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DETERMINATION OF GEOLOGICAL-GEOTECHNICAL PARAMETERS BY CORRELATIONS IN BAUXITE DEPOSITS

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Abstract: Determining the strength parameters of materials in a consolidated manner can be achieved through field investigation and laboratory analysis. In mining projects, the need for a response is practically immediate, especially in tropical regions where soils of this nature are marked. In this way, the article sought to characterize the geological-geotechnical materials that make up the common plateaus in the Amazon region, which overlie the deposits and reserves of bauxite mines, providing an initial understanding (concept) of how these layers can be approached in mining activities. The aim was to correlate the geotechnical parameters of these materials, validated in the field through the authors' experience in projects of this nature. The methodology was based on understanding a stratigraphic profile typical of the Juruti (PA) region, where geological-geotechnical investigations were carried out and correlations for tropical soils were adopted for an 18 m profile, composed initially of a layer of organic soil, followed by a layer of clayey soil, with varying depths; this overlapped the bauxite deposit. In addition, based on field tests, the materials of the plateaus were parameterized for various uses such as: exploration and development of bauxite mines in the Amazon region in general, presenting cohesion and an angle of 30 kPa and 33°. The conclusion is that this parameterization could make operations more viable by defining and understanding the geotechnical behavior of these materials.
Keywords: Bauxite; Amazonia; Geology.

INTRODUCTION

Aspects related to investigation and drilling accompany the useful life of the project. In mining, the results of this work support current and future projects, always seeking the safety of people, the environment and operations. Linked to this, field work exercises and laboratory tests are widely used to obtain reliable and traceable data, with geotechnical engineering being the discipline that safeguards these procedures and execution, in harmony with current standards and norms.

In the northern region of the country, the target of this work, the geological formation is in the form of plateaus. With the decomposition of silicates and clay minerals, much of the silica is removed, while the aluminum and iron oxides are concentrated. The formation is a rock rich in aluminum oxide, with a variable mineralogical composition of three minerals: gibbsite, diaspore and boehmite (aluminum oxyhydroxides), with subsidiary occurrences of iron oxides, clay, silica, titanium dioxide, among others (AQUINO, 2007; SOUZA, 2008). Economically mined bauxite contains alumina (Al O_{23}) at levels varying between 50 and 55%.

The need to study the behavior of these constituent materials, from a geotechnical perspective, is extremely important and of great relevance for increasingly safe operations, given the position of these commodities on the national scene and their occupation in the world ranking. Determining the best methodology and the best use of the resources needed to acquire data can vary as the geological/geotechnical profiles are drawn up, which for this work will be field tests.

Brazil is a major producer of aluminum, ranking 15th in the world, following the main companies on Brazilian soil: Mineração Rio do Norte S.A. (MRN), the largest producer of bauxite in Brazil, followed by Companhia Brasileira de Alumínio (CBA) and Hydro Mineração Paragominas (MPSA), each with similar shares of the national market. Other producers are Alcoa Alumínio S.A. and Novelis do Brasil Ltda.

SIMONI (2029) writes, according to MÁRTIRES, 2001, and SANTAN (2014), that most bauxite reserves are located in tropical and subtropical regions of the world. The world's known bauxite reserves are approximately

25.6 billion tons (2013 data). The largest producers are Guinea and Australia, with approximately 7 and 6 billion tons, respectively.

The mining method corresponds to the systematization and coordination of services to exploit a deposit, i.e. it is the technique for extracting the material, and its choice is decisive during the economic feasibility study of a mining project. The main objective of a mining method is the complete, safe and economical use of mineral substances with minimal environmental impact (LOBATO, 2012).

Keeping pits stable, access safe and operations running smoothly requires geotechnical skills and knowledge. Regardless of the depth of the pits, which in this case are shallow pits, the strength parameters of the materials and the geometry of the slopes must be established in a condition that is satisfactory for mining progress.

The strip mining system consists of removing the waste rock from a strip or block to be mined to a strip or block that has already been mined, thus reducing the distance the waste rock has to be transported and facilitating the exposure of the ore, as well as speeding up environmental recovery processes (PIMENTEL, 2009).

The study area is located in the Amazon region, in what is known as the bauxite belt, which comprises the equatorial region of the planet Earth. The region is part of an integrated bauxite production system, which includes mining, processing and transportation activities. The mining method commonly used in bauxite mines in the Amazon is strip mining, which is the most suitable for these types of deposits. The process for extracting bauxite comprises cyclical unit operations, carried out in sequential stages: plant suppression, decapping, mining and environmental recovery. Because it allows the area to be leveled and rehabilitated immediately after the ore is mined, the strip mining method has a lower environmental and visual impact. Figure 1 illustrates the operations in the bauxite mining process, which are summarized below:

- Vegetation suppression: vegetation suppression is the stage of removing vegetation located in the area where mining is to be carried out;

- Stripping: stage in which the waste rock is removed to expose the bauxite layer. In strip mining, the waste rock is not transported to a dump or waste rock pile, but deposited inside the cuts formed in the previous stages of mining. The stripping method to be used varies according to the thickness of the waste rock in the strip. Depending on the method, stripping can be done with a crawler tractor or with a large excavator and off-road truck;

- Mining: the actual ore extraction stage. Mining can be done using the continuous method, in which the equipment carries out the blasting and loading stage simultaneously, or using the traditional method, in which blasting is done with a tractor and loading with a wheel loader and/or excavator. The ore is transported to the crusher by road trucks;

- Beneficiation: the beneficiation stage aims to adapt the bauxite to the granulometric specifications and can be done by a mill, crusher, screen and cyclone;

- Rehabilitation of mined areas: in rehabilitation, the original relief is reproduced, soil rich in organic matter is added and the land is prepared to receive the seedlings that will re-establish the vegetation cover. The company's goal is to rehabilitate at a ratio of 1:1, meaning that for every 1 hectare made available during the year (mined area minus the area used for infrastructure), 1 hectare will be rehabilitated within two years;

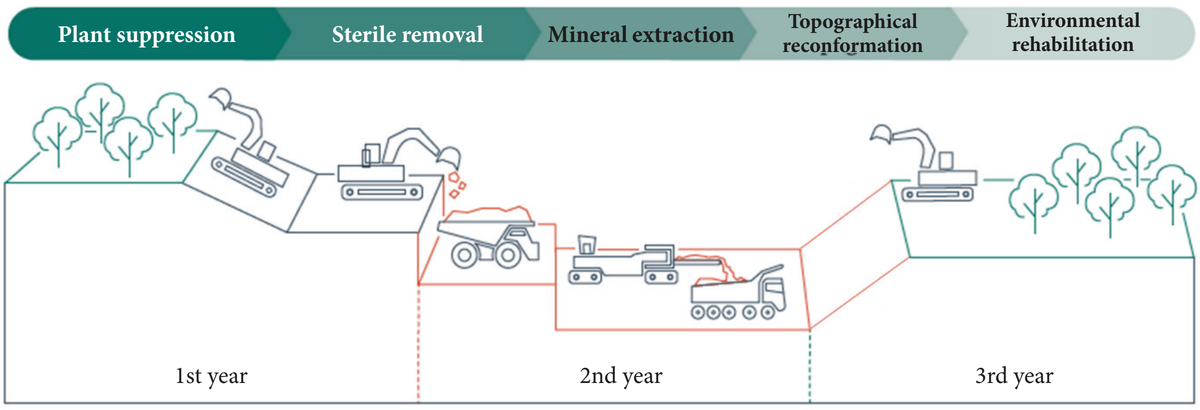

Figure 1 - Flow of the bauxite mining process.

The preparation of excavation projects and the stability of open slopes is highly dynamic and laboratory tests to determine parameters are often late in the operational process. In this way, the article sought to characterize the geological-geotechnical materials that make up the common plateaus in the Amazon region, which overlie the deposits and reserves of bauxite mines, providing an initial understanding (concept) of how these layers can be approached in mining activities, using a region in Juruti as a case study.

METHODOLOGY

The methodology was based on the compilation of NSPT results for a bauxite extraction area in northern Brazil. In this region, bauxite is extracted in plateaus, as mentioned in the introduction. These results have been corrected for 60% energy efficiency (N_{SPT60}). Initially, a characterization of the stratigraphic profile was carried out, based on information from long-term boreholes. The mineral exploration boreholes are arranged in meshes and, among other objectives, aim to determine the geological model of the mineralized body.

The product of the tests, investigations and geological model make it possible to use and apply correlations to determine geotechnical parameters. In the end, 09 boreholes were drilled, with meter-by-meter SPT tests, and 4 undeformed samples (blocks) were collected. The fact that no specific tests were carried out to determine material resistance parameters does not prevent other deterministic methods from being used to obtain them. These parameters can be defined using correlations published in the literature, together with the geological characteristics of the materials. Considering the steps (Figure 1), correlations were selected to obtain the geotechnical parameters. The profile of interest varies in thickness and depth throughout the Amazon region and can, in some cases, reach 18 m. The composition of these layers does not vary, with the initial layer being composed of organic soil, followed by a layer of clay soil, which is superimposed on the bauxite deposit.

The shear strength of clays above the pre-shear stress is characterized by the effective internal friction angle. Its value varies according to the clay content, so that it is lower when the soil is more clayey. Godoy (1983) presents (Equation 1) the correlation for defining the friction angle:

$$\phi = 28° + 0,4 \times N_{SPT} \quad (1)$$

In the drained situation for lateritic structured soils, Berberian (2015) proposed the following correlation (Equation 2) for estimating cohesion:

$$c' = N_{SPT} / 0.35 \text{ (kPa)} \quad (2)$$

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RESULTS AND DISCUSSION

The Paragominas bauxite deposits are located in the NE part of the state of Pará. The Paragominas region is marked by dissected and isolated tablelands and plateaus, covered by yellow clays (Argila Belterra) and iron-aluminum crusts superimposed on the sediments of the Ipixuna Formation to the north and the Itapecuru Formation to the south. In general, the altitude of these plateaus does not exceed 200 m, only in the southern part towards the city of Imperatriz can they reach 400 m. (KOTSCHOUBEY, et al. 2016). In general, the bauxites of Paragominas are linked to the lateritic iron-aluminum horizon of lower Tertiary age (Paleogene), which is overlain by these yellowish cream clays, known as Argila de Belterra, and the saprolite, formed of variegated or stained kaolinitic clays. Figure 2 shows the typical profile identified for the Paragominas region.

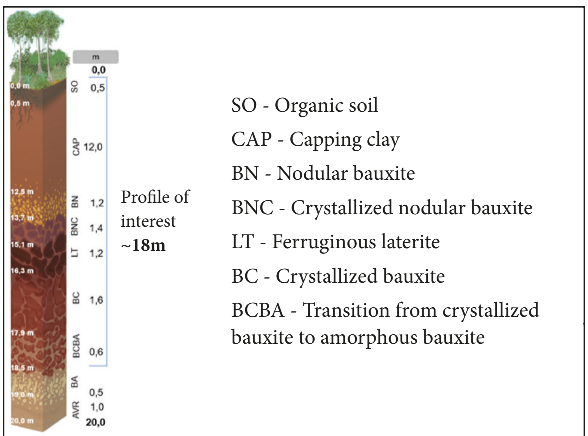

Figure 2. Typical profile of the Mineração Paragominas pit area

Considering the existing boreholes and the geological information (local and regional), the natural foundation represented by the clay has remarkable characteristics. The clay mainly has a clay-silt texture, sometimes sandy, with the possibility of laterite fragments and concretions, varying to clayey silt. The color is variable, with irregular patches of different colors (yellow, red, pink, brown, white, etc.). The clay layer is thick, with varying thickness, in some cases over 15.0 m. Figure 3 shows the number of blows of the SPT tests on this material as a function of the effective vertical stress. It can be seen that the clay has an N_{SPT} of more than 10 blows, with an average of 36 blows, with a consistency classified as hard to hard. There may be stretches of lower resistance, especially at the interface of the materials.

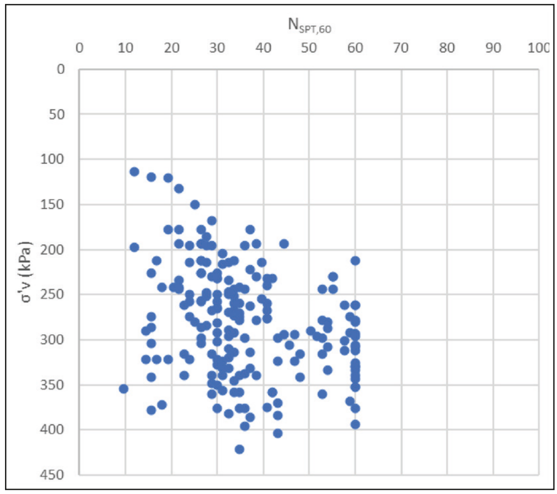

Figure 3: Relationship between effective vertical stress (σ'v) and N values $._{SPT60}$

The resistance parameters defined for the clay are shown in Table 1These were obtained from the literature and from field tests carried out. Given the variability of the N_{SPT} results for the clay, the N_{SPT} of 11 blows can be conservatively considered in equations 1 and 2. Thus, the friction angle and effective cohesion of the clay are estimated to be 33° and 30 kPa, respectively, which are quite consistent with typical tropical soils in the region with a certain level of laterization. It should be noted that local samples can reach up to 60 kPa of cohesion, as a result of the high level of laterization of the samples. Thus, the conceptual level here proves to be valid.

Material	c' (kPa)	φ (°)
Clay	30	33

Table 1. Geotechnical material strength parameters

FINAL CONSIDERATIONS

The conclusion is that the field investigation, consisting of 09 boreholes and 4 undeformed samples, combined with a good bibliographic review, associated with the field description, together with revisiting the mineral exploration boreholes on the plateau, under the auspices of tactile-visual evaluation, provide fundamental guidelines for determining the resistance parameters of these investigated materials. These parameters are then laid out on geotechnical geological plans and sections to begin a series of models that refine this input data. It is understood that the estimation of parameters by means of the NSPT can subsidize projects of this nature at a conceptual level, allowing for the development of more refined correlations through the validation of tests in complementary sampling campaigns carried out at the site.

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