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A Suggestion of Rock Mass Classification Systems for Stability of Underground Limestone Mines - A Case Study

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석회석 광산의 지하갱도 안정성평가를 위한 암반분류법 개발

Karanam U. M. Rao, **선우춘, 정소걸, 최성웅, 전양수**

초 록 자원개발에 있어서 환경문제로 석회석광산의 채굴이 노천에서 지하채굴로 점차 전환되면서 석회석 채광에 따르는 갱도의 안전문제가 대두되고 있다. 무지보로 유지해야 하는 갱도의 크기문제를 결정하는 것이 현장에서 가장 어려 문제중의 하나이다. 따라서 석회석 지하채광장과 갱도에서 *Q* 시스템과 *RMR* 암반분류법을 적용하여 지하갱도의 안전성을 평가하기 위한 암반분류법을 개발하기 위해서 두 개의 석회석 광산을 대상으로 암반조사가 이루어 졌다. 기본적으로 *Q* 시스템과 RMR 암반분류법의 상관관계를 이용하여, 석회석 광산에 적용할 수 있도록 암반분류법을 수정하였고 또한 무지보 안전갱도 폭을 결정하기 위한 새로운 시도가 이루어 졌다.

핵심어 암반분류법, 지하채굴, 석회석

Abstract Demand for limestone production from both the underground and opencast mines in Korea is gradually increasing. Increase in productivity with safe mining operations is the emphasis laid on the mining industry. KIGAM has undertaken a detailed investigation to apply *RMR* and *Q* classification system for the design of underground limestone mining operations. The field investigations were confined to the underground mines of Daesung Mining Development Co. Ltd. and Pyunghae Mines of Korean Airport Service. Modification to the standard *RMR* and *Q* for limestone mines in Korea along with the correlation between these two systems are discussed while attempts were also made to calculate the width of a safe unsupported span.

KeyWords Rock mass classification systems, Underground mining, Limestone

1. Introduction

Limestone is the single largest non-metallic ore being mined in Korea. Currently there are around 135, both underground and opencast mechanized mines in Korea. The production of limestone is on a gradual increasing trend from 71.7 million metric tons in the year 1998 to 86.0 million metric tons in the year 2002 for meeting the demands of cement industries in Korea[1,2)]. Keeping in view the need for an increase in the limestone production, the mining division of Korea Institute of Geosciences and Mineral Resources has undertaken a study to classify the rock masses with an objective to determine the stability of the underground limestone mines in Korea. Detailed field investigations including hydraulic fracturing studies to measure the in situ stresses were carried out in underground mines of Daesung Mining Development Co. Ltd and Pyunghae Mines of Korean Airport Service.

Daesung mine is located in Jecheon city of Chungbuk province. The economically viable mining operations are limited to five levels in Daesung mine, such as 475, 450, 425, 405, and 385 ML. Pyunghae underground mine is located in the North-eastern coast of Uljin city. The mine development and production operations in Pyunghae mine are confined to100, 80, 60, and 40 ML levels with around 20 m of level

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interval. The mode of ore transportation in both of these mines is by tyre mounted trucks of capacity 15 tons, and therefore the level drive dimensions are around 8 - 15 m wide and 6 - 8 m high.

The stability of underground excavations depends upon the strength of the rock mass surrounding the excavations, the dimensions of the opening and upon the magnitude of the induced stresses. Currently, there are no generally accepted methods of deciding which ground control measures are best suited to a particular mining situation and therefore the approaches are remaining to the site specific conditions. In the absence of a single accurate method, the rock mass classification method is still a much opted approach for the type of uncertainties encountered in designing of underground mining operations.

2. Description of the rock mass

The geo-mechanical descriptions of the rock mass in which the active mining operations are designed were based on the general characteristics of the discontinuities following the procedures suggested by International Society of Rock Mechanics[9]. Limestone formations of Taebaeksan basin have undergone moderate levels of tectonic activity resulting in major folds and faults. The in-situ stress measurements undertaken in these areas are in support of mild tectonic activity in this area with the average measured values of maximum and minimum horizontal stress around $0.75\sigma_v$ and $0.35\sigma_v$ respectively.

The general water condition of the underground mines of the present investigation are moderately wet at places to watery and therefore a special emphasis was laid on the weathering condition of the joints along with the determination of the strength of the joint planes. A detailed scan-line surveying of the boreholes for *RQD* values were also obtained and the corresponding values for Daesung mine, at BL/1 (between 405 ML and 385 ML) is 80% and at BL/2 (between 450 and 425 ML) is 83% (Fig.2) and for the Pyunghae mine between 60 and 40 ML is 75% while between 80 and 60 ML is 50%. The joint spacing in general was observed to be around 20 - 60 cm at a average separation of 0.05 - 0.2 cm. The joint surfaces were slightly rough coated with wet soft clayey material.

3. Mechanical properties of the limestone samples of Daesung and Pyunghae mine

The most relevant mechanical properties were determined in the laboratory for the core samples obtained from various bore holes. The tests were carried out in accordance to the procedures recommended by ISRM[9]. The results obtained from the laboratory tests are summarized in Table 1.

4. Site specific conditions of Daesung and Pyunghae mines

The ore-body in both the mines is very similar in their extent along strike and dip directions. The width of the ore-body is in between 200-300 m and with minor modifications, the standard room-and-pillar is the major stoping operation in both the mines. In this open stoping method mining progresses in a nearly horizontal or low angle direction by opening multiple stopes or rooms, leaving solid material to act as pillars to support the vertical load (Fig. 1). Since the excavation in the present case is nearly flat, the muck or the broken material is transport by 15 ton capacity tyre mounted trucks. In both the mines a detailed stope planning is nonexistent; i.e., the line extraction follows the grade values leaving the lower grade ore in pillars. The pillars though are of random dimension, however, have a general dimension of 10 m× 6 m(Fig. 2). Occasionally, spalling of the pillar was seen particularly at places where the opening width was more

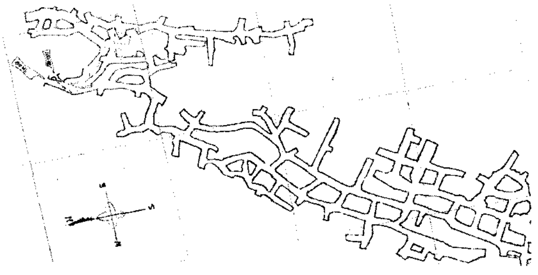


Fig. 1. Underground mine development plan of Pyunghae limestone mine (Level-80 ML)

Table 1. Mechanical Properties of Limestone of Daesung and Pyunghae mine

Property Description	*Daesung Mine*		*Pyunghae Mine*	
	Average Value (Sample- 1)	Average Value (Sample -2)	Average Value (Sample -1)	Average Value (Sample -2)
Density (g/cm^3)	2.72	2.71	2.73	2.71
Absorption Ratio (%)	0.10	0.09	0.07	0.11
S-wave Velocity (m/sec)	3190	3200	3190	2470
P-wave Velocity (m/sec)	6690	6750	6430	3960
UCS (MPa)	152	110	109	70
Tensile Strength (MPa)	10	8	10	7
Young's Modulus (GPa)	52.5	47.4	48.6	35.6
Poisson's Ratio (ν)	0.17	0.15	0.18	0.13
Cohesion (MPa)	33.3	26.67	26.5	20.5
Angle of Internal Friction(°)	46°	45°	42°	34°

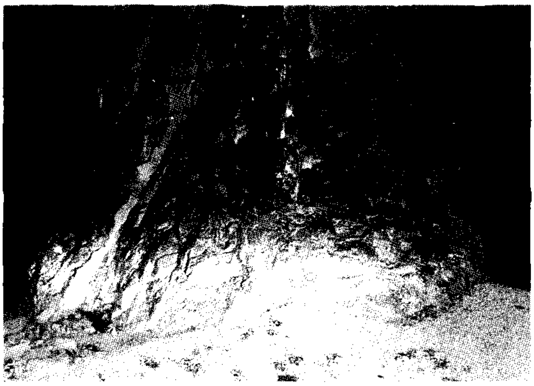


Fig. 2. A typical Pillar construction in the limestone mines at Daesung Mines

Fig. 3. Spalling of a pillar at Level D (405 ML) of Daesung mine

Fig. 4. A natural cave intersecting a room-and-pillar stope

Fig. 5. Uniform fragment size of a roof rock fall - indicative of multiple joint sets

than 20 m from the centre of the pillar to the side wall (Fig. 3).

Many natural caves and cavities were encountered along the mine openings (Fig. 4). Most of the cavities were filled with completely weathered rock mass along with soft wet clayey material. Water inflow through the cavities was dripping to moderate. Local rock falls occurred where faults and major discontinuities intersected the openings(Fig. 5).

5. Rock mass classification

Rock mass classification systems have been developed over the years to describe the rock mass or ground and to formalize an empirical approach to tunnel design. Most of the classifications systems were developed from civil engineering case histories. The different classification systems place different emphasis on various engineering geological parameters. In the recent years, classification systems have often been used in tandem with analytical and numerical tools. Therefore, there has been a proliferation of work linking classification indexes to material properties, such as modulus of elasticity, rock strength, *m* and *s* of Hoek and Brown failure criterion, etc.[10]. The values are then used as input parameters for the numerical models. Consequently, the importance of rock mass classification systems has increased over time[11].

Terzaghi's classification was evolved for estimating the rock loads for steel-arch supported tunnels[11]. After detailed studies, Cecil[13] concluded that Terzaghi's classification was too general to permit an objective evaluation of rock quality and that it provided no quantitative information on the properties of rock masses. The main significance of Lauffer's classification is in the factor of stand-up time, which is that length of time the tunnel can stand without any support. It has indeed influenced many modern classification systems. The *RQD* is a modified core-recovery percentage which incorporates only sound pieces of core that are 100 mm or greater in length. For *RQD* determination the International Society of Rock Mechanics recommends a core size of at least NX diameter (54.7 mm). Today, the *RQD* is used as a standard parameter in drill core logging and forms a basic element of the two major rock mass classification systems: the *RMR* system and the *Q*-system. Although the *RQD* is a simple and inexpensive index, it alone is not sufficient to provide an adequate description of a rock mass.

5.1 The *RMR* system

The Geomechanics Classification system or the Rock Mass Rating (*RMR*) system is one of the widely adopted classification systems for mining operations in the present times. Significant changes have been made over the years with revisions in 1974, 1975, 1976 and 1989[12]. In *RMR* classification five parameters viz. uni-axial compressive strength , *RQD*, spacing of discontinuities, condition of discontinuities, and ground water condition are grouped into five different ranges of values based on their relative importance to the overall rock mass characteristics. The sixth parameter which is the orientation of discontinuity is considered separately because the influence of discontinuity orientation depends on the engineering application, such as a tunnel, mine or a slope.

The rating of each of these parameters is summarized to give a value of *RMR*. The rating is an outcome of a supervised classification of each parameter. The calculated *RMR* value may be used to find which of five pre-defined rock mass classes the rock mass belongs to, from very good rock to very poor rock. All the parameters are measurable in the field and some of them may also be obtained from borehole data. Bieniawski[12] published a set of guidelines for estimating the stand-up time, and for selecting rock support in tunnels, based on the *RMR* value. The *RMR* value has also been used to estimate rock mass property. The *RMR* system has been used in many tunnel projects as one of the indicators to define the support or excavation classes. However, *RMR* cannot be used as the only indicator, especially when rock stresses or time dependent rock properties are of importance for the rock engineering issue.

5.2 The *Q* system

The *Q*-system of rock mass classification system was developed in Norway in 1974 by Barton, Lien and Lunde[14]. The Q-system is based on a numerical assessment of the rock mass quality using six different parameters. The six parameters are grouped into three quotients to give the overall rock mass quality Q as follows:

$$Q=\frac{RQD}{J_n}\times\frac{J_r}{J_a}\times\frac{J_w}{SRF} \tag{1}$$

Where, RQD = Rock quality designation
J_n = Joint set number
J_r = Joint roughness number
J_a = Joint alteration number
J_w = Joint water reduction number
SRF = Stress reduction factor.

The rock quality can range from Q = 0.001 to Q = 1000 on a logarithmic rock mass quality scale. The ratio RQD/J_n represents the intact rock mass block size with a maximum value of 200, J_r/J_a represents the relative frictional strength and the third quotient, J_w/SRF represents the active stress situation. This third quotient is the most complicated empirical factor and has been debated in several papers. It indeed represents four groups of rock masses: stress influence in brittle blocky and massive ground, stress influence in deformable (ductile) rock masses, and stress influence in weakness zones and swelling rock.

The Q-system is normally used as an empirical design method for rock support. Together with the ratio between the span or height of the opening and an excavation support ration (ESR), the Q values define the rock support.

The first two quotients RQD/J_n and J_r/J_a are often used in a stope design in the mining industry, but their representation of relative block size and inter-block shear resistance are not sufficient descriptions of the degree of instability. The Q-system was modified by Potvin[15] for stope design.

5.3 Rock mass classification for Mining

Rock mass classifications have been successfully applied throughout the world for tunneling operations. Unlike the tunneling operations, the underground mine openings are more controlled by time, in the sense that, the opening numbers as well as their dimensions change with the progress in the life of a mine. Most of the mines are stable in the first quarter of the life of the project. The issue of instability germinates from the later half and becomes acute at the last quarter of the life of the mine. It is precisely because as the opening dimensions increase even the most competent rock tends to exhibit the elasto-plastic deformation with the increase in the magnitudes of the stress concentrations around the multiple openings. This is likely to initiate fracturing around the opening resulting in both local wedge failure and large area failures because the effective stable block size dimensions too must have undergone a change. Secondly, due to relatively constant engineering conditions in tunneling, the stress condition has been included in the Q system and the relative orientation between the tunnel and critical joint set has been included in the RMR system. Following these approaches to a mine would result in the same rock mass having dozens of classification values through out the mine, depending upon the drift orientation, mining level and the excavation history. This would lead to significant confusion and render to rock classification values useless[11].

In the past, two approaches were followed to allow these classifications systems to be applied to mining conditions. The first approach was to try to create a complete design method from the classification systems by including other engineering and loading condition factors. The example if this type is the Mining Rock Mass Rating ($MRMR$) proposed by Laubscher[16]. The second approach consists of simplifying the classification system to only include factors dependent on the rock mass and to ignore environmental considerations such as stress and drift orientation with respect to the joints[11,17]. The resulting rating is solely dependent on the rock mass. This simplification was adopted for both RMR and Q systems. Thus Q' is the modified Q classification with SRF = 1 and RMR' for RMR after dropping the joint orientation factor.

Laubscher[16] modified the Geomechanics Classification for mining applications involving asbestos mines in southern Africa. The modifications featured a series of adjustments for RMR values to accommodate the effects of the original (in situ) and induced stresses, changes in stress, as well as the effects of blasting and weathering. Cummings et al[18] and Kendorski et al.,[19] also modified for mining applications in U.S. block caving copper mines and it has been identified as *MBR* (Modified Basic *RMR*) system. The *MBR* is an indicator of rock mass competence, without regard to the type of opening constructed in it. This *MBR* value is used in the same fashion as the *RMR* for determining support requirements.

6. Rock mass classification for underground limestone mines - a case study

Detailed fieled investigations were undertaken by the authors along all the important levels such as level A- 2nd sub-level (475 ML), B- 1st Sub-level (450 ML), C- main haulage level (425 ML) , D- 1st lower sub-level (405 ML), and E -2nd lower sub-level (385 ML) of Daesung mine and levels 60 and 80 ML of Pyunghae underground limestone mine. The mine development operations started in the year 1997 at Daesung mine, while in Pyunghae mine it started in the year 1995. The dimensions of the openings were measured. The roof condition of these mines was observed to be stable and it was observed in both the mines that no detailed roof bolting was needed in general excepting in the main haulage level. The field survey focused at the characteristic of discontinuities such as orientation, frequency of occurrence, continuity, surface roughness, water condition of the mine and the extent of weathering since they collectively play an important role in the deformation of the surrounding rock mass and the stability of an opening.

6.1 Correlation between *RMR* and *Q* system

There are a few fundamental differences between *RMR* and *Q* classification systems. *RMR* does not consider the stress condition of the rock mass, while *Q* system does not consider joint orientation and intact strength parameter. Regardless of these differences there are many correlation equations developed between the two classification systems until now(Table 2). In

Table 2. Correlation between *RMR* and *Q* rock mass classification systems

Relationship	Correlation coefficient (r)	Proposed by
$RMR = 9\ln Q + 44$	0.77 (all rock types)	Bieniawski (1976)
$RMR = 5.69\ln Q + 47$	0.85	Rutledge and Preston (1978)
$RMR = 5.4\ln Q + 55.2$	0.55	Moreno (1980)
$RMR = 5\ln Q + 60.8$	Highly scattered values	Cameron, Clarke & Budavari [23]
$RMR = 10.5\ln Q + 41.8$	0.66	Abad *et al.* [24]
$RMR = 8.7\ln Q + 38$	0.55	Kaiser & Gale [25]
$RMR = 9\ln Q + 49$	sedimentary rocks	Al - Harthi [26]
$RMR = 7\ln Q + 36$	sedimentary rocks	Turul [27]
$RMR = 5.69\ln Q + 47$	0.72 (igneous rocks)	Sunwoo and Hwang [28]
$RMR = 6.04\ln Q + 49.6$	0.84 (metamorphic rocks)	Sunwoo and Hwang [28]
$RMR = 6.07\ln Q + 50.1$	0.81 (sedimentary rocks)	Sunwoo and Hwang [28]
$RMR = 9\ln Q + 44$	Diverse origin	Choquet and Hadjigeorgiou [29]
$RMR = 13.5\log Q+44$	New Zealand	Choquet and Hadjigeorgiou [29]
$RMR = 12.5\log Q + 55.2$	Spain	Choquet and Hadjigeorgiou [29]
$RMR = 5\ln Q + 60.8$	South Africa	Choquet and Hadjigeorgiou [29]
$RMR = 43.89-9.19\ln Q$	Spain (soft rock)	Choquet and Hadjigeorgiou [29]
$RMR = 12.11\log Q + 50.81$	Canada (Hard rock)	Choquet and Hadjigeorgiou [29]
$RMR = 8.7\ln Q + 38$	Canada (Sedimentary rock)	Choquet and Hadjigeorgiou [29]
$RMR = 6.07\ln Q + 50.1$	Canada-Hard rock	Choquet and Hadjigeorgiou [29].

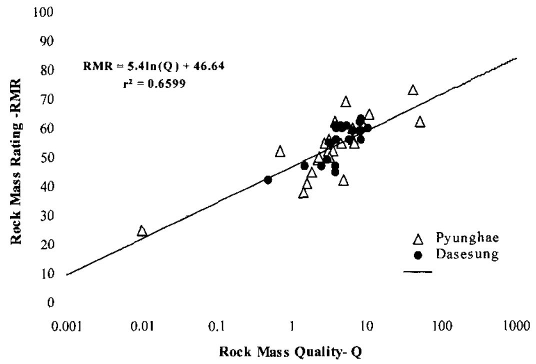


Fig. 6. Relationship between *Q* and Basic-*RMR* classification systems for Pyunghae and Daesung underground limestone mine

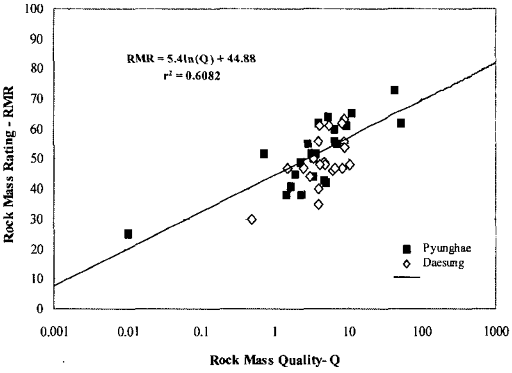


Fig. 7. Relationship between *Q* and Total-*RMR* classification systems for Pyunghae and Daesung underground limestone mine

most of the relationships the correlation coefficient is less than 0.80. Of all the correlations the best was proposed by Rutledge and Preston[21)] for the case studies from New Zealand and Sunwoo and Hwang[28)] followed by Bieniawski[20)], Moreno[22)], Cameron-Clarke and Budavari[23)] and Abad et al[24)].

In the present study, the data required for classifying the rock masses of Daesung and Pyunghae mine were collected from 44 underground locations covering all the important permanent and temporary locations. Summing up the different ratings of the parameters listed in both the classifications, the basic (unadjusted for discontinuity orientations) *RMR* and *Q* were obtained. For the comparison of results obtained in the present case study, a correlation between basic *RMR* and *Q* is drawn (Fig. 6). The correlation equation for Daesung and Pyunghae mine is, $RMR = 5.4\ ln(Q) + 46.4\ (r^2 = 0.65)$ which is similar to the previous studies(Table 2).

The influence of strike and dip orientation of the discontinuities on the stability of the openings and their correction in the basic *RMR* has been taken separately in the geomechanical classification since the importance of stability varies depending on whether the opening is permanent or temporary. A detailed surveying to measure the strike and dip of the joints was undertaken in Daesung and Pyunghae mine and from this data a total *RMR* was obtaining making suitable adjustment to the basic *RMR*. The correlation between the Total-*RMR* and *Q* is shown in figure 7.

In underground mining operations since the conditions are way different from a tunneling operations, the rock mass classification systems have been accordingly modified to suit to the mining conditions[11)]. One of the simple modifications suggested for *Q* system is to assume Stress Reduction Factor (*SRF*) = 1 and dropping joint orientation adjustment in *RMR*[11)]. The modifications for both *Q* and *RMR* were adopted for the present case study and resulting *Q*' values were correlated with the *RMR*' values(Fig. 8).

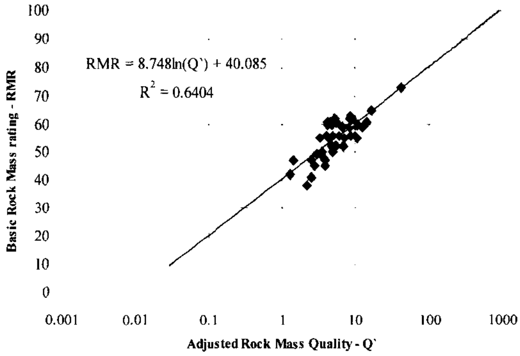


Fig. 8. Relationship between Adjusted Q' and Basic-*RMR* for Pyunghae and Daesung underground limestone mine.

7. Support Design

Design of support system for the Daesung and Pyunghae underground limestone mines is based on Basic Rock Mass Rating (*B-RMR*) as well as the Rock Quality Index (*Q*). Unlike the tunnel openings the underground mine openings are not permanent, therefore in the empirical design of mine support system based on these two classification systems the aspect of relative shorter life time of a mine has to be considered. The second major issue specific to the mining operations is that with the progress in the life of a mine the numbers as well as the dimension of openings increases and not all openings have the same degree of importance to the overall stability of a mine.

7.1 Design of safe unsupported span by *RMR*

In order to compute the safe limits of the unsupported span for the preset mines, the measured span widths were correlated with *RMR*` values. A best linear relationship(Fig. 9), is fitted taking 1.0 m as the minimum width for the present mining conditions at Daesung and Pyunghae mine which is independent of the *RMR* value and is given by Eq.(1).

$$W = 0.2264\ RMR' + 1.0 \tag{1}$$

where, W = Unsupported Span (m)
RMR' = Unadjusted Rock Mass Rating.

Since the total time the opening has been standing without any support has a negative effect on its over all stability, the total stand-up time in days for the Daesung and Pyunghae mine has been correlated with their Rock Mass Ratings(Fig. 10). The best possible linear fit is given by the Eq.(2):

$$RMR = -\ 0.005\ T_p + 65 \tag{2}$$

Where,
T_p = total stand-up time of the opening (in days)

Substituting the value of *RMR* from Eq.(2) in Eq.(1) and replacing the y-intersection of the relationship between the stand-up time of the opening versus *RMR*, with the Total-*RMR*, we get a general equation for the safe unsupported span as follows:

$$W = 0.24 \times Total\ RMR - 0.0013\ T_p + 1.0 \tag{3}$$

The suggested adjustment to the *RMR* for mining application to take care of blasting damage, change in stress concentration due to increase in number of openings, and other factors related to local geological structures is taken as 0.5 times the Basic-*RMR*[12]. The Eq.(3) for calculating the safe unsupported span involves the first term (0.24×Total *RMR*), which takes care of all the mining factors effecting the stability and the second term (0.0013×T_p), takes care of the negative effect of stand up time and a constant (1.0) which is a minimum unsupported span independent of *RMR* and time effect. Thus the Eq.(3) is complete a conservative in suggesting the safe unsupported span for Daesung and Pyunghae limestone mines.

7.2 Support design by *Q*-system

According to *Q*-system the equivalent dimension D_e is defined as the ratio of the span width to the Equivalent support ratio

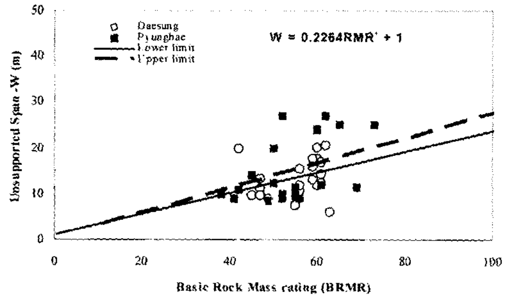


Fig. 9. Correlation between Basic Rock Mass Rating and unsupported span for Daesung and Pyunghae mine

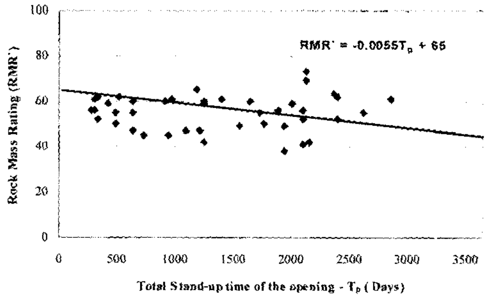


Fig. 10. A correlation between Stand-up time and Rock Mass Rating for Daesung and Pyunghae limestone mine

Table 3. The mine openings and *ESR* rating for Daesung and Pyunghae mine.

Excavation Category	Equivalent Support Ratio (*ESR*)	
Main Haulage Roadway	Permanent Opening	1.6
Underground service stations	Permanent Opening	1.6
Development drives(levels)	Semi-permanent	3.0
Room-and-Pillar stope	Temporary	4.0
50% Advanced Room-and-pillar stope	Temporary	5.0

$$D_e = \frac{Span\ width\,(m)}{Equivalent\ Support\ Ratio\,(ESR)} \tag{4}$$

Mine openings for the Daesung and Pyunghae mine are categorized as follows(Table 3):

A logarithmic curve was fit between the Equivalent dimension D_e and the Rock Mass Quality-Q’ resulting in the following equation for both Daesung and Pyunghae mines(Fig. 11).

$$D_e = 2.1927Q^{0.2787} \tag{5}$$

From the Eq. (4) and (5) the safe unsupported span can be calculated if the value of Rock Mass Quality-Q is determined for a mine.

8. Results and Discussions

On the basis of the field data *RMR* and *Q* for these locations have been computed. The safe unsupported span for the underground locations shown in figures 14 and 15 were calculated using Eq.(3) and Eq.(5) and are presented in a graphical form from Fig.12(a) to 13(b) for the sake of brevity. The safe span calculations both by *RMR* and *Q* for majority of the cases are with in comparable limits. The differences are mainly due to the selection of *ESR* value in *Q* system and in case of *RMR* calculations, the negative influence of stand-up time (Eq.3) is found to have a significant influence on the value of safe spans.

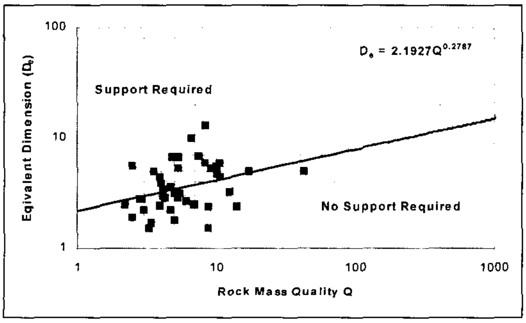


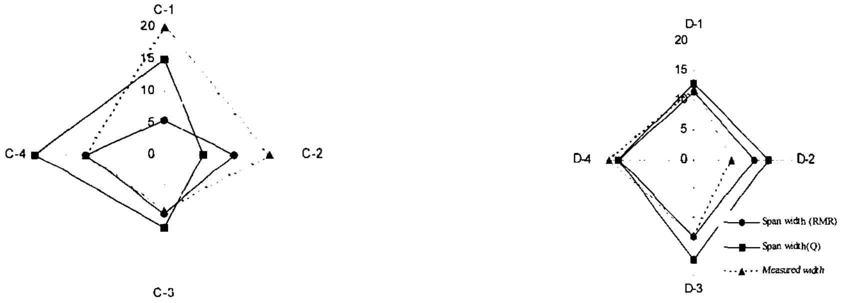
Fig. 11. Correlation between Rock Mass Quality-Q and Equivalent dimension D_e for Daesung and Pyunghae limestone mine

In Daesung mine the measured width in 475 ML (Fig. 12.a) at location A1 is exceeding by 1.7 m according to *RMR* and 2.7 m based on *Q* system. The span has been standing with out support for 274 days. Similarly the only other location in 475 ML at which the safe limits are exceeded is A2, where it is exceeded by 4.8 m (*RMR*) and 3.8 m (*Q*) and the stand up time of the span has been for 639 days. Unlike a tunnel opening not all locations have the importance in mining operations. Therefore, since the area under the influence at location A1 belongs to a level drive of certain importance compared to the temporary opening at A-2, it is suggested that sufficient roof bolting may be planned around the A1 location to secure stability of the opening. Since the rock bolts are effective when the roof is still stable, it is essential to drive rock bolts at the earliest time. In case of the locations with in 450 ML, at points B4, B5 and B7 the width is exceeding on an average by 8 m from *RMR* calculations and 12 m by *Q* system and the openings have been standing unsupported as long as 2,010 days to 1,600 days(Fig. 12.b). The points belong to a room-and-pillar stope where the stope has been widened following the high grades values. Since it is a worked out stope, though the safe limits are far exceeded, the suggested measure it is to fence the old workings as an abandoned areas. In level drive at 425 ML, the average basic *RMR* value in general are around 50 and the average value of adjusted *RMR* is 44, similarly the average *Q* value is around 4.5, categorizing the rock mass type to belong to fair rock mass of Class-III according to *RMR* classification system. The other important observation is that the stand up time of the drive has been between 1888 to 2161 days. The safe span limits therefore are exceeded by 14 m by *RMR*(Fig. 13(a)). It is further noticed that a large difference exists between the safe span limits by *RMR* and *Q*, of the order of 10 m. It is mainly due to the reason that the points between C1 to C4 belong to a temporary haulage level and the corresponding *ESR* values assigned were 1.6(Table 3). The recommendation from the present study is to reinforce the roof strata by systematic rock bolting. The safe span limits in 405 ML are found to be with in reasonable limits(Fig. 13(b)).

Pyunghae mine is relatively an older mine. The

(a) for level 475 ML

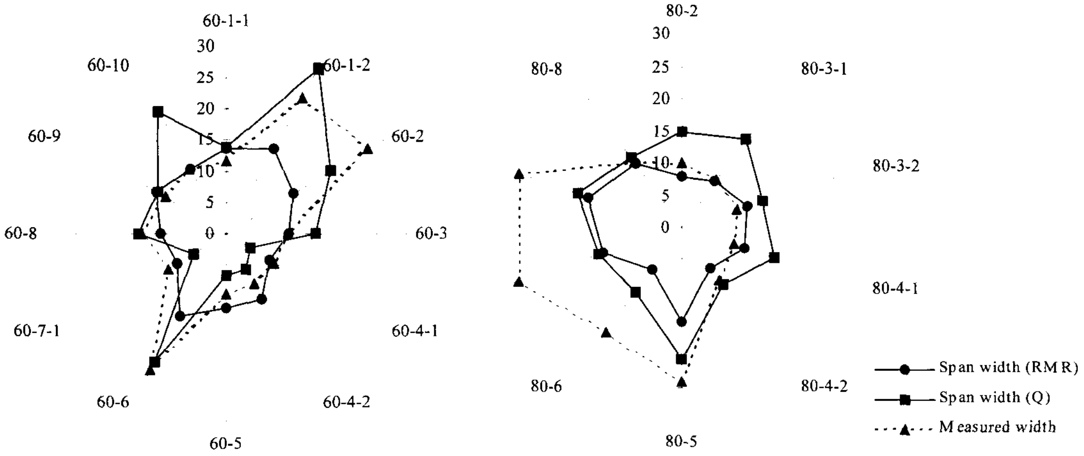
(b) for level 450 ML



(c) for level 405 ML

(d) for level 425 ML

Fig. 12. Unsupported Span for Daesung mine



(a) for level 60 ML

(b) for level 80 ML

Fig. 13. Unsupported Span for Pyunghae mine

Table 4. Suggested support system based on *RMR* and *Q* for mines of the case study

Site		Safe Span Limit (m)		Measured Span (m)	Nature of the opening	Support requirement
		RMR	*Q*			
Daesung Mine	A1	14	12.79	15.5	Semi Permanent drive	Roof bolting
	A2	8.5	9.5	13.3	Temporary level gallery	To be Isolated
	B2	10.8	16.5	17.7	Stope in operation Semi-Temporary	No support required
	B3	10.9	13.3	14.3	Stope in operation Semi-Temporary	No support required
	B4	9.7	5.3	17.8	Old working Temporary	To be abandoned
	B5	10.4	10	20	Old working Temporary	To be abandoned
	B6	10.7	14.6	9.6	Old working Temporary	To be abandoned
	B7	15.2	6.1	20.1	Old working Temporary	To be abandoned
	C1	5.4	15	20	Old drive	To be isolated
	C2	10.6	5.8	16	Level drive-Temporary haulage	Roof bolting
Pyunghae Mine	60-2	12.8	19.8	27	Old working Temporary	No support
	80-5	14.6	20.4	24	Old working Temporary	No support
	80-6	7.8	12.3	20	Old working Temporary	No support
	80-7-1	13	13.81	27	Old working Temporary	No support
	80-7-2	15.4	17.7	27	Old working Temporary	No support

main production is concentrated within the drives at 80 and 60 ML. The levels drives have been widened following room-and-pillar operations at selective places on the basis of the grade of limestone. In the level drive at 60 ML, the computed *Q* values from the filed data at location 60-1-2 is 42 and therefore the safe span dimensions based on *Q* system are as high as 30 m where as the corresponding value based on *RMR* is 15.6 m against the measured span of width 25 m. The span is with in safe limits according to *Q* system, while is exceeding the safe limits by almost 10 m based on *RMR* calculations. In the preset such anomalies between the two approaches was noticed to exist for a very few locations. The other locations where the safe span limits are exceeded lie at survey points 60-2 and 60-6. The measured span at 60-2 is more by 14 m following *RMR* and 7 m based on *Q* system and 10 m (*RMR*) and 1.5m (*Q*) at 60-6. Both the points belong to two different room-and-pillar stopes. Similarly in the level drive 80 ML, the safe span limits are exceeded at 80-5, 80-6, 80-7-1 and 80-7-2. Since all these points belong to different room-and-pillar stopes which are worked out, no support is needed and for the safety purposes the old mine out may be fenced to restrict easy accessibility.

Most of the openings in both the mines where the dimensions of the opening exceeded the safe span limits based on both *RMR* and *Q* are either the temporary level drive openings or the worked out room-and-pillar stopes. However, on the basis of the importance of the opening and the required stability, suitable suggestions of support system are made and are given in Table 4.

9. Conclusions

In the absence of universal standard analyses for determining rock support design, rock mass classification system serves as a main practical basis for the design of underground mining operations. In the present study, *RMR* and *Q* systems of classification are modified to suit the site conditions at Daesung and Pyunghae mines and are successfully applied to evaluate the safe unsupported span of the mine openings. The difference between the computed values of the safe unsupported span by *RMR* and *Q* system is marginal for majority of the location. However, at some locations the differences are very large and are mainly due to the assumed *ESR* values for *Q* system where the effect of *stand-up time considered in RMR computations* are is substantial.

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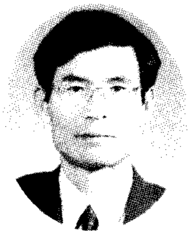

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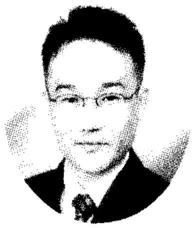

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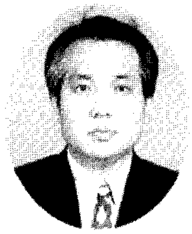

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