This document was published in ISRM Congress 2015 Proceedings - Int'l Symposium on Rock Mechanics - ISBN: 978-1-926872-25-4 and has to be cited as:
Romana, M., Tomás, R., Serón, J.B. (2015). Slope Mass Rating (SMR) geomechanics classification: thirty years review. ISRM Congress 2015 Proceedings - International Symposium on Rock Mechanics, Quebec, Canada, May 10 to 13 2015. ISBN: 978-1-926872-25-4, 10 pp.

SLOPE MASS RATING (SMR) GEOMECHANICS CLASSIFICATION: THIRTY YEARS REVIEW

* M. Romana
Valencia Technical University
*(*Corresponding author: mromana@stmr.es)*

R. Tomás
University of Alicante
Alicante, Spain

J. B. Serón
Valencia Technical University
Valencia, Spain

This document was published in ISRM Congress 2015 Proceedings - Int'l Symposium on Rock Mechanics - ISBN: 978-1-926872-25-4 and has to be cited as:
Romana, M., Tomás, R., Serón, J.B. (2015). Slope Mass Rating (SMR) geomechanics classification: thirty years review. ISRM Congress 2015 Proceedings - International Symposium on Rock Mechanics, Quebec, Canada, May 10 to 13 2015. ISBN: 978-1-926872-25-4, 10 pp.

SLOPE MASS RATING (SMR) GEOMECHANICS CLASSIFICATION: THIRTY YEARS REVIEW

ABSTRACT

The Slope Mass Rating (SMR; Romana, 1985) geomechanics classification was developed as a sequel of Bieniawski's Rock Mass Rating (RMR) system, which was almost impossible to use in slopes due to the extreme range of the correction factors (up to 60 points of a maximum of 100) and to the lack of definition of them. A detailed quantitative definition of the correction factors is one of the advantages of SMR classification. During the last thirty years the use of SMR system has been extended to many countries from the five continents and, thus, it is time to review the most interesting developments. Both RMR and SMR are discrete classifications, depending on the values adopted by the variables that control the parameters. This can cause major changes in the parameters value due to small differences in the variables value, with changes in the final rock mass assigned quality. On the other hand, geomechanics quality indexes are extremely biased. To avoid this problem, some authors have proposed continuous functions for SMR. This classification has been also adapted for its application in heterogeneous and anisotropic rock masses, for high slopes, for is application trough stereographic projection and Geographical Information Systems, has been used as susceptibility rockfall parameters and has been included in the technical regulations of several countries. Additionally, some open access computer tools have been developed for the computation of SMR. Consequently, this paper reviews: 1) the most important modifications and adaptations of slope classifications which derive directly from SMR; 2) the use of SMR throughout the world; 3) many significant papers on slopes analysed with SMR all over the world; and 4) future trends in the use of SMR.

KEYWORDS

Slope Mass Rating (SMR), Rock Mass Rating (RMR), Slopes, Slope stability, Slope support, Geomechanics classification

INTRODUCTION

Rock mass classifications are a universal communication system for engineers which provide quantitative data and guidelines for engineering purposes that can improve originally abstract descriptions of rock mass from inherent and structural parameters (Pantelidis, 2009) by simple arithmetic algorithms. The main advantage of rock mass classifications is that they are a simple and effective way of representing rock mass quality and of encapsulating precedent practice (Harrison and Hudson, 2000). Some of the existing geomechanical classifications for slopes are Rock Mass Rating (RMR, Bieniawski, 1976; 1989), Rock Mass Strength (RMS, Selby, 1980), Slope Mass Rating (SMR, Romana, 1985), Slope Rock Mass Rating (SRMR, Robertson, 1988), Chinese Slope Mass Rating (CSMR, Chen, 1995), Natural Slope Methodology (NSM, Shuk, 1994), Slope Stability Probability Classification (SSPC, Hack, 1998), modified Slope Stability Probability Classification (SSPC modified, Lindsay *et al*., 2001), Continuous Rock Mass Rating (Sen and Sadagah; 2003), Continuous Slope Mass Rating (Tomás et al., 2007), Fuzzy Slope Mass Rating (FSMR; Daftaribesheli *et al*., 2011) and Graphical Slope Mass Rating (GSMR; Tomás *et al*., 2012). Some of the above mentioned geomechaniccs classifications are variants from the original ones. SMR is universally used (Romana *et al*., 2003). SMR is computed from basic RMR (Bieniawski, 1989) which was originally proposed for tunnelling but also included a correction factor for slopes to take into account the influence of discontinuities orientation on the slope stability which was almost impossible to be used due to the extreme range of the correction factors (up to 60 points of a maximum of 100) and to the lack of definition of them in practice. In this paper a review of the last thirty years of the SMR is performed, discussing its main modifications, adaptations and applications worldwide.

THE ORIGINAL SMR CLASSIFICATION

Slope Mass Rating (SMR; Romana, 1985) is calculated using four correction factors of basic RMR (Bieniawski, 1989). These factors depend on the existing relationship between discontinuities affecting the rock mass and the slope, and the slope excavation method. It is obtained using expression (1):

$$SMR = RMR_b + (F_1 \times F_2 \times F_3) + F_4 \qquad (1)$$

where:

- RMR_b is the basic RMR index resulting from Bieniawski's rock mass classification;
- F_1 depends on the parallelism (A in Table 1) between discontinuity dip direction, α_j, and slope dip, α_s, (Table 1);
- F_2 is related to the probability of discontinuity shear strength (Romana, 1993) and depends on the discontinuity dip, $B=\beta_j$, in the case of planar failure (Table 1). For toppling failure, this parameter adopts the value 1.0.
- F_3 depends on the relationship (C in Table 1) between slope, β_s, and discontinuity, β_j, dips (Table 1). This parameter is the original Bieniawski adjustment factor (from 0 to -60 points) and expresses the probability of the discontinuity to outcrop on the slope face (Romana, 1993) for planar failure.
- F_4 is a correction factor that depends on the excavation method (Table 2).

Table 1. Correction parameters for SMR (Romana, 1985).

Type of failure			Very favourable	Favourable	Normal	Unfavourable	Very unfavourable
P	A =	$\lvert \alpha_j-\alpha_s \rvert$	>30º	30-20º	20-10º	10-5º	<5º
T		$\lvert \alpha_j-\alpha_s-180 \rvert$					
P/T	F_1		0.15	0.40	0.70	0.85	1.00
P	B =	β_j	<20º	20-30º	30-35º	35-45º	>45º
P	F_2		0.15	0.40	0.70	0.85	1.00
T			1.00				
P	C =	$\beta_j-\beta_s$	>10º	10-0º	0º	0-(-10º)	<(-10º)
T		$\beta_j+\beta_s$	<110º	110-120º	>120º	-	-
P/T	F_3		0	-6	-25	-50	-60

FAILURE: P planar; T toppling. DIP DIRECTION: α_j discontinuity; α_s slope. DIP: β_j discontinuity ; β_s: slope .

Table 2. Values corresponding to the factor F_4 (Romana, 1985).

Excavation method (F_4)			
Presplitting	+10	Blasting or mechanical	0
Smooth blasting	+8	Natural slope	+15
Natural slope	+15		

Alternatively to the values shown in Table 1, Romana (1993) proposed the following continuous function for computation of F_1 and F_2:

$$F_1 = (1\text{-sen } \lvert A \rvert)^2 \qquad (2)$$

$$F_2 = \tan^2 B \qquad (3)$$

This document was published in ISRM Congress 2015 Proceedings - Int'l Symposium on Rock Mechanics - ISBN: 978-1-926872-25-4 and has to be cited as:
Romana, M., Tomás, R., Serón, J.B. (2015). Slope Mass Rating (SMR) geomechanics classification: thirty years review. ISRM Congress 2015 Proceedings - International Symposium on Rock Mechanics, Quebec, Canada, May 10 to 13 2015. ISBN: 978-1-926872-25-4, 10 pp.

where A is the parallelism between discontinuity and slope strikes and B is the discontinuity dip (β_j).

Table 3 shows the different stability classes and the empirically found limit values of SMR associated to the different failure modes. Field experience indicates that slopes with a SMR values lower than 20 fail very quick and that no slopes with SMR value below 10 are possible. Romana (1985) also proposed some guidelines for the use of remedial measures based on SMR (Figure 1). Although the design of remedial measurements of a slope requires a detailed field work and good engineering sense, these recommendations provides a first approximation during the first preliminary stages of a project. Normally no support measures are needed for slopes with SMR values of 75-100. Even, some stable slopes have been found with SMR values of 65. Additionally, no totally reexcavated slope has been found with SMR over 30.

Table 3. Description of SMR classes (Romana, 1985).

Classes →	V	IV	III	II	I
SMR	0-20	21-40	41-60	61-80	81-100
Description	Very bad	Bad	Normal	Good	Very good
Stability	Completely unstable	Unstable	Partially stable	Stable	Completely stable
Failures	Big planar or soil-like	Planar or big wedges	Some joints or many wedges	Some blocks	None
Failure probability	0.9	0.6	0.4	0.2	0

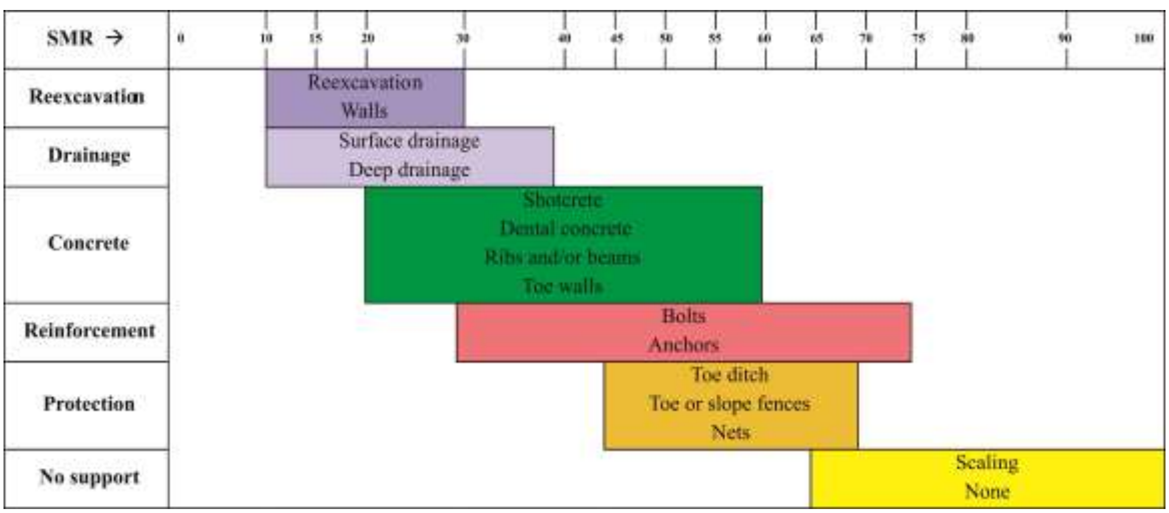

Figure 1. Slope support guidelines based on SMR (Romana, 1985).

SMR ADAPTATIONS

Since the publication of SMR in 1985, many authors have modified or adapted the SMR to their needs, modifying the methodology or the considered parameters. In next subsections, the most important adaptations, modifications, developments and applications of SMR during the last three decades are described.

Continuous functions

Tomás *et al*. (2007) proposed asymptotical continuous functions for F_1, F_2 and F_3 correction factors (Table 4) which show maximum absolute differences against original discrete functions smaller than 7 points, significantly reducing subjective interpretations in the assignation of the score to values near the border of the intervals of the discrete classification. These functions are very useful to be implemented into computer routines for SMR calculus (e.g. Riquelme *et al*., 2014a) and on Geographical Information Systems, GIS (e.g. Filipello *et al.* 2015). Roghanchi *et al*. (2013) proposed new continuous curve charts based on the fuzzy expression of F_1, F_2 and F_3, also for computing SMR.

Table 4. Continuous functions proposed by Tomás *et al.* (2007) for computing F_1, F_2 and F_3. A: parallelism between the discontinuity and the slope strikes; B: discontinuity dip, β_j; C: discontinuity and slope dip relationship.

Parameter	Planar	Toppling
F_1	$F_1 = \frac{16}{25} - \frac{3}{500}\operatorname{atan}\left(\frac{1}{10}(\lvert A\rvert - 17)\right)$ (4)	
F_2	$F_2 = \frac{9}{16} + \frac{1}{195}\operatorname{atan}(\frac{17}{100}B - 5)$ (5)	$F_2 = 1$
F_3	$F_3 = -30 + \frac{1}{3}\operatorname{atan}C$ (6)	$F_3 = -13 - \frac{1}{7}\operatorname{atan}(C - 120)$ (7)

Chinese Slope Mass Rating

Slope Mass Rating was adapted for application to high slopes by means of next expression (CSMR; Chen, 1995):

$$CSMR = E \times RMR_b + L \times (F_1 \times F_2 \times F_3) + F_4 \quad (8)$$

$$E = 0.43 + 0.57 \times (80/H) \quad (9)$$

Where H is the slope height (meters) and L considers the state of the discontinuities in the slope.

Graphical approach

Tomás *et al*. (2012a) developed a graphical method based on the stereographic representation of the discontinuities and the slope to obtain the correction parameters of the SMR (F_1, F_2 and F_3). In this approach, the SMR correction parameters are computed representing the discontinuity sets on stereographical projection and superimposing them to the proposed stereoplots, which are rotated to match both, the slope and the stereoplot dip directions. Successively, the numerical values of the correction parameters are directly obtained from stereoplots, determining the position of the discontinuity pole (for planar and toppling failure modes). The main advantages of this approach are (Tomás *et al*., 2012a): a) to perform quick calculations of the correction parameters of SMR in cases where all the slopes have the same dip with different dip direction (as in linear infrastructures trenches and open pit mining); b) the possibility of working with all discontinuities poles in order to determine the distribution of scores of the correction parameters to select the most appropriate values (e.g. minimum value).

Others approaches and tools

Besides the above described adaptations of SMR, other new uses of this classification have been performed. A novel approach consists on the application of fuzzy theory for the application of SMR. Daftaribesheli *et al*. (2011) applied fuzzy set theory to SMR classification for evaluating rock slope stability of an open pit mine. Their proposed approach, which provided satisfactory results on the assessment of the studied mining slopes, is named Fuzzy Slope Mass Rating (FSMR). Ambalagan *et al*. (1992) suggested an adaptation of the SMR for wedge failure mode. They proposed to compute the geometric relationships between the discontinuity and the slope for calculating the values originally proposed by Romana using the intersection line of the two planes from the wedge. Perri (1994) introduced the effect of anisotropy by means of a factor (f) multiplying the second term from eq. (1) varying between 0 and 1. f is computed from the shear parameters from the discontinuities (c' and ϕ') and the rock (c and ϕ). Runqiu and Yuchuan (2005) developed a specific modification of SMR for mountain highways similar to that proposed by Chen (1995). These authors correct SMR considering the height of the slope, the lithologies outcropping on the slope and the structural plane conditions (i.e. the type of discontinuity: joint, bedding plane or fault). Rahim *et al*. (2009; 2012) proposed the Modified Slope Mass Rating (M-SMR) for its use in heterogeneous formations composed of alternations of different lithologies. This is a modification in terms of parameters calculation and determination methods. Another important approach of SMR consists on the use of SMR original or modified parameters as a susceptibility parameter (e.g. Anbalagan, 1992; Cano and Tomás, 2013). Budetta (2004) incorporated SMR for hazard evaluation to the well-known Rock Hazards Rating System (RHRS) originally developed by Pierson *et al*. (1990) for the assessment of rockfall risk along roads. Additionally, SMR has been widely applied for mapping rock slope susceptibility by means of GIS developing new modules and using different approaches (e.g. Irigaray *et al*., 2003; Filipello *et al*., 2010; Yilmaz *et al*., 2012).

Riquelme *et al*. (2014a) have published, in open access format, a calculator programmed into MS Excel for calculating the coefficients F_1, F_2 and F_3 from the dip vectors of the slope (azimuth and dip) and the discontinuity (or the intersection line of planes in the case of wedge failure) called SMRTool. This routine automatically calculates auxiliary angles A, B and C (see Table 1) as well as the type of failure (wedge, planar or toppling) compatible with the geometry of the case study and provides the original (Romana, 1985) and continuous (Tomás *et al.*, 2007) SMR values, also including the class description, the stability and the modes of failure and system of support recommended by Romana (1993).

SMR VALIDATION

SMR has been worldwide used during last thirty years (Figure 1) in the following ways: a) as a geomechanics classification for rating rocky slopes; b) considering F_1, F_2, F_3 as parameters to quantify the effect of the discontinuities on the stability of the slope; c) as a complement to other methods; and d) as a preliminary and complementary method of work.

The widely application of SMR has allowed to identify some common issues (Romana *et al*., *2003*): 1) SMR geomechanics classification is slightly conservative; 2) the extreme values of F_3 proposed by Bieniawski (i.e. -50 and -60 points) are something difficult to cope with; 3) failure modes derived from SMR occur in practice; 4) excavation method has a high influence on the stability of the slope and thus its inclusion is justified; 5) the classification of slopes with berms presents practical difficulties; and 6) SMR classification system does not take into account the slope height which is very relevant for high slopes.

Tomás *et al*. (2012b) explored, analysed and visualized the relationship of the main parameters controlling SMR (i.e. RMR_b, the parallelism between the slope and the discontinuity (A), β_j and β_j) through the Worlds within Worlds method concluding that SMR is insensitive to the geometrical conditions of the slope and the rock mass for an important amount of possible discontinuity-slope geometries for which SMR is approximately equal to RMR_b+F_4. These particular cases are those in which: a) slopes affected by planar failures with β_s lower than β_j, A value (parallelism) higher than 30º, or β_j values lower than 20º in which SMR can be computed with a maximum error lower than nine points only correcting basic RMR by the excavation method, F_4. b) slopes affected by toppling failures with A value (parallelism) higher than 30º, or a $\beta_j + \beta_s$ relationship lower than or equal to 120º in which SMR can be computed with a maximum error lower than six points only correcting basic RMR by the excavation method, F_4.

This document was published in ISRM Congress 2015 Proceedings - Int'l Symposium on Rock Mechanics - ISBN: 978-1-926872-25-4 and has to be cited as:
Romana, M., Tomás, R., Serón, J.B. (2015). Slope Mass Rating (SMR) geomechanics classification: thirty years review. ISRM Congress 2015 Proceedings - International Symposium on Rock Mechanics, Quebec, Canada, May 10 to 13 2015. ISBN: 978-1-926872-25-4, 10 pp.

WORLDWIDE USE OF SMR: EXPERIENCES OF USE OF SMR

Since the presentation of SMR in 1985, it is common to find scientific, technical and educational books focused on rock mechanics or rock slope stability (e.g. Hudson and Harrison, 1997; Singh and Göel, 1999) including a specific chapter or section devoted to this classification. Additionally, nowadays, SMR is included in most of the educational programs of technical studies in Civil, Geological or Mining Engineering (e.g. Spain, India, Taiwan, etc.). SMR has been also included in the technical regulations of some countries as a classification by itself or as a quality index of the rocky slopes (e.g. India, Serbia, Italy, etc.). Currently, there are evidences of use of this index on more than 50 countries from the five continents. It has been profusely used in Asia (e.g. China and India), where its use is very common and, as previously mentioned, has been incorporated to some technical regulations.

Figure 2 summarizes the countries in which there are evidences of the use of SMR or of some adaptations derived from it.

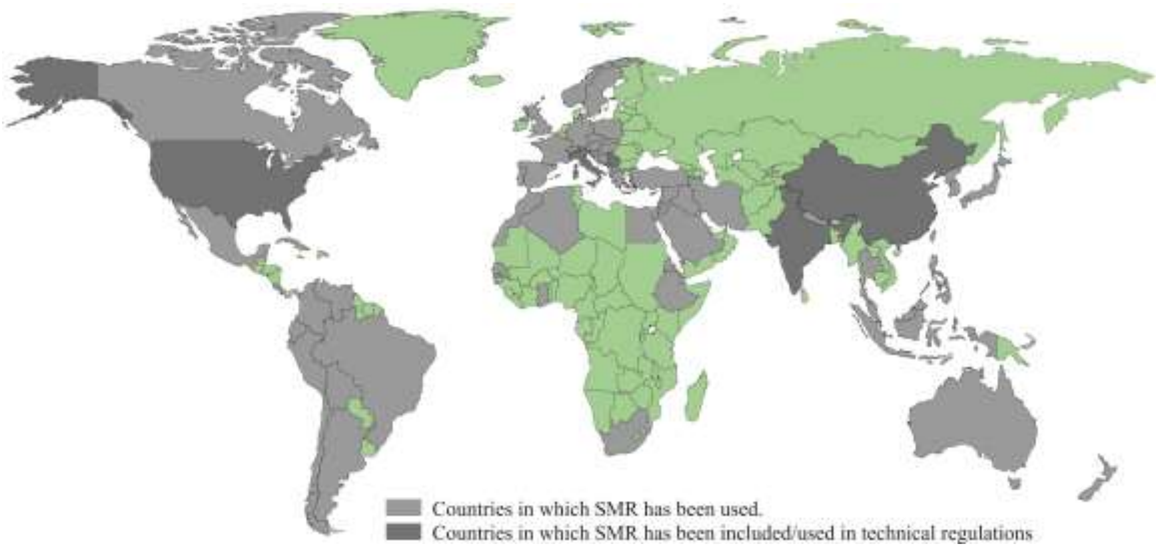

Figure 2. Countries in which there are evidences of use of SMR.

FUTURE TRENDS

The development of new remote sensing technologies for obtaining geomechanical parameters from the rock mass has risen during the last years. New photogrammetric techniques (e.g. Structure from Motion) and Light Detection and Ranging (LiDAR) allow the acquisition of precise 3D point clouds from the slopes which can be exploited for obtaining some parameters used in the application of SMR as discontinuities and slope orientations (dip and strike) in an automatic or semiautomatic way (e.g. Lato *et al*. 2009; Gigli and Casagli, 2011; Riquelme *et al*., 2014b; Alameda, 2014). Consequently, the information derived from these techniques may be used for evaluating the quality of the rock slope trough SMR in an automatic or semi-automatic way (e.g. Filipello *et al*., 2010; 2015; Alameda, 2014).

CONCLUDING REMARKS

Since the presentation of Slope Mass Rating in 1985 in the ISRM conference in Zacatecas (Mexico) it has been profusely and successfully used. The detailed quantitative definition of the correction factors is probably one of the most important advantages of SMR classification. Currently, there are evidences of use of this index on the five continents and on a high number of countries, some of which even have incorporated SMR in their technical regulations.

SMR has been broadly modified for different purposes and applications. The adaptation of SMR to high slopes, to heterogeneous or anisotropic rock masses, the modification of the discrete original functions into continuous functions and the graphical approach, are some of the proposed variations of SMR. SMR has been also spatially applied by means of Geographical Information Systems as a tool for mapping slope quality over wide areas. Some proposed methodologies even use SMR parameters for quantifying the rock fall susceptibility. In the future, the structural data derived from remote sensing techniques as photogrammetry and LiDAR may allow the automatic or semi-automatic computation of SMR.

As a conclusion, the extensive use of SMR during last thirty years has allowed the accumulation of a vast experience which has allowed to confirm the usefulness of Slope Mass Rating for the study of rocky slopes and the acceptance and recognition of this index by the international scientific and technological community.

REFERENCES

Alameda, P. (2014). *Aplicación de nuevas metodologías de adquisición de datos para el análisis de estabilidad de taludes: casos de estudio en materiales foliados de la Cordillera Bética*. PhD Thesis. In Spanish.

Anbalagan, R., 1992. *Landslide hazard evaluation and zonation mapping in mountainous terrain*. Engineering Geology 32, 269-277.

Anbalagan R, Sharma S, Raghuvanshi TK. 1992. *Rock Mass Stability Evaluation Using Modified SMR Approach*. In: Proceedings of the 6th National Symposium on Rock Mechanics. p. 258-268.

Bieniawski, Z.T., 1976. *Rock mass classification in rock engineering*, in: Bieniawski, Z.T. (Ed.), Exploration for rock engineering, Proceedings of the Symposium Expl. Rock Engineering, Johannesburg, pp. 97-106.

Bieniawski, Z.T., 1989. *Engineering Rock Mass Classification*. Wiley, Chichester, 251 pp.

Budetta, P., 2004. *Assessment of rockfall risk along roads*. Nat. Hazards Earth Syst. Sci. 4, 71-81.

Cano, M., Tomás, R., 2013. *Characterization of the instability mechanisms affecting slopes on carbonatic Flysch: Alicante (SE Spain), case study*. Engineering Geology 156, 68-91.

Chen, Z., 1995. *Recent developments in slope Stability Analysis*. Keynote lecture, in: Fujii, T. (Ed), Proc. 8th Int. Cong. Rock Mech., vol. 3, pp. 1041-1048.

Daftaribesheli, A., Ataei, M., Sereshki, F., 2011. *Assessment of rock slope stability using the Fuzzy Slope Mass Rating (FSMR) system*. Applied Soft Computing 11, 4465-4473.

Filipello, A., A., G., G., M., 2010. *Rock slopes failure susceptibility analysis: from remote sensing measurements to geographic information system raster modules*. American Journal of Environmental Sciences 6, 489-494.

Filipello, A., Mandrone, G., Bornaz, L., 2015. *Structural Data Treatment to Define Rockfall Susceptibility Using Long Range Laser Scanner*, in: Lollino, G., Giordan, D., Thuro, K., Carranza-Torres, C., Wu, F., Marinos, P., Delgado, C. (Eds.), Engineering Geology for Society and Territory - Volume 6. Springer International Publishing, pp. 721-724.

Gigli, G., Casagli, N. 2011.*Semi-automatic extraction of rock mass structural data from high resolution LIDAR point clouds*. Int. J. Rock Mech.Min.Sci.48, 187–198.

Hack, R., Price, D., Rengers, N.A., 2003. *A new approach to rock slope stability - a probability classification (SSPC)*. B. Eng. Geol. Environ. 62, 167-184.

Harrison, J.P., Hudson, J.A., 2000. *Engineering Rock Mechanics: Illustrative Worked Examples*, Elsevier Science, Oxford. 530 pp.

Hudson, J.A., Harrison, J.P., 1997. *Engineering rock mechanics: an introduction to the principles*. Pergamon Press, Amsterdam. pp. 444.

Irigaray, C., Fernández, T., Chacón, J., 2003. *Preliminary Rock-Slope-Susceptibility Assessment Using GIS and the SMR Classification*. Natural Hazards 30, 309-324.

Lato, M., Diederichs, M.S., Hutchinson, D.J., Harrap, R., 2009. *Optimization of LiDAR scanning and processing for automated structural evaluation of discontinuities in rock masses*. Int. J. Rock Mech. Min. Sci. 46, 194–199.

Lindsay, P., Campbell, R.N., Fergusson, D.A., Gillard, G.R., Moore, T.A., 2001. *Slope stability probability classification*, Waikato Coal Measures, New Zeland. Int. J. Coal Geol. 45, 127-145.

Pantelidis, L., 2009. *Rock slope stability assessment through rock mass classification systems*. Int. J. Rock. Mech. Min. 46, 315-325.

Perri, G., 1994. *Una extensión de la metodología de Bieniawski-Romana para estimar la estabilidad de taludes en rocas*. I Simposio Panamericano de Deslizamientos de tierra. Guayaquil - Ecuador, 01 al 05 Agosto de 1994. (in Spanish).

Pierson, L.A., Davis, S.A. and Van Vickle, R. 1990. *Rockfall Hazard Rating System Implementation Manual*. Federal Highway Administration (FHWA) Report FHWA-OR—EG-90-01. FHWA, U.S. Department of Transportation.

Rahim, I.A., Tahir, S.H., Musta, B., 2009. *Modified Slope Mass Rating (M-SMR) system: A classification scheme of interbedded Crocker Formation in Kota Kinabalu, Sabah, Malaysia*. Proceeding of the 8th Seminar on Science and Technology 2009 (S&T2009), 18-19 December 2009, Shangri-La's Rasa Ria Resort, Pantai Dalit, Tuaran.

Rahim, I.A., Tahir, S.H., Musta, B., Omang, S.A.K., 2012. *Adjustment factor for Slope Mass Rating (SMR) system: Revisited*. Proceeding of National Geoscience Conference 2012 (NGC2012), 22-23 Jun 2012, Hotel Pullman, Kuching, Sarawak.

Riquelme, A., Tomás, R. & Abellán A., 2014a. *SMRTool beta. A calculator for determining Slope Mass Rating (SMR)*. Universidad de Alicante. Website: http://personal.ua.es/en/ariquelme/smrtool.html (07/05/2014). License: Creative Commons BY-NC-SA.

Riquelme, A.J., Abellán, A., Tomás, R., Jaboyedoff, M., 2014b. *A new approach for semi-automatic rock mass joints recognition from 3D point clouds*. Computers & Geosciences 68, 38-52.

Robertson A.M., 1988. *Estimating weak rock strength*, in: Sastry, K.V.S. (Ed.), Proceedings of the SME Annual meeting, Society of Mining Engineering, Phoenix, pp. 1-5.

Roghanchi, P., Kallu, R. & Thareja, R., 2013. A New Expression of Three Adjustment Factors of Slope Mass Rating Classification International Journal of Earth Sciences and Engineering 6, 404-410.

Romana M., 1985. *New adjustment ratings for application of Bieniawski classification to slopes*, in: Proceedings of the International Symposium on the Role of Rock Mechanics in Excavations for Mining and Civil Works. International Society of Rock Mechanics, Zacatecas, pp. 49-53.

Romana, M., 1993. *SMR classification*: Romana, M Proc 7th ISRM International Congress on Rock Mechanics, Aachen, 16-20 September 1991V2, P955-960. Publ Rotterdam: A A Balkema, 1991. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts 30, A231-A231.

Romana M., Serón J.B., Montalar, E., 2003. *SMR Geomechanics classification: Application, experience and validation*, in: Merwe, J.N. (Ed.), Proceedings of the 10th Congress of the International Society for rock mechanics, ISRM 2003–Technology roadmap for rock mechanics, South African Institute of Mining and Metallurgy, pp. 1-4.

Runqiu, H., Yuchuan, S., 2005. Classification of Rock Mass Rating Stability in Mountain Highway Slope Geoline 2005, Lyon, France, 23-25 May 2005.

Selby, M.J., 1980. *A rock mass strength classification for geomorphic purposes: with test from Antarctica and New Zeland*. Zeitschrifts für Geomorphologie 24, 31-51.

Shuk, T., 1994. *Key elements and applications of the natural slope methodology (NSM) with some emphasis on slope stability aspects*, in: Proceedings of the 4th South American Congress on Rock Mechanics 2, ISRM, Balkema, Rotterdam, 955-960.

Singh B., Göel R.K., 1999. *Rock Mass Classification. A Practical Approach in Civil Engineering.* Ámsterdam: Elsevier.

Tomás, R., Delgado, J. & Serón, J.B., 2007. *Modification of slope mass rating (SMR) by continuous functions*. International Journal of Rock Mechanics and Mining Sciences 44, 1062-1069.

Tomás, R., Cuenca, A., Cano, M. & García-Barba, J. 2012a. A graphical approach for slope mass rating (SMR). Engineering Geology 124, 67-76.

Tomás, R., Valdes-Abellan, J., Tenza-Abril, A.J., Cano, M., 2012b. *New insight into the slope mass rating geomechanical classification through four-dimensional visualization*. International Journal of Rock Mechanics and Mining Sciences 53, 64-69.

Ünal, E., 1996. *Modified rock mass classification: M-RMR system*, in: Bieniawski, Z.T., Milestones in rock engineering, The Bieniawski Jubilee Collection, Balkema, pp. 203-223.

Yilmaz, I., Marschalko, M., Yildirim, M., Dereli, E., Bednarik, M., 2012. *GIS-based kinematic slope instability and slope mass rating (SMR) maps: application to a railway route in Sivas (Turkey)*. Bulletin of Engineering Geology and the Environment 71, 351-357.