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# Methodologies for geological-geotechnical characterization of rock masses: role of geomechanical classifications and indexes

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**Abstract.** The geological and geotechnical description and evaluation are fundamental in engineering projects and the extractive industry, emphasizing underground environments where the rock mass is subjected to high stresses. In excavating rock masses, the classification systems contribute to parameterizing the rock material and rock mass characteristics. In addition, it is essential to the definition of the support to be applied, which limits are often based on the value of the geomechanical classifications. Therefore, determining the characteristics demands structured techniques to reconcile rigour, accuracy, and efficiency in the execution of the site investigation to obtain reliable data in an integrated action of the work cycle. This study analyses the applicability and feasibility of the Geological Strength Index (GSI), based on field data collected in different underground projects. Various geological environments and distinct excavation purposes were selected to evaluate the possibility of expanding this version of the GSI to other rock types with the inclusion of the influence of groundwater on this classification.

## 1. Introduction

The characterization and evaluation of rock masses is a fundamental tool in civil works, resource extraction industry, land planning, and geoenvironmental projects. The requirement of a geotechnical study with rock mass characterization is essential to major engineering projects to define the site's feasibility, outline constructive hypotheses, and reduce geological uncertainties. De Freitas [1] states that the geological model is crucial to engineering design in that it predicts the response of a given site and its surroundings to construction. Also, from the economic point of view, the characterization of rock masses shows extreme importance since it allows estimating operation costs in different construction activities (excavations, foundations, support, fills, etc.). On the contrary, a lack and unsatisfactory comprehensive engineering geology and geotechnical studies lead to budget slippages and delays caused by geotechnical problems [2].



Geological and geotechnical characterization have undergone a remarkable evolution since the first works on the subject in the early twentieth century. Geo-professionals practice it with application in different fields to minimize uncertainties and geological variabilities, contributing to a correct study of soil and/or rock, its applications in sustainable development, and society's development [3].

Geotechnical and geomechanical classifications are complementary tools integrated into geotechnical characterization that classify and quantitatively frame rock masses based on their inherent parameters. When used correctly, rock mass classification can be a powerful tool. The classification approach is a practical basis for designing complex underground structures [4]. Although some variety of geomechanical classifications and geotechnical indexes are available, the RMR (Bieniawski 1989, 1993), the Q-System (Barton et al. 1974; NGI 2015), and the GSI (Hoek et al. 1998, 2013) are the most used in large projects. The combined and integrative use of the different geomechanical classification systems is a reliable tool for a balanced, comprehensive analysis of rock mass characteristics and behaviour [5].

In the last decades, there have been large-scale underground works in Portugal, mainly hydraulic and some railway and road works, which involved extensive characterization and evaluation of rock masses. The work in development is based on data from an underground hydraulic project in the North of Portugal (granitic environment) and a road tunnel in the North of Portugal (metasedimentary background). In addition, it is also expected to obtain data from a mining project in northern Portugal in a metasedimentary setting.

The present work aims at presenting the general methodology of the work that is being developed in the scope of the ongoing doctoral research project of the first author.

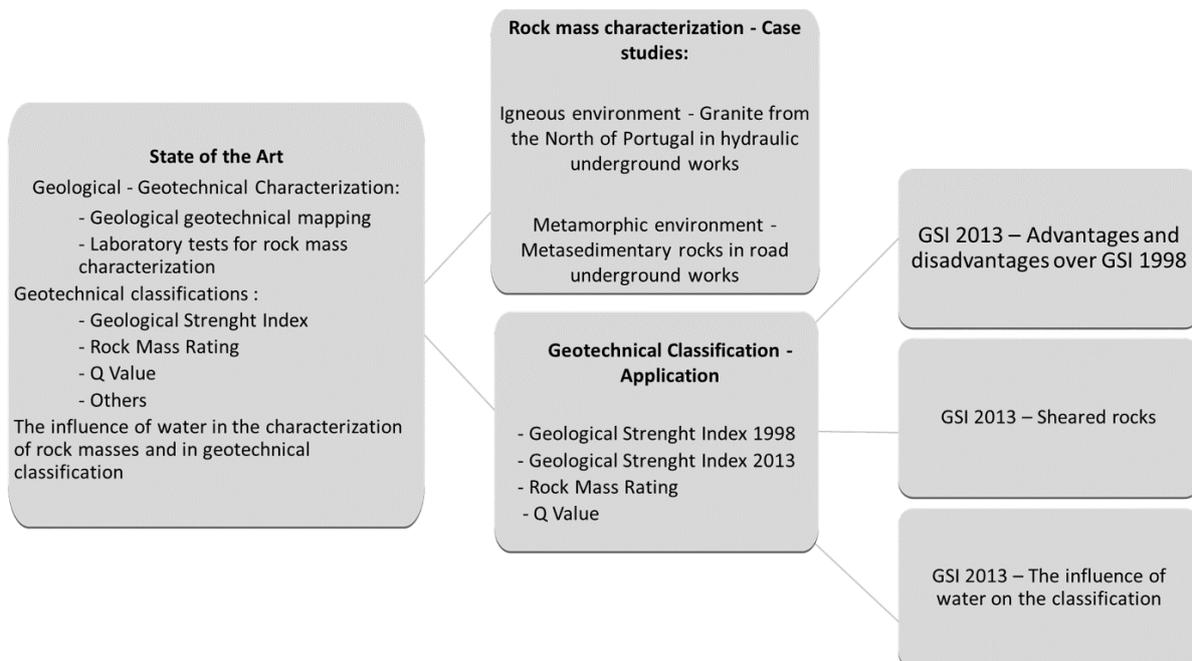


Figure 1- Flowchart summary of the methodology followed in the study

## 2. Methodologies: a brief overview

The data collected for this study resulted from the geological and geotechnical mapping of the underground excavation front integrated into the production cycle of the selected projects. In addition, the direct observation of the rock mass allowed its characterization and classification.

For the mapping of the excavation fronts, the scanline sampling technique was applied, seeking to characterize in detail the system of discontinuities and to evaluate the rock mass mechanical properties based on the field evaluation, analysis and integration with design data.

### 2.1. Mapping techniques and geological-geotechnical characterization

Geotechnical mapping in underground works is based on the characterization of rock mass discontinuities, weathering grade, and groundwater occurrence. This description relies on the collection of field data, essential to estimate the quality of the rock mass in terms of geomechanics of discontinuous media [6-9], which will define the strength, the deformability, and the permeability of the rock mass.

*2.1.1. Scanline sampling technique.* The scanline sampling technique consists of an expedite technique involving the systematic measurement and description of all the discontinuities that intersect a graduated line on the rock surface to be mapped, analyzed, and evaluated. It is commonly used in outcrops, slopes and road/railway cuts. In underground excavations, this technique is of utmost importance with the advantage of having fresh rock mass faces to observe and characterize.

The data from each survey, namely each discontinuity orientation, spacing, persistence, weathering grade, aperture, filling material and roughness, are recorded on a geological-geomechanical field sheet and then transcribed to digital spreadsheets that support all fundamental statistical data analysis and processing. Besides the statistical treatment and data compilation, it is also essential to graphically represent the collected data in geotechnical cross-sections, photos and maps, reproducing the observed and annotated aspects [10].

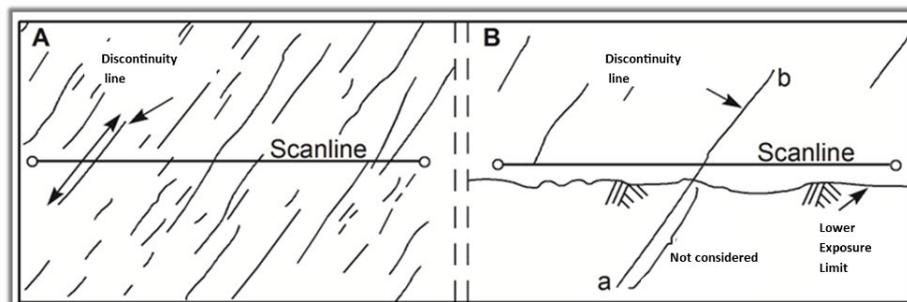


Figure 2 – Scanline sampling technique (adapted from [11]): representative schemes of discontinuities crossing a sampling line on an exposed rock mass surface. A) Case of a sampling line intersected by a family of discontinuities with variable persistence produces half-lengths of various sizes; B.) In the case of a randomly intersected discontinuity [ba] where the sampling line is close to the lower limit of exposure, it will typically only be possible to measure the half-length whose termination is visible

In the study under development, the scanline sampling technique was applied to map the excavation fronts of underground geostuctures, both at the wall and head face and characterize the rock mass. This allows to perform the stability analysis and define the rock support based on the geotechnical classifications, which systematize and parameterize the observed rock mass.



Figure 3 - Excavation face of Marão Tunnel (N Portugal) with a contact (by fault) between grey schists and quartzites

## 2.2. Geotechnical indexes and classifications: emphasis on GSI system

The geotechnical indexes and classification aim to identify the most significant parameters that influence the behaviour of a rock mass, to divide the rock mass into volumes of similar behaviour, i.e. rock mass classes of varying quality, to provide a basis for understanding the characteristics of each class of rock mass, to compare the rock conditions at one site to the conditions found at other sites, to obtain quantitative data and guidelines for engineering projects, and to provide an everyday basis for communication between engineers and geologists [12].

In the geotechnical characterization of the rock masses, detailed and systematic geological-geotechnical surveys were carried out at the rock excavation fronts to apply the geotechnical classifications, namely RMR[89], Q-value and GSI[98]. In addition, GSI[2013] was also introduced to present and discuss the validity of applying this version to heterogeneous rock masses and its applicability in the definition of rock support, mainly in underground works.

The evaluation of rock masses by GSI is based on the analysis of their geostructure in terms of structural block size and the geological-geotechnical conditions of their discontinuities, namely, the degree of alteration and roughness. Combining the two parameters (the degree of block size in terms of geostructure and the conditions of the discontinuities) provides a basis for the geotechnical classification of a wide range of rock masses with different degrees of alteration and structure [13]. In 2013, a new version of the GSI was presented to detail and quantify the existing classification chart from GSI[98]. This new version is based on a solid parameterization, introducing the RQD (Rock Quality Designation) and the state of geotechnical conditions of the surface of discontinuities. Thus, scales were added to the GSI chart, the horizontal axis is divided into 5 intervals of 9 values with a maximum of 45 points, and the vertical axis is divided into 4 intervals of 10 values with a maximum of 40 points [14]. For the horizontal scale, the authors adopted the geotechnical conditions of the discontinuities (Joint Condition, JCond[89]) defined by Bieniawski [12].

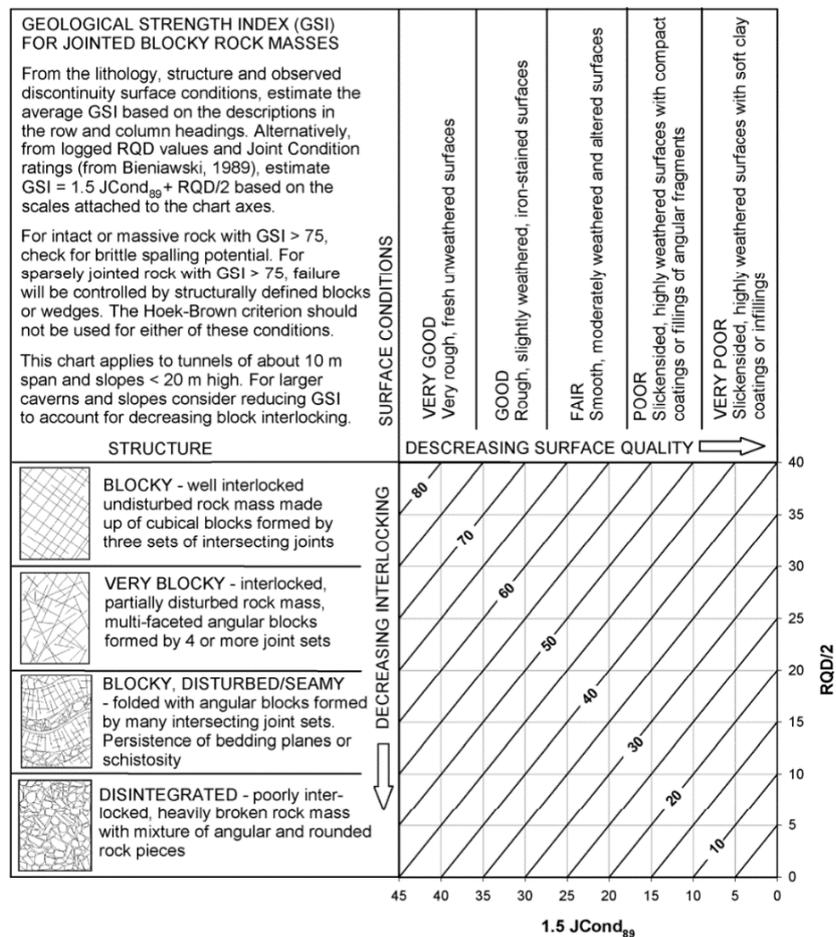


Figure 4 – Chart to GSI quantification using  $Jc_{89}$  and RQD [14]

**2.2.1. GSI|2013 in sheared rocks.** In 2001 Hoek & Marinos [15] presented a methodology to estimate the GSI and the properties of heterogeneous rock masses, using flysch as a study base. The genesis of these rocks and their tectonic heritage results in a complex structure that makes it challenging to apply the most common classification systems. To incorporate this type of material in the GSI classification, a specific classification chart was developed for this type of rock.

One of the ongoing research objectives is to integrate the rock mass observed characteristics in the most recent classification chart, making it more comprehensive and contributing to the need for application in engineering projects that develop in the types of rock masses analyzed.

**2.2.2. The influence of groundwater on GSI.** The groundwater directly influences the classification and characterization of rock masses and the underground construction [16], both by accelerating the weathering of the rock mass and by the pressure caused on the rock support and the structure.

Both RMR and Q-Value consider groundwater as a penalty in their classification mode. However, the GSI does not directly include this parameter in its evaluation, so it will be essential to estimate its influence in applying the classification in hydrogeomechanical terms [17]. Thus, this approach also presents as an objective the study of the introduction of groundwater in the GSI, using the obtained data from the characterized excavation faces.

### 2.3. Selected sites and geological backgrounds

Data from three different underground projects in Northern Portugal were selected for this study's various purposes and geological settings.

The Salomonde Dam is an infrastructure located on the Cávado river in the municipality of Vieira do Minho (Northern Portugal). The powerplant started operating in 1953, and power reinforcement works were implemented in 2015. This upgrade included excavating approximately 5,000m of tunnels with variable sections. The project was developed in the so-called “Maciço Granítico do Gerês” (granitic rock mass) inside the Gerês mountainous system, showing coarse-grained facies in the periphery and medium to coarse-grained porphyritic, towards the inner of the rock mass. There are also epi-sienites composed of reddish feldspar and green minerals, with a very low percentage of quartz. Despite the good quality of the rock mass where this project was developed (with occasional sheared zones associated with faults), the complexity was related to the number of underground structures developing close to others, sometimes overlapping in level.

The Marão tunnel is part of the Marão motorway project, developed between Amarante and Vila Real (Northern Portugal). It consists of two parallel tunnels with approximately 5,667m each, totalling 11,335m of the tunnel, crossing the Serra do Marão and generally developing in the WSW-ENE orientation. Serra do Marão mountainous system is part of the Central-Iberian Zone [18], and metasedimentary geological formations, ranging from Cambrian to Lower Devonian, and the regional mega-structures Manta and Gaiva faults [19] are interested in the excavation. This underground work was a challenge from the geotechnical point of view due to the geological complexity of the formations crossed and the engineering design solutions, the depth range (maximum -515 m), and the groundwater's influx during the excavation.

The present study also aims to count on data from a mining project started in 2020, temporarily suspended but is expected to start soon. This project is located in Armamar (Northern Portugal) in the Vila Seca – Santo Adrião tungstiferous deposit within a low-grade metamorphic series with intense folding. This belt contacts the Lamego–Penedono–Escalhão antiform structure and the North with the Vila Real–Carviçais structure, composed of two-mica variscan granitic rocks (syn to tardi-Variscan D<sub>3</sub>) [20].



Figure 5 - Location of the study sites concerning the local geology (N Portugal)

### 3. Discussion

Site geological and geotechnical characterization and rock classification systems evaluation are pillars in designing and analyzing large engineering projects of rock masses. Hence, the safety of excavations and project economy and schedule is essential its constant development, adaptation, and updating, as much as possible based on data collected in the practical application in real works.

This study aims to analyze the data resulting from the characterization of rock masses in deep underground works already performed (about 300 meters in Marão Tunnel and about 400m in Salamonde Dam; N mainland Portugal). Furthermore, the ongoing research aims to analyze and compare the GSI versions (1998 and 2013), attesting to the most recent version reliability and its development.

Some preliminary results of the research already developed were published [5], where it was concluded, for an analysis of the data obtained from the application of the 1998 and 2013 versions based on the characterization of 74 excavation faces, that the 2013 version tends to be more conservative in adverse geotechnical conditions. Figure 6 presents a comparison chart between the two versions relative to RMR|98. The indicator values of poor-quality rock mass-produce lower GSI|2013 values. However, in rock mass with reasonable quality, the difference is less substantial, with no higher prevalence of values for one version relative to the other, and in rock mass with better geotechnical conditions, generally higher values are obtained for the GSI|2013. Moreover, the quantification of the considered parameters (particularly those related to the characteristics of the discontinuities) reduces the uncertainty.

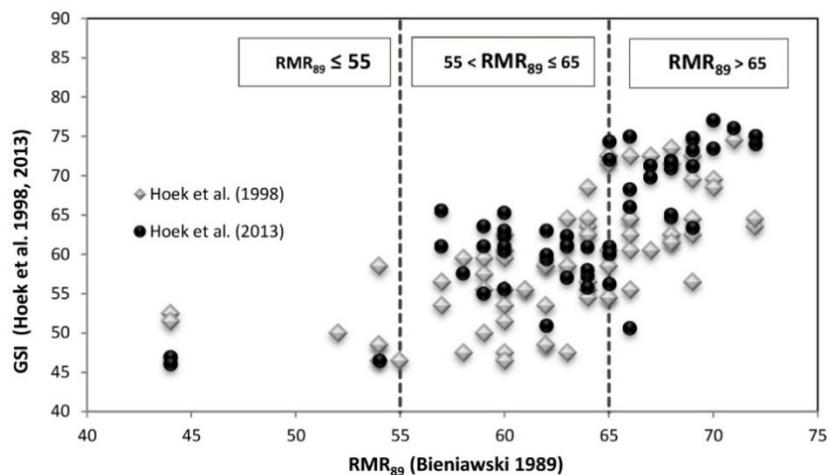


Figure 6 - Graphical comparison of the data obtained for the different GSI versions (Hoek et al. 1998, 2013) and their correlation with RMR|89 [5]

### 4. Final Remarks

This study contributes to rock mass characterization, focusing on the Geological Strength Index and its latest version published in 2013. This is a geotechnical index in constant development due to its high applicability in engineering practice, although the experience in case studies of the latest version is still scarce. Therefore, the methodology expects to use three case studies where data of rock mass characterization in underground excavation fronts were obtained to analyze and evaluate the application of GSI|2013 by comparison with the 1998 version. Also, the relationship with the other geomechanical classifications, and the possibility of proposing a chart that encompasses sheared, weak rocks and contemplates the influence of groundwater in the classification system are under development.

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