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SMR Geomechanics classification: Application, experience and validation

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The SMR geomechanics classification system (adaptation of RMR for slopes) is reviewed with data from 87 actual slopes in Valencia. In a research project, SMR has been applied by a GIS system, as a method to forecast stability problems in future road construction. As a result of this work a methodology for GIS application has been developed.

On revient sur la classification geomechanique SMR (une adaptation du RMR pour talus et pentes) avec les dates de 87 talus existant autour de Valencia. Dans le cadre d'un projet de recherche SMR a été appliquée, avec un système GIS, comme méthode de prévision de stabilité problèmes dans la construction de futures routes. Une méthodologie pour l'application du GIS a été développe.

Das Geomechanische Einteilungssystem SMR (eine Anpassung des RMR an Böschungen) wird an Hand der Daten von 87 Böschungen im Gebiet von Valencia überdacht. In einem Forschungsprojekt wurde das SMR in einem Geographischen Informationssystem (GIS) als Methode zur Vorhersage von Stabilitätsproblemen bei zukünftigen Straßenbauprojekten eingesetzt. Das Ergebnis dieser Arbeit ist die Entwicklung einer Methodologie für die GIS-Anwendung

Introduction

RMR "Rock Mass Rating" geomechanics classification (also called CSIR) was introduced and developed by BIENIAWSKI (1973, 1984, 1989) deal extensively with RMR (and other geomechanics classification systems). A good recent reference to RMR application to tunnels in BIENIAWSKI (1993). RMR has become a standard for use in tunnels and many professionals apply it to describe any rock mass. ORR (1996) has given a good overview of the RMR use in slopes. LAUBSCHER (1976), HALL (1985) and ORR (1992) proposed different relationships between RMR value and limit angle for slopes. STEFFEN (1978) classified 35 slopes and concluded that "results had a statistical trend". ROBERTSON (1988) established that when RMR > 40 the slope stability is governed both by orientation and shear strength of discontinuities whereas for RMR < 30 the failure develops across the rock mass.

In the 1976 version, the "rating adjustments for discontinuity orientation" for slopes were: very favourable 0, favourable – 5, fair –25, unfavourable –50, very unfavourable –50, very unfavourable –60. No guidelines have been published for the definition of each class. A mistake in this value can supersede by far any careful evaluation of the rock mass, and classification work becomes both difficult and arbitrary. ROMANA (1985, 1993, 1995) proposed a new addenda to RMR concept, specially suited to slopes. BIENIAWSKI (1989) has endorsed the method.

SMR Classification system

The "Slope Mass Rating" (SMR) is obtained from RMR by adding a factorial adjustment factor depending on the relative orientation of joints and slope and another adjustment factor depending on the method of excavation.

$$SMR = RMR_B + (F_1 \times F_2 \times F_3) + F_4$$

The RMR_B (see Table 1) is computed according Bieniawski´s1979 proposal, adding rating values for five parameters: (i) strength of intact rock; (ii) RQD; (iii) spacing of discontinuities; (iv) condition of discontinuities; and (v) water inflow through discontinuities and/or pore pressure ratio.

The adjustment rating for joints (see Table 2) is the product of three factors as follows:

(i) F_1 depends on parallelism between joints and slope face strike. Its range is from 1.00 to 0.15. These values match the relationship: $F_1 = (1 - \sin A)^2$ where A denotes the angle between the strikes of slope face and joints.

(ii) F_2 refers to joint dip angle in the planar mode of failure. Its value varies from 1.00 to 0.15, and match the relationship: $F_2 = tg^2 B_j$ denotes the joint dip angle. For the toppling mode of failure F_2 remains 1.00.

(iii) F_3 reflects the relationship between slope and joints dips. Bieniawski´s 1976 figures have been kept (all are negative).

(iv) F_4 (adjustment factor for the method of excavation has been fixed empirically.

Table 3 shows the different stability classes. The empirically found limit values of SMR for the different failure modes are listed in Table 4. All slopes with SMR values below 20 fail very quickly. No slopes have been registered with SMR value below 10. Many different remedial measures can be taken to support a unstable slope. The study of a potentially unstable rock slope is a difficult task requiring careful field work, detailed analysis and good engineering sense in order to understand the relative importance of the several instability factors acting on the slope. No classification system can replace all that work. However, they may be of some utility indicating the normal limits of use for each class of support measures (see Table 5). The choice between them is out of the scope of the classification system. The support measures can be grouped in six different classes:

(i) No support	None. Scaling
(ii) Protection	Toe ditches. Fences. Nets
(iii) Reinforcement	Bolts. Anchors
(iv) Concreting	Shotcrete. Concrete. Ribs. Walls
(v) Drainage	Surface. Deep. Adits.
(v) Reexcavation	

Normally no support measures are needed for slopes with SMR values of 75-100. There are some stable slopes with SMR values of 65. No totally reexcavated slope has been found with SMR over 30.

Validation

Many authors have published case records and checking of SMR classification applied to actual slopes in different countries: Brazil, Greece, India, Italy, Korea, Mexico, Spain (see Table 6 for references)

ZUYU (1995) has adapted SMR to the Chinese local conditions with two additional factors for height of slope (if higher than 80 m) and for conditions of joints. The system, called CSMR (Chinese Slope Mass Rating) has become “a national standard for slopes” to be used in design and construction of dams and hydroelectric power stations.

Most of the authors deal with cases, covering one or several actual slopes. SMR concepts has been used in three different ways: a) as a geomechanics classification, b) taking F_1, F_2, F_3 as a risk parameter (generally in natural slopes) and c) as a complementary method of work. Most of the authors agree that: 1) SMR geomechanics classification is slightly conservative, 2) the extreme values of F_3 proposed by Bieniawski (-50, -60) are something difficult to cope with, 3) failure modes proposed by SMR do occur, in practice, 4) excavation method is important (and inclusion of factor F_4 is justified). 5) classification of slopes with berms is difficult and 6) SMR classification system does not take account of slope height. The last two conclusions are a drawback of the classification. In soil-like materials (and in some soft rocks) the SMR classification can give misleading results (when the failure is almost circular and classification uses joints properties as parameter). Probably some correction should be added for the block size (relative to slope height).

A systematic validation process has been done by the Geotechnic Engineering Department of the Polytechnic University of Valencia. Jorda & Romana (1997) (with reference in Jorda et al, 1999), studied 57 big road and railway slopes near Valencia, with heights between 10 and 65 m and aged between several months and more than 100 years. As these slopes are placed in operating roads and railways, all are fully or partially stable (class II and/or III). For each slope: SMR value and actual state were compared. In more than 80% of the cases both values were almost coincident. Maximum difference in 55 cases was 5 points (in the limit of the field estimation normal error). There is a tendency to the calculated values being slightly minor than the observed ones, a conservative trend that is perhaps partially due to the existence in the sample of “young” slopes which can develop instabilities with time. When comparing the SMR proposed support methods with the observed ones there is a general coincidence with some differences: shotcrete appears in more cases than proposed and some slopes have no support with SMR values of 50, well below the SMR value of 65 proposed as a limit by the SMR classification.

In the GISLYT research project other 30 slopes (in roads and railways) were evaluated. The range of heights was 30-40 m and age was from several months to more than 150 years old (railway slopes). 24 from 30 slopes are in the same stability class and 15 from 30 are in the same stability subclass. Again observed behaviour is slightly better than predicted one.

Application of SMR by a GIS system

A joint Spanish research project (5 Universities and 2 Technologic Institutes) have dealt with application of Geographic Information System (GIS) to the forecast of stability problems in natural and excavated slopes, in soils and rocks. For rocks the SMR was chosen as instability predictor. The aim was to establish thematic maps of the geomechanics properties of the rock masses in order to be able to estimate the stability conditions in future slopes, to be excavated along new communication lines, or in isolated cases (pits, housing developments…).

Work was done in a 1:10.000/1:5.000 scale, covering two major and several local roads and two railways. The terrain was composed of (from Cretacic to Quaternary) limestone, sandstones, conglomerates, alluvial, beach deposits and miscellaneous fills. Topographic data were obtained from a “terrain digital model” and field data were gathered in 69 field stations. The more than 20.000 geomechanics parameters obtained were “regionalised” (neither interpolation nor extrapolation was convenient) in three groups of properties: rock´s, joints and water. Criteria for designs of “regions” were lithology, tectonic style, morphology, topography, climate and biotope. Values for each parameter were assigned statistically in each area (means – or mode – in the centre and extrapolation in the limit, buffer zones) obtaining 5 “thematic” maps.

The basic RMR was obtained from the “thematic” maps and checked with the field observations. Buffer correction has been done for special zones, like faults, rifts and scarps. The SMR index can be generated in three different ways: for the natural slopes, along one orientation or for a slope

Table 1 RMR_B= BASIC RMR = Σ RATINGS (BIENIAWSKI, 1979)

PARAMETER	INTERVALS						
UCS (MPa) UNCONFINED COMPRESSIVE STRENGTH OF INTACT ROCK MATERIAL	*<250*	*250-100*	*100-50*	*50-25*	*<25*		
					25-5	*5-1*	*<1*
	15	*12*	*7*	*4*	*2*	*1*	*0*
RQD (%) ROCK QUALITY DESIGNATION	*100-90*	*90-75*	*75-50*	*50-25*	*<25*		
	20	*17*	*13*	*8*	*3*		
SPACING (mm) BETWEEN DISCONTINUITIES	*>2000*	*2000-600*	*600-200*	*200-60*	*<60*		
	20	*15*	*10*	*8*	*5*		
CONDITION OF DISCONTINUITIES ROUGHNESS, PERSISTENCE, SEPARATION, WEATHERING OF WALLS AND GOUGE	*VERY ROUGH SURFACES NO SEPARATION UNWEATHERED WALL ROCK NOT CONTINUOUS*	*SLIGHTLY ROUGH SEPARATION < 1 mm SLIGHTLY WEATH. WALLS NOT CONTINUOUS*	*SLIGHTLY ROUGH SEPARATION < 1 mm HIGHLY WEATH. WALLS*	*SLICKENSIDED WALLS Or GOUGE < 5 mm Or SEPARATION1-5 mm*	*SOFT GOUGE >5 mm or SEPARATION >5 mm CONTINUOUS*		
	30	*25*	*20*	*10*	*0*		
GROUNDWATER IN JOINTS (PORE PRESSURE RATIO)	*COMPLETELY DRY (0)*	*DAMP (0-0.1)*	*WET (0.1-0.2)*	*DRIPPING (0.2-0.5)*	*FLOWING (0.5)*		
	15	*10*	*7*	*4*	*0*		

Table 2 $SMR = RMR_B + (F_1 \text{ x } F_2 \text{ x } F_3) + F_4$ (ROMANA, 1985)

ADJUSTING FACTORS FOR JOINTS (F_1, F_2, F_3)	***αj = DIP DIRECTION OF JOINT*** ***αs =DIP DIRECTION OF SLOPE***	***βj = DIP OF JOINT*** ***βs = DIP OF SLOPE***			
	VERY FAVOURABLE	*FAVOURABLE*	*FAIR*	UNFAVOURABLE	*VERY UNFAVOURABLE*
PLANE FAILURE $\lvert\alpha j-\alpha s\rvert$ = TOPPLING $\lvert\alpha j-\alpha s-180^\circ\rvert$ =	*> 30º*	*30º - 20º*	*20º - 10º*	*10º - 5º*	*< 5º*
F_1 VALUE	*0.15*	*0.40*	*0.70*	*0.85*	*1.00*
RELATIONSHIP	**$F_1 = (1- \mathrm{sIn}\, \lvert\alpha_j-\alpha_s\rvert)^2$**				
$\lvert\beta j\rvert$ =	*< 20 º*	*20º-30º*	*30º-35º*	*35º-45º*	*>45º*
F_2 VALUE PLANE FAILURE	*0.15*	*0.40*	*0.70*	*0.85*	*1.00*
F_2 VALUE *TOPPLING*	*1.00*				
RELATIONSHIP	**$F_2 = tg^2\, \beta j$**				
PLANE FAILURE $\beta j-\beta s$ =	*>10º*	*10º-0º*	*0º*	*0º-(-10º)*	*<(-10º)*
TOPPLING $\beta j+\beta s$ =	*< 110º*	*110º-120º*	*>120º*	*-*	*-*
F_3 VALUE	*0*	*-6*	*-25*	*-50*	*-60*
RELATIONSHIP	**F_3 (BIENIAWSKI ADJUSTMENT RATINGS FOR JOINTS ORIENTATION, 1976)**				
F_4 ADJUSTING FACTOR FOR EXCAVATION METHOD	**F_4 = EMPIRICAL VALUES FOR METHOD OF EXCAVATION**				
	NATURAL SLOPE	*PRESPLITTING*	*SMOOTH BLASTING*	*BLASTING or MECHANICAL*	*DEFICIENT BLASTING*
F_4 VALUE	*+15*	*+10*	*+8*	*0*	*-8*

Table 3 DESCRIPTION OF SMR CLASSES

CLASS Nº	*Vb*	*Va*	*IVb*	*IVa*	*IIIb*	*IIIa*	*IIb*	*IIa*	*Ib*	*Ia*
DESCRIPTION	*VERY BAD*		BAD		*FAIR*		*GOOD*		*VERY GOOD*	
STABILITY	COMPLETELY UNSTABLE		*UNSTABLE*		*PARTIALLY STABLE*		*STABLE*		*COMPLETELY UNSTABLE*	
FAILURES	*BIG PLANAR or SOIL-LIKE*		*PLANAR or BIG WEDGES*		*SOME JOINTS or MANY WEDGES*		*SOME BLOCKS*		*NONE*	
SUPPORT	REEXCAVATION		*IMPORTANT / CORRECTIVE*		*SYSTEMATIC*		*OCCASIONAL*		*NONE*	

Table 4 PROBABLE FAILURES ACCORDING SMR VALUES

PLANE FAILURE			VERY BIG			*MAJOR*				*NONE*						
WEDGE FAILURE						*MANY*			*SOME*				*VERY FEW*		*NONE*	
TOPPLING					*MAJOR*			*MINOR*			*NONE*					
MASS FAILURE		POSSIBLE				NONE										
SMR →	*0*	*10*	*15*	*20*	*30*	*40*	*45*	*50*	*55*	*60*	*65*	*70*	*75*	*80*	*90*	*100*
REEXCAVATIÓN		*REEXCAVATIÓN WALLS*														
DRAINAGE		*SURFACE DRAINAGE* *DEEP DRAINAGE*														
CONCRETE				*SHOTCRETE* *DENTAL CONCRETE* *RIBS and/or BEAMS* *TOE WALLS*												
REINFORCEMENT					*BOLTS* *ANCHORS*											
PROTECTION							*TOE DITCH* *TOE or SLOPE FENCES* *NETS*									
NO SUPPORT											*SCALING* *NONE*					

Table 5 SUGGESTED SUPPORT METHODS

Table 6. Some selected references on SMR

Country	Reference	Year
Spain	Collado & Gili	1988
Spain	Romana & Izquierdo	1988
India	Anbalagan	1991
Greece	Tsimbaos & Telli	1991
Greece	Angelidis et al	1992
Spain	Chacon et al	1992
Spain	Salueña & Corominas	1992
Mexico	Ayala & Aguirre	1994
Italy	Budetta et al	1994
Brazil	Nonato & Gripp	1994
México	Padilla	1994
Korea	Hyun-Koe et al	1995
USA	Mehrotra et al	1995
China	Zuyu Chen	1995
Italy	Eusebio et al	1996
India	Sharma et al	1996
Spain	Calderón & Gonzalez	1997
Spain	Jordá & Romana	1997
Italy	Calcaterra et al	1998
Spain	Jordá et al	1999
France	El Sáyeb & Verdel	1999
Italy	Ronzani et al	1999
Spain	Irigaray et al	2000
Spain	Romana et al	2001
Spain	Seron et al	2001

References can be provided by mromana@stmr.com

with prefixed orientation. The adjusting factor F_1, F_2, F_3 can be obtained from the "terrain digital model" and mapped. Also the product F_1 x F_2 x F_3 can be mapped (Irigaray et al, 2000; Ronzari et al, 1999). Model validation was done comparing the actual results in a field station with the results generated by a model, in which this station was not included. Table 7 shows validation results suppressing one station each time.

Table 7. Validation of RMR results suppressing one station

Station	Field value	Model value	RMR
A 16	66	69.56	+3.56
A 20	64	70.27	+6.27
A 21	67	67.81	+0.81
T 20	72	70.30	-1.70
T 21	72	71.10	-0.90

In the area one highway slope was unstable (class IV) during construction requiring massive support. The model detected the problem from neighbours field stations. Therefore it is possible to use GIS systems to get regional values for RMR and SMR, but an important field work is necessary. The product of correction factor F_1 x F_2 x F_3 can be regionalised with less fieldwork and gives an excellent indication of slopes stability risk.

Final remark

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