Some considerations on the applicability of major geomechanical classifications to weak and complex rocks in Tunnelling

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Rock mass classification has proven to be a useful tool both for empirical design of tunnels and for evaluation of the basic properties of a rock mass. However, the available classifications were mainly derived from experiences in hard rock tunnelling and their applicability to weak and complex rocks needs to be verified. This paper presents a useful review of the definitions and the characteristics of weak and complex rocks, and a critical assessment of the potential of the major, original classification systems and the corresponding modified versions for application to these rocks. Some significant examples, derived from experiences in tunnelling in weak and complex rocks, are discussed.

Alcune considerazioni sull'applicabilità delle principali classificazioni tecniche a rocce tenere e/o complesse nel "Tunnelling"
Le classificazioni tecniche della massa rocciosa sono generalmente considerate un utile strumento per la progettazione delle opere in sotterraneo e la stima delle caratteristiche geomeccaniche della massa rocciosa. Tuttavia, i principali sistemi classificativi sono spesso basati sull'esperienza nel tunnelling acquisita dagli autori in rocce di buona resistenza meccanica e l'applicabilità in rocce tenere e/o complesse risulta di solito problematica. Il presente articolo, dopo una parte introduttiva sulla terminologia e le principali caratteristiche di tali rocce, analizza l'affidabilità ed i limiti delle principali classificazioni nel medesimo contesto geostrutturale. Alcuni significativi esempi sull'esperienza nel tunnelling, in rocce tenere e/o complesse sono in proposito evidenziati.

Quelques considerations sur l'application des principales classifications techniques aux roches tendres et/ou complexes dans le "Tunnelling"
Les classifications techniques des roches sont, généralement, considérées comme des instruments utiles pour les études d'ouvrages en souterrain et pour l'évaluation des caractéristiques géomécaniques des roches. Cependant, les classifications disponibles proviennent souvent des expériences de tunnelling en roche dure et leur application à des roches tendres et/ou complexes doit être vérifiée. Cet article présente, tout d'abord, la terminologie et les caractéristiques de ces roches et analyse, ensuite, l'affidabilité et les limites des principales classifications dans un même contexte géostructurale. L'on présente, également, des exemples significatifs dérivant de l'expérience dans le tunnelling en roches tendres et/ou complexes.

1. Introduction

In current ground engineering practice, particularly in tunnelling, rock mass classifications are often indiscriminately used in a variety of geomechanical situations encountered, causing inevitably negative influences on the correct development of a project.

This paper aims to make a more detailed examination of the subject, with particular reference to the applicability of classification systems in the context of weak rocks and/or complex formations, which are widespread in Italy and often encountered by underground excavations.

For the sake of clarity, it is worthwhile recalling a number of basic concepts regarding such rocks, underlining their different meanings and the relative classification systems used in the geotechnical literature.

Basically, by definition is that a rock is termed a 'weak rock' when it is characterised by low mechanical resistance and a rock is defined as a 'complex rock' when it is non- homogeneous in lithological and/or structural terms (AGI, 1979). There is also an area of overlap, where a rock can be both weak and complex (e.g. some Tertiary sequences).

2. Weak rocks

In reality, the term "weak rock" is frequently used to gather in a single definition all rocks (intact and rock mass) having poor mechanical characteristics, including soft rocks, weathered rocks, intensely fractured rock masses, and rock masses consisting of alternate sequences of hard and weak lithotypes. A qualitative classification of weak rocks based on lithological characteristics was recently proposed by Clerici (1992).

Barla (1990) made a distinction between an 'intrinsic' and an "extrinsic" weak rock: the former is characterised by low mechanical resistance due to the very nature of the materials (genesis and diagenesis) while the latter is produced by alteration phenomena or specific epigenetic processes.

According to Sciotti (1990), weak rocks have the following main characteristics:

- high deformability,
- strong dependence of resistance on the degree of saturation and/or temperature,
- sometimes marked susceptibility to alteration phenomena.

Numerous attempts have been made to classify rocks based on unconfined compressive strength: as shown in Fig.1 the range for weak rocks is generally from 0.5-1.2MPa (lower limit - transition to soils) to 12 - 25MPa.

The soil/rock transition can be defined qualitatively by the loss or no-loss of diagenetic cohesive bonds upon immersion in water. Morgestern and Eigenbrod (1974, see Fig.1) quantified the passage from argillite to clay using specifically the loss of undrained cohesion: when the loss is more than 60% the material is classified as a clay.

Concerning the upper limit of weak rock (i.e., the

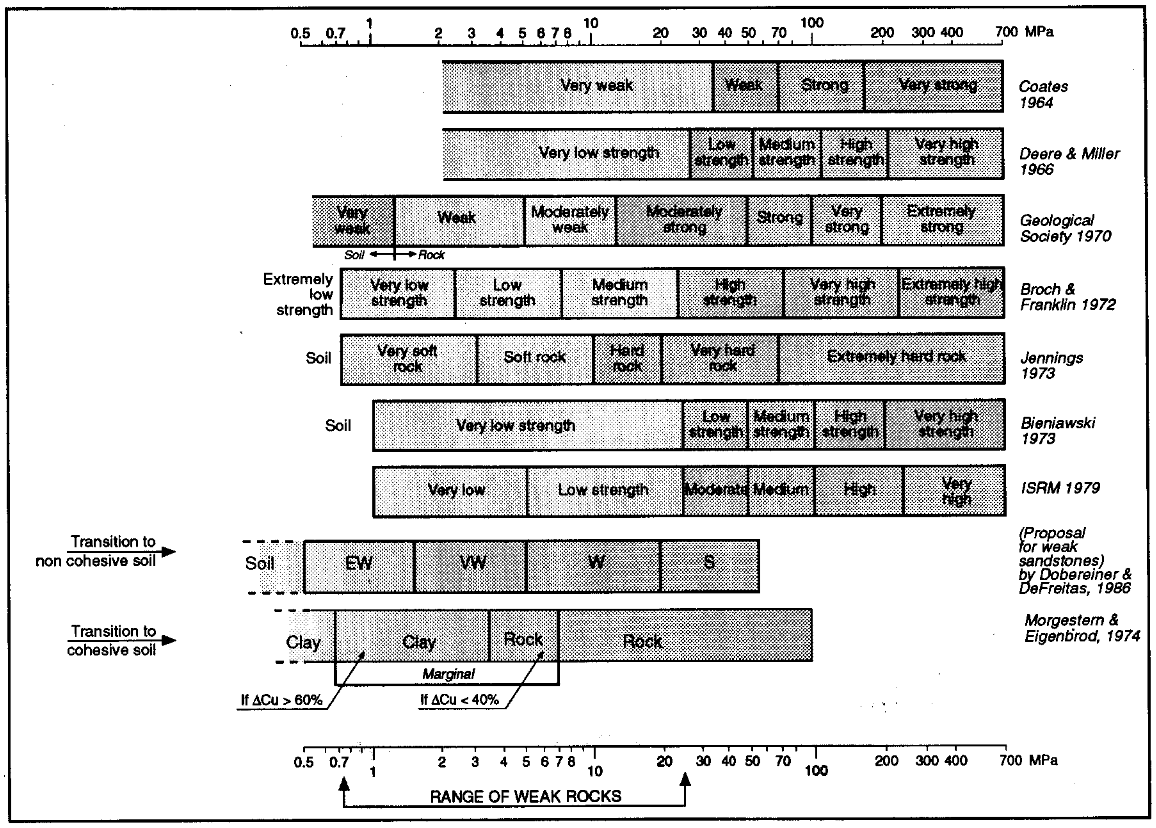


FIG. 1 - *Rock classifications based on unconfined compressive strength* (BIENIAWSKI, 1984; DOBEREINER & DE FREITAS, 1986)

transition from weak rock to strong rock), in the author's opinion the value of 15MPa suggested by Barla (1990) is quite appropriate; therefore, among all the available classifications the one proposed by the Geological Society of London, where 12.5MPa is used as the transition between moderately weak rocks and moderately strong rocks, is preferred.

It is interesting to observe that the shear strength of a very weak rock material may differ only slightly from that along discontinuities in the same rock mass, and thus the scale effect on weak rock is generally less important.

Some example classification systems adopted for weak rocks are given in Fig. 2, showing the main parameters utilised. As can be observed, the various systems are all based essentially on the durability and deformability of the rock. It is noted that this kind of classification has, generally, a low practical utility in tunneling.

3. COMPLEX ROCKS

As mentioned above, inhomogeneity in lithology and/or structure is broadly speaking the essential characteristic of a complex rock. According to Morgestern (1977), it is possible to distin-

		DURABILITY				STRENGTH AND DEFORMABILITY		
		Swelling	Slaking	Sensitivity to water				
		ε_D	I_{d2}	W_L	I_p	I_s	C_o	E_s
1.	Morgestern & Eigenbrod (1974)			O				
2.	Deere & Gamble (1971)		O		O			
3.	Olivier (Oviston) (1976)	O					O	O
4.	Olivier (Geodurability) (1976)	O				O		
5.	Franklin (1979)		O		O	O		

$\varepsilon_D = \frac{\Delta L}{L}$ "Duncan free swelling coefficient"
I_{d2} = Slake Durability Index (2° cycle)
W_L = Liquid limit
Ip = Plasticity index
Co = Unconfined compressive strength
Es = Secant deformation modulus

FIG. 2 - *Some classifications of weak rocks*

guish between "geological" complexity related to lithological and/or structural characteristics, and "geotechnical" complexity characterised by unpredictable and strong variations of the geotechnical properties.

The factors determining the geotechnical complexity are reported in Fig.3, and the basic types of complexity are classified in Fig.4 according to the proposal of the "Associazione Geotecnica Italiana" (AGI, 1979). Using the same distinction proposed for weak rocks, it is possible to observe that Type 1 elementary complexity is substantially "intrinsic", while the Type 2 is "extrinsic". From an engineering point of view and with specific reference to Italian complex formations, it is also possible to distinguish between three main geolithological groups: calcareous-pelitic, pelitic and arenaceous-pelitic, and the A/P ratio (A = arenaceous; P = pelitic) represents an important classification index for the last group.

4. "Poor" rock mass

To complete the above definitions for weak and complex rocks, it is also worthwhile drawing attention to the concept of "poor" rock masses. The term "poor rock mass" is preferred by the author to describe rock masses with low mechanical quality, which does not necessarily presuppose a weak intact rock material but includes any type of rock which is distinguished on the large scale by marked geomechanical weaknesses produced, for example, by tectonization. In this manner, the term "extrinsic weak rock" can be reserved to emphasize the effect of alteration on intact rock, while the general term "weak rock" can be used exclusively to describe the rock material.

Table 1 presents the various definitions of poor rock masses in the major rock mass classification systems.

It is also noted that Robertson and Kirsten (1987) defined "weak rock mass" as any rock mass whose value of unconfined compressive strength is less than about 0.7MPa. In the author's opinion, the term "weak rock mass" should only refer to a rock mass whose intact material is weak. Furthermore, a "weak rock mass" is always a "poor rock mass", but the opposite is not necessarily true.

5. Applicability of existing classifications to weak and complex rocks

The major rock mass classifications used in tunnelling including Bieniawski's RMR System, Barton's Q System, and Wickham's RSR System, are essentially based on experiences acquired from

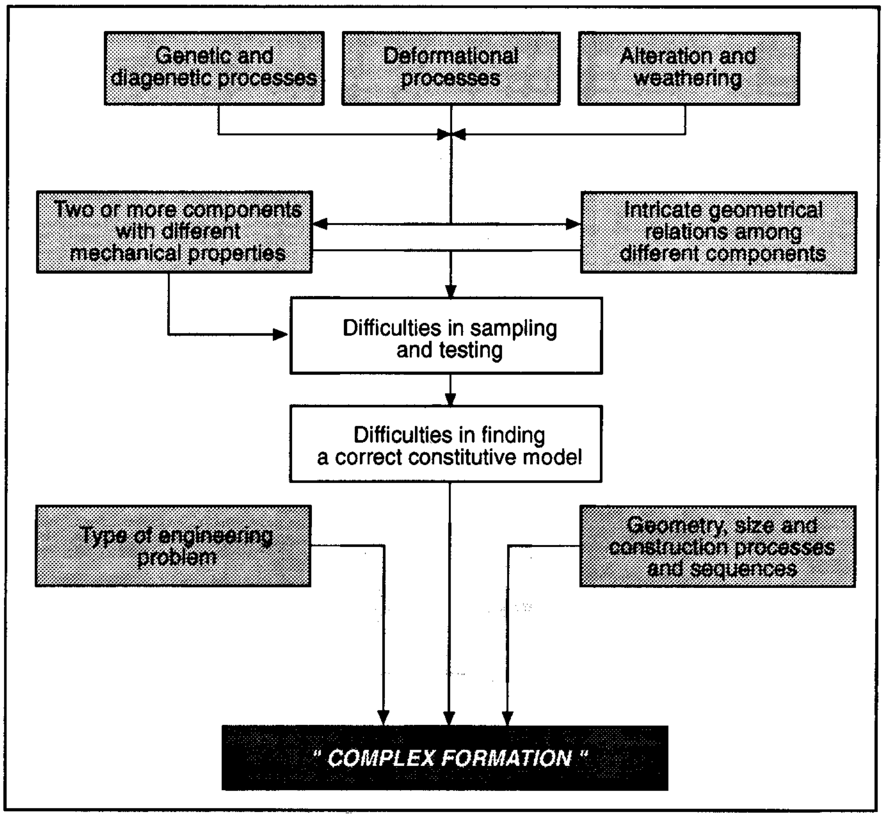


Fig. 3 - *Factors determining the geotechnical complexity* (Agi, 79)

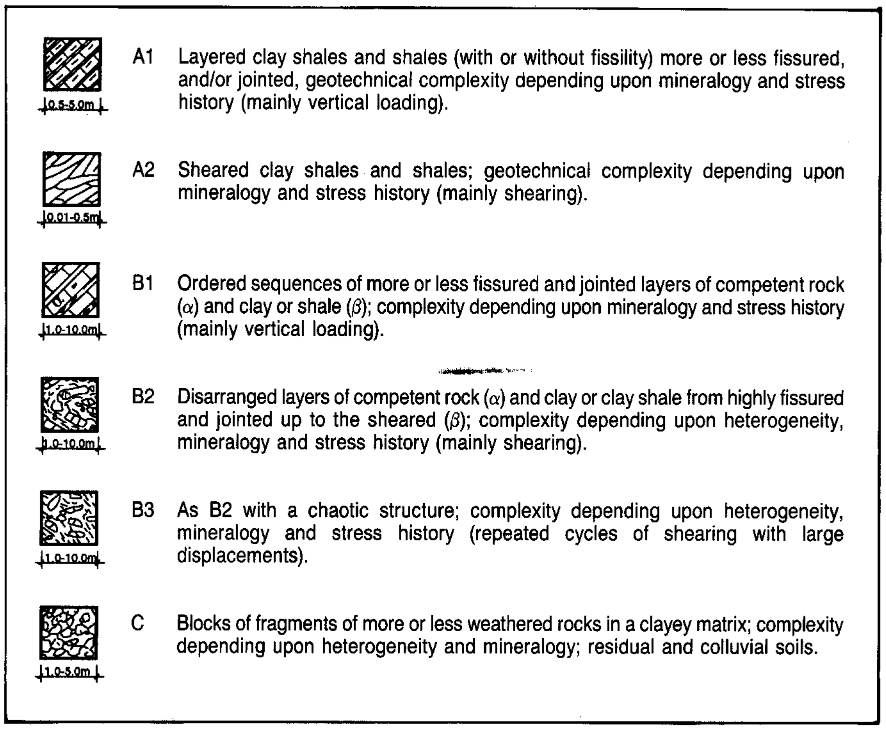


Fig. 4 - *Types of elementary complexities* (Agi, 79)

Tab. 1 - *Definition of poor rock masses in various classification systems*

Bieniawski	(1973): RMR < 41		Classes IV-V
Barton	(1974): Q < 1		Classes VII-IX
Deere	(1964): RQD < 25%		
Terzaghi	(1946):		Classes VI-IX

hard and discontinuous rocks. The application of such classification systems to rock masses made up of weak and/or complex rocks is complicated by the following main factors:

1. difficult even impossible to correctly evaluate the classification parameters;
2. theoretically applicable but practically unreliable, since the output results are not fully representative of the rock mass;
3. alterability of the rock is not adequately taken into account , when required.

In order to support these arguments, an attempt was made to evaluate (Fig.5) the real possibility of quantifying the input parameters required by the major classifications, paying attention to the reliability of the corresponding output results based on Geodata's experience in tunneling in weak and complex rocks.

For the sake of simplicity, equal weight was as-

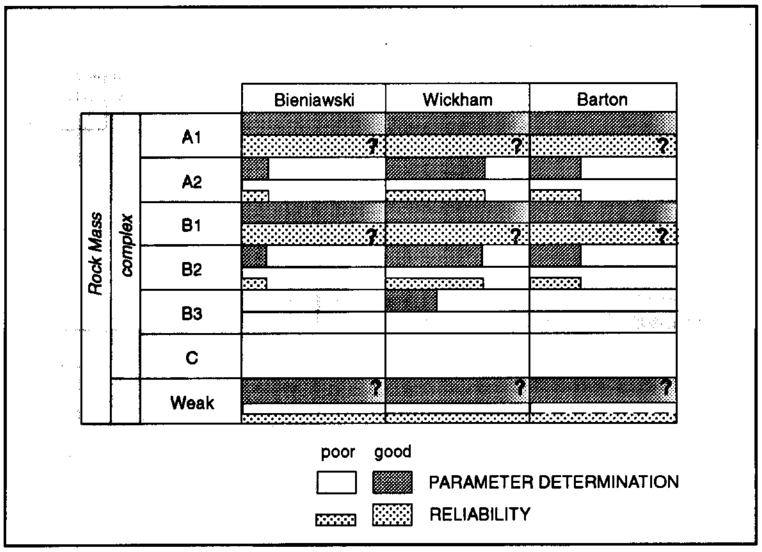


FIG. 5 - *Applicability of various technical classifications (qualitative)*

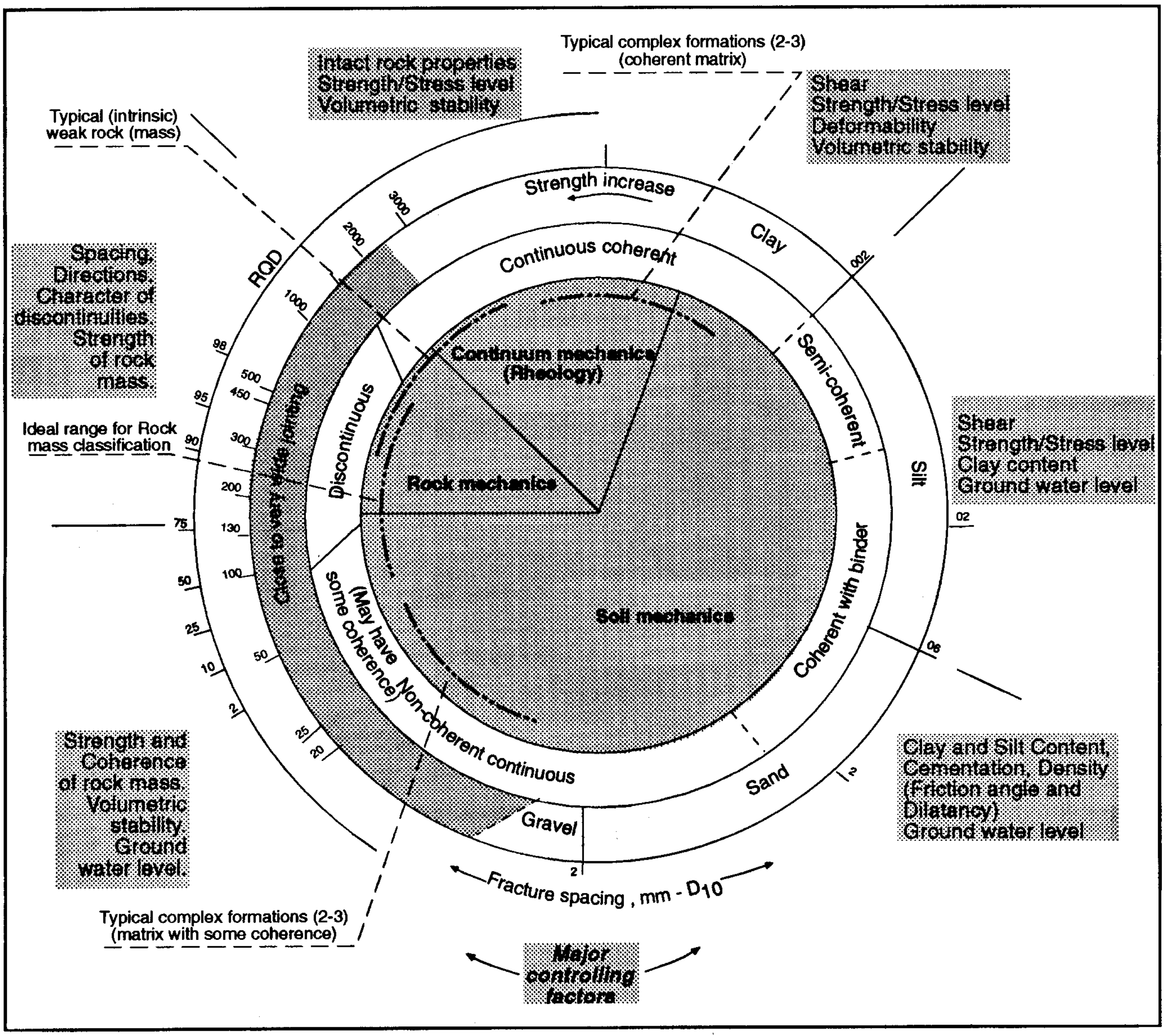


FIG. 6 - *Unified classification of geologic materials symplified after Deere (1966), for tunnel diameter of about 6m*

signed to each individual classification parameter and the results of Fig.5 are only indications of the degree of parameter determination and reliability. For example, if only 3 parameters out of 6 were correctly defined, the parameter determination index would be 50%.

Nevertheless, the degree of parameter definition and reliability vary considerably depending on the type of rock, and in particular this type of analysis shows that:

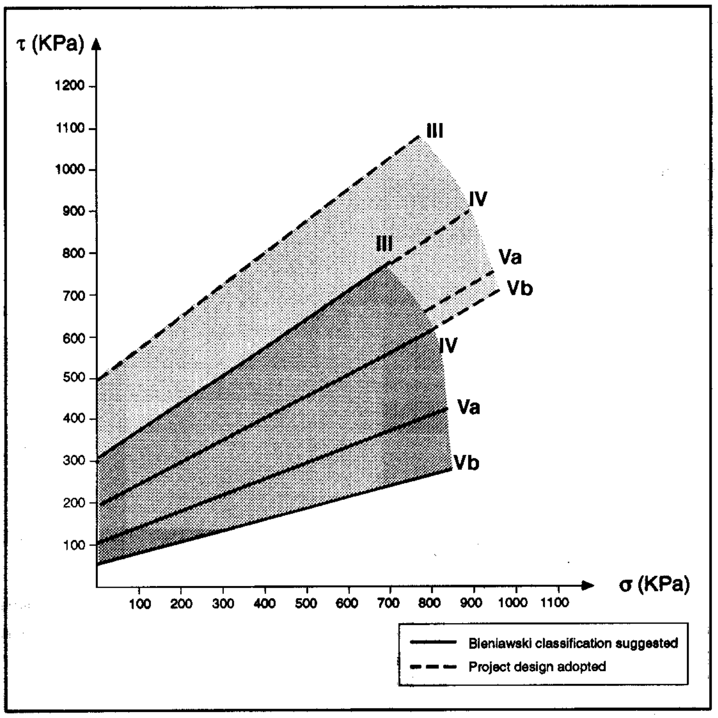
1. The application of the main classification systems to the field of complex rocks should preferably be limited to those with a Type 1 elementary complexity, in other words that originated by genetic and/or diagenetic processes. It should be noted that this is valid on if the presence of clay is localized and comparable to discontinuity infillings.
2. With regard to weak rocks, the degree of parameter determination can be often high, but the reliability of the results is generally low. It is worth noting that if a rock is both weak and complex, the use of technical classifications is not advisable.
3 Among the 3 classifications examined, that of Wickham et al., which is less complicated than the other two, appears to be the most appropriate for complex rocks, whereas for weak rocks that of Barton et al. tends to be more preferable due to inclusion of the stress reduction factor (SRF) in the system.

The "Unified classification of geological materials" proposed by Deere in 1969 is of considerable interest in the present context. A simplified form of this classification is shown in Fig. 6 for a 6m dia. tunnel. According to Deere, using the excavated diameter, D, of the tunnel as a reference, the surrounding medium can be considered discontinuous if the spacing of discontinuities lies approximately in the range between 0,2D and 0,01D, otherwise the medium can be considered continuous even if it is anisotropic.

If it is considered reasonable that the technical classifications should basically be applied to the area of rock mechanics indicated in Fig. 6, one may observe, when attempting to place weak and complex rocks in the diagram, that:

- The majority of weak intrinsic rocks are young, generally of post-orogenic age, and have undergone a less intense tectonic deformations. As a result, their degree of fracturing and fracture frequency are relatively low, such that the rock masses tend to fall in the field of continuum mechanics.
- Complex rocks of type 2 or 3 are marked by strongly deformed lithoids embedded in argillaceous matrix. When the weak matrix is dominant, according to Deere, in the most cases the rock mass can be considered as continuous media, whether coherent or not depending on the structure itself of the matrix. Generally, the material tends to be incoherent when they are "scaly" and with extremely weak links between the scales.

FIG. 7 - *Shear strength parameters: A comparison between the values suggested by the classification system of Bieniawski and those actually adopted for the design for weak to moderately strong rocks of tertiary sedimentary basin*



Therefore, all the observations presented above confirm the major problems, both conceptual and practical, involved in the application of current rock mass classifications to the field of weak and complex rocks. It must be added that whenever used, the various classifications should be compared and the output should be systematically checked using in-site and laboratory tests.

Figures 7 and 8 compare the results obtained at different stages of characterisation related to several railway tunnels in northern Italy through weak to moderately strong rocks of Tertiary age (marls, siltstones, sandstones, etc.). The shear strength parameters obtained from the initial characterization by applying Bieniawski's classification were considerably lower than those defined on the basis of in-site and laboratory tests; on the other hand, the deformability was considerably overestimated. It should be noted that classification was still applied but only for the purpose of engineering geological zoning.

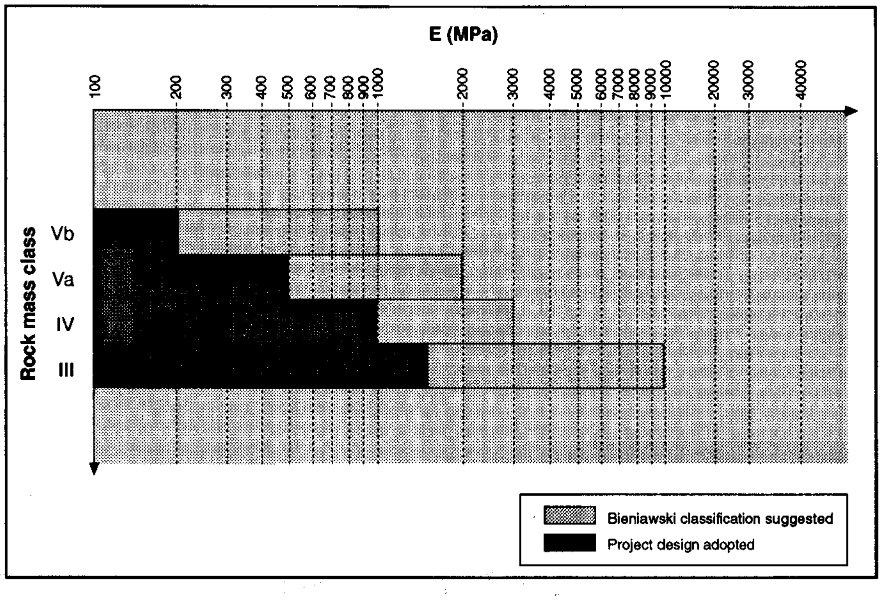


FIG. 8 - *Deformation modulus: A comparison between the values suggested by the classification system of Bieniawski and those actually adopted for the design for weak to moderately strong rocks of tertiary sedimentary basin*

6. Geomechanical classes and behaviour classes

Another important aspect which appears to have been emphasized in the geomechanical context related to weak and complex rocks, is that the technical class of a rock mass defined using the various classification systems described above does not necessarily correspond to the actual "behaviour class" which is affected by the initial stress present at the tunnel grade. In this respect, only Barton's system tends to yield better results, due to the use of SRF. Recently, Geodata has developed a rapid method (Grasso et al., 1993) for correlating between Bieniawski's classification and the "Degree of squeezing" (Jethwa, 1982) or the "behaviour classes" specified by Rabcewicz (1964), through analysis of the redistributed stresses around the excavation.

Figs. 9 and 10 report a significant experience in complex rocks obtained during construction of the dual-track Serena tunnel (6900 m), which is part of the extension of the Pontremolese Railway line. In the stretch crossing the flysch formation named "Argille e Calcari" with a maximum overburden of 150 m, highly squeezing conditions were frequently observed and systematic reinforcement with radial bolting was required. From a geotechnical point of view, the the elementary complexity of the rock mass varied between Type B1 and Type B2 while using Bieniawski's classification it was determined as Class 5. However, the rock mass showed a quite different behaviour depending on the geotechnical complexity, with the highly squeezing conditions being related only to Type B2.

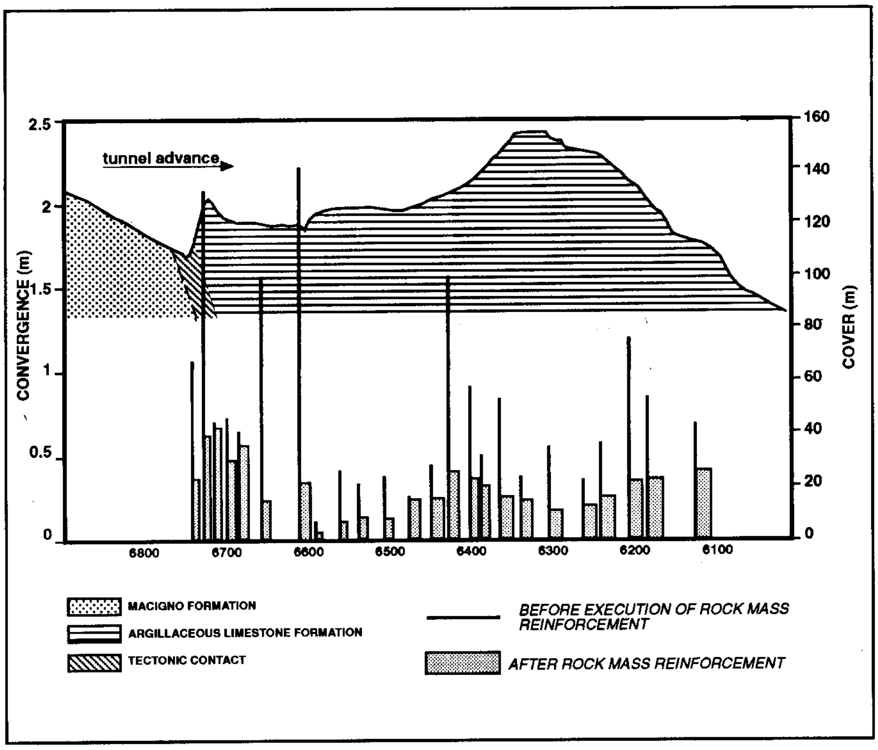


FIG. 9 - *Serena tunnel: geologic profile and deformation phenomena*

7. Modified rock mass classifications

Numerous attempts have been made in the past to modify the major classification systems for application to weak rocks. Table 2 presents a summary of some examples of modifications of Bieniawski's and Barton's systems, together with their potential field of application. Fig. 11 compares the typical parameters used in the main classifications with those introduced in the respective modified systems. It is noted that majority of the modified systems were not conceived for application to tunnelling.

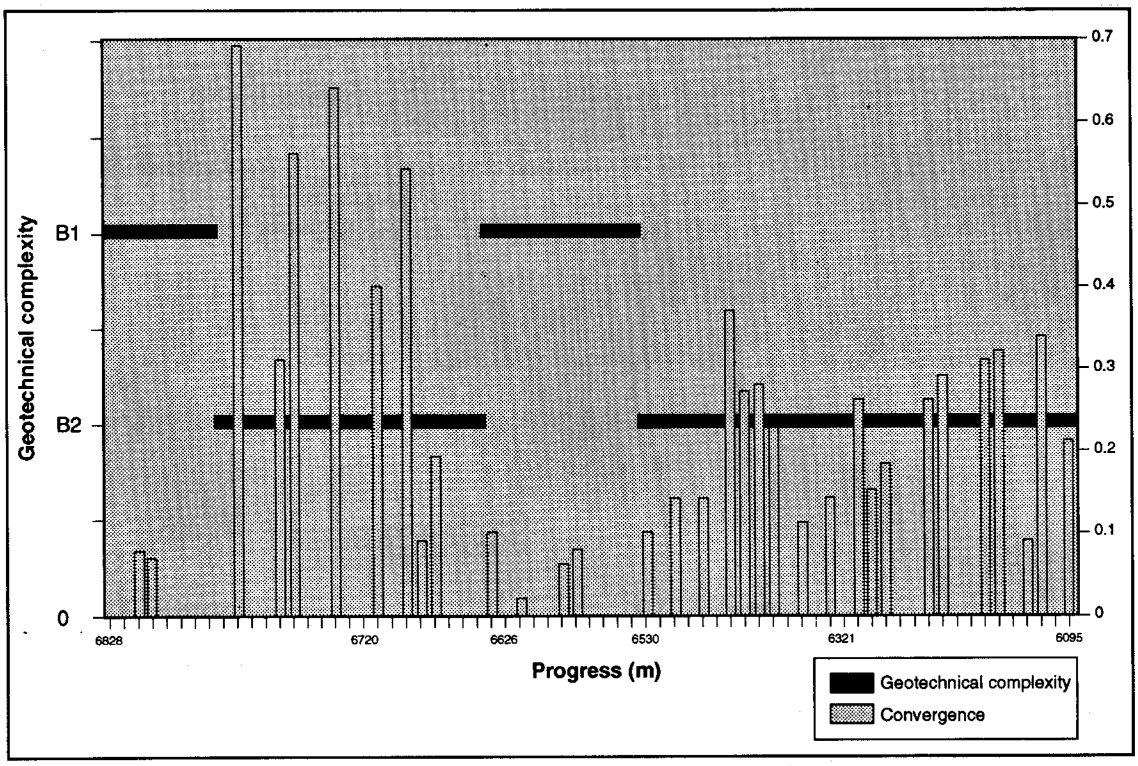


FIG. 10 - *Serena tunnel: deformation phenomena and geotechnical complexity*

As in the case of weak rock material classification (cf. Fig. 2), most of the modified systems for rock masses introduced alterability as a classification parameter, which is of considerable relevance above all in mining and slope engineering. In tunnelling, the phenomenon of alteration tends to be avoided by using appropriate technical interventions, and the application of the modified classifications may lose sense where a marked degradation of the rock mass is not really expected. In addition, the introduction of alterability generally tends to reduce the ratings of intact rock material, whose weighting in the current classifications (particularly the RMR system) is already low with respect to the corrisponding weighting assigned to discontinuity. For reasons discussed in section 2, regarding "scale effect", for weak rock mass this situation should be reversed to give a higher rating to intact rock. In making their modifications to RMR system, Unal et al. (1992) introduced a weathering coefficient (proportional to the slake durability index) and applied the coefficient to the ratings of point load strenght, RQD and joint conditions, but, in the final result, the ratio between the weighting for intact rock and that for discontinuities was basically unchanged.

A) Modifications made to the RMR System of Bieniawski

				Application field
a	Laubscher & Taylor	(1976)	MRMR system (*)	Mining
b	Robertson & Kirsten	(1987)	SRK system	Slopes
c	Venkateswarlu & Al.	(1989)	CMRS system	Mining
d	Unal, Ozkan, Ulusay	(1992)	"U.O.U"	Various

B) Modifications made to the Q System of Barton et al.

e	Cravero & Al.	(1991)	"C.I.G.M"	Tunneling
f	Verman & Al.	(1990)	(for squeezing condition)	Tunneling

Note (*) general modifications for discontinuous rock masses

TAB. 2 - *Exemples of classification systems modified for weak rock masses*

8. CONCLUDING REMARKS

To complement and to summarize what has been discussed previously, the following statements regarding the application of technical classifications to weak and complex rock masses in tunnelling can be made:

- The classifications can be a useful but never exhaustive instrument for geomechanical evaluation of rock masses. In this sense, it is generally recommended to restrict their use for geomechanical zoning and preliminary derivation of the main properties of the rock mass;
- It is also advisable to apply different classification systems and compare the results obtained from each system.
- The technical classifications are often incapable of defining the actual 'behavioural class' of the rock mass.
- The closer the rock mass resembles a discontinuous and resistent medium, the higher the reliability of the technical classifications will be.
- Their applicability tends to be governed by the elementary geotechnical complexity, such that it is generally restricted to Type 1.
- In most modified classifications for weak rock masses, adequate account is taken of the alteration potential of the rock, but they should be applied only to those situations where the phenomenon can be reasonably expected.
- Difficulties still persist in applying them to some rock masses with particular elementary complexities and in general to rock masses which are continuous compared to the size of the cavity. In such cases, it is more correct to derive the design values using the soil or the continuum mechanics approach.
- Finally, for classification of weak rock masses it is suggested to assign higher weighting for intact rock properties than for characteristics of discontinuities.

	Rock mass characteristics	Technical classification: RSR (original)	RMR (original)	MRMR (modified)	SRK (modified)	CMRS (modified)	U.O.U (modified)	Q (original)	C.I.G.M (modified)
1.	Geological description : rock type, lithology, texture, weathering, geologic structure.	●				●		●	●
2.	Total drill core recovery and RQD.		●	●	● (h)		●	● (SRF)	● (SRF)
3.	Unconfined compressive strength of intact rock.		●	●	●	●	●		
4	Water condition.	●	●	●		●	●	●	●
5.	Discontinuity: N° of families - Spacing / Joint conditions / Relative orientations	● ● ●	● ● ●	● ● ●	● (h) ● ●	●	● ● ●	● ●	● ●
6.	Pre-existing and induced stress states			● (adj.)				● (SRF)	● (SRF)
7.	Swelling properties							● (SRF)	●
8.	Durability			● (adj.)		●	●		
9.	Deformability								●

Note

(h): HRQD "handled RQD"

(adj.): Considered for rating adjustment

SRF: Stress Reduction Factor

Applicable in tunnelling

FIG. 11 - *Representative parameters of major rock mass classification systems*

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