Determination of frictional resistance pair Jr/Ja using a friendly – graphical approach in the Q-slope empirical method.

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Abstract. The Q-slope index is a new geomechanical classification for slope [1] that has become popular and is spreading throughout the world. It is currently being applied in various lithologies, in different countries, mining and civil projects. The Q-slope allows engineers to adjust and optimize slope based on field observations of some geomechanical and geometric parameters that are easy to obtain. The selection of the value of each of the different parameters is made based on tables [2] some of whose parameters are the same as in the tunnel Q index, e.g. roughness (Jr), alteration (Ja), RQD etc. However, if the rock engineering has to analyse many slope with different properties, it is not so intuitive to work with very detailed tables and descriptions. We have therefore based ourselves on the concept of the graphic Geological Strength Index [3] that uses short descriptions and designs. In this investigation we have selected the two parameters that form the pair of frictional resistance Jr / Ja (joint roughness number and joint alteration number. This Jr / Ja coefficient is very important since it is the multiplied by a correction factor for favorable or unfavorable orientation called O-factor. This O-factor is one of the novelties of the Q-slope compared to the “classic” Q of tunnels. Throughout the investigation we have simplified the descriptions of Jr and Ja (referring the reader to the previous works to know these parameters in greater detail) and created some graphic images that are easy and friendly to implement on site with a multiple choice table.

1. Introduction
Geomechanical rock mass classifications are widely accepted in the scientific and technical world for their simplicity and adaptability in different studies worldwide. Rock Mass Rating (RMR) and Q-index have been successfully applied worldwide in both civil and mining underground works [4, 5]. Since its appearance,Bieniawski's RMR has been the fundamental basis of multiple adaptations that try to improve the method to make it applicable to specific areas of study and diverse technical situations.

The main and “popular” adaptations of the RMR for slopes are Laubscher's Mining Rock Mass Rating -MRMR (1990) and Romana's Slope Mass Rating -SMR (1985) [6]. The most recent empirical method for stability analysis of road slopes, train lines and open pit mining is known as Q-slope. The main
novelty of this empirical method consists in studying the stability of rocky slopes and adjusting the angles of slopes as construction work progresses [2].

On the other hand, the Geological Strength Index (GSI) [7] is a strength index for fractured rock masses. The success of the application of this index and its high degree of diffusion lies in its visual character, which uses graphs that can be compared directly in the field and establish a numerical value [8, 12]. It is evident that in all cases in which rock mass stability is studied it is necessary to apply analytical, kinematic, limit equilibrium or finite or discrete element models [9]; however, this type of analysis requires that the works under study have the personnel and sufficient time for the modelling and calculations that allow obtaining design data complying with acceptable safety factors. The lack of time or skilled personnel makes the application of computational methods impractical on certain occasions due to the speed with which construction teams undertake the works and the increasingly shorter contractual terms. Considering this aspect, the Q-slope is currently the only method that, as construction works are carried out, provides an acceptable orientation on the application of stable slope angles in the long term or until the complementary analysis that ratify the values adopted on site [1].

2. Empirical methods analysed

2.1 Q-slope

The Q-slope has been developed as a complementary method to the Q-system, allowing the principles proposed by Barton to be applied to multiple surface and underground engineering projects. The method uses for its analysis six parameters RQD, Jn, Jr, Ja, Jw and SRF [1]. The present study addresses the relationship between Jr (roughness) and Ja (alteration) which are later corrected by the favourable or unfavourable orientation of the main discontinuities that form the specific failure pattern in the slope. The equation proposed by Barton and Bar in 2015 [1] (Eq. 1) analyses three fundamental aspects of the rocky massif, i) the size of the blocks present in the slope, ii) the state of the joints and iii) the environmental, anthropic and stress state variables of the rocky massif.

\[ Q_{\text{slope}} = \frac{\text{RQD}}{J_n} + \left( \frac{J_r}{J_a} \right)_0 + \frac{J_{\text{vice}}}{\text{SRF}_{\text{slope}}} \]  

The authors [1] provide tables for both field and office work where descriptions of the analysed parameter and the qualification values can be found, which for our study are Jr and Ja respectively. Field grades can be processed in the field or later in desk calculations to determine Q-slope values and slope dip angle.

| Table 1. The descriptions and ratings Jr Joint roughness number [2]. |
|---|---|
| a) Rock wall contact, b) contact after shearing |
| A | Discontinuous joints | 4 |
| B | Rough or irregular, undulating | 3 |
| C | Smooth, undulating | 2 |
| D | Slickensided, undulating | 1.5 |
| E | Rough or irregular, planar | 1.5 |
| F | Smooth, planar | 1 |
| G | Slickensided, planar | 0.5 |
| c) No rock-wall contact when sheared |
| H | Zone containing clay minerals thick enough to prevent rock-wall contact | 1 |
| J | Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact | 1 |
Table 2. The descriptions and ratings for Joint alteration number [2].

|   | Description                                                                 | Rating |
|---|-----------------------------------------------------------------------------|--------|
| A | Tightly healed, hard, non-softening, impermeable filling, i.e., quartz or    | 0.75   |
|   | epidote.                                                                     |        |
| B | Unaltered joint walls, surface staining only.                                | 1      |
| C | Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc. | 2      |
| D | Silty- or sandy-clay coatings, small clay fraction (non-softening).           | 3      |
| E | Softening or low friction clay mineral coatings, i.e., kaolinite or mica. Also chlorite, talc, gypsum, graphite, etc., and small quantities of swelling clays. | 4      |
|   | b) Rock-wall contact after some shearing (thin clay fillings, probable thickness ≈ 1-5mm) |        |
| F | Sandy particles, clay-free disintegrated rock, etc.                          | 4      |
| G | Strongly over-consolidated non-softening clay mineral fillings.             | 6      |
| H | Medium or low over-consolidation, softening, clay mineral fillings.         | 8      |
| J | Swelling-clay fillings, i.e., montmorillonite. Value of Ja depends on percent of swelling clay-size particles, and access to water. | 8 – 12 |
|   | c) No rock-wall contact when sheared (thick clay/speedy rock fillings)       |        |
| M | Zones or bands of disintegrated or crushed rock and clay (see G, H, J for description of clay condition). | 6, 8   |
|   | or                                                                           | 8, 10  |
| N | Zones or bands of silty- or sandy-clay, small clay fraction (non-softening). | 5      |
| OPR| Thick, continuous zones or bands of clay (see G, H, J for description of clay condition). | 10, 13 |
|   | or                                                                           | 13, 20 |

2.2 Geological Strength Index (GSI)

The GSI System is a graphical method (figure 1) that is widely used in underground projects due to the ease that the method offers in identifying problems present in the field. The strength of the Geological Strength Index lies in the fact that the graphs proposed by the authors [11,12] allow to quickly visualize complex problems that cannot be addressed by other geomechanical classification methods such as RMR.
3. Results

The approach that we recommend to estimate the Jr and Ja values is based on the GSI user-friendly graph. The methodology used in the present study for the elaboration of friendly graphs that allow to analyze the parameters Jr and Ja was structured in four phases: i) compilation of information on methods and techniques of evaluation of rocky masses, ii) selection of methods and techniques of the most important geomechanical analyzes in recent years, iii) analysis of benefits and limitations of the methods and iii) development of a proposal.

For the collection of bibliographic information, the different publications of the existing rock mass characterization and evaluation methods were considered, defining the benefits and difficulties of the methods in order to later develop instruments that consider their strengths and propose a user-friendly geomechanical analysis material.

After analysing the rock mass evaluation methods, the Q-slope was chosen as the most current geomechanical classification method that considers multiple analysis variables without becoming a very complex method from a kinematic or computational analysis point of view. In the same analysis, the GSI index was distinguished by its wide application and diffusion worldwide, as well as its easy application in the field. From the Q-slope, the parameters that were considered the most relevant to assess the state of joints of the rock mass were selected and a graph was designed that encompasses the two parameters considering that both Jr and Ja analyze the state of joints (figure 2).

In the graph proposed in this research, the concepts that relate the two parameters a) Rock wall contact, b) contact after shearing c) No rock-wall contact are combined, and they are contrasted with the roughness and the type of filling present in the discontinuities. The graph allows to quickly and accurately compare the areas of weakness present in the rocky massif, allowing its analogue to be found in the proposed graphs with its consequent saving of much-needed and scarce time and resources in field surveys. The graph allows a better understanding of the analyzed parameters and consequently improves the transfer of the concepts proposed by the authors of the Q-slope method.

Figure 1. Visual graph to determine values of GSI in rock masses [12]
4. Conclusions
The present work does not pretend to change the concepts and theories proposed by the creators of the Q-slope method, who studied 96 stable, quasi-stable and unstable slopes in mining and road projects in Australia, Papua New Guinea, Laos and Panama [1]. Our contribution consists of determining the Jr and Ja parameters graphically and not by means of tables (figure 2). The main objective of this study is to improve understanding of the existing method and make it more visible not only in the scientific community but also among professionals who apply other methods such as RMR, SMR and GSI in solving complex geomechanical problems on a day-to-day basis of their professions. The correct application of the graph will considerably reduce the survey times in the field and improve the valuation in the office with the consequent reduction in costs associated with these processes.

![Figure 2](image-url)  
**Figure 2.** Proposed graph to determine the values of Jr and Ja of the Q-slope. The values are those of the original Q slope parameters [4] [9]
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