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GEOLOGICAL-GEOTECHNICAL PROPERTIES OF A COLLUVIAL SOIL IN A NATURAL SLOPE CUT BY A PIPELINE

PROPRIEDADES GEOLÓGICO-GEOTÉCNICAS DE UM SOLO COLUVIONAR EM ENCOSTA NATURAL CORTADA POR UMA DUTOVIA

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ABSTRACT - The Serra do Mar, in the state of Paraná, Brazil, is marked by a relief with unstable areas, which is eventually subjected to mass movements along their slopes, primarily caused by the large amounts of rainfall that occur in such area. Within this scenario fits a pipeline conduit for the transportation of fuels, often bordering slopes in a situation of precarious balance. It is widely known that lithological, structural and geomorphic features play a major role in the slopes stability. Thus, it is important to understand the dynamics of these movements in order to preserve the physical integrity of the duct. Areas where the slope represents critical points of instability were selected for the study along the pipeline section. The main objective of this work is to investigate the geological and geotechnical features of the area cut by the pipeline in order to assess possible mass movements. This work was achieved by a combination of field research, remote sensing, characterization of the colluvial soils and obtaining of geomechanical and hydraulic parameters.
Keywords: Colluvial soil; Natural slope; Mass movement; Geological investigation; Creep.

RESUMO - A Serra do Mar caracteriza-se como uma região marcada por relevo com áreas instáveis, tendo como um dos principais problemas geotécnicos os movimentos de massa. Nessa faixa também ocorrem os maiores índices pluviométricos do Brasil. Dentro desse cenário insere-se uma malha dutoviária para transporte de combustíveis, muitas vezes margeando encostas em situação de equilíbrio precário. As características litológicas, estruturais e geomórficas condicionam a estabilidade das vertentes. Estes fatores, em conjunto com a intensidade pluviométrica da região, caracterizam um cenário de alta susceptibilidade a movimentos de massa. No que tange o prejuízo que esses eventos trazem, principalmente em relação à preservação da perfeita funcionalidade do duto, torna-se importante o entendimento da dinâmica desses sítios. No intuito de se manter a integridade física do duto, foram selecionadas para estudo as áreas onde se situam as encostas que representam os pontos críticos de instabilidade ao longo do trecho da dutovia. Tem-se, então, como principal objetivo do presente trabalho, a investigação geológico-geotécnica voltada à correção de movimentos de massa, por meio da investigação de campo, do sensoriamento remoto e da caracterização e obtenção dos parâmetros geomecânicos e hidráulicos dos solos coluvionares de uma encosta natural, atravessada pelo duto, sob processos de movimentação de massa.
Palavras-chave: Solo coluvionar; Encosta natural; Movimento de massa; Investigação geológica; Rastejo.

INTRODUCTION

The Serra do Mar (SM), a mountain range that runs along the southern and southeastern Brazilian coast, from Rio de Janeiro to Santa Catarina states, has been characterized as a region marked by landslides and slope movements. As approached by Maack (1981); Bigarella (2003); Carmignani & Fiori (2009), the combination of lithological, structural and geomorphological features and distribution of rainfalls play a major role on slope stability which is directly associated with mass movements, causing accidents in many social and environmental spheres.

This belt is cut by important roads and pipelines which transport goods from and to the harbors located on the coast. And there is a pipeline to transport of fuels which often borders slopes in a situation of precarious balance. The pipeline is buried and no presents flexibility in the longitudinal direction. Regarding the mass movements and the damages that these events bring, for what it alone already represents but also in relation to the preservation of perfect functionality of the pipeline, become important to understand the dynamic of these sites.

In order to preserve the pipeline physical integrity and to avoid accidents as the one that occurred in Morretes, Brazil (Albarello, 2012), the present work aims to investigate the geological and geotechnical features of soils collected close to pipeline, with especial focus on the mass movements corrections, establishing basis for the stabilization project of the critical slope in the studied area. Critical point is understood as the places which present evidences of mass movements occurrence.

To achieve the proposed objective, it was used a combination of methods, including field investigations, analyses by remote sensing, and laboratory tests to classify and to determine the geotechnical parameters of the soils involved in the mass movement processes..

GEOLOGICAL ASPECTS AND LOCATION OF THE STUDY AREA

The Serra do Mar (SM), an elongated mountain range parallel to the South Atlantic border, is composed by a proeminent relief that reaches about 1.000 km between the states of Rio de Janeiro and Santa Catarina. The combination of tectonic events and regional climate variations have shaped the relief of the SM, which is believed to be structurally conditioned (Nascimento et al., 2014).

The study area of this work is located in the southern portion of the SM mountain range. It is locally composed of Neoarquean/Paleoproterozoic banded and massif gneisses and granulites from the Luís Alves Complex (e.g. see Kaul, 1997 for geological description). Their compositions comprise tonalite-granodiorite orthogneisses with variation to more basic granulites. Cenozoic alluvial and colluvio-eluvial deposits occur in the southwest of the area as showed in the geological map proposed by Mineropar (2006) and CPRM (2015), and observed in Figure 1.

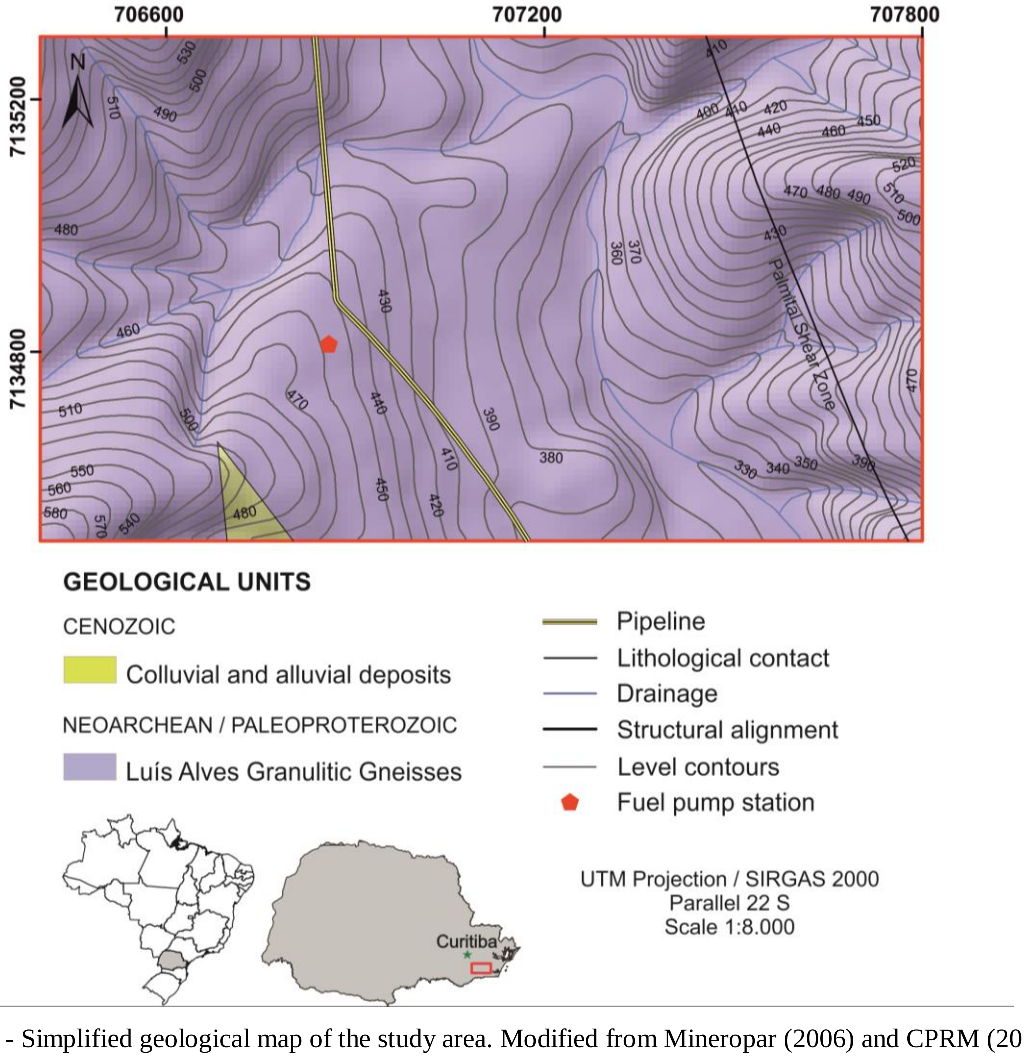

Figure 1 - Simplified geological map of the study area. Modified from Mineropar (2006) and CPRM (2015).

Based on the slope curvature map (Figure 2) – in which hills are classified according to their landforms as convex, concave and flat (Troeh, 1965); Cruden & Varnes (1996) – the western region of the area comprises convex and concave slopes, characterizing a scenario of embedded valleys. Landforms that prevail in study area are elongated tops and crests with rectilinear and planar slopes and "V" valleys, as proposed by Mineropar (2006).

The slope curvature map has been used in regional and semi regional susceptibility analyses of mass movements. The slope curvature map describe the physical features of a drainage basin that interfere in superficial and sub superficial water flux behavior in the surface. Furthermore, this behavior influence directly in the dynamic of mass gravitational movements and erosive processes. Slopes with convex and concave curvature control divergent and convergent flux, respectively, and are thus named spreader and collector slopes. The flux is invariable in the flat areas, being parallel and following the direction of the slope dip.

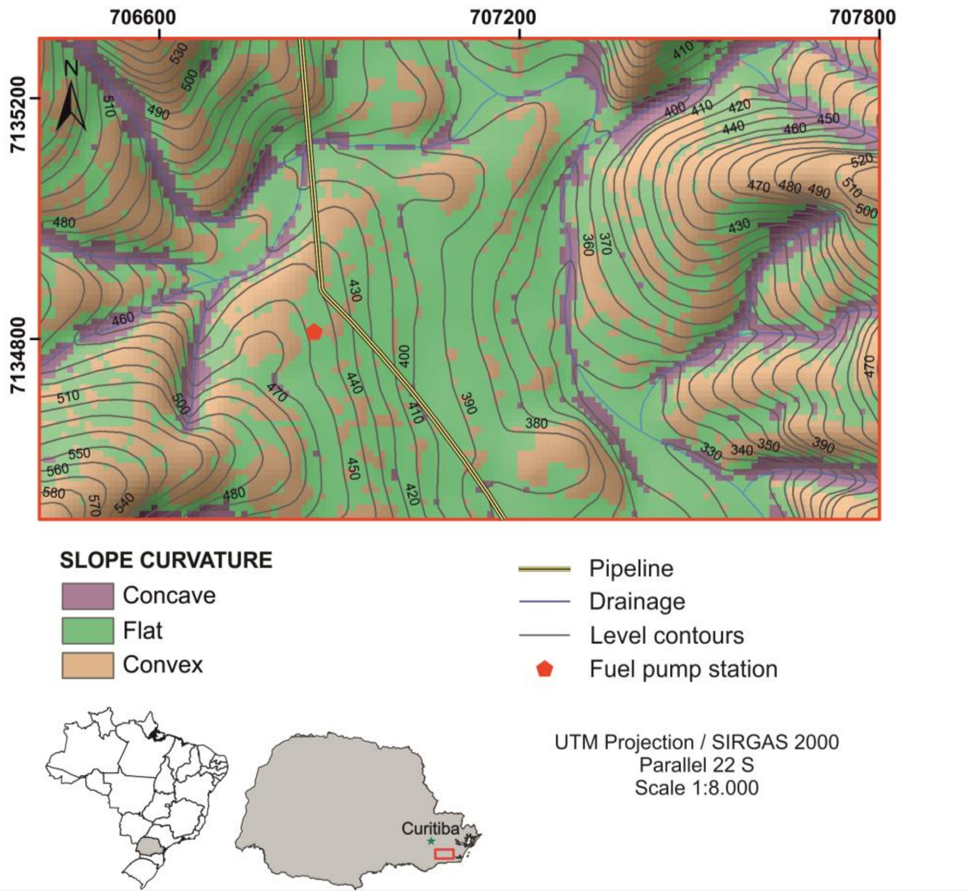

Figure 2 - Slope curvature map of the study area.

The influence of the relief on soil development manifests by its interference in the water dynamics and in the erosion and sedimentation processes. It is also important to consider the surface characteristics and the superficial and sub superficial water percolation. Thus, areas with gentle topography and permeable soils facilitate rainwater infiltration. In this case, pedogenetic processes act more actively in higher depths. If the surface soil is poorly permeable, much of the rainwater flows on the surface, saturating the covering materials. Nevertheless, in areas with steep slopes much of the rainwater is lost in lateral spreading favoring the erosive processes and delaying the pedogenesis. In this case the soils formed are poorly developed and with thin thickness (Oliveira & Brito, 1998).

The target slope of this study, due to be located in the foot of a hillside, works as base level to the colluvium material. Furthermore, the modest inclination and smooth profile of the slope (Figure 2) have contributed to the development of a thick soil layer with dense vegetal cover. Bigarella (2003) points out that the residual soils located at the bottom of the Serra do Mar belt may have eventually been formed by colluviums, which constitute debris deposits originated from the upper parts of the Serra do Mar.

METHODS

According to Skempton & Hutchinson (1969), the study of a slope behavior involves the geomorphological analysis of the stability conditions and corrective ways to prevent or to soften the effects of any mass movement. To achieve our objective, which consists in a geological-geotechnical investigation to prevent mass movements, we used analyses by remote sensing and laboratory testing to classification and determination of the geotechnical parameters of the soils involved in the mass movement processes.

The geological-geotechnical investigation was based on laboratory and field data. Field data was useful to classify and determine the geotechnical properties of the materials involved in the mass movements processes. Two soils were sampled at the base and the top (413 and 428 m, respectively) of the target slope (Figure 3).

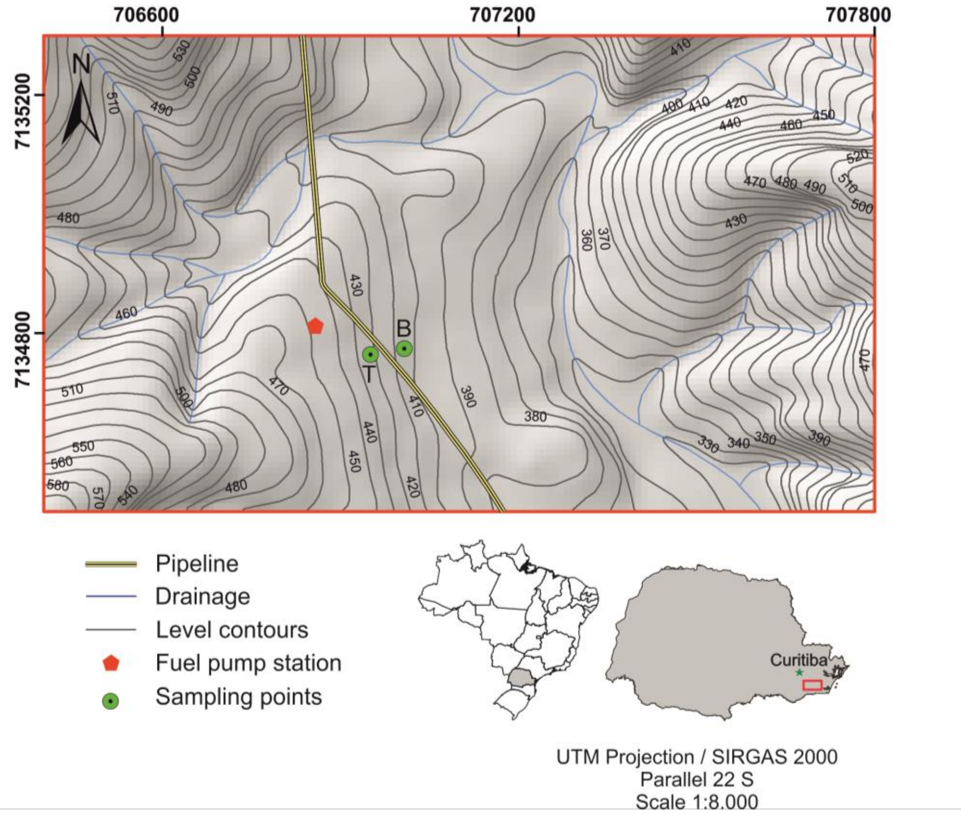

Figure 3 - Map showing the location of the sampled soils. Base quote (B): 413m; top quote (T): 428m.

Undisturbed and deformed samples were collected and kept hermetically closed to preserve in situ humidity conditions. All tests were carried out in the Geotechnical Laboratory of Instituto Lactec, following technical standards normalized by the Associação Brasileira de Normas Técnicas (ABNT) and the American Society for Testing and Materials (ASTM).

Field Investigation

The geological investigation of slopes generally begins with field surveys, aiming to map geological and pedological features and to identify instabilities and potential agents that may lead to mass movements. Main aspects to be analyzed in the field include: rock content, weathered soil profile, geological structures, instability and movement features, water upwelling areas and saturation zones, slope geometry and anthropic interference. Further-more, particular attention should be given to the base and the top of slopes in potentially unstable regions (Oliveira & Brito 1998).

The mass movements inventory is an important method to elaborate a database with predictive features, hence, it is useful to investigate the indications of past mass movements. Therefore, the field investigation aimed at identifying: (i) the possible evidences that reflect the instable condition of the analyzed slope; (ii) the current and past mass movements; (iii) the morphological and geological aspects of these movements; (iv) the features and potential agents of deflagration of the mass movements processes; (v) the alteration of soil profile.

The relationship between typological classification of these phenomenon and deflagration agents assume special relevance, being an important theoretical foundation for studies and development of prevision models.

Remote Sensing

Remote sensing was applied in order to investigate the past mass movements as scars mapping of soil slides that are not clearly seen in the field due to vegetation growth over time. Despite landslides comprise past movements, their deflagration can be reactivated in case the conditions that led to rupture are repeated. The slide scars database was acquired using Google Earth Pro software, based on a chronological visual analyses of satellite images (2010-2016), using the vegetation absence as a criteria to identify scars.

Soil Classification

The procedure to classify soils - determination of soils characteristics to distinguish different types of soil - for engineering purposes, is preceded by characterization. The basics for soil characterization is the aspects description, or important characteristics to elucidate the soils features (Oliveira & Brito, 1998).

The testing characterizations included: specific gravity, Atterberg limits and particle size testing, normalized by technical standards of ABNT, as: NBR 6508, NBR 6459 and NBR 7180, and NBR 7181, respectively. The calculation of physical indexes is demonstrated in Lambe & Whitman (1969).

Geotechnical Properties Determination

Geomechanical Parameters

The geomechanical parameters of soil shear resistance were obtained by triaxial tests. This method consists in the application of hydrostatic strain state and an axial loading over a 50 mm long and 100 mm high cylindrical soil specimen under Consolidated Isotropic Undrained (CIU) condition. In this case, the drainage is allowed just in the first stage of testing which dissipate the pore pressure originated by the specimen confinement during consolidation stage and restricting pore pressure output during shear stage.

To summarize, estimating strength and compressibility in a specific subsoil point, it is important to know the effective point stress at that moment which is crucial to evaluate the pore pressure (Lambe & Whitman, 1969). The CIU testing, therefore, indicate the undrained resistance as a function of consolidation pressure – indicated by pore pressure variation. The testing was ended after an axial deformation of 15% and all data were processed in a data acquisition computer system. The execution of triaxial testing were normalized by the international technical standard BS 1377-8:1990 (British Standard, 1990).

Hydraulic Parameters

The study of water percolation (permeability) in slope instabilities is very important because the effective stress depends of the pore pressure which is affected by water percolation (Pinto, 2006). The coefficient of permeability (k) is determined by the velocity of water across a sample, which can either have a constant load or a variable load.

Variable load is used when the coefficient of permeability is low. This test is based on Darcy's Law, assuming the existence of direct proportionality between the flux velocities and the hydraulic gradients. According to the technical standard NBR 14545 (ABNT, 2000), it is admitted the continuity of flow without soil volume variation and total saturation of sample. The technical standard determines that the coefficient of permeability has to be acquired with water flowing across the soil in regime of laminar flow. In this study, the permeability tests were done with variable load using a rigid-wall permeameter in which the sample has no contact with the cell wall, with a bentonite sealing ring. Specimens are cylindrical sizing 100 mm in diameter and 100 mm in height.

K values are different in the horizontal and vertical directions – parallel and perpendicular directions to stratification planes – due to soil stratification. The massif average permeability depends on the flow direction related to the layers orientation. Based on Darcy's Law (Lambe & Whitman, 1969), both the horizontal and vertical hydraulic gradient in each layer is constant, considering a continuous flow. Therefore, all tests were carried out with flow in both directions. The difference between the procedures for horizontal and vertical flow consisted in changes of water lines position related to water percolation.

RESULTS AND DISCUSSIONS

The study area was characterized morphologically as sub-leveled hills with round tops, concave-rectilinear slopes interspersed by convex slopes with high alterability degree. It was observed an alteration mantle with intermediate to large thickness, presenting colluvium material and well developed pedological horizon, along with rock fragments (granulitic gneisses). In a visual-tactile description, the material located at the base of slope is light brown comprises a clay silty soil with minor fine-grained sand, locally showing gravels. The soil located at the top of the slope is red brown, composed of a clay silty material with minor fine-grained sand and considerable amounts of gravel.

The points where were found evidences reflecting the slope unstable condition, and the agents and features that trigger deflagration of mass movements processes, are presented in Figure 4. The identification and classification of past and actual mass movements are described in the sequence.

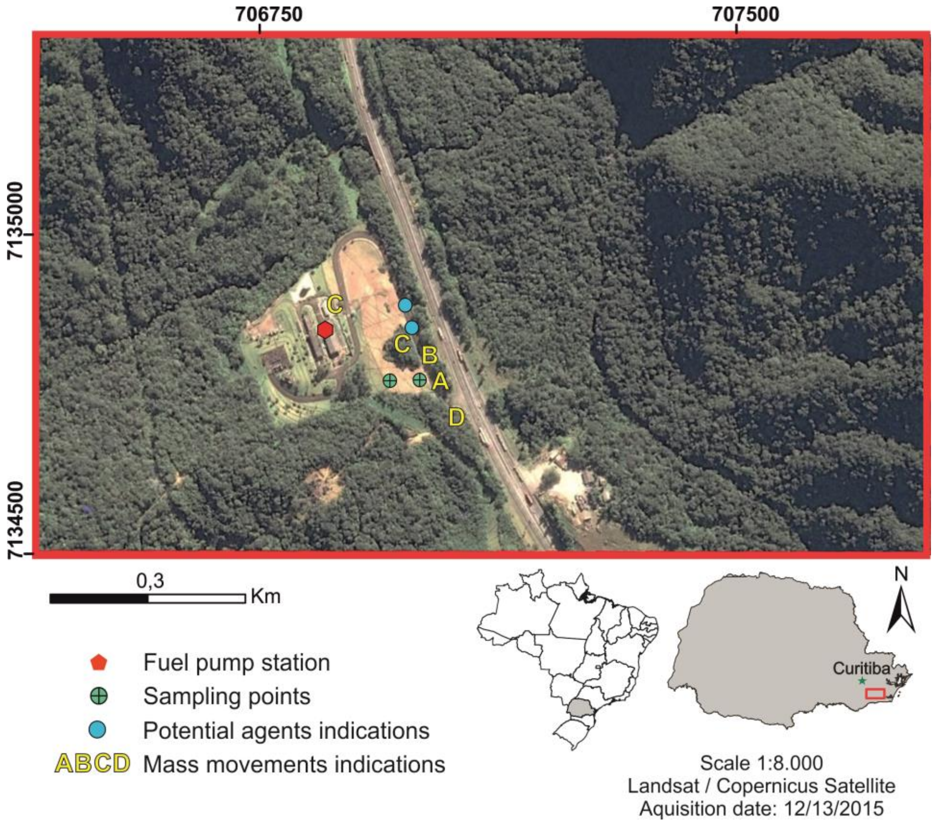

Figure 4 - Cartographic representation of areas showing features and agents that enhance mass movement.

Figure 5 - Rolled rock block. The rock blocks come from the granitoids of Serra do Mar Suite, which are shown as lithological contact, to the west, with the Granulitic Gneisses Luís Alves.

The past mass movement observed and classified as rock fall is evident in the area by the presence of rocky blocks (Figure 5). The rocky blocks represent the breakdown of the Serra do Mar Suite granites which is not observed in the study area (CPRM, 2015), yet occurs as a lithological contact with Luís Alves Granulitic Gneisses on the west. Likewise, Carvalho et al. (2007) argue that the occurrence of breakdown processes is conditioned by the presence of rock outcrops in abrupt slopes, being potentialized by thermal amplitudes leading to dilatation and contraction of the rock.

This sort of destabilization is directly associated with both the rock fracturing conditions and high slope declivity which allow the isolation and detachment of one or more blocks downhill. The fall of rock blocks is a process expected to occur in the study area due to the conditions of the slope. However, it was difficult to reach areas of fresh rock to observe the rocky massif fracturing conditions during the field surveys. Thus, such process was considered in the susceptibility analyses because fragmented rock blocks were observed in the pipeline area.

The soil movement, named soil creep, is evident by the acting of different processes such as the breaking of the retaining wall situated at the foot slope, a place considered critical point (Figure 6); the presence of tension cracks on the roadbed adjacent to the wall (Figure 7); and the presence of tilted fences and trees situated on the middle of the slope (Figure 8). It should be noted that the combination of the elements described above led to the typological classification of acting mass movements, discarding the possibility that tension cracks had occurred in constructive problems consequence. According to Carvalho et al. (2007), the process of soil creep does not show a defined rupture surface (movement plan), and its evidences are cracks observed in all of the natural land extension, which evolves gradually, and trees or any other fixed frame with variable tilting. The main anthropic cause of such process is the cut of slopes that interfere in its stability.

Figure 6 - Broken retaining wall in the way situated at the foot of the slope considered critical point.

Figure 7 - Tension cracks on the roadbed adjacent to the wall.

Figure 8 - Tilted fences and trees situated on the said slope.

Colluvial soils are commonly subjected to soil creep phenomenon. This type of movement can be active for hundreds of years and its velocity is seasonal and controlled by groundwater level. According to Varnes (1978), the progressive action of soil creep can be considered a weakening and decreasing shear strength process, thus, favoring the rupture. Soil creep in slopes triggers gravitational cracks development at which soil mass preferentially move. Rock fall, however, despite representing a past movement, can be reactivated in case conditions the led to rupture are satisfied. This phenomenon integrates a natural process of relief development.

Potential intrinsic agents of destabilization were observed in the analyzed hillside foot. Superficial drainage channels (Figure 9) were constructed in some areas along the slope which collect rainwater. The water flows from the top to the base of the slope at these channels. However, intense rainfall may lead to an increase of water flow in these drainage channels, causing water upwelling points due the elevation of the groundwater level and zones of soil super saturation – both considered intrinsic potential agents of destabilization. Moreover, the soil humidity is also increased due to higher infiltration degree, consequently leading to soil saturation. As a consequence, slope rupture is favored due to a decrease of the suction and of the shear resistance by enhancement in pore pressure.

Figure 9 - 1) Groundwater upwelling point; 2) Soil water logging zone.

Regarding the mass movements only indicated by satellite image analysis, it was possible to identify by the inventory of Figure 10, that the study area was subjected to landslides, as highlighted in the yellow circles. The slides on the hillsides, disregarding the circular and disconfining of the base (of locally occurrence), can occur by two ways: planar slides (translational) and deep slides (rotational) (Varnes, 1978). Although planar shallow slide is more frequent, it involves a thin layer of superficial soil (order of 1 m) and results in low volume of material mobilized downhill, which is considered poorly damaging. On the other hand, deep slides involve saprolithic soils, saprolite and the weathered rock massif, mobilizing great volumes of material. Therefore, despite deep slide movements have been regarded to be less frequent, it may cause more damage to the pipeline. However, one of the most important influencing factors that deflagrate this type of movement is the high fracturing degree of the massif, which was not observed in the area.

The study area shows the continuous acting of mass movements related to gravitational processes, which transported residual soils, colluvium material, rocky blocks, bent trees and cracks on the roadbed adjacent to the slope. There is an important theoretical basis to the development of predictive models by the relationship between the typological classification of the occurred phenomenon (and in occurrence) and the deflagration agents.

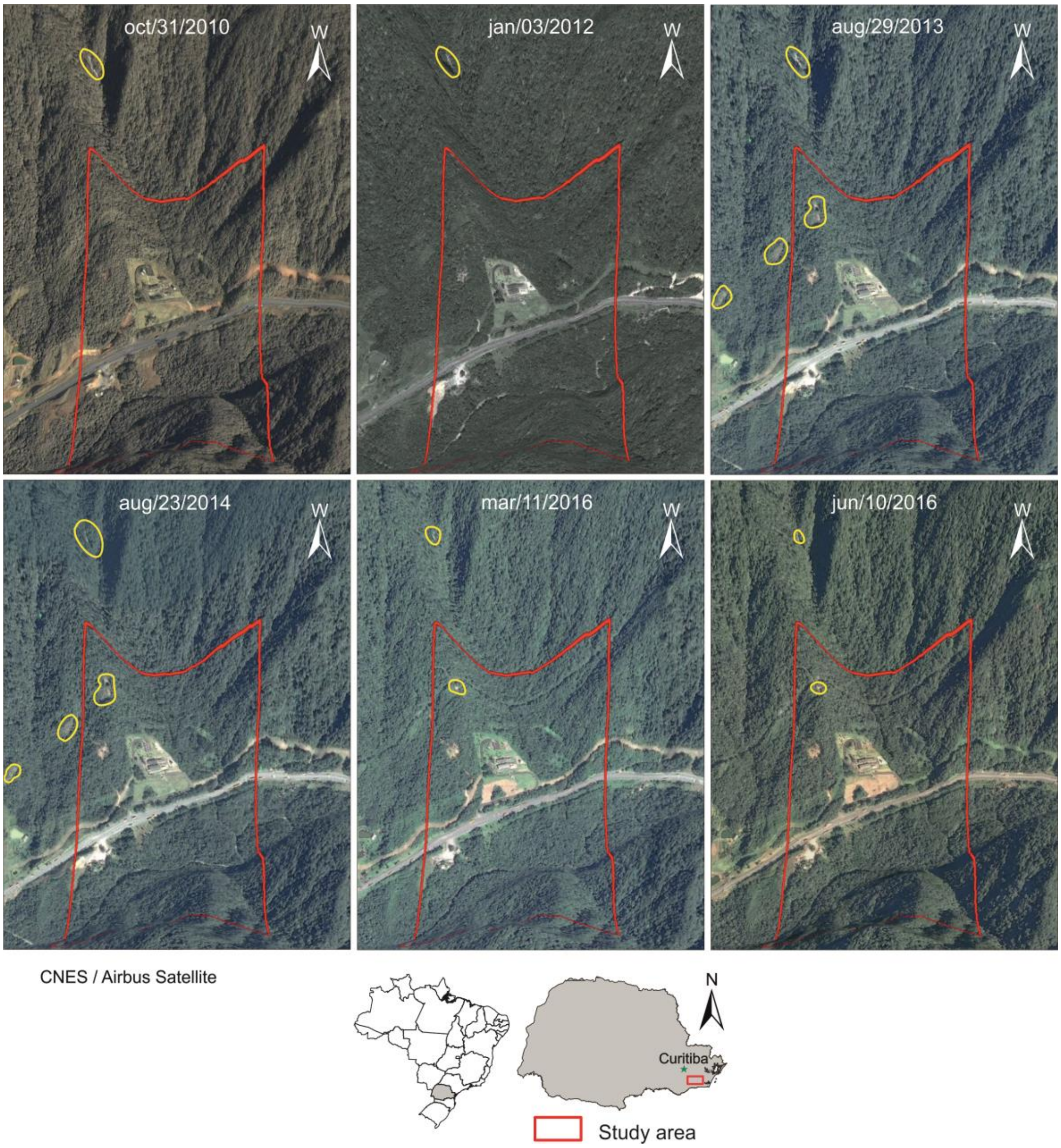

Figure 10 - Landslide scars inventory in the study area and adjacencies. The representation of the area is in 3D visualization, and the yellow circles highlight the scars.

Physical indices parameters of the materials involved in the mass movements processes were acquired with disturbed sample extracted from the quotes of 413 m (base) and 428 m (top) of the slope. Table 1 shows the result of the average amount of particle size (NBR 7181/2016) and Figures 11 and 12 display the particle size distribution curves. It should be noted that these tests were carried out with dried soil and with the use of deflocculating agent. Both samples presented a high concentration of silt particles (Table 1). Nevertheless, the base soil was classified as silt clay sandy soil and the top soil as silt sand clayey.

Table 1 - Granulometric analysis of the sampled soils. Being: w: water content; e: void ratio; S: degree of saturation.

	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	w (%)	e	S (%)
Base	27,7	55,4	16,2	0,7	47,4	1,11	96,3
Top	16,1	60,9	20,2	2,8	46,4	1,35	89,9

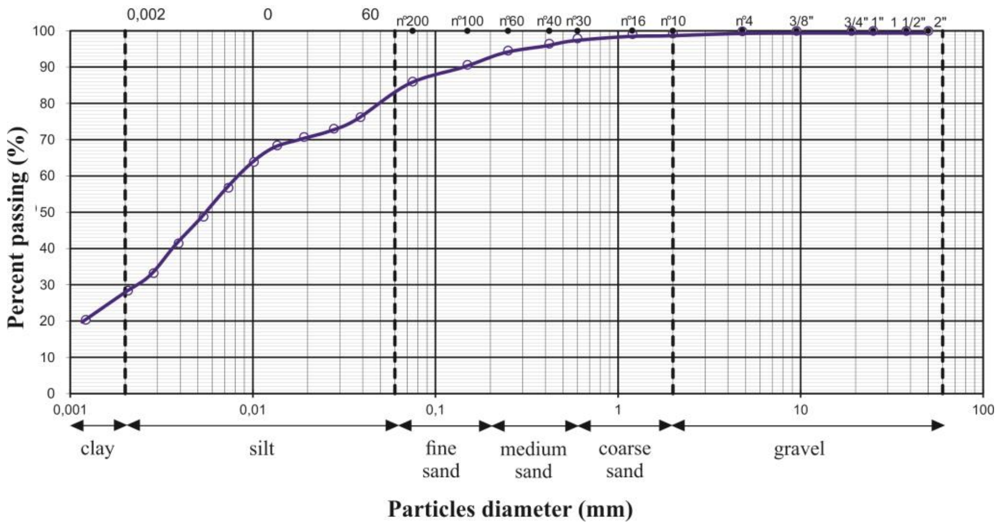

Figure 11 - Particle size distribution curve of base soil.

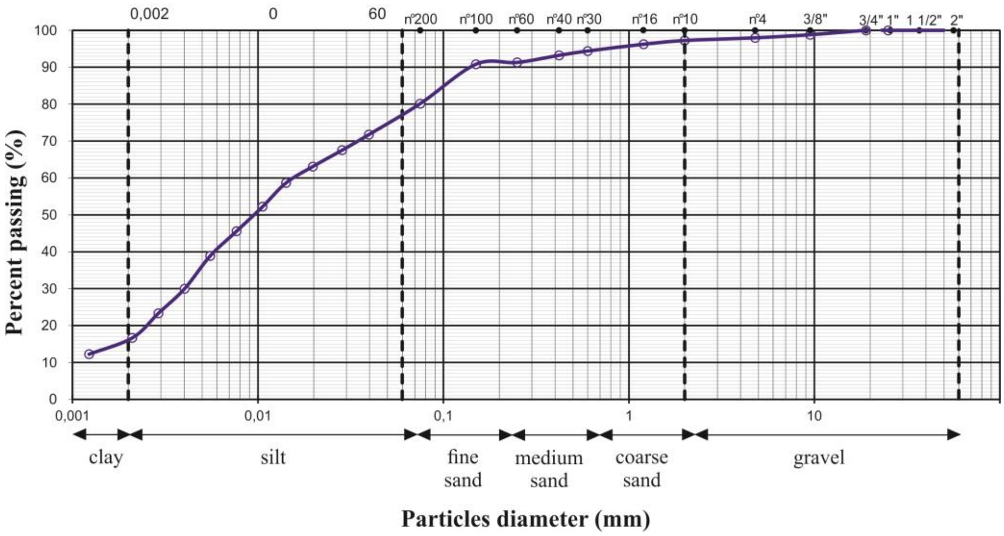

Figure 12 - Particle size distribution curve of top soil.

Lacerda (2010) points out situations in which colluvial layer can exhibit a volume of void in situ of the same order than a overburden layer of a residual soil, depending on the colluvial soil genesis. If the colluvium is formed by a translational or rotational slide of the residual soil, it should preserve the features of the residual soil. Lacerda (2010) still argues that the natural void volume of the soil varies according to the mineral content of the parent rock and its weathering degree. However, colluvial soils are generally comprised of clay sandy materials with varying size blocks. Their heterogeneity is characterized by low consistence and saturated material.

The Atterberg limit tests, normalized by technical standards NBR 6459/2016 and NBR 7180/2016, as well as the specific gravity of a soil grain (γ_s), by NBR 6502/2016 and NBR 6508/2016, are presented in the Table 2. In both samples, the natural water content are between liquidity limit (LL) and plasticity limit (LP) values, indicating that the fine particles of the soil are in the plastic state. According to the plasticity indexes (IP), both samples were characterized with intermediate plasticity (7<IP<15). To evaluate the potential of clay fraction in the soil plasticity and cohesion, the activity index (IA) was calculated, as proposed by Skempton and demonstrated in (PINTO, 2006). The base soil was classified as inactive (IA<0,75) and the top soil as normal (0,75<IA<1,25).

Table 2 - Atterberg limits and state indexes of the sampled soils. Being: γs: specific gravity of a soil grain; LL: liquidity limit; LP: plasticity limit; IP: plasticity index; IA: activity index; USCS: Unified Soil Classification System; ML-MH: inorganic silt soil with intermediate plasticity.

	γ_s (kN/m³)	LL (%)	LP (%)	IP	IA	USCS
Base	26,9	51	39	12	0,43	ML-MH
Top	27,3	51	38	13	0,81	ML-MH

According to the Unified Soil Classification System (USCS), and based on the plasticity chart, both samples (base and top) were classified as inorganic silt soil with intermediate plasticity (ML-MH), in other words, insignificant volumetric deformation is observed when extern charges is applied. The silt technical features obtained by particle size tests agree well with both the technical standard NBR 6502 (ABNT, 2016) and USCS classification.

The triaxial tests were done to obtain the pore pressure variation curves versus axial strain (Δu x ε_a) and the stress path – lower effective stress versus medium effective stress (t x s'). The graphic representation for the base soil are shown in Figures 13 and 14, and for the top soil in Figures 15 and 16.

Through the stress path it is possible to determine a and α values – a is the value of line intersection with the y-axis, and α is the angle with the horizontal (x-axis). The cohesive intercept (c) and the internal friction angle (ϕ) values are determined from the a and α values. The formulas to find ϕ and c are in Lambe & Whitman (1969) and are presented in equations 1 and 2, respectively.

$$sen\,\phi = tg\,\alpha \qquad (1)$$

$$c = \frac{a}{\cos\phi} \qquad (2)$$

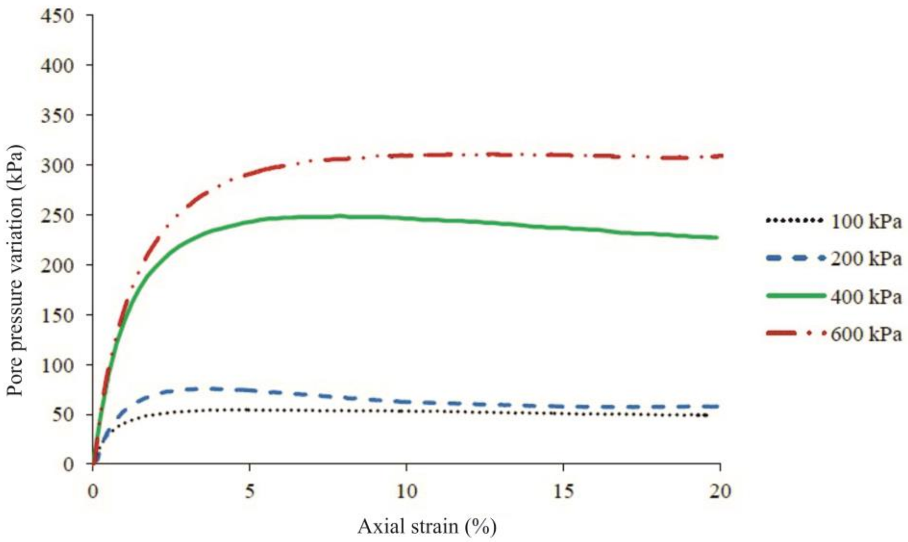

Figure 13 - Pore pressure variation versus axial stress curves of the base soil.

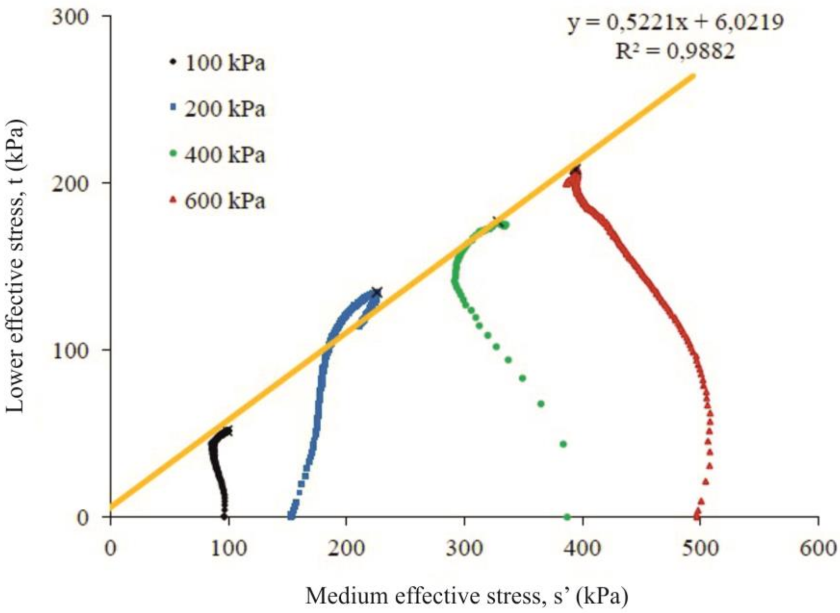

Figure 14 - Medium effective stress versus lower effective stress of the base soil.

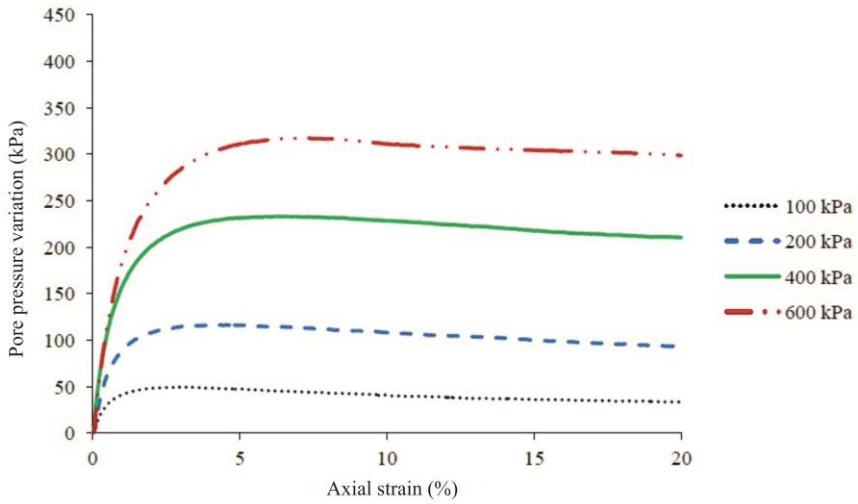

Figure 15 - Pore pressure variation versus axial stress curves of the top soil.

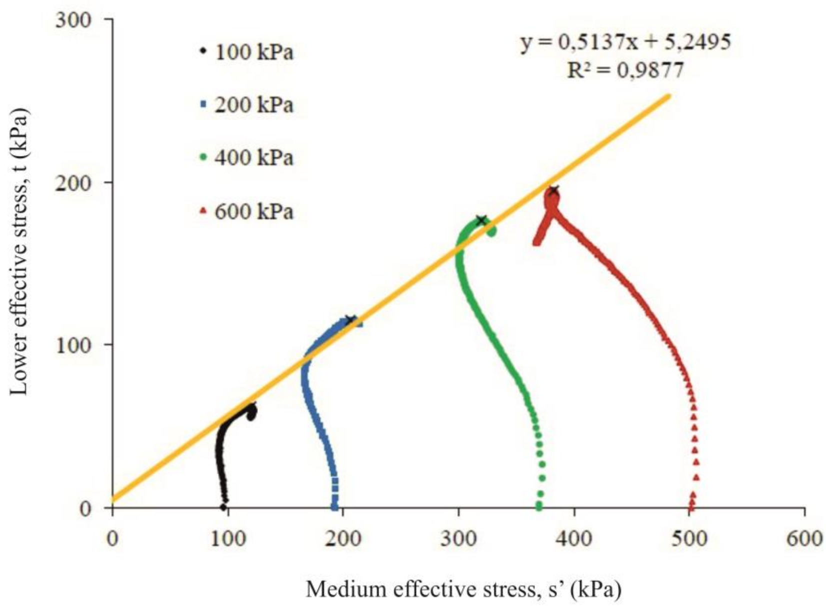

Figure 16 - Medium effective stress versus lower effective stress of the top soil.

The stress path curves of the base soil show no occurrence of a clear shear strength peak after the rupture for stresses of 100, 400 and 600 kPa. However, the effective stress of 200 kPa presents a strong downward trend. Insignificant pore pressure variation ($\Delta u \times \varepsilon_a$) for any of the effective stresses applied is observed. Combining the equations 1 and 2 and the stress path in Figure 14, it was possible to determine a cohesive intercept of 7,1 kPa and an internal friction angle of 27,6º.

The stress path for the top soil, on the other hand, show a clear peak of shear strength after the rupture for stresses of 100, 200 and 400 kPa, and a shear strength peak after the rupture at the stress of 600 kPa. The pore pressure variation present a downward trend. Combining the equations 1 and 2 and the stress paths in Figure 16, it was determined a cohesive intercept of 6,1 kPa and an internal friction angle of 30,9º.

The cohesion and internal friction angle for both soils collected (base and top) are equivalent to values determined for colluvial soils, as in Silveira (2003) and Silveira (2008). The low cohesion expected for this type of soil is related to the high percentage of silt and sand particles.

The results of the hydraulic characterization tests are shown in Table 3, which display k values obtained in the permeability tests (compare with Table 4 which gives typical values of permeability coefficient as in Pinto (2006), based on the grain sizes) for flows established in both horizontal and vertical directions. In Silveira (2008), k values for colluvial soils obtained during the percolation stage in the triaxial equipment varied between 1,8 to 7,5 x 10^{-6} m/s.

Table 3 - Values of k obtained by permeability testing using variable load.

	Horizontal flux	Vertical flux
Base	$1{,}62 \times 10^{-7}$	$1{,}53 \times 10^{-6}$
Top	$3{,}77 \times 10^{-6}$	$2{,}62 \times 10^{-6}$

Based on the geotechnical test, it is observed that both samples (base and top soil) present similar geomechanical behavior defined as normally consolidated soils – not submitted to a vertical effective stress larger than the current. Despite the absence of a peak in the pore pressure variation curve, it was concluded that it is an uncompacted soil. The hydraulic behavior for both samples display permeability coefficients characteristic of typical silty soils.

It is important to notice that just using a tactile-visual characterization it would not possible fit them as been the same type of soil. Stands out that the heterogeneity in relation to the colors and the particle size variation is common for a typical colluvial soil. Therefore, both samples were classified as colluvial soils because they present the same geotechnical behavior. This colluvial material may have been formed by residual soils situated on the upper part of the slope and later transported hillside by natural erosive processes or by gravitational mass movements.

CONCLUSIONS

The colluvial soil that comprises the slope represents a constant danger for the pipeline because it may be a product of past mass movements deposited under minimum stability conditions, without any structuring or cementation, and with extreme heterogeneity of textures, resistance and permeability – inherent characteristics of this type of soil.

The field surveys aided to comprehend the changes in the landscape and in to understand the dynamic of the past and acting events in the study area. These phenomena are part of the local relief evolution process and they are recurrent in function of the existence of triggering agents (tilt, altitude, lithology, pedology and mainly high rainfall indexes during summer). Referring to the appropriate terminology to define the main acting phenomena, it is possible to classify it as a soil creep. It was shown a constant acting of gravitational mass movement processes, which transport residual soils, colluvial material, rocky blocks, bend trees and develop structures on the roadbed near the slope. The relationship between the typological occurred phenomena classification (and in acting process) and the deflagration agents, there is an important theoretical base to develop predictive models to prevent these processes.

The particle size classification according to the ABNT can be divided in two types: silt clay sandy and silt sand clayey, considered for sample collected at the base and top slope, respectively. The clay activity indicates that they are inactive. Based on USCS classification, both samples are defined as silt soil with intermediate plasticity with insignificant volumetric deformation under external loads.

The water upwelling observed on the slope base can be related to the rise of the subsurface water level in these points or just to water logging areas. The soil located uphill is relatively more permeable (larger void index and higher amounts of sand and gravel), which can directly influence the water infiltration and the flow of rainwater, leading to water concentration in the inferior parts of the slope. The increase in the water infiltration degree elevates the soil humidity, saturating it leading to a decrease of the suction and the shear resistance due to a rise in pore pressure at the slope base. Supporting this hypothesis, the base soil presented a saturation degree higher than the top soil – 96.3% and 89.9%, respectively (both sampled under the same natural conditions). Increased saturation in the foot slope can contribute to the creep movement, enhancing the instability of the slope and leading to slope rupture.

To summarize, it is concluded that the slope can move slowly in the form of creep, constantly, with slight increase of speed either in the rainy seasons, or in a pulsating way, associated with the rain season. The creep phenomenon may lead to the rupture of the duct, implying serious socio-environmental problems. The previous movements, classified as rock fall and landslides – although there are no indications or they do not represent sufficient bases for affirmation of the repetition of occurrence – can contribute to the damage of the pipeline if the conditions that led to the outbreak of these processes is repeated.

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