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Case Studies: Prediction of Rock Mass Behaviour by the Geomechanics Classification

by

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SUMMARY. After a brief review of the present state of knowledge concerning engineering classifications of jointed rock masses, a classification system developed in South Africa and known as the Geomechanics Classification is described. It is shown how this classification provides an engineering assessment of rock masses, based on a rating system of the most significant geological parameters and how this leads to direct practical guidelines such as selection of rock support and reinforcement measures.

The main part of the paper is devoted to case histories involving recent applications of the Geomechanics Classification to tunnels, caverns, slopes and foundation problems in civil engineering and to haulage and chamber stability as well as to caveability assessment in mining projects. Results from these case studies, most of which are failure cases, demonstrate that rock mass behaviour can be effectively assessed, for practical engineering purposes, by means of the Geomechanics Classification.

1 INTRODUCTION

In recent years increasing attention has been paid to engineering classifications of rock masses and publications by Wickham et al (Ref. 1), Bieniawski (Ref. 2 & 3) and Barton (Ref. 4) have demonstrated the considerable benefits that can be derived by employing a classification approach in engineering practice. There are a number of reasons for this situation. Firstly, there is an urgent need for better communication between the engineer and the geologist or between the designer and the contractor when dealing with rock masses in a given project. To avoid misunderstanding, rock mass conditions must be described in such a way that they are meaningful and unambiguous for engineering purposes and yet incorporate the most significant geological parameters. Secondly, because of the complex nature of the rock there is still much to be learned about the behaviour of jointed rock masses, so that design methods in rock mechanics still incorporate a high degree of empiricism. Thus a classification approach, which encompasses observation, experience and engineering judgment, is a most valuable design tool and sometimes even the only one. Finally, there is convincing evidence, from the many successful years of application of various classification approaches in Austria (Ref. 5), that rock mass classifications deserve more widespread use. This was also substantiated on an international scale by a recent general report on engineering geology and underground construction (Ref. 6) which emphasized that the most promising developments in assessing ground conditions would be the emergence of classification systems involving numerical values for rock mass conditions.

A detailed review of the numerous rock mass classification systems developed to date was given in Ref. 2 & 4 from which it became apparent that for a classification system to be most useful, a number of requirements must be fulfilled. These are:

- (i) simplicity of form, clarity of terminology and flexibility to accept improvements and revisions;
- (ii) incorporation of the most significant geological parameters, all of which must be measurable in

the field;

(iii) provision of ratings to distinguish the relative importance of the chosen classification parameters;

(iv) inherent generality enabling estimation of overall rock mass conditions independent of the type of excavation;

(v) ability to provide quantitative data for engineering designs of specific structures to be built in rock;

(vi) specification of 'check-and-balances' measures to avoid unlimited applications which could be unjustified or even dangerous.

Although some of the classification systems currently in use in various parts of the world, incorporate one or more of the above requirements, none satisfies all of them. As a result, an engineering classification system of jointed rock masses known as the Geomechanics Classification was developed in South Africa early in 1973 to meet these requirements. To date the Geomechanics Classification has been successfully applied in both mining and civil engineering and to problems ranging from tunnels, caverns, slopes and foundations to haulages and chambers. It is even used to estimate caveability of ore in block caving mining. Full records were kept of all case histories, with improvements and revisions being introduced to ensure that the predicted rock conditions correspond to actual observations during construction. Special attention was paid to these failure cases which could yield information on the accuracy of the Geomechanics Classification.

It is the purpose of this paper to share these experiences with the reader and to demonstrate the benefits and potential of this classification system.

2 THE GEOMECHANICS CLASSIFICATION

The Geomechanics Classification is an engineering classification of jointed rock masses. It incorporates the following six parameters which are

considered most significant in the behaviour of rock masses.

- (a) Uniaxial compressive strength of rock material
- (b) Drill core quality RQD
- (c) Ground water conditions
- (d) Spacing of joints
- (e) Condition of joints
- (f) Orientation of joints.

It was found (Ref. 2 & 4) that there was no single parameter or index which could describe fully and quantitatively a jointed rock mass for engineering purposes. Various factors have different significance and only if taken together can they satisfactorily describe a rock mass. Thus, while the RQD is an essential parameter it is not wholly sufficient since it disregards the influence of joint roughness, continuity, orientation and gouge (joint infilling) material. With the aid of RQD it is not normally possible to assess the true spacing of joints (mean distance separating the planes of weakness measured in the direction perpendicular to the joint planes).

All of the above classification parameters can be measured in the field, including the uniaxial compressive strength which is determined by a diametral point-load test on unprepared drill core (Ref. 7).

The Geomechanics Classification is given in Table I. While this table is self-explanatory, it should be noted that in order to enable the Geomechanics Classification to be used in many applications, one must first arrive at a general rock mass quality assessment ('basic in-situ rock mass value'), irrespective of the envisaged engineering project. This is achieved from the first five classification parameters. Subsequently, the ratings are adjusted for strike and dip orientations of joints depending whether one deals with a tunnel, a slope or a foundation (see next section).

To apply the Geomechanics Classification, the geologist first divides a rock mass into a number of structural regions, each region having certain uniform features and similar characteristics which will necessitate only one type of support. He then determines the classification parameters for each structural region from his measurements in the field. For this purpose a special input data sheet was developed (Ref. 2). Next the engineer, in collaboration with the geologist assigns the importance ratings to the classification parameters.

Once the importance ratings of the classification parameters are established, the ratings for the five individual parameters (Section A of Table I) are added giving first the basic in-situ rating for the rock mass (i.e. its structural region under consideration), with higher ratings describing better rock mass conditions. This basic rating is next adjusted in accordance with Section B of Table I to give the final rating for the rock mass. Section C of Table I groups the final ratings into five rock mass classes. Section D of Table I gives the practical meaning of each rock mass class so that they may be related to specific engineering problems. This will be discussed further when dealing with case studies.

3 CASE HISTORIES

The best method of testing a rock mass classification system, is to check its reliability in actual case studies. Since, however, all classification systems are evolved on the basis of practical experience and are conservative in nature, there is

a danger of perpetuating a practice of over-design. This can be avoided only if case records involving rock failure are available against which safety margins in rock classification applications can be determined. Unfortunately, such information is seldom published.

Ever since the Geomechanics Classification was proposed at the beginning of 1973, new case histories were sought and recorded and in particular those involving stability problems and failure of rock. In addition, in all the many rock engineering problems involving the author's organization, the classification was applied as a matter of routine and all experiences were carefully evaluated. This combined with applications of this classification system by other organizations in South Africa and elsewhere, provided sufficient data - including failure cases - to build up confidence in it and to establish its accuracy. It was particularly fortunate that enough failure cases were available to provide meaningful interpretation.

Space does not permit full treatment of all the case histories but selected examples will be given of failure case histories from widely ranging applications which will demonstrate the versatility, accuracy and benefits of the Geomechanics Classification. These case histories represent civil and mining engineering applications and involve tunnels, chambers, slopes, foundations and mine haulages.

4 TUNNELS AND CHAMBERS

A tunnel of horseshoe cross-section, 5 m in width and 6 m in height was driven by drilling and blasting in fractured dolerite. The roof was unsupported and a 2,5 m span by 6 m in length collapsed eight hours after blasting creating a large cavity over 3 m high. The tunnel rating was determined as follows:

Parameter	Value	Rating
Material strength	50 - 100 MPa	7
RQD	25 - 50%	4
Spacing of joints (in sets)	(1) 0,3 - 1 m (2) 50 - 300 m (3) 0,3 - 1 m	15
Condition of joints	Tight continuous joints with slightly rough surfaces, hard joint wall, gouge < 5 mm thick	6
Ground water inflow	< 25 litres/min	7
BASIC IN-SITU ROCK VALUE		39
Adjustment for orientation of joints	Very unfavourable	-12
FINAL TUNNEL ROCK VALUE		27

In the case of tunnels, the output from the Geomechanics Classification is the average stand-up time for an unsupported rock span to fail. An unsupported span is the width of the tunnel or the distance from support to the face if this is less than the width of the tunnel. The full relationship between span and stand-up time according to the Geomechanics Classification, is given in Fig. 1 from which it will be seen that a rating of 27 in the

TABLE I

GEOMECHANICS CLASSIFICATION OF JOINTED ROCK MASSES

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

1	Strength of intact rock material	Point-load strength index	> 8 MPa	4 - 8 MPa	2 - 4 MPa	1 - 2 MPa	Use of uniaxial compressive test preferred		
		Uniaxial compressive strength	> 200 MPa	100 - 200 MPa	50 - 100 MPa	25 - 50 MPa	10-25 MPa	3-10 MPa	1-3 MPa
		Rating	15	12	7	4	2	1	0
2	Drill core quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of joints		> 3 m	1 - 3 m	0,3 - 1 m	50 - 300 mm	< 50 mm		
	Rating		30	25	20	10	5		
4	Condition of joints		Very rough surfaces. Not continuous. No Separation. Hard joint wall rock.	Slightly rough surfaces. Separation < 1 mm. Hard joint wall rock.	Slightly rough surfaces. Separation < 1 mm. Soft joint wall rock.	Slickensided surfaces OR Gouge < 5 mm thick OR Joints open 1-5 mm. Continuous joints	Soft gouge > 5 mm thick OR Joints open > 5 mm. Continuous joints		
	Rating		25	20	12	6	0		
5	Ground water	Inflow per 10m tunnel length	None		< 25 litres/min	25 - 125 litres/min	> 125 litres/min		
		Ratio $\frac{\text{joint water pressure}}{\text{major principal stress}}$	OR 0		OR 0,0 - 0,2	OR 0,2 - 0,5	OR > 0,5		
		General conditions	OR Completely dry		OR Moist only (interstitial water)	OR Water under moderate pressure	OR Severe water problems		
	Rating		10		7	4	0		

B. ADJUSTMENT FOR JOINT ORIENTATIONS

Strike and dip orientations of joints		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Ratings	Tunnels	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

C. ROCK MASS CLASSES AND THEIR RATINGS

Class No	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock
Rating	100 ← 90	90 ← 70	70 ← 50	50 ← 25	< 25

D. MEANING OF ROCK MASS CLASSES

Class No	I	II	III	IV	V
Average stand-up time	10 years for 5 m span	6 months for 4 m span	1 week for 3 m span	5 hours for 1,5 m span	10 minutes for 0,5 m span
Cohesion of the rock mass	> 300 kPa	200 - 300 kPa	150 - 200 kPa	100 - 150 kPa	< 100 kPa
Friction angle of the rock mass	> 45°	40° - 45°	35° - 40°	30° - 35°	< 30°
Caveability of ore	Very poor	Will not cave readily. Large fragments	Fair	Will cave readily. Good fragmentation	Very good

TABLE II

THE EFFECT OF JOINT STRIKE AND DIP ORIENTATIONS IN TUNNELLING

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Dip 0° - 20° irrespective of strike
Drive with dip		Drive against dip		Dip 45°-90°	Dip 20°-45°	
Dip 45°-90°	Dip 20°-45°	Dip 45°-90°	Dip 20°-45°			
Very favourable	Favourable	Fair	Unfavourable	Very unfavourable	Fair	Unfavourable

above example falls in the first quarter of Class IV which is 'poor rock' ranging from 25 to 50. The expected stand-up time is determined from Fig. 1 for rating 27 and a span of 2,5 m which leads to a stand-up time of 2 hours. Note that the actual case (point X in Fig. 1) represents a rating of 38.

Comments: (a) The predicted stand-up time of 2 hours by comparison with the actual value of 8 hours (predicted rating 27 versus actual rating of 38) indicates a built-in safety margin of the Geomechanics Classification. A special check of this aspect was maintained by monitoring of tunnel convergence and by borehole extensometer measurements. This safety margin is further supported by another failure case study described previously (Ref. 3) which involved a tunnel of Class II - 'good rock'; the predicted rating was 75 versus the actual rating of 81. In addition, a large underground chamber, 20 m in width, also of Class II, had a predicted rating of 73 and it stood unsupported for 8 months giving a rating of 85.

(b) To facilitate adjustment of ratings given in Section B of Table I, it is necessary to decide whether strike and dip orientations are favourable or not. In the case of tunnels, reference should be made to Table II which is to be used in conjunction with the Geomechanics Classification.

(c) Longer stand-up time in a given rock mass can be achieved once suitable support measures are introduced. These support measures constitute primary support (sometimes known as the temporary support) and they aim at ensuring tunnel stability until the permanent support is installed. They depend on such factors as the depth below surface (field stresses), tunnel size and shape and the method of excavation. The primary support measures are given

in Table III which represents the modern technological practice in the USA, Europe and South Africa. It should be noted that although the support measures listed in Table III are given as primary support, they will probably be able to carry the final load ever acting on the tunnel. Nevertheless, since our knowledge of tunnel engineering is far from complete, elimination of permanent support altogether may not be justified at this stage.

A solution to the above problem is to conduct certain field measurements in the tunnel during construction. On this basis, the initial design could be adjusted to conform to the behaviour of the rock mass. The measurements can also indicate to which extent the thickness of the final lining may be reduced. The most common field measurements are: precise levelling, convergence measurements across the tunnel cross-sections, borehole extensometer measurements around the tunnel circumference and pressure measurements in the lining or at the rock/concrete interface.

(d) The input data necessary for the Geomechanics Classification are well within the scope of a normal site exploration programme. Special caution must, however, be exercised in the case of shales and other potentially swelling rock types. For such rocks, slake-durability and swelling tests should be applied as extra classification criteria.

(e) Further failure case studies involving tunnels and chambers are plotted in Fig. 1.

5 SLOPES

In order to demonstrate the applicability of the Geomechanics Classification to rock slopes, two failure cases will be considered, one involving a deep road cutting and one an open pit mine.

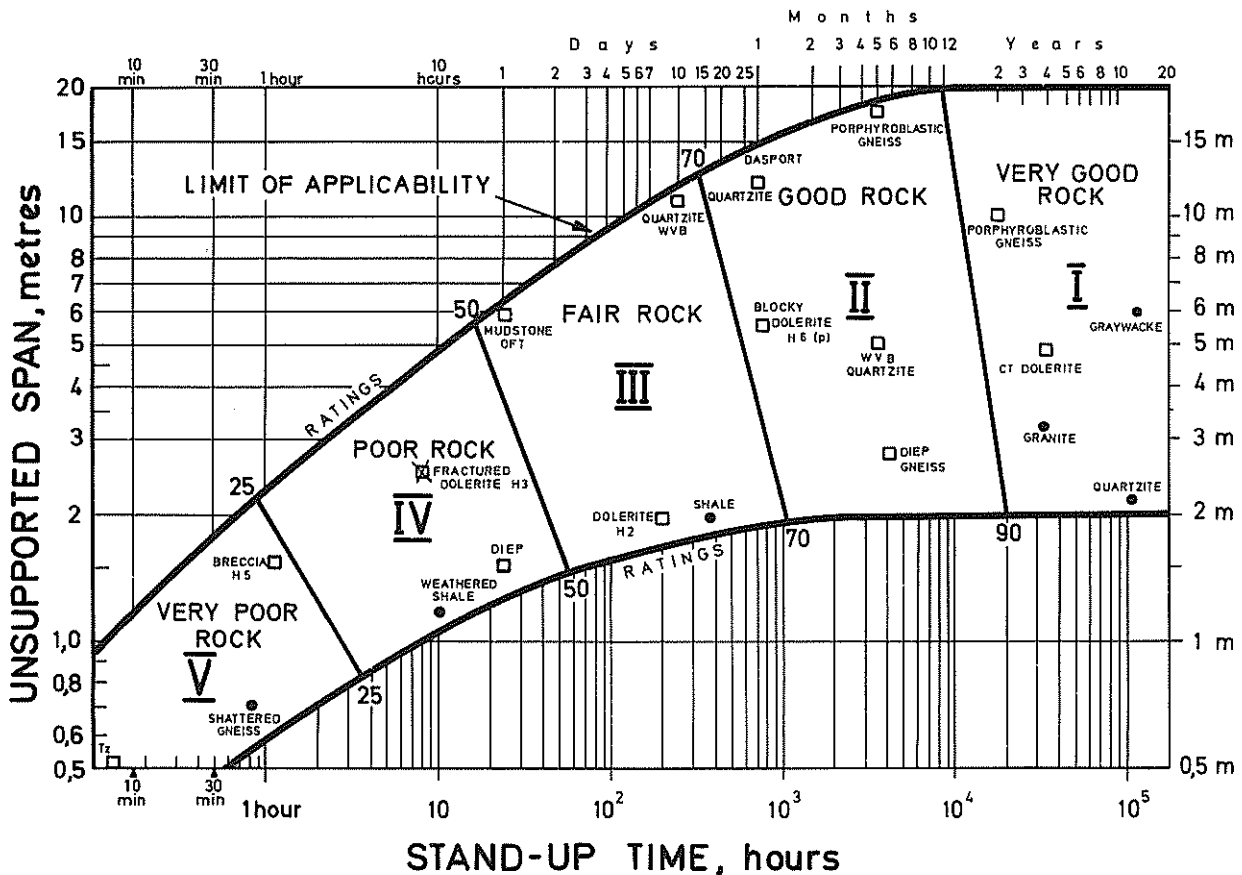


Fig. 1 Geomechanics classification of rock masses for tunnelling. South African case studies are indicated by squares while those from Alpine countries by dots.

TABLE III

GUIDE FOR SELECTION OF PRIMARY SUPPORT IN HORSESHOE-SHAPED TUNNELS
WIDTH: 5 - 12 m, VERTICAL STRESS BELOW 30 MPa, CONSTRUCTION BY DRILLING AND BLASTING

Rock mass class	Excavation	Primary support		
		Rockbolts* (length for tunnel of 10 m width)	Shotcrete	Steel sets
I	Full face 3 m advance	Generally no support required except for occasional spot bolting		
II	Full face 1,0-1,5 m advance	Locally bolts in crown 2-3 m long, spaced 2-2,5 m with occasional wire mesh. Complete 20 m from face.	50 mm in crown as basis for waterproof	None
III	Top heading and bench 1,5-3 m advances in top heading	Systematic bolts 3-4 m long, spaced 1,5-2 m in crown and walls with wire mesh in crown. Complete 10 m from face.	50-100 mm in crown and 30 mm in sides	None
IV	Top heading and bench 1,0-1,5 m advance in top heading	Systematic bolts 4-5 m long, spaced 1-1,5 m in crown and walls with wire mesh. Complete 10 m from face	100-150 mm in crown and 100 mm in sides. Support to be installed as excavation proceeds	Occasional light ribs spaced 1,5 m where required
V	Multiple drifts 0,5-1 m advance in top heading	Systematic bolts 5-6 m long, spaced 1-1,5 m in crown and walls with wire mesh. Bolt invert. Complete 5 m from face	150-200 mm in crown, 150 mm in sides and 50 mm on face. Apply shotcrete as soon as possible after blasting	Heavy ribs spaced 0,75 m with steel lagging. Close invert

* 20 mm diameter, fully resin bonded, length $\frac{1}{2}$ tunnel width

(a) A slope failure in the vicinity of a road tunnel portal involved some 1200 m³ of rock. The portal (\approx 50 m high) had been excavated in slightly to completely weathered jointed quartzite which was underlain by a sill of amphibolite. An investigation had shown that toppling failure of the quartzite blocks was caused by shear displacement within the weak decomposed amphibolite forming the base of the slope. Slope stability analyses indicated unstable conditions (factors of safety below unity) from considerations of shear failure in amphibolite and from considerations of stability against toppling of overlying quartzite blocks forming the top of the slope. The amphibolite region had a rating of 15 while the failed quartzite region was rated -1. The slope rock mass value for the amphibolite region yielded an output from the Geomechanics Classification as : $c = 60$ kPa and $\phi = 18^\circ$. By comparison, actual test results gave $c = 3$ kPa and $\phi = 24^\circ$. These two low values, giving a factor of safety of 0,7, resulted in shear movement in the amphibolite which caused toppling failure of the quartzite.

(b) A large open pit diamond mine consists of horizontally disposed dolerite (30 m), shale (70 m) and melaphyre (100 m). Stability of a section of this mine was in question and, in fact, a part of the slope had failed. Detailed geological investigations were conducted (mostly in underground tunnels) enabling accurate determination of all the classification parameters. In addition, extensive tests were undertaken to provide input data for slope stability analyses. Furthermore, the slope was extensively monitored and a survey of stable slopes at adjacent mines was undertaken. Thus an excellent opportunity for correlating classification predictions with field observations was afforded.

The Geomechanics Classification applied to this mine yielded the following ratings: 63 for dolerite (Class III), 26 for shale (Class IV) and 75 for melaphyre (Class II). The output data for the shale were: cohesion of 100 kPa and friction angle of 33° . These figures were used in a slope stability analysis for determining safe slope angles. These angles in turn were compared with those found stable in the existing slopes which was further confirmed by slope monitoring. In this way, the application of the Geomechanics Classification to rock slopes was clearly established as a reliable approach.

6 FOUNDATIONS

The Geomechanics Classification has so far been applied in two major rock foundation problems, both involving large bridges. To date the classification has not been applied to dam foundations, for lack of opportunity, but there is no reason why this should not be attempted. One of the bridge foundation problems where the classification was applied was particularly interesting because it also involved a large scale in-situ test (double cable jacking test). Further particulars are as follows:

The bridge foundations were 22 m by 11 m in area and extended down to a depth of about 15 m, located in weathered migmatitic bedrock. The main problem was whether foundation displacements would be within the design limits of a rigid arch bridge but concern was also expressed regarding the overall stability of the abutments against bearing capacity failure. The project was important enough to warrant a large scale in-situ test, in addition to geological mapping, laboratory testing and drill core analyses.

On the basis of a cable jacking test and subsequent monitoring of the completed structure, a modulus of deformation of the rock mass of about 500 MPa was obtained. An unexpected phenomenon was the total failure of the rock mass during the final load increment in the cable jacking test. A bearing capacity analysis gave a cohesion value of 1,7 MPa (assuming $\phi = 0$) and hence an estimated value of 3,4 MPa for the in-situ unconfined strength of the rock mass. The Geomechanics Classification produced a rating of 36 - Class IV : 'poor rock'.

The Geomechanics Classification is applied to foundation problems to predict the modulus reduction factor ($E_{\text{rock mass}}/E_{\text{rock material}}$) in accordance with Fig. 2. In the present example, a rating of 36 yields a modulus reduction factor of 0,15. Since laboratory tests on the migmatite rock material gave an average modulus of deformation of 3,0 GPa, the in-situ modulus was obtained as 450 MPa as compared with 500 MPa determined in the in-situ cable test.

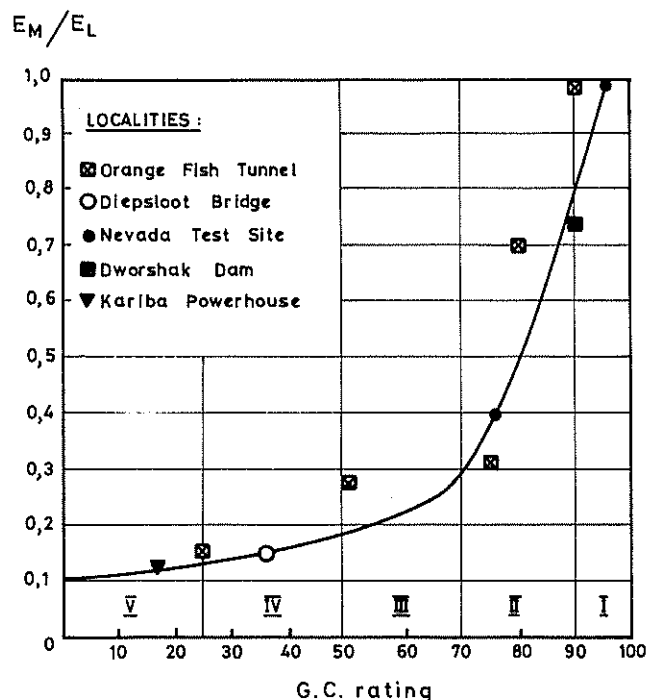


Fig. 2 Relationship between Geomechanics Classification rating and ratio of static deformation modulus of rock mass E_M to that of rock material E_L

7 MINING

The Geomechanics Classification has by now been applied extensively in the field of mining both to determine haulage and chamber stability as well as caveability of ore. In fact, this Classification is used today in Rhodesia (Ref. 8) as a standard approach for assessment of rock conditions in asbestos mines. Interesting modifications to this classification were introduced by Laubscher (Ref. 8) to suit all mining situations. They involve further adjustments, in addition to the adjustment for joint orientations, and are given below:

	Intact strength	RQD	Joint condition	Total
Weatherability	-2	-3	-11	-16
Field/induced stresses			+6 to -21	+6 to -21
Changes in stresses			+6 to -21	+6 to -21

If the Geomechanics Classification is subjected to more than one adjustment in mining situations, the maximum reduction is limited to 35.

The classification has been used with much success for selection of primary support for mine haulages and chambers in accordance with the guide given in Table III. It should be noted in this connection that it is recommended that chambers should only be excavated in rock masses with adjusted classes of III or better.

For caveability assessment, Ref. 8 gives a guide relating each rock mass class to : undercut area, fragmentation, angle of cave, the extent of the failure zone and secondary blasting (see also Section D of Table I).

8 CONCLUSIONS

The quoted case studies clearly demonstrate the potential of the Geomechanics Classification in civil engineering and mining applications. The author would therefore like to urge all interested readers to use this classification and to inform him of any applications since he wishes to keep a complete record of all case histories. It must, however, be remembered that a classification approach is only a means towards a goal and cannot fully replace final engineering design. It basically represents an empirical approach and must be cross-checked during construction by suitable field measurements. Once this is done, the Geomechanics Classification is a very powerful tool for assessing rock mass conditions, selecting support or rock reinforcement measures and enabling effective communication on engineering projects.

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