ANALYSIS OF ROCK MASS CLASSIFICATIONS FOR SAFER INFRASTRUCTURES

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ABSTRACT

In the construction of land transport infrastructures such as roads, highways, or railways, one of the factors that determine their design most is the characteristics of the terrain through which they run. Additionally, tunnels have become one of the most adopted solutions to reduce environmental impact. The characteristics of the rock mass are a key point to decide the layout of the tunnel and its construction method. However, the rock masses are discontinuous, anisotropic, and heterogeneous media, so their classification and knowledge are needed for a safer design of these infrastructures.

The rock mass is not an industrial material with “pre-established” properties and behaviours, but rather a natural material that needs to be analyzed, understood, and standardized. The need to understand the behaviour of the rock mass has led throughout modern history to the use of different standards, which lead to the development of geomechanical classifications, with the aim of establishing a common language that translates the very advanced geological language in the macro and microgeological behaviour, which is needed for applications in civil engineering. In the last decades of the 20th century, and in the present 21st, the efforts in the process of understanding the intact rock and the rock mass has been constantly increasing because a better understanding of the rock mass behaviour implies a better result in reached in projects involving affection to rock masses. This paper briefly reviews the history of rock mass classifications, their implications in rock mechanics and their applicability in the definition of behaviours as a function of natural conditions and human action, as well as their direct implication in some fields of the transport infrastructures management with regard to hazard and risk assessment.

1. INTRODUCTION

The construction of infrastructures generates physical and geometrical changes of the ground in which they are integrated. It is necessary to have an explicit knowledge of the behaviour of the ground, as it will usually modify the natural equilibrium of the ground, which is constantly changing due to physical and geological processes.

The understanding of the micro and macro geological context is needed for its consideration in design processes. Therefore, the relationship between geological and engineering disciplines is required for proper design, construction and use. This article highlights the importance of the interpretation of the rock masses in which infrastructures are developed, from the point of view of design, construction and operation management.

The implication of Rock Mass Classifications (RMC) in the assessment of the safety and durability of infrastructures is addressed in this article through different risk and hazard indices, together with cases of infrastructure application and management.

2. GEOLOGY AND ROCK ENGINEERING

The geological model on which an infrastructure is built must encompass both the microscopic scale of the materials and their macroscopic scale and their geological evolution. Civil, mining and rock engineering intensively analyse the behaviour of industrial materials, and this same understanding should be transferred to natural materials such as soils and rocks, since, due to natural or anthropic processes, changes in their behaviour and, consequently, their action on infrastructures are imposed to them. For this reason, the relationship between engineering projects must be complemented with precise geological models. Civil and mining engineering have been designing structures on rock masses for centuries, using the principles of rock mechanics and engineering (Hoek, 2007).

The rock mass encompasses both the scale effect of the material that make it up, as well as its intrinsic characteristics as an isotropic material, and the singularities that make it anisotropic.

2.1 Geology in the engineering context

An understanding of the geological environment is required for proper design of excavations and foundations in infrastructures, whether tunnels, slopes or structures. Often, misconceptions are made in order to save costs and time in the development of projects, starting from extensive borehole investigation in the area under study, without taking into account the geological environment and its evolution in which the small-scale investigations are integrated (Hoek and Bray, 1977; 1989).

The geological setting, its configuration and state, has direct implications on the rock mechanics design with aspects such as: tectonic stresses, metamorphic processes, history of overburden and erosion discharges, as well as the modelling of the terrain by them, cooling processes of igneous material, sediment desiccation, etc (Palmstrom and Stille, 2015).

The influence of geological factors on rock mechanics, starting from the problem of mechanics of materials, has to do with the material sensu stricto and the forces that are imposed to it (Hudson and Harrison, 2000). From these basic principles of mechanics, basic forces and stresses are imposed to the rock mass, to which are added the physical actions of exogenous agents such as water and air and the action of these over time. It is well known that all the natural actions to which the rock mass has been exposed (rock intact + discontinuities) are processes of geological origin.

2.2 Rock mass units

The rock mass conceptually consists of two elementary units (Figure 1). Based on the geological conditions of the environment, the so-called intact rock and discontinuities are the main units defining the rock mass. In addition to these fundamental units, there are singularities of geological and hydrological origin, such as faults, karst, saturation, etc.

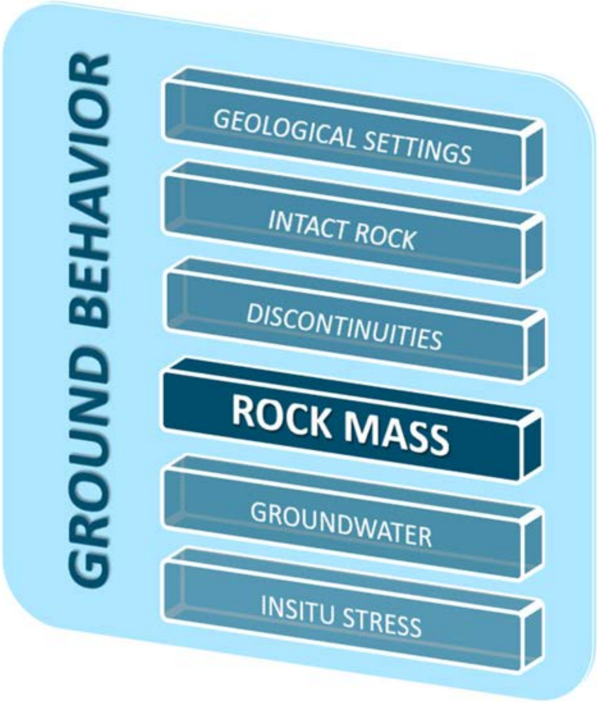

Fig. 1 - Ground behaviour and fundamental units

Homogeneous, isotropic material consisting of mineral aggregates, which can be crystals with or without preferred orientation or ammorphic masses, is called intact rock (Wittke, 2014). The aggregate of crystals and the matrix in which they are embedded, i.e. the mineral skeleton, exhibit mechanical properties that are used in rock engineering.

In various scientific publications, the rock mass is defined as a heterogeneous material consisting of fragments and blocks of rock of different sizes, intact or altered, with their defects, separated by a series of discontinuities, such as joints, faults, bedding planes, etc., which also vary in composition in space and time (Bieniawski, 1989; Potvin et al. 2012; Palmström 1996; Hoek and Brown 1980).

From the point of view of the fundamental units of the rock mass, intact rock and discontinuities, geological compression is essential, since the genesis of the material, its composition and physical-chemical properties, and consequently its mechanical properties, depend on the geological processes that the material has undergone throughout its geological history.

Likewise, within the geological history, the succession of tectonic processes generates stresses in the materials creating folding, compressional/distensive structures (faults). The physical/chemical changes (geomorphological/metamorphism) determine the structure and behaviour of the materials, as well as the topography modelled by the geological history. The evolution of the rock mass and its spatial distribution, episodes of kinematic instability and dissolution processes occur. These processes generate the natural conditions for the evolution of the relief, to which anthropic modelling must be added.

The singularities that characterize the rock mass, defined as the set of planes of weakness that interrupt the cohesion of the intact rock, are named with terms such as discontinuity, fracture, joint, lithoclase, with a common meaning in the specific literature.

2.3 Rock mechanics and Civil Engineering Project

Rock mechanics plays a fundamental role on the feasibility of a civil engineering project developed in a rocky environment. The principles and applications of rock mechanics are nowadays encompassed in what is known as Rock Engineering (Hoek, 2007). As mentioned above, Rock Engineering is closely related to the geological context, its interpretation and adaptation to engineering needs.

Mainly, but not only, solutions for infrastructure projects based on tunnels have been the ones that impose a lesser impact on the environment. At the same time, tunnel design for civil engineering projects has increased continuously during the last 70 years. Rock engineering requires well-structured development processes (Figure 2), always starting from a geological basis and how it conditions the success of the project.

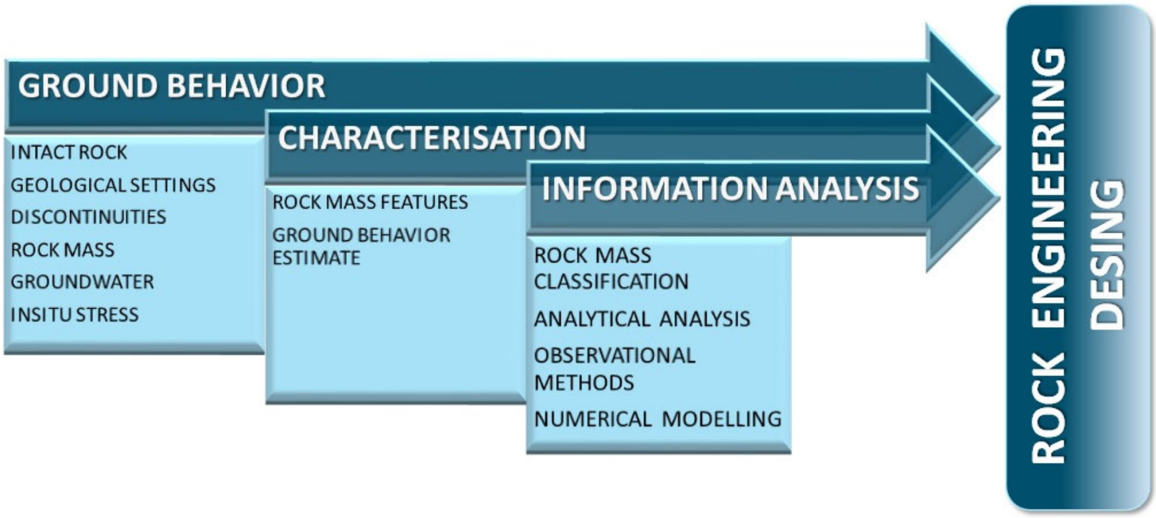

Fig. 2 - Rock mass units and Rock engineering relationship (based on Palmstrom, 2015)

With the structure of the basic processes required in a Rock and Civil Engineering project, the appropriate tools must be used to evaluate and develop the final design approach with the following items:

- Rock engineering processes (Figure 2)
- Feasibility
- Risk Management
- Estimation of time and cost of the project

From the Rock Engineering point of view, the geological context, its application to the design principles and the use of the needed tools for it, aims at achieving a design with the safety factors imposed by the standards, as well as the evaluation of the risks and costs necessary to carry out the design.

In both slope stability and foundations the processes have to be governed by the principles of Rock Engineering, but the design and construction of tunnels involves constant verification of the initial conditions during construction, as the uncertainty of material changes and investigation intensity may not be appropriate. Both geological and investigation uncertainty have a direct implication on the risk and costs of tunnel construction.

3. ROCK MASS CLASSIFICATIONS

3.1 Philosophy

Taxonomy is the science that deals with classifications, starting from theoretical aspects that involve foundations, principles, procedures and rules (Singh and Goel, 1999).

Throughout modern history, the rock mass has been the target of analysis, understanding and generation of indexes or languages to describe its quality or performance from an engineering point of view, but above all its stability and safety under modifications of its natural original state.

The rigour of the studies that lead to each RMC, as well as the simplification in the description of their nature and state summarised in different categories and/or parameters, make Rock Mass Classifications (RMC) a powerful tool that is easy to understand as well as widely used in different fields and stages of an engineering project. However, the application of RMC has to be exhaustive in its determination so that it can be assumed with guarantees as the basis of empirical design.

3.2 State of art

The development of geomechanical classifications began mainly to provide a tool for the construction of tunnels and mines. Later evolution led to their use also in the design of slope stability and bearing capacity of foundations.

Since first rock mass classifications appeared, the basic idea has been to reflect both aspects: the intact rock and the conditions and characteristics of the discontinuities that separate the rock into blocks, fragments or masses, thus making up the rock mass. Therefore, historically, an attempt has been made to categorize the basic aspects of an isotropic and homogeneous material from the matrix scale to the anisotropy and discontinuities that form the rock mass, depending on the scale assessed.

Thus, it is verified that the rock mass must be described as a discontinuous, anisotropic and heterogeneous material. Table 1 details the most common geomechanical classifications, with some others of minor relevance or use in rock mechanics projects (Cosar, 2004; Fernandez-Gutierrez, et al. 2017).

Rock Mass Classification	**Author**	**Application Areas**
Protodyakonov	Protodyakonov (1907)	Tunneling
Rock Load	Terzaghi (1946)	Tunneling and steel support
Stand-up time	Lauffer (1958)	Tunneling
Rock Quality Design (RQD)	Patton (1967)	Core logging and tunneling
Rock Structure Rating (RSR)	Wickham et al. (1972)	Tunneling
Rock Mass Rating (RMR)	Bieniawski (1973, 1989, 2014)	Tunnels, mines, slopes and foundations
Rock Mass Quality (Q index)	Barton et al. (1974, 2002)	Tunneling, mining, foundations
Strength-Block size	Franklin (1975)	Tunneling
Basic geotechnical classification	ISRM (1981)	General

Rock Mass Classification	**Author**	**Application Areas**
Rock Mass Strength (RMS)	Stille et al. (1982)	General
Slope Mass Rating (SMR)	Romana et al. (1985)	Slopes stability and support
Modified Rock Mass Rating (M-RMR)	Ünal and Özkan (1990)	Mining
Slope Mass Rating (SMR)	Romana et al. (1985)	Slopes stability and support
Rock Mass Index (RMi)	Palmström (1996)	Tunneling
Rock Condition Rating (RCR) and Rock Mass Number (N)	Goel et al. (1996)	Tunneling
Geological Strength Index (GSI)	Hoek et al. (1997, 2013) Cai et al. (2004)	All underground excavations
Rock Mass Quality Index	Aydan et al. (2014)	Rock mass properties
Rock Mass Quality Slope (Q Slope)	Barton and Bar (2017)	Slopes, cliffs

Table 1 – Compilation of Geomechanical Classifications

Most of geomechanical classifications, as shown in Table 1, were proposed to help engineers during design of tunneling and mining supports. Taking advantage of the development of these indices, the fields of applicability of RMCs, such as slope and foundation stability and the estimation of rock mass properties, have been extended.

Talking about the origin of the classifications, the one that has gained more relevance throughout history has been RQD (Deere and Patton, 1971) due to its integration in other indexes and its applicability in tunnels, slopes. It also allows the possibility of its estimation in any rock outcrop.

Historically, the most widely used classifications, mainly for the design of tunnels, are: RMR, Q index, GSI, and RMi. These RMCs have been listed in order of relevance in terms of their use in projects.

3.3 Description and relationships

The relationships between the most relevant geomechanical classifications will be shown below, based on the parameters that are considered or evaluated in each one of them. The formulations of each classification are also summarised.

3.3.1 Rock Mass Rating (RMR)

The Rock Mass Rating, RMR, was initially proposed by Bieniawski (1974; 1975; 1976; 1979; 1989). It is an index that evaluates the competence of the rock mass based on 6 parameters:

- R_1: Intact rock strength.
- R_2: Rock quality designation (RQD).
- R_3: Joins Spacing (J_s).
- R_4: Joints conditions (J_c).
    - $R_{4.1}$: Persistence
    - $R_{4.2}$: Aperture
    - $R_{4.3}$: Roughness
    - $R_{4.4}$: Joint weathering
- R_5: Groundwater Condition
- R_6: Discontinuities orientation correction.

Equation (1), established by Bieniawski (1974; 1989; 2000), is based on the arithmetic sum of the parameters participating on the classification. Since 2000, there are trends involving the parameters R_2 and R_3 ($R_{2\text{-}3}$) (Bieniawski, 2011) in order to determine the joint/meter scores from 40 to 0 for jointless masses (0 joints/meter) to extremely jointed rock masses or sugar cubes (50 joints/meter), shown in Equation (2).

$$RMR_{c(73-89)} = R_1 + R_2 + R_3 + R_4 + R_5 + R_6 \tag{1}$$

$$RMR_{c(89)} = R_1 + R_{2-3} + R_4 + R_5 + R_6 \tag{2}$$

The characterization without the water effect (R_5) and the correction for the orientation of the discontinuities with respect to the construction element (tunnel, slope, and foundation) is called RMR_b (basic), shown in Equation (3).

$$RMR_b = R_1 + R_2 + R_3 + R_4 \tag{3}$$

In 2014, the relation of the original 6 parameters is updated to Equation (4) and renamed RMR_{14} (Celada et al. 2014) using 3 factors, named F_0 (which is approximately R_6, according to 1974-1989's classification), F_e (excavation method adjustment) and F_s (stress-strain associated with tunnel face behaviour).

$$RMR_{14} = (RMR_b + F_0) \times F_s \times F_e \tag{4}$$

The rock mass is classified into 5 classes according to standardised methodology scores.

3.3.2 Rock Mass Quality (Q index)

The Quality Index, developed by Barton and co-workers in 1974 (Barton et al. 1974) and in later years (Barton et al. 1976;, 1977; 1980), also uses 6 parameters to estimate rock mass behaviour:

- Rock Quality Design (RQD).
- Joint set number (J_n).
- Joint roughness (J_r).
- Joint alteration number (J_a).
- Joint reduction number (J_w)
- Stress Reduction Factor (*SRF*).

Equation (5) defined by the author, is divided into 3 ratios, each one being indicative of three very important concepts in Rock Mechanics.

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \tag{5}$$

Where some parameters are grouped:

- Block Volume = RQD/J_n
- Shear strength = J_r/J_a
- Active Stress = J_w/SRF

In 2002, in order to establish correlations with other ground parameters the original author (Barton, 2002) presented the modified index, Q_c, which relates the simple compressive strength of intact rock (σ_c) to the Q index, reducing the quality of the rock mass for values of Q < 100, Equation (6).

$$Q_c = \sigma_c \times \left(\frac{Q}{100}\right) \tag{6}$$

The rock mass is classified into 9 classes or categories, which according to Grimstad et al. (2004) are recommended for tunnel support technologies.

3.3.3 Geological Strength Index (GSI)

Geological Strength Index (GSI), was developed in 1995 by Hoek et al. (1995). This qualitative observational index originally related the structure of the rock mass according to the degree of fracturing and its volumetric arrangement, together with the state of the rock mass itself in its surface (Sanchez et al. 2017).

This index is constantly being reviewed and updated by different authors. An example of this, is the calibration of Cai and Kaiser (Cai et al. 2004) shown in Figure 3 which includes the relation to the joints condition. Russo (2007) also includes to this the *jC* parameter of RMi, which is based on quantitative parameters. Both are included in classification abacuses.

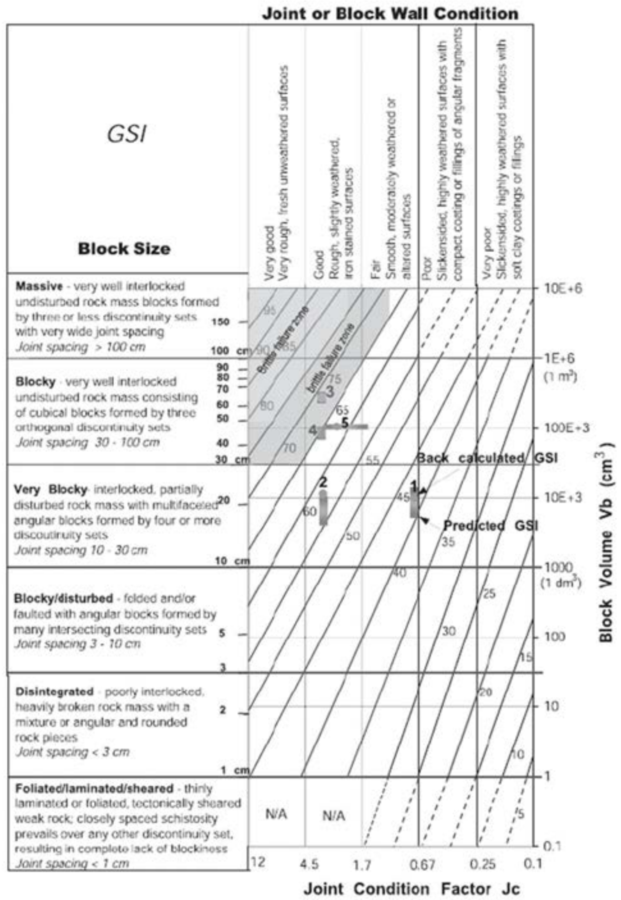

Fig. 3 - Hoek's chart for the determination of the GSI modified by Cai, Kaiser et al. (2004)

Hoek et al. (2013) related the joint condition ($JCond_{RMR89}$) of RMR_{89} (3), Equation (7) and the parameters defining the shear strength of the joints (J_r and J_a), according to Q system, Equation (8), so that the GSI value and its classification can be obtained based on the most common geomechanical characterisations.

$$GSI = \left(1{,}5 * JCond_{RMR_{89}}\right) + \frac{RQD}{2} \tag{7}$$

$$GSI = \frac{52\frac{Jr}{Ja}}{\left(1+\frac{Jr}{Ja}\right)} + \frac{RQD}{2} \tag{8}$$

Based on the graph, the rock mass is classified into 6 block size ranges and 5 rock mass states, related to each other by the score obtained.

3.3.4 Rock Mass Index (RMi)

Rock Mass Index (RMi) was developed by Pälmstrom in Oslo (Norway) in 1995 (Palmström, 1995) taking into account the main parameters of the rock mass and intact rock. This classification relates the uniaxial compressive strength of intact rock to the shear strength properties of the joints that divide the rock into blocks.

Relationships are differentiated for jointed rocks, Equation (9), and massive rocks, Equation (10).

$$RMi = \sigma_c * JP = \sigma_c * \sqrt{j}C \times {V_b}^D \tag{9}$$

$$RMi = \sigma_c * f_\sigma = \sigma_c * \left(\frac{0{,}05}{Db}\right)^{0{,}2} \tag{10}$$

Where σ_c is the uniaxial simple compressive strength of the intact rock, *JP* is the joint index that defines the conditions of persistence, aperture and roughness of the joints, V_b and D_b are the parameters defining the volumetric and surface geometry respectively. *D* is a correction parameter for the joint condition *jC*. f_σ is the massivity factor of the rock mass.

3.3.5 Relationships and Correlations

As has been briefly described, each RMC considers a different relationship between the fundamental units of the rock mass, such as the intact rock and the discontinuities that divide it, being these two main concepts the ones that are common to all classifications.

In Figure 4, it is schematically shown which parameters of the geomechanical characterisation of the rock mass are evaluated by each RMC, as well as the relationship with the geological and geomechanical models that have to integrate the rock mechanics designs and their relationship with civil engineering projects. Some classifications developed for tunnel support, such as RMi, include factors such as the number of joint families and the orientation in relation to underground excavation, water affection or stress state, for the estimation of the recommended support, but not in the geomechanical classification sensu stricto.

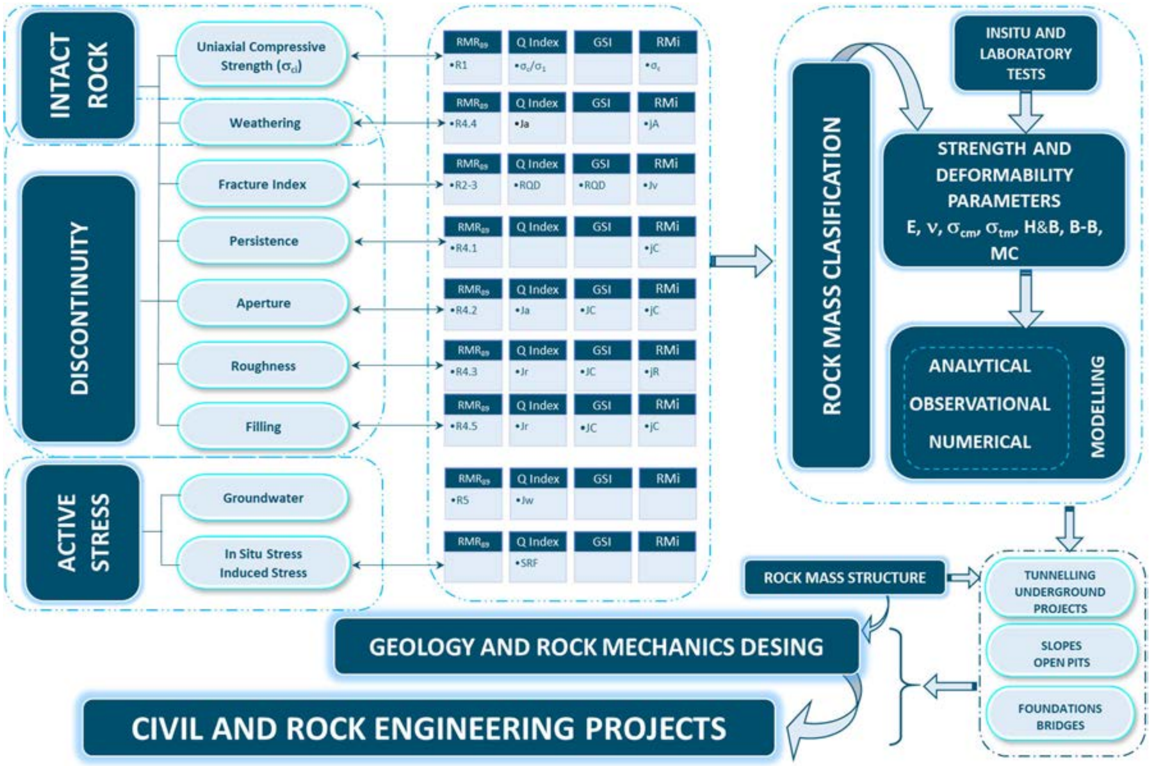

Fig. 4 - Rock Mass Classifications and Civil Engineering Projects

On the other hand, RMCs have been studied to propose a great number of correlations, mainly between RMR and Q and between RMR and GSI. There is a large number of authors and correlations between various geomechanical systems or indices in the specific literature. In this article we show graphically some correlations, obtained for specific lithologies, since it is considered by the authors, that in the field of correlations, lithologies of similar sedimentary and tectonic environments, show better fitting than general correlations for any type of lithology (Sánchez et al. 2016; Fernandez-Gutierrez et al. 2017). Figure 5 shows the correlations between RMR and Q, both generally, as well as the one developed by Fernandez-Gutierrez et al. (2017), which analyzes the relationship for fine-grained sedimentary rock formations.

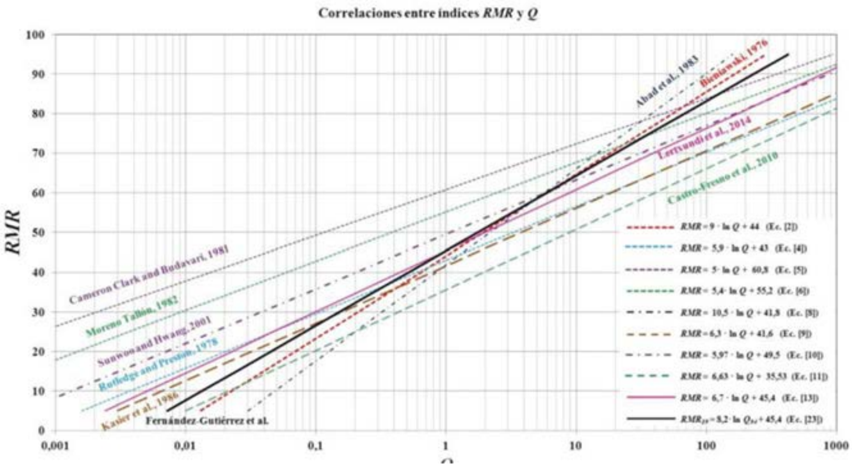

Fig. 5 - RMR-Q correlations (Fernández-Gutiérrez et al. 2017)

Figure 6 shows the comparison of correlations between RMR and GSI for different lithologies in Andean environments (Sánchez et al. 2016) compared to the original one proposed by Hoek (Hoek 1995).

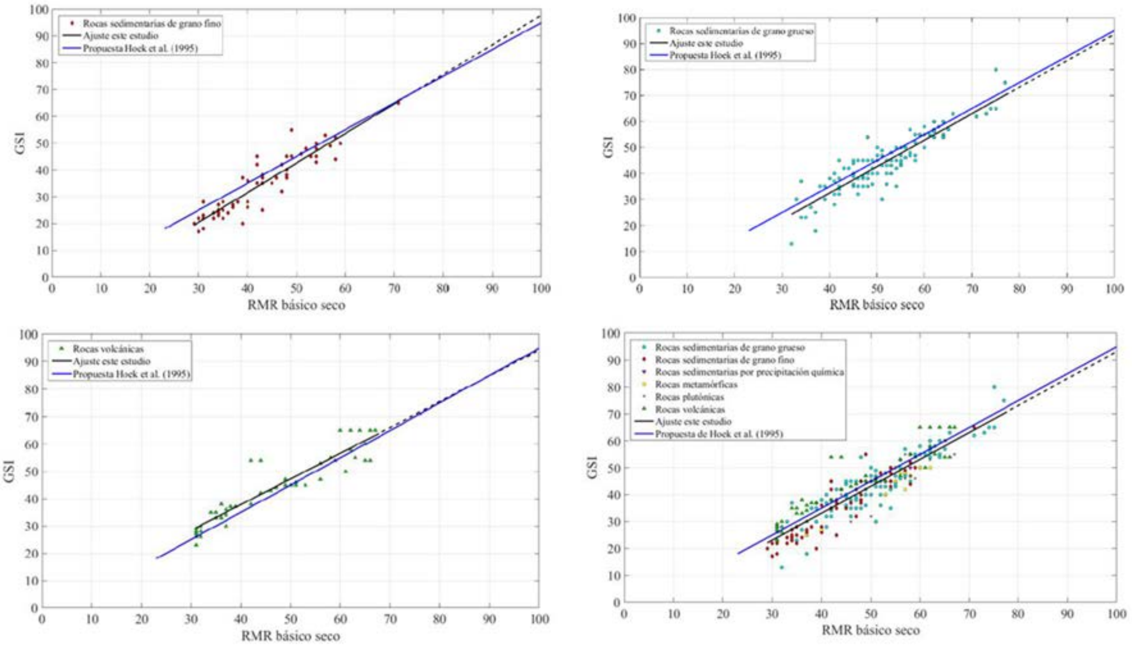

Fig. 6 - RMR-GSI correlations in Andean environments (Sanchez et al. 2016)

4. ROCK MASS CLASSIFICATIONS FOR SAFER INFRAESTRUCTURES

As shown so far, the relationship of geology with geomechanical characterization and design plays a very important role in the final designs of a civil engineering project. Therefore, a bad design, either due to the lack of budget, lack of importance given to the role of rock mechanics, or lack of expert judgement, has serious implications in relation to the safety, risks, durability and final costs of an infrastructure.

In the specific literature, there are numerous cases of the relationship between design costs and construction costs due to causes usually referred to as geological. Some of these causes may be difficult to detect, but many others are due to a lack of rigour in the design.

Figure 7 (Palmstron et al. 2015) shows the sequence of an underground excavation project and the influence of a good design (rock mechanics and engineering) over the final costs, compared with a bad design where the final cost is increased. It can be seen how the costs and time during the construction and operation phases can be very high when proper management of design fails.

Generally, an infrastructure project is designed under the regulations of each country, the Eurocode 7 and the specifications of each infrastructure owner.

A rigorous approach should impose that each design of slopes, walls, foundations, embankments and tunnels had to be verified during construction according a Factor of Safety requirement, comparing this with the design.

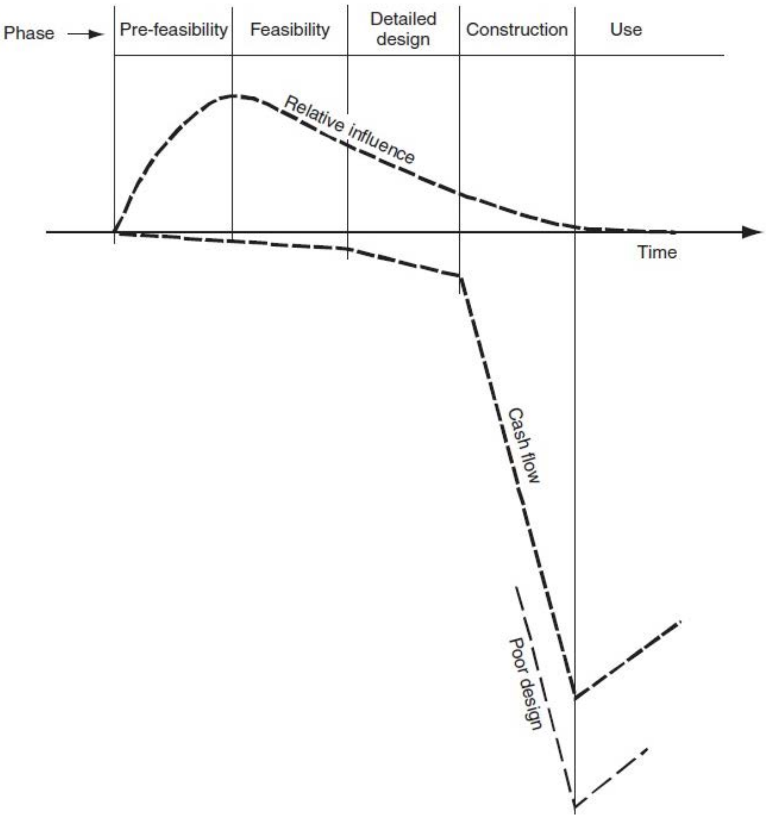

Fig. 7 - Relationship between costs and project stages (Palmström, 2015).

The analysis and implications of the factors of safety requirements by any Rock and Civil Engineering projects is not the subject of this paper.

4.1 Infrastructure risk management

Once the construction phase of the infrastructure has been completed, it should be mandatory to verify the available Factor of Safety (FoS) compared with respect to that proposed or deduced during design phase. This one should be the starting point for verifying the evolution of the finished works during its operation life. In most cases, this post-construction condition is not correctly assessed, which generates increased maintenance and risk remediation costs. These costs are often higher than those during the construction phase and also involve the users.

The relationship of the probability of failure to the safety factor (Figure 8) is related to the quality in engineering studies, (Silva et al. 2008). In this study, based on the analysis of real cases in dams, it is stated that for the cases of high FoS (Factor of Safety), high failure probabilities can be associated with the quality of the engineering projects.

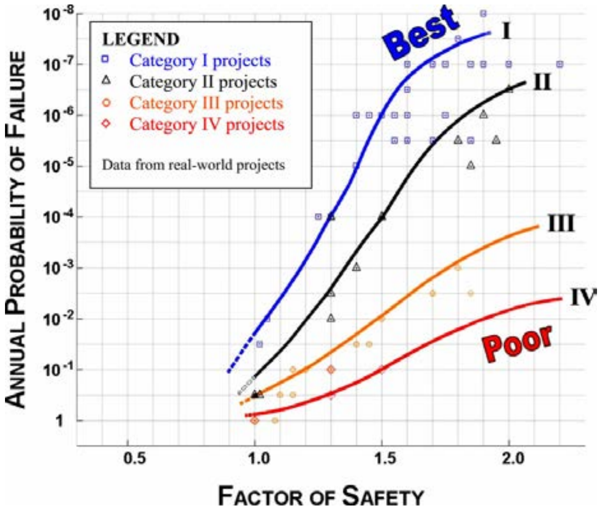

Fig. 8 - Factor of safety versus annual probability of failure (Silva et al. 2008).

Figure 9 adapts the flow chart defined by Fell (Fell et al. 2008), defining risk assessment and risk management analysis process, which can be generally applied to infrastructures with risks due to ground instabilities (slopes, foundations or tunnels), taking as final target risk mitigation and management strategies. The hazard of a phenomenon has a fundamental weight on the degree of risk, which is ultimately defined by exposure and vulnerability (UNISDIR 2009).

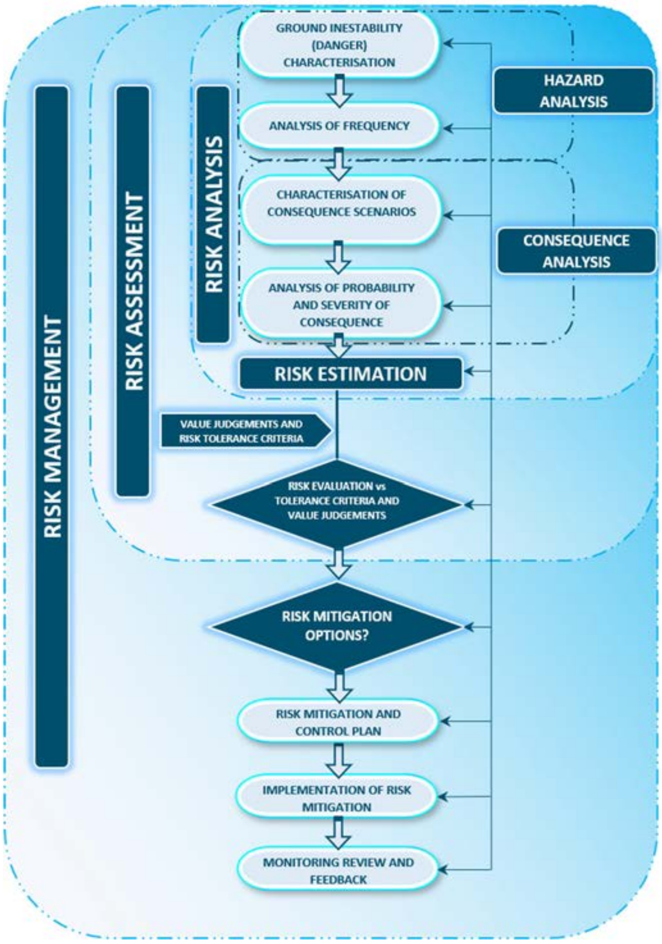

Fig. 9 - Framework of geotechnical risk network (based on Fell et al. 2008)

4.2 Risk management in tunnels

In this section, only the geotechnical risks which can occur in a tunnel are considered. The involvement of the rock mass in the construction of tunnels results in a series of geological and geotechnical risks which have to be assessed in the design and construction of tunnels. (E Matos et al. 2006).

Figure 10 shows the relationships between the technical expert involved in tunnel design, associated with geology and rock engineering, including technical and economic feasibility.

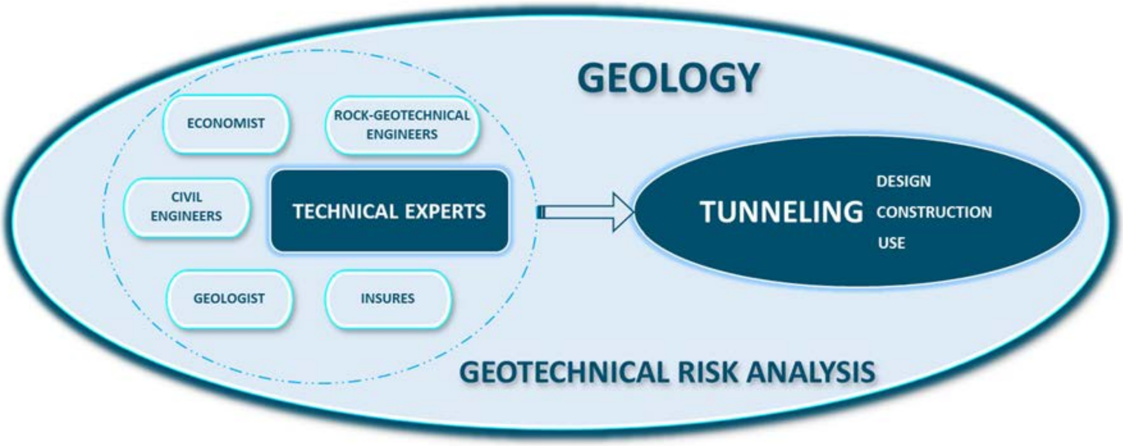

Fig. 10 - Elements involved on risk analysis in tunnels (based on Matos et al. 2006).

Some typical geotechnical risks might be:

- Unstable slopes or rock falls at road o rail infrastructures or tunnel portals.
- Problems with construction through fault zones, low strength of the rock mass, lack of stability and squeezing conditions
- Potential effects of the project to the environment, such as settlements or vibrations.
- Changes of the natural water regime, water inrush in tunnels
- Karst conducts and cavities
- Earthquake loads

As an example of the treatment of geotechnical risks in tunnels, the study of the underground museum in Salzburg (Schubert, 2006) is presented. In the analysis, which started in 1990, the geotechnical hazards were classified into risk factors and solutions were found to mitigate them, thus reducing the costs which were initially assessed.

Table 2, relates the geological risk factors and their probability of occurrence in Monte Carlo analysis, obtaining the volume of ground affected. In addition, the risk factors with the associated potential costs (horizontal axe) are schematically shown in Figure 11.

Geotechnical risk factors	Probability of occurrence		Quantity	Unit
	From	To		
R1 loose, un—cemented conglomerate	1%	3%	96.000	m^3
R2 need of grounting to strengthen of rock mass	5%	10%	12.000	m^3
R3 need of surface treatment of conglomerate	30%	70%	3.000	m^3
R4 extensive water seepage	0%	2%	96.000	m^3
R5 major unfavorable joint, need of pre-stressed anchors	50%	150%	10	Stk
R6 treatment of caves	110%	130%	1.000	m^3

Table 2 - Geotechnical risk factors quantity and probability of occurrence.

4.3 Risk management of slopes

Road and railway infrastructures, with linear designs, usually in some of their sections are located in areas that require excavation for geometric fitting, generating slopes.

In the case of rock slopes, in addition to characterization, analytical, observational and numerical studies, geological and geotechnical risk assessments should be carried out during design and construction. Geological risk assessments, in this case of slope instabilities in transport infrastructures, should be confronted by infrastructure managers using specific tools such as hazard and risk indices.

In this section, mention is made of the implications of geomechanical classifications and rock mass characterisation applied to hazard and risk indices in various studies.

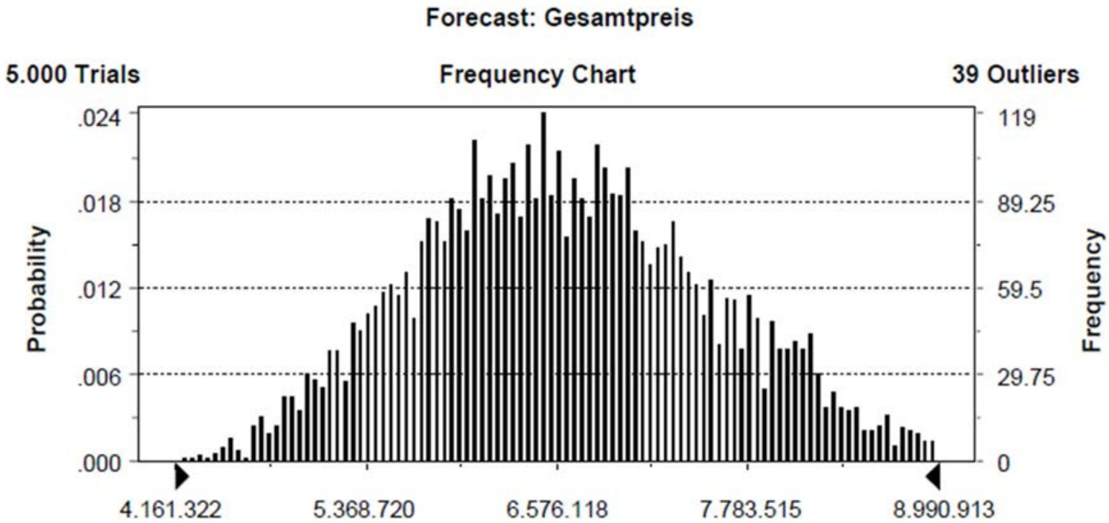

Fig 11 - Geological geotechnical risk factors and their expected cost variation (Schubert, 2006)

The *Rockfall Hazard Rating System (RHRS)* developed by Pierson, 1990 in Oregon for FHWA, considers qualitative rock mass criteria, modified by Budetta (2004) using the SMR (Romana, 1995) geomechanical slope index. This index has 9 exponential scoring categories. The methodology bases its classification on 9 factors grouped into geometry, infrastructure characteristics, geology and geomechanics, climatology and frequency of rockfall instabilities (Geoconsult, 2019). The purpose of the methodology is the evaluation of the characteristics of the infrastructure to allow rockfall conditions according to the original methodology (Pierson, 1990), but adapted to any kinematic instability of the rock mass, planar, wedge, toppling failure (Budetta, 2004). Depending on the danger posed by the hazard, the magnitude and frequency are evaluated, as well as the road platform, in relation to the visibility and distance of reaction of the drivers in case of falling of any object on the road. The volume of this object as well as the slope of the route are also considered.

Geoconsult in 2018 adapted methodology proposed by Budetta (2004) according to Spanish road standards, analysing 27 km of road to categorise the existing risks on the A-136 road in Huesca (Figure 12).

In this case, the infrastructure owner is provided with a tool for monitoring the risks present on the road, as well as with a strategic plan with mitigation measures and criteria for maintenance investment prioritization.

Figure 13 shows the dispersion in the estimation of geomechanical quality in rock slopes defined with RMRb and SMR.

Logically, the rock mechanics and geology component in the risk assessment of this methodology is a key issue, as it is a geological hazard process.

Fig. 12 - Map of a sector of the A-136 road classified with RHRS (Geoconsult, 2018).

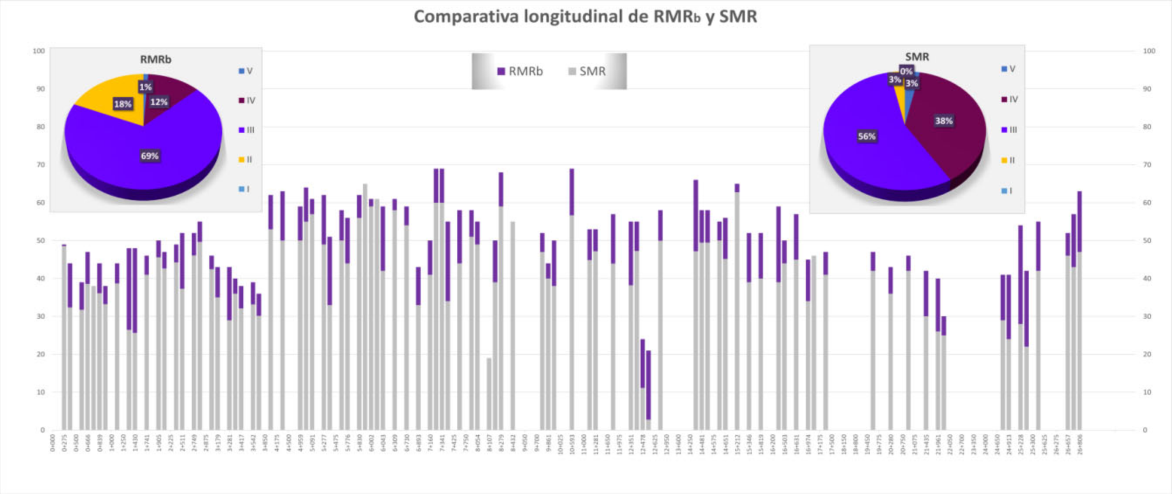

Fig. 13 - Comparison of the geomechanical quality according to RMR_b and SMR in the rock slopes of the A-136 road.

On the other hand, Corominas et al. (2017) used a single quantitative risk assessment criterion (QRA, ECR Spanish acronym) for road infrastructures in Gipuzkoa. This methodology was introduced by Fell et al. (2008).

Quantitative Risk Assessment, QRA, (Fell et al. 2008; Corominas et al. 2017) consists on the quantitative determination of risk based on the probability of failure/breakage and its consequences (Fell et al. 2005), in Risk Points (PoR Spanish acronym) located along the infrastructure analysed in the study.

Parameters are defined as Cost Units (CU) for all situations, considering direct and indirect costs, based on affection and closure conditions of infrastructure due to incidents (mainly of geological hazard such as slopes failures in rock mass). Phenomena related to the rock masses which usually can cause fail in the operation and whose common descriptor is the amount of damage to the infrastructure have been included in Table 3.

Notation	***Mechanism***	***Discipline***	***Cost Unit evaluation***
DR	Rockfall	Rock Mechanics	CU / m^3
CD	Debris Flow	Geotechnical Engineering	
EC	Support Failure	Rock and Civil Engineering	
RL	Brittle failure (lanslide)	Geotechnical and Rock Engineering	CU / m^3 and length

Table 3 – Failure Mechanism, Discipline and Cost Units (based on Corominas et al. 2017).

5. CONCLUSIONS

Geological models and their relationship with the characterization of the rock mass have a fundamental role in rock mass classifications (RMC) for the adequate development of Rock and Civil Engineering projects.

The construction of tunnels, slopes and foundations in transport infrastructures must be undertaken through a well-structured process of analysis and design of the stability of the rock mass in which they are located. The quality of the engineering studies and their control during construction have a direct relationship with the costs of the infrastructure, implying that a low-quality project may involve more failures per year, even with an adequate safety factor, as the uncertainty of the process and investigation intensity followed during the design and construction phases are possibly higher than high quality projects.

Risk assessments of transport infrastructure against geological hazards associated with rock mass stability have a direct relationship with infrastructure operation and costs for the owner and users.

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