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An Application of the GIS in the Engineering Classification of Rock Masses

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ABSTRACT. A comparison is made of the application of two major systems or rock mass characterization, namely Rock Mass Rating (RMR) and Rock Mass Quality (Q system). The two systems used to classify the rock masses of Jabal Setarah, a mountain in the Al-Baha area within the Arabian Shield. Geographic Information System (GIS) technique was used utilizing the RMR and Q systems to produce rock mass zonation maps. The studied mountain is composed of coarse grained quartz syenite. The RMR and Q systems were calculated and compared using field measurements. A logical agreement was found between the obtained GIS maps of the two rock mass rating systems. Some discrepancy was observed which might be related to the application of the rating systems in an arid region although these systems are designed for humid regions. The rock quality, engineering properties and the mountain size suggest that suitability of the mountain to be quarried for dimension stone. In addition the Slope Mass Rating (SMR) system was used to calculate the slope stability of the quarry. The SMR system results were compared with the conventional method of slope stability analysis and two maps were produced using GIS. The two GIS maps of SMR system and the conventional method were found to have good agreement.

Introduction

Rock mass classification for engineering purposes include description and grouping of intact rock and discontinuities. The rock mass rating (RMR) and the Q are quick systems to evaluate the rock mass properties which are more difficult to assess and provide direct guidance for engineering design. The conventional way is to calculate the rock mass value based on RMR or Q parameters for some scattered points and classify the rocks using specified tables in each point. Since the rock mass rating for the entire area surrounding the measured points is not known, the points having the same values are grouped together in a map. The boundary that separates each group is subjective and depends on personal judgment. The major achievement of this research is that it extends rock characterization and its applications from limited field measurements into an entire area. Another advantage is that it simplifies the calculation and classification and the resulting maps can be easily retrieved with great precision. The improvement was achieved in two stages: a) by producing a map showing the spatial distribution of the individual engineering parameter, and b) by superimposing the different maps that represent the engineering parameters to calculate the rock mass rating based on RMR or Q systems.

Rock mass classification was originally developed for tunnel, but it can be also applied to surface excavation, mining and various aspects of engineering geology. It is proposed to excavate a hypothetical tunnel across the mountain in the E-W direction. The ultimate purpose of using GIS in this research is to provide support for making a decision on the best location of the tunnel alignment across the mountain based on spatial data. GIS technique was applied in various fields of earth sciences (Belward and Valenzuela, 1991, Bonham-Carter, 1994, Peuquet and Marble, 1990, and Krumm *et al*., 1991). But no attempts were made to apply it in rock mass classification. Rock mass classification was applied in a relatively small mountain known as Jabal Al Setarah, 150 km south east of Al Taif and 50 km north east of Al Baha city (Fig. 1). The site was chosen because it is ideal for this type of application, made up of one rock type, and completely isolated from the surrounded mountains. The parameters in the two systems were measured along ten profiles across the mountain. The RMR was extended to slope stability analysis using Slope Mass Rating (SMR) (Romana, 1985).

Geology

The studied area is located in the south western part of the Arabian Shield that extends in western Saudi Arabia along the Red Sea and ranges in width from 150 km to 680 km (Fig. 1). The rocks in the Arabian Shield are mainly igneous and meta-volcanics of Precambrian age in addition to sedimentary rocks of Cambrian age (Brown *et al*., 1989). The rocks in the surrounding area belong to Ablah group (750-835 m.y.). It was deposited during a second sequence of andesitic volcanism in the form of coarse clastic sedimentation (Greenwood, 1975). The rocks are composed of basal sedimentary volcanic units (Rafa and Jerup formations) and an upper sedimentary units (Thurat Formation). The Rafa

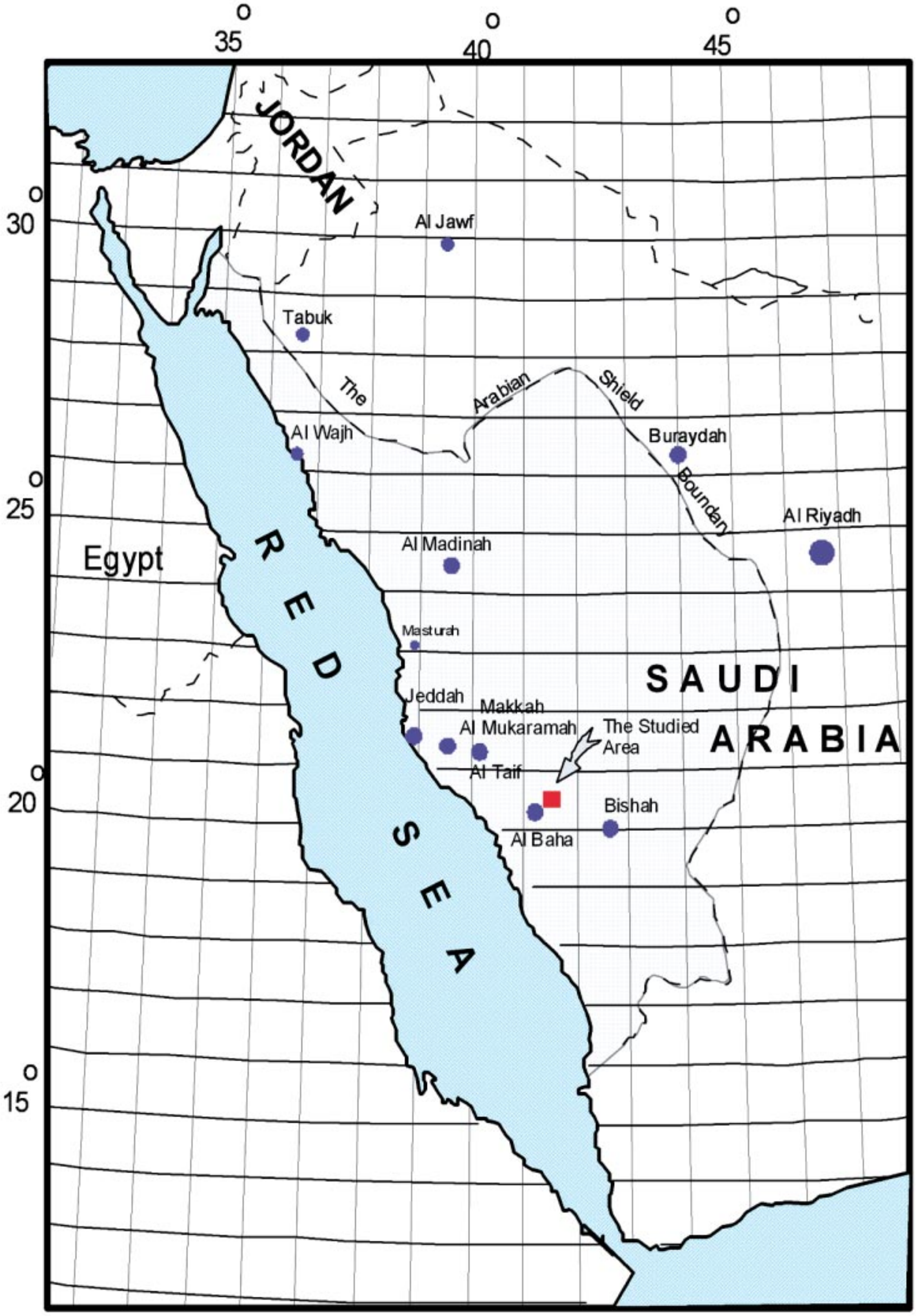

FIG. 1. Location map of the studied area.

formation rests with angular unconformity upon rocks of Jeddah group. The unit lies unconformably on isoclinally folded rocks of the Jeddah group and contains amygdalloidal greenstone cobbles in basal conglomerate. Jerup formation consists of andesite, rhyolite flow rocks and pyroclastic rocks deposits, that contain clastic and marble layer. Thurat formation consists of coarse red to brown arkosic wacky, and locally contain gravel channel deposits. The coarse grained size, cross bedding and thick boulder conglomerate suggest that the rocks are of continental origin. The unit is metamorphosed to the lower green schist facies and slip cleavage is well developed in finer grained sedimentary rocks. The area was affected by Ranyah orogeny, which is part of Hijaz tectonic cycle and Najd faulting system. The rocks were intruded by diorite series.

Al Setarah is a small elongated inselberg, 1300 m long, 150 to 300 m wide and could reach a height of 60 m (Fig. 2-a). The rock surface is smooth, fractured and faulted in some parts (Fig. 2-b). Other parts are exfoliated and form isolated large boulders (about 100 m^3). It is composed of coarse grained quartz syenite with brownish pink weathered surfaces.

Rock Mass Classification

Classification, in general, is defined as the arrangement of objects into groups on the basis of their relationship. The rock mass classification systems are based on the most predominant design approach, which is the empirical approach. The first rock mass classification system was proposed by Terzaghi in 1946 for tunneling with steel support. Numerous other schemes have been proposed but the widely used are the RMR and the Q systems. They produce a description of the rock mass in the form of classes. The RMR value provides five such quality classes and the Q system provides nine.

The RMR system

The rock mass rating (RMR) was proposed by Bieniawski during the period 1972-1973 (Bieniawski, 1973), and subjected to several modifications with more case histories (Bieniawski, 1989, 1993). This classification was devised to guide judgment through standardized procedures and description and provide a proper and simple systematic design aid. It is based on the following six parameters that can be measured in the field or obtained from borehole data:

a) Uniaxial compressive strength
b) Rock quality designation
c) Spacing of discontinuities
d) Groundwater conditions
e) Condition of discontinuities

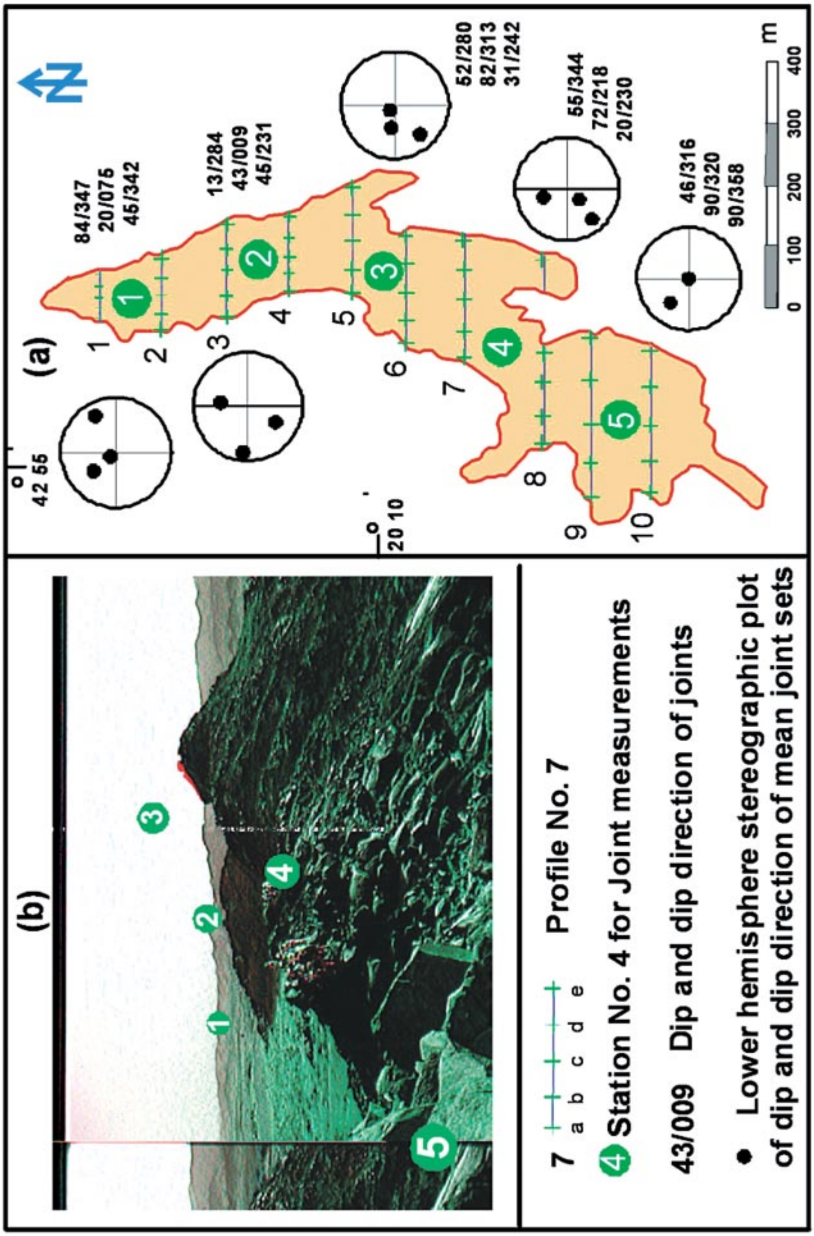

FIG. 2. The outline and a top view of Al Setarah mountain showing the measured profiles and the stations for joint measurements.

f) Orientation of discontinuities

In order to apply this method, the rock mass is divided into a number of structural domains or zones. Each zone would be geologically similar and would show the same engineering properties. The six classification parameters for each zone are determined from the field measurements and entered onto the input data sheet. The rating of the first five parameters can be obtained from the specified table using the numeric value of that parameter. The rock mass rating (RMR) equals the summation of the individual rating contributed by the five parameters. The rock mass rating places the rock into one of the five categories with rock quality ranging from 0 to 100. A higher rating indicates a better rock mass condition. The sixth parameter is restricted to the influence of strike and dip orientation of the discontinuities. It is treated in a separate table depending on the engineering applications such as slope, foundation or tunnel. Unlike the other parameters, the value of the sixth parameter will be given by a qualitative terms such as favorable or unfavorable.

The Q system

The Q system is a quantitative classification that was proposed by Barton *et al*. (1974) based on numerous tunnel case histories. It utilizes three factor: a) the size of the joint blocks, b) the shear strength of the block surface, and c) the environmental conditions influencing the behavior of rock mass. Each factor is made up of two parameters. The first factor represents the overall structure of the rock mass and its numerical value equals the RQD divided by the number of joint sets (J_n). The second factor is an indicator of the interblock shear strength of the joints given by joint roughness (J_r) divided by the wall rock condition and/or filling material (J_a). The function $\tan^{-1}(Jr/Ja)$ represents the rock friction angle. The third factor is the active stress and is equal to the water pressure (J_w) divided by the total stress condition (SRF). The overall rock mass quality (Q) is obtained by multiplying the above mentioned factors (equation 1):

$$Q = (RQD / J_n) \times (J_r / J_a) \times (J_w / SRF) \qquad (1)$$

The range of Q values extend from 0.001 to 1000, a wide range that covers the whole spectrum of rock mass qualities.

Slope Stability

Stability in a rock slope is determined by the combined levels of natural and induced instability in the host rock mass. It is usually assessed by the tedious conventional method that involves plotting the poles to slope on a stereonet (Hoek and Bray, 1977, and Matheson, 1983). The poles are then grouped and contoured and the representative of each group is evaluated in term of the proposed design slopes. A relatively new and simple method for assessing slope stability is the SMR system proposed by Romana (1993). It is a significant extension to the RMR system, where the RMR-values (RMR_{BASIC}) was numerically adjusted by subtracting the newly proposed adjustment factor for discontinuity orientation ($F_1xF_2xF_3$), and adding a new adjustment factor for method of excavation (F_4). The SMR value is given by the form:

$$SMR\ (RMR_{SLOPE}) = RMR_{BASIC} - (F_1xF_2xF_3) + F_4 \qquad (2)$$

where:

- F_1 associated with parallelism between the slope and the discontinuity strike direction;
- F_2 related to the discontinuity dip for plane failure;
- F_3 concerning the slope angle compared to the discontinuity dip angle.
- F_4 related to the excavation method

The SMR is simple to be used and have the capability to change the assumptions for the slope face and iterate the calculation. Table (1) shows the numerical values of the required factors to adjust RMR_{BASIC} to RMR_{SLOPE}, together with the SMR classes.

TABLE 1. The SMR rating system (from Romana, 1985 and Bieniawaski, 1989).

Case		Very favorable	Favorable	Fair	Unfavorable	Very unfavorable
P	$\|\alpha_j - \alpha_s\|$	> 30º	30º – 20º	20º – 10º	10º – 5º	< 5
T	$\|\alpha_j - \alpha_s - 180\|$					
P/T	F_1	0.15	0.40	0.70	0.85	1.00
P	$\|\beta_j\|$	< 20º	20º – 30º	30º – 35º	35º – 45º	> 45º
T	F_2	0.15	0.40	0.70	0.85	1.0
T	F_2	1	1	1	1	1.0
P	$\beta_j - \beta_s$	> 10º	10º to 0º	0º	0º to (– 10º)	≤ – 10º
T	$\beta_j - \beta_s$	> 110º	110º to 120º	> 120º		
P/T	F_3	0	– 6	– 25	– 50	– 60

P = plane failure α_s = slope dip direction α_j= joint dip direction
T = toppling failure β_s = slope dip β_j = joint dip

Table 1. Continued.

Method	Natural slope	Presplitting	Smooth blasting	Regular blasting	Deficient blasting
F_4	+15	+10	+8	0	–8
$SMR = F_1 \times F_2 \times F_3) + F_4$					
Tentative Description of SMR Classes					
Class No.	V	IV	III	II	I
SMR	0 - 20	21 - 40	41 - 60	61 - 80	81 - 100
Description	Very poor	Poor	Fair	Good	Very good
Stability	Very unstable	Unstable	Partially stable	Stable	Fully stable
Failures	Large planar or soil like	Planar or large wedges	Some joints or many wedges	Some blocks	None
Support	Re-excavation	Extensive corrective	Systematic	Occasional	None

The Field Measurements

The required field data for both RMR and Q were collected along ten profiles in order to divide the rock mass into zones of similar engineering behavior. Each profile was divided into five equally spaced station (Fig. 2-a), and projected on two separate maps. Eight engineering parameters required by both the RMR and Q systems were measured in every station (Tables 2 and 3). Each map shows the zonations of similar parameter values. The uniaxial compressive strength (UCS) of rock was estimated in the field by using the Schmidt hammer. The procedure of the International Society for Rock Mechanics was used to convert the measured R-values to UCS values (Anon, 1978). The UCS values were also supported by few measurements using the point load testing machine (Franklin *et al*. 1971, and Brook, 1977).

The dip and dip direction of the discontinuities were measured in five equally spaced stations at the crest of the mountain (Figure 2-a). A total of 100 readings were obtained in each station, and their analyses were used in the slope stability analysis. The tunnel walls stability was tested along the east-west direction and the slope face dips 80º toward the north or south.

The GIS Operations

A geographical information system (GIS) is a computer system which implies that the locations of the data items are known (Bonham-Carter, 1994). The GIS has a data management capabilities with accurate cartographic output. Data

TABLE 2. The measured parameters for the RMR system.

Profile and station	RMR										
	Strength		RQD		Joint spacing		Rating of joint condition	Ground-water	Rating	Zone Number	Rock mass classification
	MPa	Rating	%	Rating	cm	Rating					
1 – a	46	4	98	20	500	20	0	15	59	III	Fair
1 – b	82	7	84	17	22	10	10	15	49	III	Fair
1 – c	49	4	98	20	50	10	10	15	59	III	Fair
1 – d	71	7	98	20	33	10	10	15	62	II	Good
1 – e	75	7	98	20	250	20	10	15	72	II	Good
2 – a	45	4	98	20	33	10	10	15	59	III	Fair
2 – b	46	4	98	20	500	20	25	15	84	I	v. Good
2 – c	50	4	98	20	66	15	10	15	64	II	Good
2 – d	93	7	75	17	14	8	0	15	47	III	Fair
2 – e	77	7	98	20	250	20	10	15	72	II	Good
3 – a	45	4	98	20	10	10	0	15	49	III	Fair
3 – b	71	7	98	20	33	10	10	15	62	II	Good
3 – c	94	7	98	20	50	10	25	15	77	II	Good
3 – d	75	7	88	17	25	10	10	15	59	III	Fair
3 – e	73	7	98	20	50	10	10	15	62	II	Good
4 – a	76	7	98	20	200	15	10	15	67	II	Good
4 – b	73	7	98	20	140	15	0	15	57	III	Fair
4 – c	81	7	98	20	66	15	10	15	67	II	Good
4 – d	71	7	98	20	66	15	10	15	67	II	Good
4 – e	75	7	98	20	650	20	10	15	72	II	Good
5 – a	47	4	98	20	50	10	0	15	49	III	Fair
5 – b	44	4	98	20	140	15	10	15	64	II	Good
5 – c	46	4	98	20	250	20	10	15	69	II	Good
5 – d	46	4	98	20	250	20	0	15	59	III	Fair
5 – e	93	7	98	20	500	20	10	15	72	II	Good
6 – a	46	4	96	20	33	10	0	15	49	III	Fair

TABLE 2. Continued.

Profile and station	RMR										
	Strength		RQD		Joint spacing		Rating of joint condition	Ground-water	Rating	Zone Number	Rock mass classification
	MPa	Rating	%	Rating	cm	Rating					
6 – b	90	7	98	20	50	10	0	15	52	III	Fair
6 – c	72	7	98	20	50	10	10	15	62	II	Good
6 – d	73	7	98	20	100	15	10	15	67	II	Good
6 – e	74	7	98	20	330	20	0	15	62	II	Good
7 – a	49	4	95	20	33	10	0	15	49	III	Fair
7 – b	48	4	87	20	33	10	0	15	49	III	Fair
7 – c	45	4	98	20	66	15	0	15	54	III	Fair
7 – d	100	7	98	20	200	15	0	15	57	III	Fair
7 – e	79	7	98	20	200	15	10	15	57	III	Fair
8 – a	43	4	62	13	13	8	0	15	40	III	Fair
8 – b	45	4	64	13	14	8	10	15	50	III	Fair
8 – c	89	7	98	20	140	15	0	15	57	III	Fair
8 – d	46	4	98	20	66	15	0	15	54	III	Fair
8 – e	25	2	98	20	50	10	10	15	57	III	Fair
9 – a	47	4	98	20	33	10	10	15	59	III	Fair
9 – b	41	4	95	20	20	10	10	15	59	III	Fair
9 – c	45	4	95	20	33	10	0	15	49	III	Fair
9 – d	69	7	98	20	50	10	0	15	52	III	Fair
9 – e	67	7	98	20	66	15	10	15	67	II	Good
10-a	74	7	98	20	160	15	10	15	67	II	Good
10-b	46	4	98	20	100	15	10	15	64	II	Good
10-c	83	7	98	20	66	15	10	15	67	II	Good
10-d	47	4	98	20	50	10	0	15	49	III	Fair
10-e	38	4	98	20	50	10	0	15	49	III	Fair

TABLE 3. The measured parameters for the Q systems.

Profile and station	Q – Systems								
	RQD %	Joint set number (Jn)		Joint roughness number (Jr) Rating	Alteration (Ja)		SRF	Q	Class
		No.	Rating		mm	Rating			
1 – a	98	1 + r	2	2	10	0.75	2.5	52	Very Good
1 – b	84	3 + r	2	2	2	0.75	2.5	45	Good
1 – c	98	3 + r	2	2	3	0.75	2.5	52	Very Good
1 – d	98	3 + 4	2	2	2	0.75	2.5	52	Very Good
1 - e	98	3 + r	2	2	3	2	2.5	20	Good
2 – a	98	2 + r	3	3	2	0.75	2.5	52	Very Good
2 – b	98	1	2	2	1	0.75	2.5	52	Very Good
2 – c	98	3 + r	2	2	5	0.75	2.5	52	Very Good
2 – d	75	3 + r	3	3	3	0.75	2.5	40	Good
2 – e	98	3 + r	2	2	3	2	2.5	17.6	Good
3 – a	98	1	2	2	10	2	2.5	17.6	Good
3 – b	98	1	2	2	3	0.75	2.5	52	Very Good
3 – c	98	3 + r	12	2	1	0.75	2.5	9	Fair
3 – d	88	3 + r	12	2	2	0.75	2.5	7.8	Poor
3 – e	98	2 + r	6	2	2	0.75	2.5	17.6	Good
4 – a	98	3	9	2	3	0.75	2.5	11.8	Good
4 – b	98	3 + r	12	3	10	0.75	2.5	13.2	Good
4 – c	98	3 + r	12	2	2	0.75	2.5	8.8	Fair
4 – d	98	4 + r	15	2	2	0.75	2.5	6.9	Fair
4 – e	98	4 + r	15	2	4	2	2.5	2.5	Poor
5 – a	98	3 + r	12	3	10	0.75	2.5	13.2	Good
5 – b	98	3 + r	12	2	2	0.75	2.5	9	Fair
5 – c	98	3 + r	12	2	3	0.75	2.5	9	Fair
5 – d	98	4 + r	15	2	10	0.75	2.5	6.9	Fair
5 – e	98	3 + r	12	2	2	0.75	2.5	9	Fair

TABLE 3. Continued.

Profile and station	Q – Systems								
	RQD %	Joint set number (Jn)		Joint roughness number (Jr) Rating	Alteration (Ja)		SRF	Q	Class
		No.	Rating		mm	Rating			
6 – a	96	3 + r	12	2	10	0.75	2.5	9	Fair
6 – b	98	3 + r	12	2	10	0.75	2.5	9	Fair
6 – c	98	3 + r	12	2	5	0.75	2.5	9	Fair
6 – d	98	4 + r	15	1.5	3	0.75	2.5	5.4	Fair
6 – e	98	3 + r	12	1.5	10	1	2.5	5.4	Fair
7 – a	95	3 + r	12	3	10	7	2.5	1.5	Poor
7 – b	87	4 + r	15	3	10	7	2.5	1.0	Poor
7 – c	98	3 + r	12	1.5	10	7	2.5	0.5	Poor
7 – d	98	4 + r	15	1.5	10	3	2.5	1.5	Poor
7 – e	98	3 + r	12	3	3	0.75	2.5	13.2	Good
8 – a	62	3 + r	12	2	10	7	2.5	0.5	v. Poor
8 – b	64	3 + r	12	3	3	0.75	2.5	8.4	Fair
8 – c	98	4 + r	15	1.5	10	3	2.5	1.5	Poor
8 – d	98	3 + r	12	1.5	10	3	2.5	1.5	Poor
8 – e	98	4 + r	15	1.5	20	3	2.5	1.5	Poor
9 – a	98	2	4	3	5	0.75	2.5	40	Good
9 – b	95	2 + r	6	2	3	0.75	2.5	17.1	Good
9 – c	95	3 + r	12	3	10	7	2,5	1.4	v. Poor
9 – d	98	4 + r	15	2	10	7	2.5	1.0	v. Poor
9 – e	98	3 + r	12	3	5	0.75	2.5	13.2	Good
10 – a	98	3 + r	12	2	3	0.75	2.5	9	Fair
10 – b	98	3 + r	12	2	2	0.75	2.5	9	Fair
10 – c	98	3 + r	12	2	10	1	2.5	6.4	Fair
10 – d	98	3 + r	12	1.5	10	1	2.5	4.9	Poor
10 – e	98	3 + r	12	2	10	1	2.5	6.4	Fair

input include scanning and digitizing, and the common data structures are vector, raster and tabular. Vector means that point in a drawing is defined by pair of spatial coordinates. That lines are built up by a series of ordered points. Areas are represented by boundary lines, also held digitally as strings of connected points. A raster is a lattice of pixels (picture elements) in which the data is held digitally in a grid of cells (Dueker and Kjerne, 1989, Bonham-Carter, 1994). As a comparison with CAD (the Computer-Aided Drafting) or CAM (the Computer-Aided Mapping), the GIS possesses the analytical ability and keeps track of the spatial relationships among the pixels. A variety of GIS software tools are available. The one used in this study is IDRISI software, which is an easy to use microcomputer program. It gives the user a flexibility in drawing, editing, and producing maps in a short time. GIS applications must be preceded by base map preparation. The site map must be scanned and then digitized on-screen. Cartalinx program was implemented for data input. It uses a vector graphics model for the digital description of spatial data for each base map. The curved lines that represent the boundaries proceed in stream mode. They are built by a series of connected straight-line segments defined by vertices to form areas (polygons) representing the different values.

IDRISI software was applied to perform three operations: a) data management, b) data transformation, and c) map recoding. Digitization is part of data management in which the mountain boundary and the measured field data were captured from a scanned geological map of the site. Therefore, the digitized base maps for each parameter are exported to the GIS software as a coverage along with the attribute table recording the range of values for that parameter. The maps were converted from vector (points) into raster models (polygons) to perform the remaining operations. The field measurements were restricted to stations, the values in between were interpolated in each pixel by IDRISI as a raster model.

The GIS Results

When linear interpolation was applied first, the histograms show that the resulting interpolated values are continuous which contradict some field observations (Fig. 3). For example, if the RQD is 98% in one station and 64% in an adjacent station due to a fault (such as stations 8b and 8c, Table 3), GIS program will continuously assign gradual values ranging from 98% to 64% to the area in between (Fig. 3). The same argument applies for the joint set from station 3-b to 3-c, joint alteration from 7-c to 7-d, and joint condition from 2-a to 2-b (Tables 2 and 3). Some of the measured points were displaced in the obtained base maps or simply disappeared. As an alternative, interpolation was achieved using Thiessen method. It creates polygons about a set of irregularly

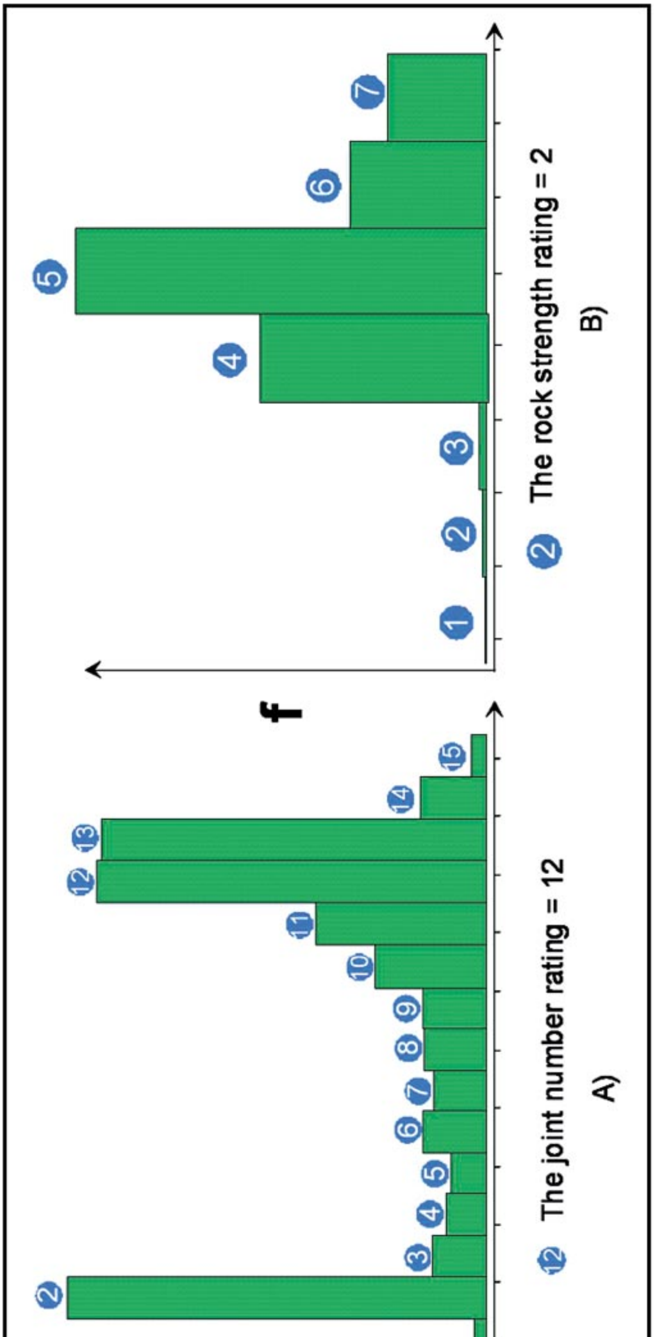

FIG. 3. The histogram of the distribution of: A) joint number (Jn), and B) rock strength values.

distributed points. The polygons are derived by drawing divisions exactly half-way between the original points such that each pixel is assigned to its nearest sources point. The degree of accuracy of Thiessen method was accepted since the original value of each parameter in the obtained base maps appeared in their correct locations and were grouped along with the interpolated values into polygons. They vary in spatial dimension with stepped boundary (Figs. 4 and 5).

Since the rock mass classification requires the combination of multiple data layers the produced base maps were subjected to sophisticated overlay operations. The polygons of a map for the first parameter, in this operation, are superimposed on the polygons of the next map of the second parameter. A new set of polygons common to both maps is produce. The same procedure is repeated to include the required parameters, which leads to a composite map.

The last operation involves maps recoding or reclassification, where classes are reassigned to reveal a new spatial pattern map. The final composite maps represent the rock mass classification for each system, and were prepared based on the individual engineering parameters in a form of raster files for each system. The boundary between the different rock mass ratings is based on standardized mathematical procedures to calculate the rock quality classes in each system (Figs. 6-a and b). This will fix the position of the boundary line between two given areas (polygons), and minimize human judgment and error related to boundary line which can not be checked by field inspection. It can be seen that the rock mass quality which ranges from very good to very poor is represented in both systems. Rock quality in the northern part of the mountain above profile (5) has better quality than the southern part.

As an application for the RMR, it is intended to investigate the appropriate and safe tunnel alignment across the mountain along lines; A-A", B-B", and C-C". Table 4 summarizes the direction of the selected lines and discontinuities that will affect the stability of the northern and southern tunnel walls in each location. The amount of dip of the slope face (tunnel wall) was assumed 80º for both walls and the rocks will be cut by regular blasting ($F_4 = 0$, Table 1). Table 5 shows the calculated discontinuities factors (F_1, F^2, and F_3). A sample of the SMR calculation is shown in Tables 6 for the selected locations based on SMR rating (Table 1). The overall evaluation of rock stability is classified as fully stable to poor where the lowest RMR were used for each rock class. As a result, the safest tunnel alignment is A-A" followed by C-C" while line B-B" is not safe. The southern wall in line A-A" is fully stable and requires no rock support. The degree of stability of the northern wall in line A-A" and southern wall in line C-C" are fair which implies that some wedge failure may occur. Large planar or wedge failure are expected along line B-B" due to its poor stability in both walls.

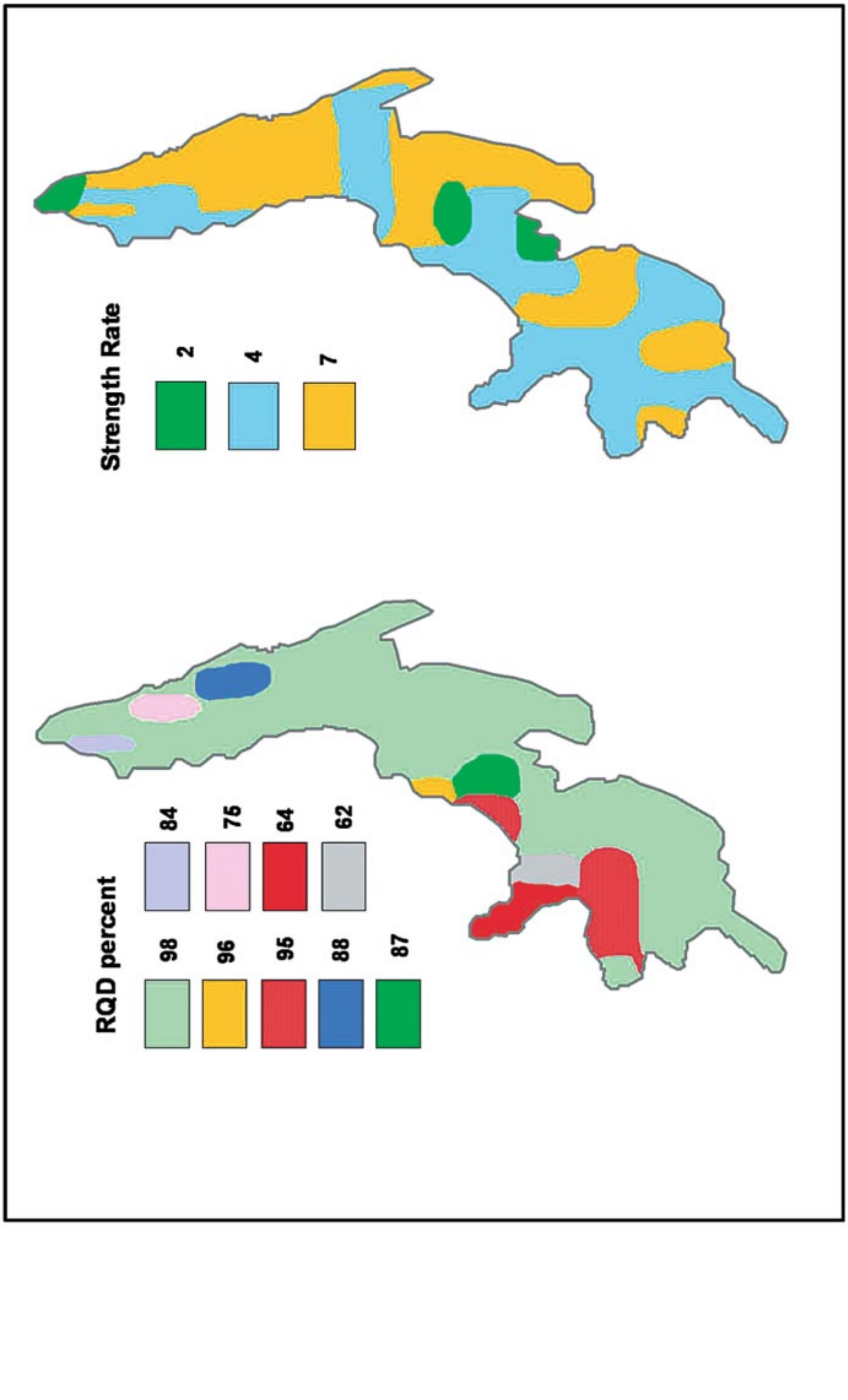

FIG. 4. The distribution of the RQD% and rock strength.

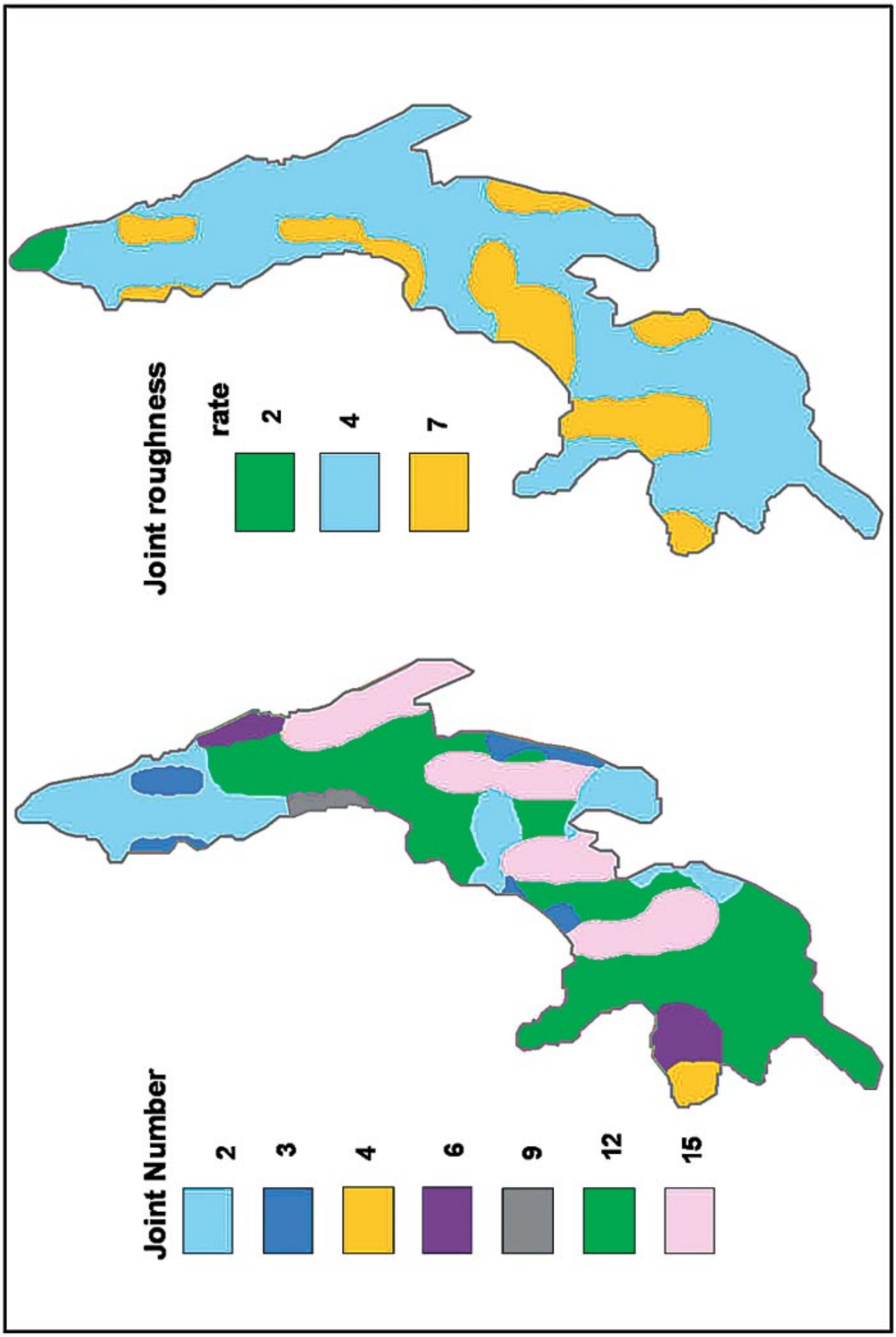

FIG. 5. The distribution of the joint number (JN) and joint roughness (Jr).

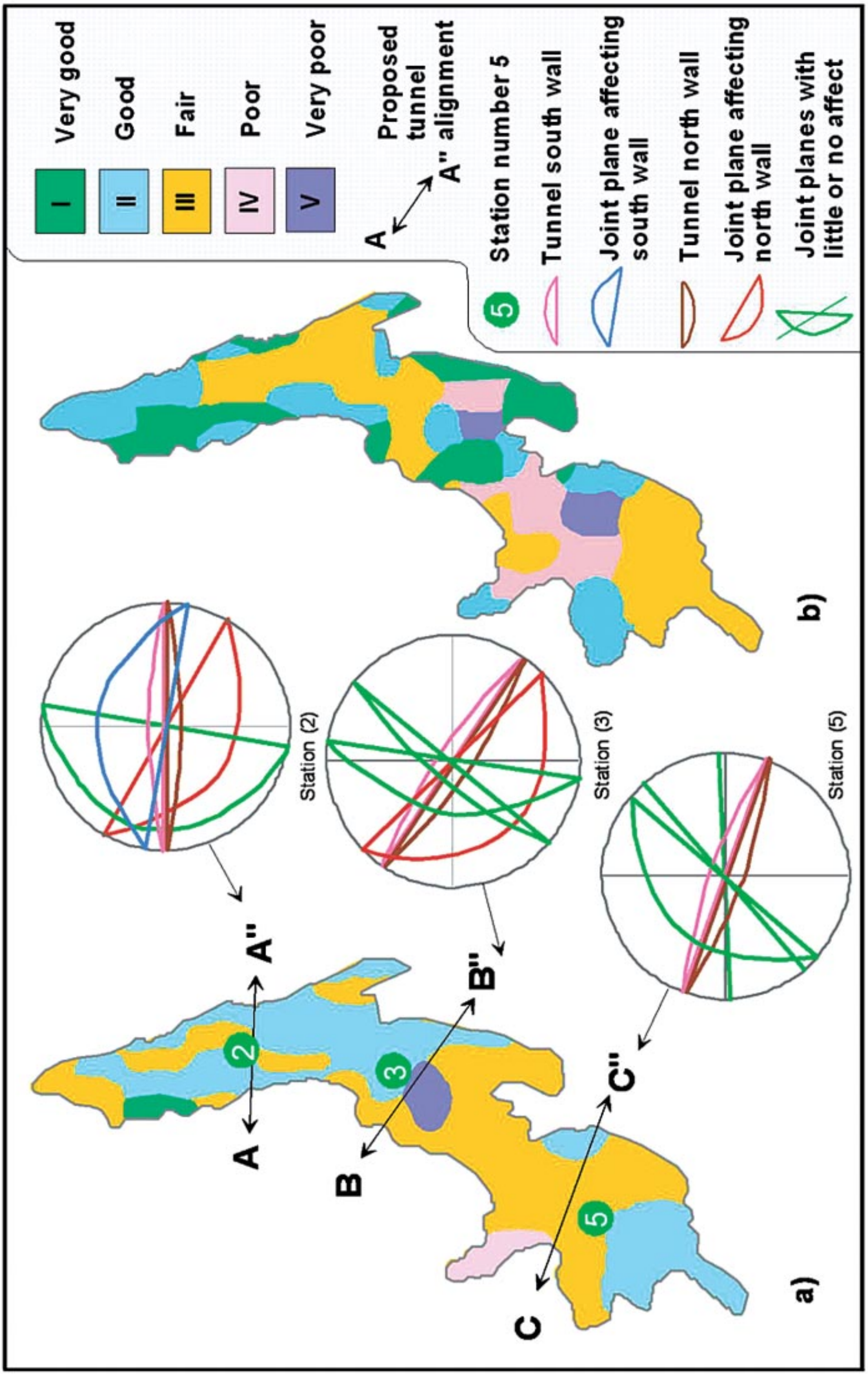

Fig. 6. Rock mass classification for: a) RMR systems; and b) Q system.

TABLE 4. The effective discontinuities in the northern or southern walls for the proposed alignment.

Proposed tunnel alignment (Figure 6)		Station no. (Figure 2)	Northern wall (Slope face)	Southern wall (Slope face)
Line	Direction			
A – A'	90º	2	45 / 231º	43 / 9º
B – B'	120º	3	31 / 242	82 / 313
C – C'	100º	5	Will not be effected by any joint	46 / 316

TABLE 5. A sample of the calculation of the factors for discontinuities orientation (F_1, F_2, and F_3).

Proposed tunnel alignment	Slope face dip direction	Joint dip and dip direction	Joint dip direction (α_j) , (ξ)	(α_j) , (α_s) (ξ)	F_1	Joint dip (β_j)	F2 (= β_j)	($\beta_j - \beta_s$) (ξ)	F_3
A – A'	0º Southern wall	43 / 9º	9º	9º (9º – 0º)	0.85	43º	1.0	– 37º (43º – 80º)	– 60
	180º Northern wall	45 / 231º	231º	51 (231 – 180)	0.15	45	1.0	– 35 (45 – 80)	– 60
B – B'	120º Northern wall	31 / 242º	242º	32º (242 – 210)	0.15	31	0.70	– 49 (31 – 80)	– 60
	20º Southern wall	81 /313º	313º	57º (313 – 360) – 20	0.15	82º	1.0	2º (82 – 80)	–6
C – C'	10º Southern wall	46 / 316º	316º	54º (316º – 360) – 10º	0.15	46º	1.0	–34º (46º – 80º)	– 60

TABLE 6. The estimated SMR values based on equation (2).

Proposed tunnel alignment	Slope face	The lowest value of RMR	Discontinuity factor (F_1, F_2, and F_3)	SMR	
				Rating (Eq. – 2)	Description (Table 1)
A – A'	Southern wall	41	– 51.0	92	Fully stable
	Northern wall		– 9.0	50	Fair
B – B'	Northern wall	20	– 6.3	26	Poor
	Southern wall		– 0.9	21	Poor
C – C'	Southern wall	41	– 9.0	49	Fair

Since the two systems have some common parameters, the two systems can be numerically linked. The obtained RMR-values (Table 2) and Q-values (Table 3) were implemented to develop the following relationship:

$$RMR = 55 + 2.3 \ln(Q) \qquad (3)$$

The minimum and maximum RMR values are classified as good rocks. Much of the detail of RMR variation in (Figures 6 a) are lost when converted by Eq. 3.

Discussion

The classes variation and resolution of the produced map mainly depends on the influence of discontinuities; joint spacing (Js) and joint condition (Jcon) in the RMR system and joint number (Jn) and joint alteration (Ja) in the Q system. The discrepancy is also related to the distance and number of the surrounding measured points. The abrupt spatial change in joint spacing, joint roughness and number and RQD are related to the field stress direction and stress concentration. The rock reaction is not expected to be spatially homogenous. Thiessen method was successful to overcome this difficulty. It calculates the rock mass rating for each station and reduce the error in linear interpolation of the spatially discontinuous data.

Today, the RMR-system and Q-system are the most commonly used. They were originally developed for estimating the support necessary for tunnels excavation. Their use must provide some overall guidance and not as the sole design tool since none of them are supported on scientific grounds. The selection to use one system should be related to either the project or site. In hydroelectric pressure tunnel or radioactive waste repositories, the *in situ* stress and proximity of the tunnel to the ground surface are two of the most important parameters (Arnold, 1993). The RMR system cannot help under these circumstances. On the other hand, the RMR is suitable for traffic tunnel where the tunnel wall stability can be evaluated by the SMR method using GIS as a tool. The Q system cannot be used for predicting the rock modulus (E) below a dam if the stratified nature of the rock mass means that there is a significant anisotropy of stiffness. One of the advantages of the Q-system is to estimate a crude measure of the rock block size, and active stress. The block size in the mapped area ranges between 6 to 50 cm. These values are crude and the larger block should be several times this size (Barton *et al*. 1974). Surface outcrops yield low active stresses and the SRF is therefore ineffective factor for shallow conditions and when it was combined with dry or minor inflow it produced constant active stress.

The RMR and Q systems include somewhat different parameters and therefore can not be strictly correlated. In general, they are consistent in classifying the studied area with a difference of one class, in most cases, between them.

However, some differences are present in few locations between the original RMR and the RMR calculated by equation (2). The discrepancies are possibly related to the marginal values in the category. They are also due to the unequal spacing between the measured profiles (Fig. 2-a). The number of profiles seems to be adequate, with an average spacing of 1/10 the mountain length. The closer spacing distance in the northern part of the mountain helped in getting more detailed information. There are variations in the location and extent of each rock mass zonation (Figs. 6-a and b). The difference between the two maps is also due to the subjectivity in the filed description as given by the RMR-system and the Q-system.

The differences may be attributed to: The measured values of discontinuity frequency and RQD depend on the direction of measurement and this is not accounted for in either system.

1. The range of values in the RMR system are from 0 to 100 while those for the Q- system are more detailed and extend from 0.001 to 1000. The limits of the rock quality, whether poor or good, are not numerically the same.

2. The joint roughness in RMR includes joint aperture which will give low rock rating. Joint aperture is not accounted for in the unfilled discontinuities in the Q-system.

3. Stress is not included in the RMR system, the intact strength of the rock is not included in the Q system. Either of these parameters could be a fundamental cause of failure in certain circumstances.

4. The shear zone could exist while it is not included in the RMR or Q system. The shear zone dominates the potential failure mechanism in rocks

Furthermore, the two systems were originally designed for humid region conditions. The individual parameters are independently converted to ranges of values. The influence of water in arid conditions is almost nil. Similarly Jw is neutral in both systems due to arid environment. The chemical weathering in arid conditions is not enough to cause the alteration of feldspars to kaolinite. The feldspars in the field and under the microscope are still fresh, and the rock fractures are filled with rock fragments, not clay. The effect of water plays a major part in the present system of classifying rock mass weathering. But the present scale have no direct relevance to their engineering significance (Price, 1993). Since both the Q-system and RMR-system were not specifically developed for arid environments, further developments of these systems are necessary. Incorporating more parameters to suite the conditions under arid environment might be feasible following the approach proposed by Hudson and Harrison (1992).

Conclusion and Recommendations

The GIS overlay and analysis can produce quick and reliable rock mass rating map using either the Q-system or RMR-system. The extent of GIS application depends on the data type; whether it is continuous or discontinuous. The GIS program can be applied directly if the collected data are continuous like geochemical elements, and geophysical variables. The engineering parameters of the RMR and Q systems are not spatially continuous. The GIS application would lead to imprecise maps if it is based on measured points of discontinuous variables. Therefore, it is suggested to apply Thiessen method to overcome this problem. The Q-system is more conservative and complicated to use. However, its rock mass rating is relatively high because the joint separation is not accounted for. The RMR system on the other hand is easier to use and more feasible and can be extended to slope stability by the SMR method. Rock weathering under arid climate is different, and both systems may not fully describe the joint alteration due to the absence of water. Therefore, it is recommended to adjust both systems to reduce the weighing factor of water and replace it with some other factor that might be more effective in arid conditions.

References

Anon (1978) Suggested methods for determining hardness and abrasiveness of rocks, *Int. Jr. of R. Mech. and Min. Sci. & Geomech.,* **V. 15:** 89-97.

Arnold, P.N. (1993) The development of a rock engineering systems methodology, *Ph.D. Thesis,* Imperial College, London, 377 p.

Barton, N., Lien, R. and **Lunde, J.** (1974) Engineering classification for rock masses for the design of tunnel support, *Rock Mech.* **6:** 189-236.

Belward A.S. and **Valenzulea, C.R.** (editors) (1991) Remote sensing and geographical information systems for resource management in developing countries, *Kluwer Academic Pub.* The Netherland, 502 p.

Bieniawski, Z.T. (1973) Engineering Classification of Jointed Rock Masses. *Trans. S. Afr. Inst. Civ. Eng.* **15:** 335-344.

Bieniawski, Z.T. (1989) Engineering rock classifications, *John Wiley & Sons* 203 p.

Bieniawski, Z.T. (1993) Classification of rock masses for engineering: the RMR system and future trends, In Hudson (edit. in chief) Comprehensive rock engineering, **v. 3,** Pergamon Press, Oxford, pp. 553-573.

Bonham-Carter, G.F. (1994) Geographic information systems for geoscientists, Pergamon Pub. Ontario (Canada), 398 p.

Brook, N. (1977) A method of overcoming both size and shape effects in point load testing. Proc. Conf. Rock Eng. British Geotechnical Society, Newcastle upon Tyne, pp. 53-70.

Brown, G.F., Schmidt, D.L. and **Huffman, A.C.** (1989) Geology of the Arabian Peninsula – Shield area of western Saudi Arabia. U. S. geological survey professional paper 560-A, U. S. Government printing office, Washington.

Dueker, K.J. and Kjerne, D. (1989) Multipurpose cadastre: terms and definitions: Technical papers, ACSM-ASPRS, *Annual Convention,* Baltimore, Maryland, **v. 5,** pp. 94-103.

Franklin, J.A., Broch, E. and **Walton, G.** (1971) Logging the mechanical character of rock. *Trans. Inst. Min. Metall.,* **80A,** pp. 1-9.

Greenwood, W.R. (1975) Geology of the Al Aqiq Quadrangle, sheet 20/40D, Kingdom of Saudi Arabia. **GM-23** scale 1:100,000.

Hoek E. and **Bray J.W.** (1977) Rock Slope Engineering, Institute of Mining and Metallurgy, London, 402 p.

Hudson, J.A. and **Harrison, J.P.** (1992) A new approach to studying complete rock engineering problems, *QJEG,* **v. 25,** pp. 93-105.

Krumm, R.J., Erdmann, A.L. and **Joselyn, M.G.** (1991) Illinois geographic information system, application to environmental management, *Illinois State Geol. Surv.* Champaign, Illinois, Circular **140,** 32 p.

Matheson G.D. (1983) Rock Stability Assessment in Preliminary Investigations – Graphical Methods. Department of the Environment, Department of Transport, *Transport and Road Research Laboratory Report LR* **1094.**

Peuquet, D.J. and **Marble D.F.** (1990) Introductory readings in geographic information systems, Taylor & Francis Pub. , London, 370 p.

Price, D.G. (1993) A suggested method for the classification of rock mass weathering by a rating system, *QJEG,* **v. 26,** pp. 69-76.

Romana, M.R. (1985) New adjustment ratings for application of Bieniawaski classification to slopes. Proc. Int. Symp. Rock Mech. Excav. Min. Civ. Works. *ISRM,* Mexico City, 59-68.

Romana, M.R. (1993) A geomechanical classification for slopes: *slope mass rating, in Comprehensive Rock Engineering,* **v. 3,** ch. 23 (Hudson, J. D., ed.) Pergamon Press, Oxford, 575-599.

Terzaghi, K. (1946) Rock defects and loads on tunnel support, Rock tunnelling with steel support, ed. Proctor, R.V.and White, T., Commercial Shearing Co., Youngstown, OH, p. 15-99.

تطبيق نظام المعلومات الجغرافية في تصنيف كتل الصور

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المستخلص. تصنيف كتل الصخور هو نظام أساسي في هندسة الصخور يعتبر فيها نظامي أر إم أر والكيو الأكثر استعمالاً. ويمثل هذا النظام خواص الصخور معتمداً على عدة معاملات هندسية يمكن قياسها ميدانياً في نقاط معدودة. وتقسم الكتل الصخرية إلى نطاقات لها نفس الخصائص الهندسية وتفصل هذه النطاقات المختلفة بحدود يتم رسمها بناءً على التقدير الإنساني. وقد ازدادت دقة حسابات تصنيف كتل الصخور في هذه الدراسة بسبب التحول من الاعتماد في الحسابات من النقاط المقاسة فقط إلى استخدام هذه النقاط لتقدير القيم في كامل المساحة المحيطة بهذه النقاط باستعمال نظام المعلومات الجغرافي. أجريت الدراسة على جبل الستارة بالقرب من الباحة المكون من صخور الكوارتز سيانيت. واتضح أن من غير المناسب استعمال التقدير الخطي لأن البيانات المقاسة غير متصلة. ولزيادة الدقة تمت الاستعانة بنظام المعلومات الجغرافي لمعالجة البيانات وتغطية الخرائط وتصنيفها. واستخدمت طريقة ثايسن لاستنباط النقاط البينية، فهذا يقلل من الخطأ الناشئ من التقديرات الإنسانية ويثبت معياراً رياضيًا ثابتًا لرسم الحدود الفاصلة بين نطاقات الصخور يمكن تكراره بدقة في حالة استعادة رسم الخرائط. وتم مقارنة نظامي أر إم أر والكيو وربطهما بعلاقة رياضية. ولوحظ وجود عدد من الفروقات قد تعزى إلى أن النظم المستعملة تم تطبيقها في هذه الدراسة لمنطقة جافة بينما تم تصميمها أصلاً لمنطقة رطبة.