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A rock mass classification system for the design and safety analysis of slopes

Un système de classification de massifs rocheux pour le projet et l'analyse de sécurité des pentes

Ein Gebirgsklassifikationssystem für den Entwurf und die Sicherheitsanalyse von Hängen

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ABSTRACT: A rock slope classification scheme leading to slope stability assessment is in development in which factors are introduced to compensate for weathering and excavation disturbance and produce a rating for an imaginary unweathered and undisturbed 'reference' rock mass. The classification thence allows assessment of the stability of the existing or any new slope in the reference rock mass, with allowance for any influence of excavation method or (future) weathering.

RÉSUMÉ: Un système de classification pour des pentes (naturels ou artificiels) d'un massif rocheux est développé et résulte en une détermination de la stabilité des pentes. Le système comprend des facteurs pour compenser pour l'altération et l'endommagement par le méthode de l'excavation. Le résultat est une appréciation numérique pour un massif rocheux qui n'est pas altéré ni creusé - le massif rocheux de 'référence'. La stabilité de la pente nouvelle ou la pente existante est classé en le massif rocheux de 'référence' avec des facteurs compensatoires pour l'altération (future) et l'excavation.

ZUSAMMENFASSUNG: Ein Klassifikationssystem für die Stabilität von Felshängen ist in Entwicklung. Das System enthält Faktoren für Verwitterung und Ausbruchsart. Das Resultat ist ein Wert für ein Fels der nicht verwittert und nicht ausgebrochen ist - der 'Referenz'-Fels. Die Stabilität des neuen oder existierenden Hanges ist dann klassifiziert im 'Referenz'-Fels mit Faktoren für Ausbruch und (zukünftige) Verwitterung.

1 INTRODUCTION

Rock mass classification schemes developed for underground works (Bieniawski, 1989, Barton, 1976, 1988, Laubscher, 1990) result in recommendations for support; some systems also apply to rock slope stability (Bieniawski, 1989, Romana, 1985). However, the use of rock mass classifications developed for underground works leads often to unsatisfactory results when applied to near-surface applications such as rock slope stability, and a new rock mass classification system for slopes has been developed based on the Laubscher system.

The rock slope classification system was developed during three years of research in the Falset area in the north-east of Spain. Here new roads have recently been built through a mountainous terrain, necessitating a large number of new road cuts. Rocks in the Falset area vary from Tertiary conglomerates to Carboniferous slates and include rocks containing gypsum, shales, granite (fresh to completely weathered), limestone and sandstone, thus giving the opportunity to assess slopes in different materials. Different methods of excavation were used for the old and the new road cuts, allowing comparison of different excavation methods. Road cuts made for old roads some 40 to 60 years ago could be compared to road cuts not more than 4 years old. Also local variations in weathering, the influence of weathering, and the susceptibility of the rocks to weathering as a factor in slope stability could be studied in detail in the area.

Existing old and new slopes have been classified and assessed on stability by the staff and students of ITC and the Technical University,

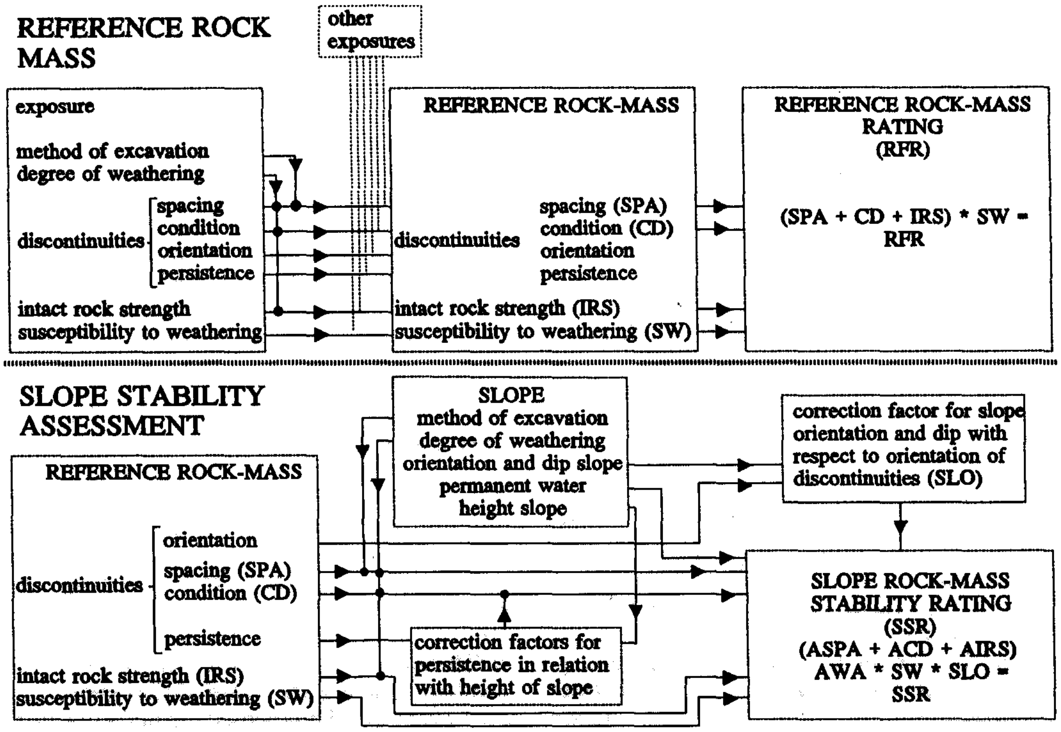


Figure 1: Classification scheme (● = correction factor applied to rock mass parameter).

the low strength of the intact material but by the numerous closely spaced bedding planes.

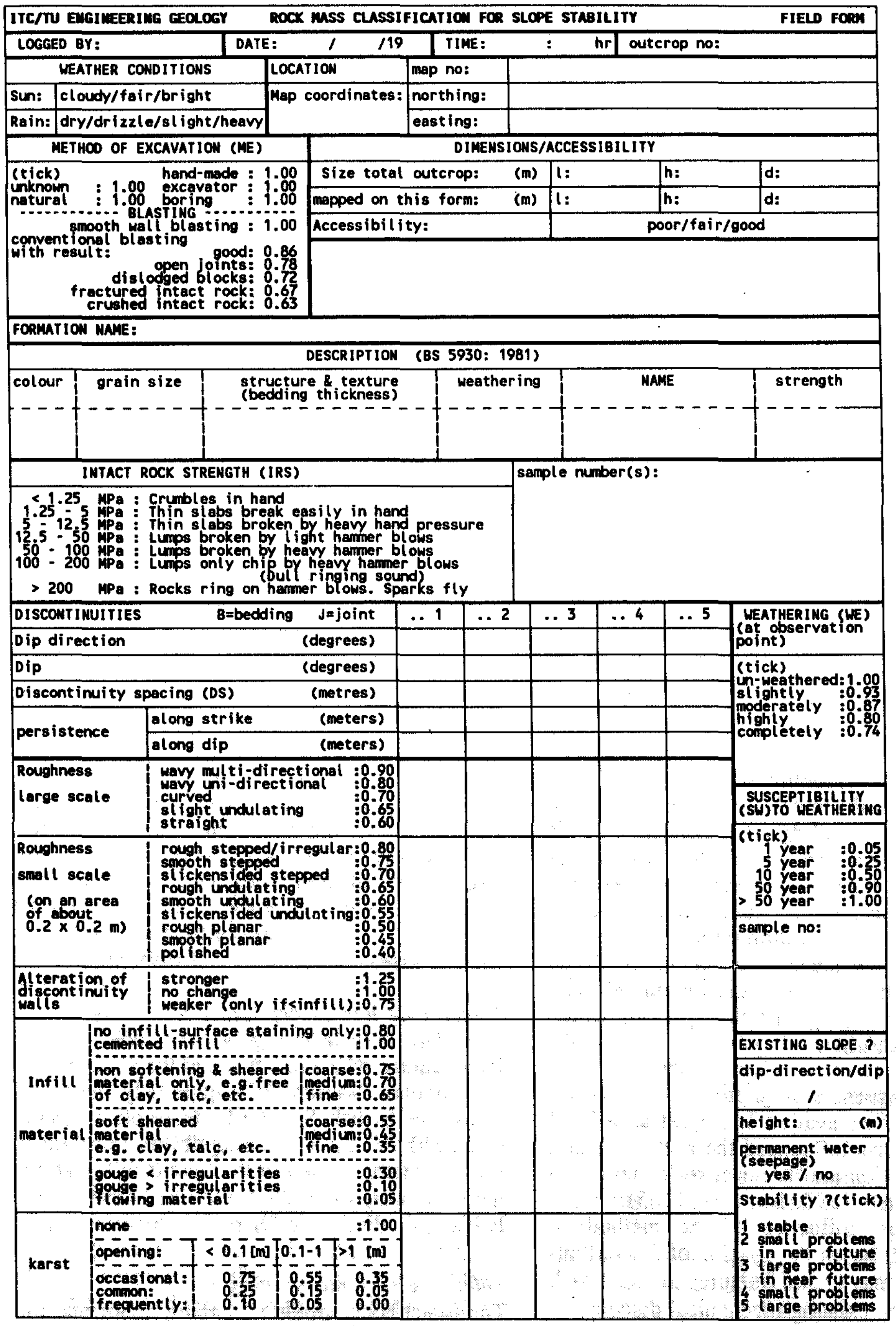
Unless the rock is very weak it is unlikely that a rock slope will fail by failure through truly intact rock. However, the purpose of including intact rock strength in the system is to give an assessment of wall rock strength of the discontinuities. The intact rock strength points for the classification system are equal to the intact rock strength in MPa (taken as the median value for the strength range within which the rock falls) divided by 10 up to a maximum of 10 points.

Discontinuity spacing
Taylor (Taylor, 1980) produced a graphical method to derive factors describing discontinuity spacing of three discontinuity sets, thus defining block size and block form. This approach has been found to be very useful also for slope stability and as yet no modifications have been made. The maximum rating of the spacing, corresponding to the largest blocks, is 25 points.

Condition of discontinuities
The condition of discontinuities includes the items relating to roughness (large and small scale), alteration of discontinuity walls and infill material, as shown in fig.2. Laubscher (1990) makes a distinction between condition factors for wet and dry rocks. In the slope classification system only the factors for wet rocks have been used for reasons described in section 3. As to yet no reasons for changes in these factors have arisen.

For calcareous rocks it was found that a factor had to be included for karst and solution phenomena. It has been observed that these often occur along discontinuity planes. Water percolates through the discontinuity and dissolves the calcareous material from the wall. Karst and solution phenomena have a distinct weakening influence on slopes cut in these rocks and factors have been incorporated to allow for this.

Laubscher (ibid) takes into account in his final RMR rating only the condition factor of the



ITC/TU ENGINEERING GEOLOGY **ROCK MASS CLASSIFICATION FOR SLOPE STABILITY** **FIELD FORM**

LOGGED BY:
DATE: / /19
TIME: : hr
outcrop no:

WEATHER CONDITIONS
Sun: cloudy/fair/bright
Rain: dry/drizzle/slight/heavy

LOCATION
map no:
Map coordinates: northing:
easting:

METHOD OF EXCAVATION (ME)
(tick)
unknown : 1.00
natural : 1.00
hand-made : 1.00
excavator : 1.00
boring : 1.00
------------ BLASTING ------------
smooth wall blasting : 1.00
conventional blasting
with result:
good: 0.86
open joints: 0.78
dislodged blocks: 0.72
fractured intact rock: 0.67
crushed intact rock: 0.63

DIMENSIONS/ACCESSIBILITY

Size total outcrop: (m)	l:	h:	d:
mapped on this form: (m)	l:	h:	d:
Accessibility:	poor/fair/good		

FORMATION NAME:

DESCRIPTION (BS 5930: 1981)

colour	grain size	structure & texture (bedding thickness)	weathering	NAME	strength

INTACT ROCK STRENGTH (IRS)
< 1.25 MPa : Crumbles in hand
1.25 - 5 MPa : Thin slabs break easily in hand
5 - 12.5 MPa : Thin slabs broken by heavy hand pressure
12.5 - 50 MPa : Lumps broken by light hammer blows
50 - 100 MPa : Lumps broken by heavy hammer blows
100 - 200 MPa : Lumps only chip by heavy hammer blows (Dull ringing sound)
> 200 MPa : Rocks ring on hammer blows. Sparks fly

sample number(s):

DISCONTINUITIES B=bedding J=joint		.. 1	.. 2	.. 3	.. 4	.. 5
Dip direction (degrees)						
Dip (degrees)						
Discontinuity spacing (DS) (metres)						
persistence	along strike (meters)					
	along dip (meters)					
Roughness large scale	wavy multi-directional :0.90 wavy uni-directional :0.80 curved :0.70 slight undulating :0.65 straight :0.60					
Roughness small scale (on an area of about 0.2 x 0.2 m)	rough stepped/irregular:0.80 smooth stepped :0.75 slickensided stepped :0.70 rough undulating :0.65 smooth undulating :0.60 slickensided undulating:0.55 rough planar :0.50 smooth planar :0.45 polished :0.40					
Alteration of discontinuity walls	stronger :1.25 no change :1.00 weaker (only if<infill):0.75					
Infill material	no infill-surface staining only:0.80 cemented infill :1.00 non softening & sheared material only, e.g.free of clay, talc, etc. coarse:0.75 medium:0.70 fine :0.65 soft sheared material e.g. clay, talc, etc. coarse:0.55 medium:0.45 fine :0.35 gouge < irregularities :0.30 gouge > irregularities :0.10 flowing material :0.05					
karst	none :1.00 opening: < 0.1 [m] / 0.1-1 / >1 [m] occasional: 0.75 / 0.55 / 0.35 common: 0.25 / 0.15 / 0.05 frequently: 0.10 / 0.05 / 0.00					

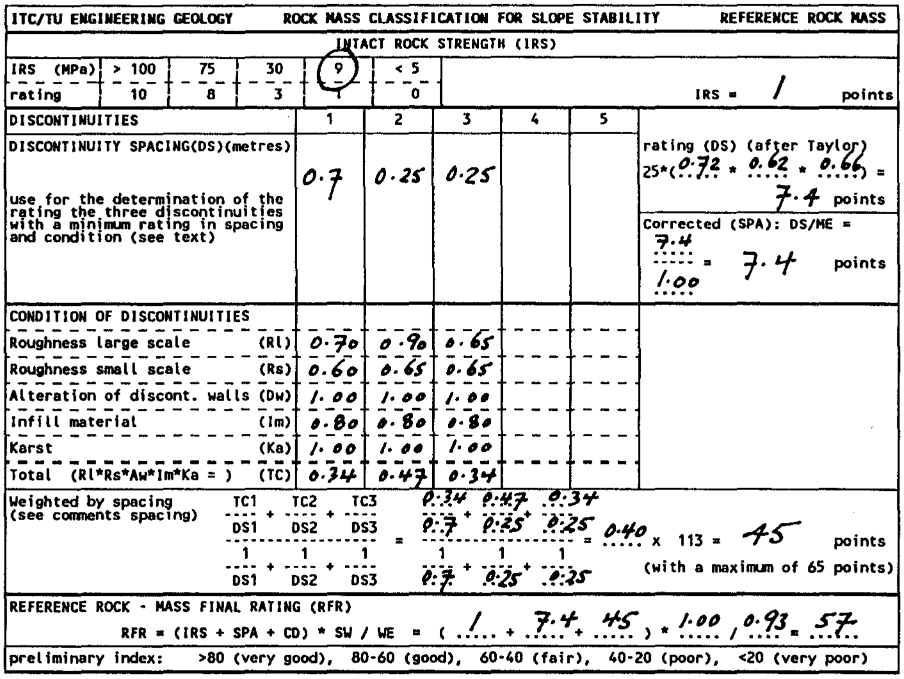
WEATHERING (WE) (at observation point)
(tick)
un-weathered:1.00
slightly :0.93
moderately :0.87
highly :0.80
completely :0.74

SUSCEPTIBILITY (SW)TO WEATHERING
(tick)
1 year :0.05
5 year :0.25
10 year :0.50
50 year :0.90
> 50 year :1.00

sample no:

EXISTING SLOPE ?
dip-direction/dip
/
height: (m)
permanent water (seepage)
yes / no
Stability ?(tick)
1 stable
2 small problems in near future
3 large problems in near future
4 small problems
5 large problems

Figure 2: Slope classification field form.



ITC/TU ENGINEERING GEOLOGY	ROCK MASS CLASSIFICATION FOR SLOPE STABILITY	REFERENCE ROCK MASS

INTACT ROCK STRENGTH (IRS)

IRS (MPa)	> 100	75	30	[✓ 9]	< 5
rating	10	8	3	1	0

IRS = 1 points

DISCONTINUITIES	1	2	3	4	5
DISCONTINUITY SPACING(DS)(metres) use for the determination of the rating the three discontinuities with a minimum rating in spacing and condition (see text)	0.7	0.25	0.25		
CONDITION OF DISCONTINUITIES					
Roughness large scale (Rl)	0.70	0.90	0.65		
Roughness small scale (Rs)	0.60	0.65	0.65		
Alteration of discont. walls (Dw)	1.00	1.00	1.00		
Infill material (Im)	0.80	0.80	0.80		
Karst (Ka)	1.00	1.00	1.00		
Total (Rl*Rs*Aw*Im*Ka =) (TC)	0.34	0.47	0.34		

rating (DS) (after Taylor) 25*(0.72 * 0.62 * 0.66) = 7.4 points

Corrected (SPA): DS/ME = $\frac{7.4}{1.00}$ = 7.4 points

Weighted by spacing (see comments spacing)

$$\frac{\frac{TC1}{DS1}+\frac{TC2}{DS2}+\frac{TC3}{DS3}}{\frac{1}{DS1}+\frac{1}{DS2}+\frac{1}{DS3}} = \frac{\frac{0.34}{0.7}+\frac{0.47}{0.25}+\frac{0.34}{0.25}}{\frac{1}{0.7}+\frac{1}{0.25}+\frac{1}{0.25}} = 0.40 \times 113 = 45 \text{ points}$$

(with a maximum of 65 points)

REFERENCE ROCK - MASS FINAL RATING (RFR)

RFR = (IRS + SPA + CD) * SW / WE = (1 + 7.4 + 45) * 1.00 / 0.93 = 57

preliminary index: >80 (very good), 80-60 (good), 60-40 (fair), 40-20 (poor), <20 (very poor)

Figure 3: Reference rock mass calculation form.

most prominent discontinuity set or the discontinuity set with the most adverse influence on the stability of an underground excavation. This was found to be too simple for slopes, for failure is often not determined by one main discontinuity set but by multiple sets, as in wedge failure. The condition rating has therefore been taken as the mean value of the condition rating for those three discontinuity sets, weighted inversely against the spacing, which give the worst rating.

Method of excavation

The method of excavation is treated as a local feature which has influenced the rock mass at a particular location and is not a rock mass constant (Laubscher, 1990, Romana, 1985).

The greatest influence of the method of excavation will be on the spacing of discontinuities. Blasting may create fractures in intact rock material, widen existing mechanical discontinuities and open integral discontinuities to become mechanical. Blasted slopes may thus have closer discontinuity spacings than natural slopes. The differentiation of rock masses into the classes 'not blasted' and 'blasted' (with the sub-class good and poor blasting) as proposed by Laubscher (1990) and Romana (1985) was found to be too simple. Some more classes, recognisable in the field, have been included (fig.2). The method of excavation is not likely to influence the intact rock strength and has not been found to significantly influence the factors used to assess the condition of discontinuities.

Weathering and susceptibility to weathering

The state of weathering is considered to be a local feature which has changed the rock mass at a particular location. It is presently described using the British Standards descriptive system (BS 5930, 1981). The susceptibility to weathering is a factor related to the time it will take for the rock mass to weather one class down in the British Standard table for rock mass weathering.

Reference rock mass rating

The intact rock strength, spacing factor and the condition of discontinuities are considered rock mass parameters which have at a particular location been influenced by weathering while the discontinuity spacing has been influenced by the method of excavation. In the calculation to produce the end rating for the 'reference rock mass' the discontinuity spacing (DS) is divided by a method of excavation factor (ME) to compensate for excavation disturbance which thence gives a discontinuity spacing rating (SPA).

The sum of the intact rock strength (IRS), discontinuity spacing (SPA) and discontinuity condition (CD) ratings, multiplied by the sensitivity to weathering rating (SW), is divided by the observed weathering rating (WE) to give the reference rock mass rating (RFR). Ratings etc. are given in fig. 2; an example calculation is given in fig.3.

RFR values have been found to vary from about zero up to 80. While low rated rock masses might be expected to give more problems than high rated masses, the rating is not directly related to the stability of any new slope in the rock mass, for this will depend on slope orientation.

4.2 Slope stability assessment

The space limitations to this paper preclude a detailed description of the calculations required to assess the stability of any proposed slope to be excavated in the reference rock mass. However, the essential elements of this calculation include:

1. A comparison between the orientation of the proposed slope with that of the observed discontinuities, relative to the dimensions of the slope.
2. A modification of the discontinuity spacing rating to allow for the anticipated method of excavation.
3. An allowance for the weathered condition of the rock mass into which the slope will be cut.
4. An allowance for the development of weathering in the cut slope after excavation.

It is generally recognised that the persistence of discontinuities is important in slope stability. In most classification systems the persistence is only taken into account as a qualitative rather than a quantitative factor. For the slope stability system it was found that persistence could have such a large influence on stability that a qualitative factor was not suitable but that an explicit factor had to be formulated. Persistence is recorded on the field form, but is, for the moment, only brought into play in the slope stability assessment. The persistence factor modifies discontinuity condition (CD) in the calculation, being used to increase slope shear strength for less persistent discontinuities.
The final slope stability rating (SSR) is assessed by the formula:

$$SSR = (AIRS + ASPA + ACD) * AWA * SLO * SW \quad (1)$$

where AIRS is the adjusted intact rock strength, ASPA is the adjusted discontinuity spacing and ACD the adjusted discontinuity condition rating. AWA is factor relating to any possible permanent water flow through the rock slope, SLO is a correction factor for slope orientation and dip related to the orientation of discontinuities.

5 PRELIMINARY RESULTS

So far 140 rock slopes have been classified, generally from 5 to 15 m high but ranging up to 50 m, and representing a large variety of rock types excavated by various means. Mostly the stability assessment has been made on the slopes already existing. SSR ratings range from about zero to about 80 and have been compared with either visual or calculated assessments of stability. A comparison between rating and stability is given in fig.4, in which minor and major future problems are those which are anticipated to occur within about 10 years. Minor present problems imply minor rock falls; major present problems implies immediate danger from major instability.

6 DISCUSSION AND CONCLUSIONS

The major limitation of the system is that single features, such as faults or shear zones, are not incorporated in the system but have to be dealt with separately.

Experience has shown that the slope classification system loses its validity for slopes with dips of less than 35°. This is not a major problem for most slopes in hard rock will be stable at dips of less than 35°.

An advantage of the system is that it gives the option to define rock mass geotechnical units which have within the unit the same geotechnical characteristics, independent of local weathering and the method of excavation. The slope classification system, compared to block theory,

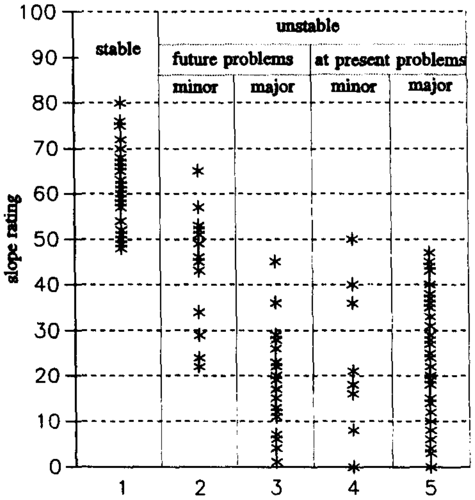


Figure 4: Slope rating vs. visually anticipated stability.

kinematic analyses and various slope classification systems, also gives a stability assessment in cases where the discontinuities are not the main source of failure, but where, for example, buckling of small blocks or susceptibility to weathering causes (in time) failure of the slope.

The system is in development. The authors have assembled data from 140 slopes and will gather more data. This is stored in dBase III; using a normal PC about 200 classifications can be calculated in less than 2 minutes. No doubt the system will be modified from that herein described to better assess slope stability.

The system involves fairly complicated calculations, and, in comparison with other rock mass classification systems, is more elaborate in structure and calculation. However, this is not likely to be a draw-back of the system in a time where computers are widely available both for office and field use.

The system is suitable to be incorporated into a GIS environment. The parameters can be interpolated independently and final rock mass ratings can be calculated at given locations.

Due to space limitations it is not possible to give all details of the classification system in this article. Interested readers are encouraged to contact the authors for more detail.

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