetrical, since as observed in the information collected in a particular event, it took more time to saturate the layer at 70 cm than the layer at 1 m [6].

From the analyzed information it can be inferred that the lag time depends not only on the heterogeneity of the material but also on the rate of precipitation over time, so special attention should be paid to high-rate events since the response time to situations of instability generated by

these is shorter [22].

From the analyzed Information the maximum volumetric humidity that reaches the soil at 30 and 60 cm deep is around 58%, and at 100 cm about 48%.

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