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Analysis of RQD Index in the Rocky Massif of Cacimba Cercada Tunnel in the Adductor Canal at Alagoas/Brazil

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Abstract- The knowledge of geomechanical and structural parameters is essential in any project with structures built on rocks or rock masses. The present work had as main objective the mechanical classification along the rocky massif of the Cacimba Cercada Tunnel located in the state of Alagoas/Brazil, through the RQD (Rock Quality Designation) index. In addition, the potential containment structures that could be applied were evaluated, whenever the geomechanical classification indicated regular mass or poor quality. The proposed methodology was based on the division of the Cacimba Cercada Tunnel into three regions (entrance, center and exit) also on the analysis of the polling reports jointly with the assessment of the geological and geotechnical domains present in the area. In this way, the results obtained showed that the region of the entrance obtained an average RDQ equal to 24.80%, being classified as very poor quality. While the region in the center of the tunnel had a result of average RQD equal to 57.84%, being classified as a regular quality. The zone exit obtained an average RQD result equal to 34.28%, being classified as poor quality. Based on the exposed results, it is imperative to use containment structures to avoid possible falling rock blocks and landslides during the execution of the project and after its completion.

Keywords- *Classification of Rocky Massifs, Geological Discontinuities, Cacimba Cercada Tunnel*

I. Introduction

The geological-geotechnical knowledge about the place of implementation of a civil work is very relevant. The description of the mechanical behavior of the constituents of the rock mass allows studies to be carried out to investigate the technical and economic feasibility of carrying out any work in the mass, thus contributing to the best characterization from the measurement of the minimum parameters necessary for classification.

According to HOEK and BROWN (1980), when analyzing a given region in the scope of rock mass engineering, it is intended to conceive and establish the necessary parameters in a broad framework in order to respond to the mechanical, geometric and constructive aspects as well as the aspects of operational security of a structure built in a massif (apud, GONÇALVES, 2016).

The characterization of a given area is carried out through knowledge of the geological formation and outcrops of the constituent materials. When it comes to rocky exit, mechanical classifications are used in accordance with the specificities of each work.

Classification systems are used to characterize rock masses through a set of properties identified by direct observation and tests carried out in situ or on samples collected in surveys. The purpose of these classifications is to systematize the set of geotechnical elements into classes, associating these classes with a pattern of behavior, providing quantitative information for design purposes, making the project more efficient and decision making more consistent.

The set consisting of the rocky matrix and composed of all the discontinuities present is called rock massif, being characterized, strictly speaking, by a heterogeneous material, due to the presence of numerous imperfections, whether in microscale or perceptible to the naked eye.

The study of the mechanical behavior of rocks, over time, was a major factor for the advancement of civil engineering works allowing the geological and geotechnical characterizations of the massifs to be increasingly complete. In works, in which the execution involves stability analysis, it is necessary to characterize the massif totally, especially in works of art such as bridges, dams and tunnels.

The evaluation of the geotechnical quality of the massif is the main objective of the application of the geomechanical classifications that, from then on, will allow to choose the most suitable system for the execution of a certain underground excavation work, as well as to indicate the most appropriate type of support during the execution of the work, by observing and carrying out tests, for example, to obtain the Massif Quality Index - RQD, in order to minimize the potential and effective risks of accidents during the work (NETO, 2007).

According to Bieniawski (1989), the classification of rock mass is widely used in rock engineering and is a means of empirical approximation and, thus, a way of basing and portraying the performance of complex underground structures (apud, NETO, 2007).

The first quantitative criterion to characterize the quality of the massif was the RQD - Rock Quality Designation (DEERE, 1964, apud NOVAIS, 2017, p. 35). The criterion had the purpose of developing a system for the construction of tunnels and for providing supports, but ended up being used as a reference parameter for other classifications. The RQD was presented at the time when the rock quality information was obtained only by geological description or by a percentage of borehole recovery (DEERE & DEERE, 1988, apud NOVAIS, 2017).

The present work was developed within the scope of the classification of rock masses with the application of the RQD indexes. In order to apply these classifications, it is essential to study the mechanical and structural characteristics of the rock mass that, in the present work, consisted of a case study, the analysis of the Cacimba Cercada Tunnel for the construction of a rectangular channel located in section IV of the Adductor Canal at Alagoas state, between the municipalities of São José da Tapera and Senador Rui Palmeira.

II. OBJECTIVE

The present research work had as main objective to address the most relevant geological, geotechnical and geomechanical aspects related to the execution of underground excavations in rock masses, to identify and analyze the discontinuities identified in the Cacimba Cercada Tunnel, classifying it, according to the RQD index and if the rock mass is classified as unstable, foresee measures against instability.

III. MATERIALS AND METHODS

The proposed methodology for this research work involved two complementary phases, in the first stage, an extensive field work was carried out with the execution of rotary boreholes and the collection of rock cores for the recognition of structural elements, such as failures and fractures , in the second phase, the data collected, processed and analyzed in order to classify the rock massif of the Cacimba Cercada Tunnel in accordance with the RQD (Rock Quality Designation) Index.

After carrying out the rotary surveys and the collection of testimonies, a division of the Cacimba Cercada Tunnel area was carried out in three regions: a) Entrance; b) Center and c) Exit. This compartmentalization was necessary to group the field reports in regions and thus proceed to a more detailed classification.

For the classification by the RQD Index, 6 points were used along the Cacimba Cercada tunnel, of these, 2 points are located in the Entrance region and correspond to the surveys (SM 121 + 490 and SM 121 + 580), two other Central points (SM 121 +770 and SM 121 + 900) and, finally, 2 points in the Exit region (SM 122 + 260 and SM 122 + 370).

Subsequently, the interpretation and analysis of the survey bulletins was conducted in order to identify the geological-geotechnical domains and to prepare the profile of the region of the Alagoano Wilderness. Then, in order for each region to obtain its average RQD classification, data was compiled and processed for each survey bulletin.

For the calculation of the RQD Index, only testimonies obtained equal to or greater than 10 cm are used. The RQD value is calculated through the sum of the stretches greater than 10 cm, divided by the length of the maneuver barrel, as shown in Equation 1.

$$\text{RQD} = \frac{\Sigma\ \text{Barrel Fragments>10cm}}{\textit{Total length of the barrel in the maneuver}}\ x\ 100 \qquad (1)$$

The calculation of the average RQD per sounding point is represented by the average of the RQD over the depth. The region's RQD (Entrance, center and exit) is obtained by the average between the surveyed points, Equation 2 illustrates the calculation:

$$\text{Region RQD (\%)} = \frac{\textit{Average RQD of point}1\ (\%) + \textit{Average RQD of point}2\ (\%)}{2} \qquad (2)$$

Finally, the need for containment structures was assessed according to the RQD Indexes in each of the regions compartmentalized in the Cacimba Cercada Tunnel.

IV. RESULTS

In terms of results, it can be reported that the geology of the Cacimba Cercada Tunnel is inserted in the region in the Structural Province of Borborema, inserted in the geological context of the Intrusive Suite Itaporanga as shown in Figure 1, covering rocks of the gneissic-migmatitic base, from the Archean to the Paleoproterozoic (comprised between 2 billion and 500 million and approximately 1 billion and 600 million years ago) and the metamorphic sequence arising from tectonic events that occurred during the Meso and Neoproterozoic (comprised between 1 billion and 541 million years ago). (CPRM, 2009).

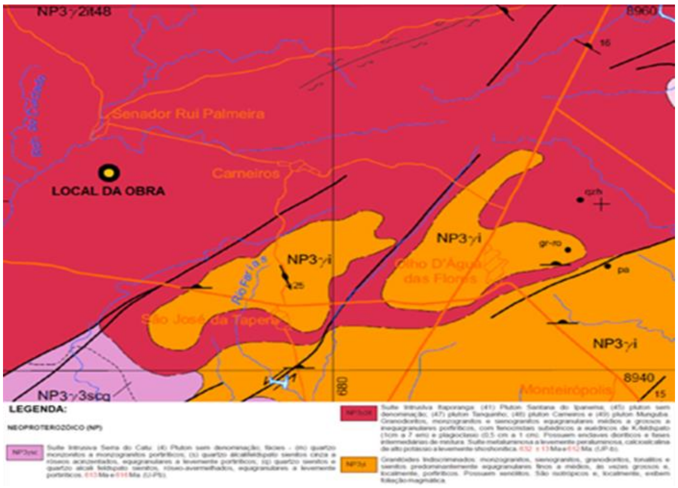

Figure 1. Geological map. Source: CPRM (2009).

The Intrusive Suite comprises the outcrop rocks in the midwest and northeast portions of the state of Alagoas, more precisely in the Pernambuco-Alagoas Domain. This entire geological record was responsible for affecting the rock masses, regionally and at different scales, due to the effects of intense shear and whose predominant direction is N45E, as shown in Figure 2.

The direction and plunge of the shear zones and the discontinuity plans are the main conditioning factors for the excavations of the Tunnel, whose direction is developed in the N120º (N30W), that is, the crossing of these alignments occurs with angles almost orthogonal to the excavation of the tunnel, from 70 to 80 degrees between one axis and the other, with a predominant dive towards SE.

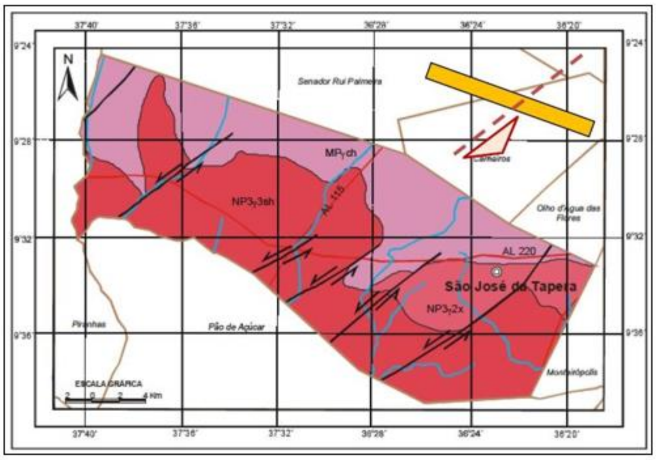

Figure 2. Geological map in the region of the work. Highlight the tunnel direction and the presence of faults in the oblique direction (NE) with a predominant slope for SE. Source: CPRM, 2009.

Rocks from the Itaporanga Intrusive Suite, with variable orientations, dominate the tunnel area. The rocks identified are, in general, massive, and may have bent structures, according to the regional deformation phases. The granite found is mostly isotropic, but it can show orientation of the phenocrystals. From a structural point of view, granitoids have a predominantly massive structure, but in several cases they can show a well-marked foliation (ALMEIDA, 2018).

In summary, it is clear that the critical regions found through the study of the geological / geotechnical profiles revealed unfavorable conditions for excavation, mainly in the region of the tunnel shell, due to the low coverage in healthy rock, altered material with soil behavior (ALMEIDA, 2018).

About the Tunnel Entrance region, it must be emphasized that in both surveys, a superficial layer of soil was found classified as silty sand with boulders, whose thickness variation was 3 meters. The soundings were impenetrable to percussion in approximately 1.50 meters of depth. It was possible to identify C1 coherence, which corresponds to a break with difficulty with the hammer stroke, which produces fragments with sharp edges, with fire-digging properties. Table 1 shows the data used for the analysis of the RQD.

TABLE I. RQD CLASSIFICATION OF POINTS SM 121 + 490 AND SM 121 + 580.

SM 121+490			SM 121+580		
DEPTH (m)	RQD (%)	Classification	DEPTH (m)	RQD (%)	Classification
9.30	9	Very Poor	7.46	45	Poor
10.80	20	Very Poor	8.96	7	Very Poor
12.30	11	Very Poor	10.46	12	Very Poor
13.80	27	Poor	11.96	25	Very Poor
15.30	53	Regular	13.46	16	Very Poor
16.80	85	Good	14.96	35	Poor
18.30	7	Very Poor	17.96	11	Very Poor
-	-		19.46	9	Very Poor
-	-		20.96	19	Very Poor
-	-		23.60	14	Very Poor
Mean	30.29	Poor	Mean	19.30	Very Poor

Along the depth, from the average RQD found in the two locations, there is an RQD for the plunger calculated by Equation (3) of:

$$RQD(Entrance) = \frac{30.29\%+19.30\%}{2} = 24{,}80\% \qquad (3)$$

The initial section of the tunnel with RQD of 24.80% was classified as very poor. The degree of fracturing is conditioned to the intense shear of the region and is manifested locally with greater intensity, mainly by the fractures present in the gneissic rocks found during the drilling, that both places, F1 / F2 indices were found conditioning to a medium fracture, despite the RQD index classifying as a lower quality. At both points, no water was found after 24 hours.

It is important to highlight the occurrence of certain frequency intensification passages of the discontinuities associated with shear zones of local and regional character, with RQD of the order of 15%, or even with sectors of less covering the rocky top where the values found are less than 10 %.

Regarding the middle of the tunnel, it was possible to perceive a superficial layer of soil basically composed of silty sand with boulders (fragments of altered rock), with a difference in thickness of 3 meters. The soundings were impenetrable to percussion, close to 1.50 meters in depth. A C1 coherence was also found, as identified in the previous point. Table 2 presents the data used for the analysis of the RQD.

TABLE II. TABLE 2 - RQD CLASSIFICATION OF POINTS SM 121 + 770 AND SM 121 + 900.

SM 121+490			SM 121+580		
Depth (m)	RQD (%)	Classification	Depth (m)	RQD (%)	Classification
13.50	8	Very Poor	5.00	36	Poor
15.00	43	Poor	8.50	20	Very Poor
16.50	27	Poor	8.00	81	Good
18.00	49	Poor	9.50	90	Excellent
19.50	42	Poor	11.00	83	Good
20.00	13	Very Poor	12.50	81	Good
21.00	13	Very Poor	14.00	80	Good
24.00	30	Poor	15.60	100	Excellent
25.50	89	Good	17.00	79	Good
27.00	27	Poor	18.50	95	Excellent
28.50	71	Regular	20.00	100	Excellent
			21.50	75	Regular
			23.00	95	Excellent
			24.50	85	Good
			26.00	93	Excellent
			27.50	57	Regular
			28.00	80	Good
Mean	37.45	Poor	Mean	78.23	Good

During the depth of the SM 121 + 770 survey, the RQD is classified as poor, mainly due to the subvertical fractures present in the gneissic rocks found between 20 and 22 meters.

At SM 121 + 900, the conditions found were better, showing that the rocks were in conditions closer to healthy rock, with a reduction in the RQD in the initial meters due to the presence of changes in the rocks present in the soil layer, notes a RQD average of 78.23%.

A joint analysis of the two points, based on the average RQD, found an RQD value for the middle of the tunnel, through Equation (4).

$$RQD(Center) = \frac{37.45\%+78.23\%}{2} = 57{,}84\% \quad (4)$$

Thus the middle of the tunnel was characterized as regular. In both places, no water was found after the 24-hour period.

In the Exit region was identified a layer of soil consisting basically of silty sand with boulders, with an average thickness of 2 meters. The soundings were impenetrable to percussion in 1.00 m of depth. The survey also indicated a C1 consistency. Table 3 shows the data used for the analysis of the RQD.

In general, based on the average RQD found in the two locations, there is an RQD for Exit, calculated from Equation (5):

$$RQD(Exit) = \frac{28{,}20\%+40{,}36\%}{2} = 34{,}28\% \quad (5)$$

TABLE III. TABLE 3 - RQD CLASSIFICATION OF POINTS SM 122 + 260 AND SM 122 + 370.

SM 121+490			SM 121+580		
Depth (m)	RQD (%)	Classification	Depth (m)	RQD (%)	Classification
5.00	9	Very Poor	1.80	54	Regular
8.00	35	Poor	2.80	51	Regular
9.50	7	Very Poor	3.70	66	Regular
12.50	33	Poor	6.20	81	Good
14.03	32	Poor	7.70	59	Regular
15.53	75	Regular	9.00	9	Very Poor
17.03	63	Regular	9.62	11	Very Poor
18.53	14	Very Poor	11.00	19	Very Poor
20.03	7	Very Poor	14.00	48	Poor
21.53	7	Very Poor	15.50	39	Poor
			21.00	7	Very Poor
Mean	37.45	Poor	Mean	78.23	Good

From the result obtained it is understood that the quality of the rock is poor. The rocky massif presents passages with a high degree of fracturing, varying between F5 and F4 predominantly.

At both points, no water was identified after the 24-hour period. A large alternation of hard altered rock with soft altered rock was found in the region of the tunnel ceiling with low coverage in healthy rock.

V. CONCLUSIONS

The present work of conclusion of the course sought to approach several geological, geotechnical and geomechanical aspects related to the execution of underground excavations in rock masses. This proposal was concluded from the case study of the Cacimba Cercada Tunnel, with the analysis of discontinuities and classifications according to the RQD Index.

In general, the rock mass analyzed by means of the drilling is inserted in an area predominantly of little altered rock, with places of greater degree of alteration, becoming very fractured, the latter predominant feature along the tunnel. The data from the investigations (surveys) did not indicate the presence of water, which becomes a positive factor since there is no percolation force in the massif.

Regarding the results, the Entrance has a RQD of 24.80%, classified as very poor, evidenced by the fractures present along the depth. In the middle of the tunnel, the quality of the massif is superior to that of the center, indicating an RQD of 57.84% being classified as a regular massif. Finally, at the exit, a RQD of 34.28% was identified, defining it as a massif of poor quality.

From the analysis of the results of the classifications, the need for stabilization processes in the tunnel is evident. In this regard, the most suitable solutions are those that consist of the best cost / benefit ratio, which means prioritizing the use of part of the resources. (labor, materials and equipment) from the region itself. It stands out as forms of stabilization the use of risers, wire mesh, shotcrete, the use of metal crankshafts, pitching campaigns, jet grouting, nailing, among other techniques that can be used to avoid possible displacements.

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