ROCK QUALITY ASSESSMENTS IN THE VICTORIA PROJECT TUNNEL

by Dr. P.G.R. Dharmaratne

Introduction

Victoria Project

Victoria Project, the largest of the five projects in the Accelerated Mahaveli Programme, is situated about 120 km north - east of Colombo. The project consists of a double concrete dam of 120 m in height, over 5.8 km long power tunnel and a power house. The project expects to generate 210 mw of electricity at the completion of the first stage.

Power tunnel has the shape of a horse-shoe with a height and width of 7.2 m, and 6.2m, circular when concreted. The tunnel was excavated by the full face drill and blast method, and passed through ground consisting largely of garnetiferous quartz gneiss, granulite, quartzite, quartz granulite and limestone.

The rock mass varies from unweathered to highly weathered, and dry to very wet. Overbreaks and uneven tunnel periphery due to faults and foliation planes are observed. Rock bolts, shotcrete and concrete are adopted as temporary supports and the tunnel lined with 500 mm concrete for final use. (Fig 1).

Rock Quality Assessments

Rock mass classifications have long been recognised as a useful method to assess conditions of rocks for engineering purposes. The classification systems define the nature of the rock mass in understandable terms, which enables effective communication between technical personnel involved in the project concerned. If the experience in construction and supervision of underground excavations in similar rock conditions elsewhere is available, an engineer can take design decisions with a high degree of confidence. For a person with less experience, some form of rock mass classification system enables him to relate the conditions of the site being considered to the conditions encountered by others. The recognised rock mass classification systems basically depend on the experience gathered by the authors in different conditions. As such, rock mass classifications have been successfully applied all over the world (1-13) in both mining and civil engineering projects. In fact sometimes the classification approach serves as the only really practical basis for the design of complex underground rock engineering projects. During the recent past, construction contracts have incorporated a rock mass classification as a part of the preliminary site investigations (14).

Many rock mass classification systems have been proposed from different civil engineering projects, reflecting the specific nature of the site. The Terzaghi rock load classification (15), dominant in the USA for over 35 years, is basically

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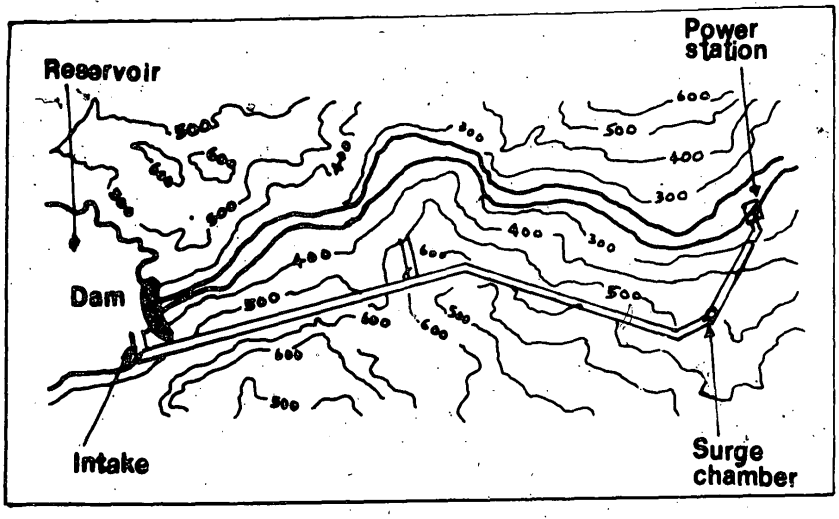

FIG. 1. (i) PLAN OF VICTORIA PROJECT TUNNEL

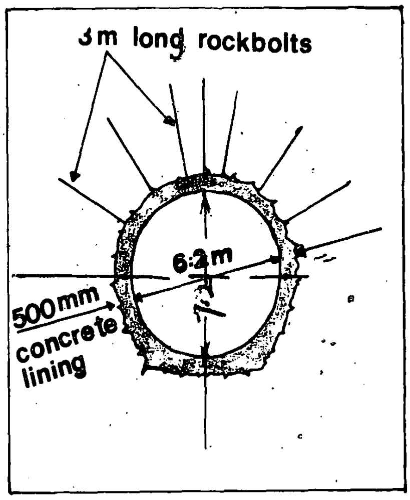

FIG. 1. (ii) CROSS SECTION THROUGH POWER TUNNEL

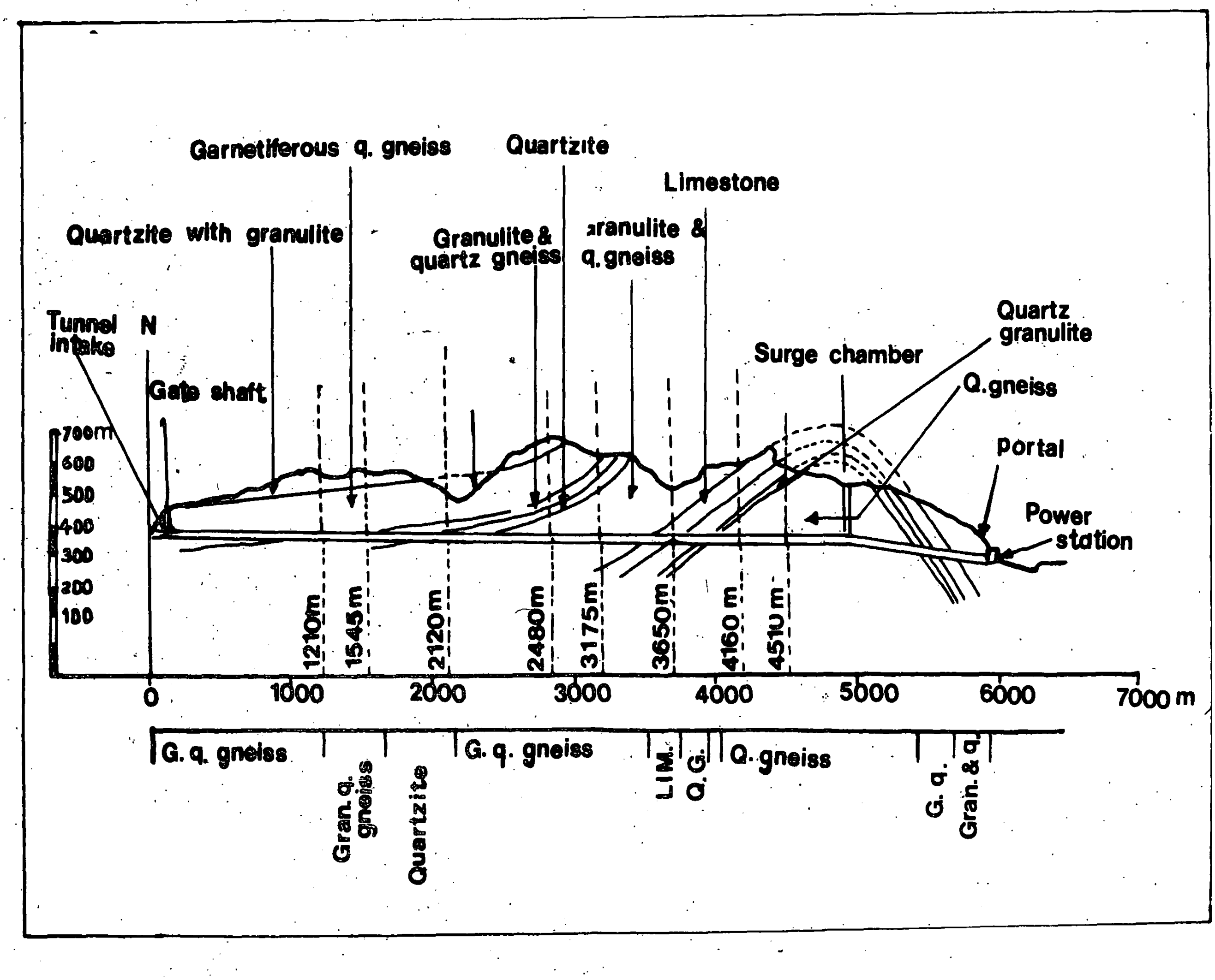

FIG.1. (iii) LONGITUDINAL SECTION OF VICTORIA PROJECT TUNNEL

applicable to tunnels with steel supports and not suitable to modern tunnelling methods using shotcrete. The concept of "stand up time" of an unsupported span proposed by Lauffer (16) was a considerable step forward in the development of rock mass classification systems (5). Deere's simple but practical approach, in relating RQD to support, added a new thought, but it desregarded the other important rock parameters which effect the rock mass stability (17). Many authors found that RQD is the best single parameter to describe a rock mass but it can be considerably improved if other factors are taken into consideration.

The use of a single rock parameter to explain the behaviour of the rock mass surrounding an excavation has been inadequate. Accordingly Geomechanics classification, NGI classification and Laubscher's modified Geomechanics classification incorporate the best aspects of previous classification and principal rock material and mass parameters. The rock mass conditions of Victoria project were analyzed using these three systems which have been widely used all over the world in civil and mining engineering projects.

Geomechanics Classification System

Geomechanics classification proposed by Bieniawski (12) of the South African Council for Scientific and Industrial Research (CSIR) included the strength of intact rock material, Rock Quality Designation (RQD), spacing of joints, condition of joints and Ground water condition. Bieniawski recognised that each parameter does not necessarily contribute equally to the behaviour of the rock mass. For example an RQD of 90 and a uniaxial compressive strength of intact rock material of 200 MPa would suggest that the rock mass is of excellent quality, but heavy inflow of water into the same rock mass could change this assessment dramatically. Five parameters are grouped into five ranges and points or ratings are allocated to each range of values for each parameter and an overall rating for the rock mass is arrived at by adding the ratings for each of the parameters. This overall rating must be adjusted for joint orientation by applying the corrections as given by Bieniawski (12). According to Geomechanics classification rock mass can be classified into one of the five classes. The final output from the Classification is the stand-up time of an unsupported rock span for given rock mass rating and support estimations.

NGI Tunnelling Quality Index (Q)

Barton, Lien, Lunde of the Norwegian Geotechnical Institute (NGI) proposed an index for the determination of the quality of the rock mass. The numerical value of this index Q is defined by,

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF} \qquad (1)$$

Where RQD - Rock quality designation, Jn-joint set number, Jr-joint roughness number, Ja - joint alteration number, Jw - joint water reduction factor and SRF - Stress reduction factor.

The six parameters are grouped into three factors of engineering significance.

1. RQD/Jn represents the overall structure of the rock mass and also found to be a measure of block size.

ii. Jr/Ja is a measure of roughness and degree of alternation of the joint walls. Approximately Tan^{-1} (Jr/Ja) is equal to the shear strength of joint.

iii. Jw/SRF is a measure of active stress with Jw representing water pressure which has an adverse effect on the shear strength of joints due to reduction in effective normal stress.

A large amount of information is included in several tables by Barton et el(2-4), to obtain parameters in the equation No. 1. For example a rock mass consisting of two joint sets has Joint set number (Jn) 2 and Joint roughness number (Jr) for a smooth undulating joint is 2. Similarly many possible combinations of properties of joints have been included with suitable ratings. Q value is dervied by substituting suitable ratings obtained from Tables with respect to the rock mass properties.

In order to relate the rock mass quality Q, to the behaviour and support requirements of an underground excavation, a quantity called equivalent dimension De is defined as;

$$De = \frac{\text{Excavation span (Diameter or height)}}{\text{Excavation support ratio (ESR)}}$$

The ESR is related to the use for which the excavation is intended and the extent to which some degree of instability is acceptable (2-4).

Support recommendations are given in 38 categories and the total number of rock masses defined in this classification exceeds 300,000 (3).

Laubscher's Modified Geomechanics classification

The classification system is basically that of Geomechanics classification but rigorous modifications were proposed on the method of determining rock mass parameters and ratings (5). The rock mass parameters used in the classification are RQD. Intact rock strength, Joint spacing, condition of joints and Ground water. The approach is that the rock mass is assigned an in-situ value regardless of its position in space, provided the stress environment does not exceed 30 Mpa. A Graph has been given to obtain ratings for multijoint systems. In-situ rating for the rock mass is obtained in a manner similar to that of Geomechanics clasification. But the total rating obtained by summing up individual ratings is adjusted with respect to adverse conditions and effects. Thus adjusments to the In-situ rating is made on account for weathering, field and induced stresses, changes in stresses due to mining, strike and dip orientation and blasting effects. The adjustment percentages are given in different tables (5). Accordingly adjustment percentage for smooth wall blasting is 97% and for poor conventional blasting 80%. The In-situ rating is adjusted according to the above variations and the adjusted rating is obtained. Laubscher has established support recommendations in relation to In-situ ratings and adjusted ratings (5).

Use of Rock Mass Classifications for Estimating Support

An alternative to the theoretical approach to rock support, is to use experience as a basis for the estimation of support requirements. The classification systems discussed above based on studies made on different parts of the world. The support recommended by Bieniawski is basically for civil engineering tunnels of approximately 10m span, excavated by drill and blast methods at depths less than 1000m below surface.

NGI classification system is based on the analysis of over 200 case studies. This provides an excellent basis for estimating the maximum unsupported span which could be excavated in a rock mass of known quality (Q). Thus Barton et el established,

$$\text{Span} = 2\ \text{ESR} \times Q^{0.4}$$

Where ESR = excavation support ratio depend on the nature of the opening.

Q = Rock mass quality.

Bieniawski also established a relationship between Erock mass/Erock material ratio and rock mass rating (where E is the modulus of deformation). This enables one to estimate the modulus of deformation of rock mass, knowing only the modulus of deformation of rock material which can be obtained from Laboratory testing.

The NGI classification system can be applied to highly stressed rock masses too and hence the provision of applying it to near surface or very deep exavation is available. Barton et al pointed out that there are over 300,000 different geological combinations that can be represented with NGI system. According to Hock and Brown (21), this degree of refinement is not justified and that tends to distract from the main purpose for which the classifications are developed, i.e. to provide general guidance to the engineering feasibility studies when detailed exploration is not possible.

The modified geomechanics classification proposed by Laubscher, provides a means of applying the approach to mining situations. The bolt patterns recommended by Laubscher, bear directly on the cavability and fragmentation of the rock mass and are used to assess whether the cave mining method can be employed. The adjusted rock mass rating of hanging wall and the ore body are used to propose the cavability and the fragmentation. The angle of cave, the extent of failure zones and pit wall angle in open cast mines are also recommended on the basis of in-situ and adjusted ratings.

Geotechnical Factors Considered important for the Classification Systems

Regional Stresses

The magnitude, and the direction of regional stresses are significant for the assessment of rock conditions for mining, and civil engineering construction. The stresses in an area are a result of geological history. When an excavation is made in rock, stress changes take place. These changes are more significant in mining operations and induced stresses in tunnelling can have an influence on the condition of joints by keeping the joints in compression, by increasing the possibility of shear movement or by allowing joints to open. When dealing with small tunnels, stresses are insignificant for rock mass classifications except, in the case of mining situations.

Shear movements and open joints were visible along the tunnel in Victoria Project. Stresses were calculated on the basis of depth and the density of rock. Stresses were not very high since the maximum depth of the tunnel from the surface was less than 300m.

Intact Rock Strength

If the discontinuities in a rock mass are widely spaced or if the rock is weak or altered, the properties of the intact rock may influence the behaviour of the rock mass. The properties of the rock material influence the behaviour of the discontinuities whose characteristics depend on rock material as well as their geometry. Therefore the rock material strength should be considered in assessing the rock mass condition (18).

The uniaxial compressive strength can be measured by standard laboratory tests or estimated from the point load test. Different forms of point load strength indices have been proposed by Franklin (19) and Brook's (20). Franklin's I_s (50) requires 50 mm diameter cores whilst Brook's T_{500} requires chisel cut or machine cut specimens of $500 mm^2$ cross sectional area. It is observed when testing strong rocks for I_s (50), rock near the loading points chips off and hence requires a large number of specimens to get consistent results. But testing as suggested by Brook (20), gives a clear tensile fracture across the loading points. Sample collection and testing is easier for the T_{500} test as the specimen size is smaller. Furthermore it has the advantage that T_{500} tests can be carried out in natural moisture content with chisel cut specimens.

Rock of different strengths were observed along the tunnel.

eg. Limestone = 70MPa, Gneiss = 150MPa

The influence of other parameters on the different rock types with same joint spacing differ greatly.

Rock Quality Designation (RQD)

The concept of rock quality designation (RQD) was proposed by Deere (17). The RQD is a quantitative index based on a core recovery procedure in which the core recovery is determined incorporating only those pieces of hard, sound core which are 100 mm or greater in length.

Hence;

$$RQD\% = \frac{(\text{length of core pieces 100mm}) \times 100}{\text{length of core run}}$$

It has been found that the RQD is useful in classifying rock masses for the selection of tunnel support systems. (17).

Joint sets with different spacings occur along the Victoria tunnel and hence different Rock quality designation (RQD) values were anticipated.

Weathering

Due to long term water flow, certain rock types whether rapidly and this aspect is important when deciding support systems.

Weathering affects rock strength, RQD and condition of joints. Rock strength will decrease slightly if weathering takes place along microstructures. The RQD percentage can be decreased by an increase in fractures as the rock weathers. The main influence of weathering is on the condition of the joints by alteration, either of the joint wall rock or the joint filling.

Rocks along the Victoria tunnel have under-gone different degree of weathering. Same rock was found to be un-weathered or moderately weathered in different places and hence weathering is a key factor in excavation and designing of tunnels supports.

Discontinuities

Any break in the rock mass is termed a discontinuity, and it may be a joint, fault or a bedding plane. The presence of discontinuities greatly affects the rock mass condition; and the location of discontinuites in relation to the engineering structures, the orientation, the frequency and the infilling materials are important. The importance of joint orientations in assessing rock mass conditions has been discussed by many authors (1-5).

Discontinuities with different infilling materials, thickness and spacing were observed in the Victoria tunnel. Discontinuity intersections have called for individual consideration due to formation of potentially dangerous blocks.

Ground Water

Ground water has numerous detrimental effects on the properties of rock material and rock masses. Water reduces the shear strength of joints and exerts "Pore Pressure" on the lining of an excavation. In addition to the uplift effect on slopes, the presence of tension cracks increases the degree of instability. Gradual transformation of rock mass properties, through hydration, swelling, erosion or solution can take place. The rock mass permeability and the rate of water flow into the opening are important to note.

In general, Victoria Tunnel was dry except in cases where highly weathered rock associated with ground water created serious problems. This resulted in outfall tunnel collapse forcing the engineers to re-align the tunnel.

Field Study Procedure

The site investigation was carried out in the Victoria project for over a period of 6 months and during the field work exposed tunnel sections and tunnel sections and tunnel faces after blasting were logged. The structural regions of the tunnels with significant differences in lithology, weathering rock mass structure or water seepage etc were identified and studied separately.

A steel tape was stretched along the wall and intersected discontinuities were recorded with their characteristics. Blasting induced fractures were carefully avoided.

The observations were recorded in a tabular form as discontinuity location, dip and dip direction, characteristics and water flow. The intact rock strengths were determined by selected samples from each structural region. At least 8 samples were colected and tested on the point load tester.

The field data collected by logging over 200m of the tunnel length were summarized into input data sheets as suggested by Bieniawski (2). These input data sheets consist of parameters pertaining to the different structural regions identified on the basis of lithology, weathering, rock mass structure or water seepage etc. The parameters included in the data sheet were RQD, strength of intact rock, degree of weathering, number of joint sets and their spacing, condition of joints and dip and dip directions of joint sets. It was convenient to obtain values of parameters from these sheets for the analysis of rock mass conditions of each structural region. (Table 1)

Analysis of results

Rock masses were assessed according to the geomechanics classification (RMR), the NGI system (Q) and Laubscher's modified geomechanics classification. Table 2 was obtained by the procedure described in section 1.2. Details of the procedure may be found else where (1,3,5). Table 3 shows the support estimations derived on the basis of rock mass classifications and actual support installed. It is evident that in most cases the support estimated from the Q system is too daring and that from Geomechanics classification is most conservative.

Very often support estimations from the modified geomechanics classification closly agreed with the actual support installed. When dealing with weathered rock masses, the supports derived from the modified geomechanic classification system seem more realistic.

The plot of RMR Vs lnQ gives an equation of; RMR = lnQ + 40.6 as compared to Bieniawaski's RMR =9 lnQ + 44 (2). Bieniawski obtained the corelation from over 100 case studies and hence his equation seems more appropriate to use.

Conclusions

The qualitative descriptions of rock masses by different rock mass classifications are similar but the support recommendations differ. The complex geotechnical parameter combination proposed by Barton does not provide an improved support recommendation over the other systems investigated. The support derived from the Q system is too daring while that from geomechanics classification is most conservative.

Laubscher's modified geomechanic classification predicts support very close to what is actually required. This trend is similar in different sites studied.

When dealing with weathered and wet rock conditions, Laubscher's modified geomechancis classifications seem very appropriate. The adjustments proposed by Laubscher for the in-situ rating make a distinction between his system and the other systems studied.

The RMR value of the geomechanics classification lies between In-Situ rating and Adjusted Rating of Laubscher's modified system. This indicates that the adjustment proposed by Laubscher gives a refinement to the RMR value.

The reason rock mass classifications which were under investigation incorporate RQD and joint spacing as two separate rock mass parameters. It is obvious however, that both RQD and joint spacing are two parameters describing the frequency of discontinuities in a rock mass. It is worth considering whether the inclusion of RQD and joint spacing as two separate parameters in a classification is justified.

Furthermore, RQD may mislead workers in cases where the rock core consists of pieces all just above 100 mm or all just below 100 mm. One may argue that these are two exceptional cases but it is interesting to note that the former gives RQD of 100% while latter gives RQD of 0, although the rock mass conditions in both cases may be almost the same.

Suggestions for further work

To ascertain the validity of support estimation from different classifications these should be installed in different sections of a tunnel and there performances studied. It is important that selected tunnel sections are similar in rock mass conditions. Further it must be observed over a certain period, possibly a few years, to investigate the long turn stability. This could be supported by convergence measurements of unsupported tunnel sections.

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Appendix 1 - Abbreviations

R - Rough
SR - Slightly Rough
S - Smooth
C - Continuous
NC - Not Continuous
HW - Hard Wall
SW - Soft Wall
WG - With Gouge
NG - No Gouge
Uw - Unweathered
Sw - Slightly Weathered
Mw - Moderately Weathered
Hw - Highly Weathered
G.gua.gneiss - Garnetiferous quarts gniess
Utg - Untensioned grouted
tg - tensioned grouted

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Table 2

Rock Mass ratings from different classification systems

No.	Q	CSIR	Laubschers's System	
			Insitu rating	Adjusted rating
1	25	72	71	58
2	297	84	86	75
3	21	62	72	46
4	15	53	66	45
5	2	33	54	23
6	711	92	84	71

Table 1

Geotechnical Parameters on different Rock Masses

No.	Rock Type	RQD%	IRS (MPa)	Joint Spacing (m)	Joint Condition	Infilling type and Thickness	Ground Water
1.	Quartzite	98	166	.52/.6/1.9	R/C/HW/NG	$<$ 0.1mm open Stains only	Moist only
2.	Uw.G.qua. gneiss	99	146	1.5 + Random	R/C/WH/NG	$<$ 0.1mm open Stains only	Dry
3.	Sw.G.qua. gneiss	98	153	.66/.73 + Random	S/C/SW/W	1mm sheared rock	Moist only
4.	Mw.G.qua. gneiss	60	152	.39 + Random	S/C/SW/WG	1-2 mm sheared rock	Moist only
5.	Hw.G.qua. gneiss	52	152	.45/0.5 + Random	S/C/SW/WG	2-5 mm sheared rock	Moist only
6.	Limestone	100	70	Random only	R/NC/HW/NG	tightly healed	Dry

(see Appendix 1 for abbreviations)

Table 3

Support Predictions and Actual Support

No	Rock Type	CSIR (RMR)	NGI (Q)	Laubscher's System	Actual support
1	Quartzite	3m long, 2.5m spaced bolts in crown with occasional wire mesh and 50mm shotcrete as required	No support required	Generally no support but locally joint intersections might require bolting	Patterned grouted bolts at 1-1.5 m spacing
2	Uw.G.qua. gneiss	No support except spot bolting	No support required	No support required	Patterned grouted bolts at 1-1.5 m spacing
3	Sw.G.qua. gneiss	3m long, 2.5m spaced bolts locally in crown, occasional wire mesh	No support required	Patterned grouted bolts at 1 m spacing	Patterned grouted bolt at 1m spacing
4	Mw.G.qua. gneiss	4m long. 1.5-2m spaced bolts, shotcrete 50-100 mm on crown and 30 mm on sides	Bolts (Utg) 1m spacing shotcrete 20-30 mm	Patterned grouted bolts at 1m spacing	Patterned grouted bolts at 1m spacing, occa. wire mesh
5	Mw. G.qua.gneiss	4-5 long, 1-1.5m spaced bolts with wire mesh, shotcrete 100-150mm on crown 100mm on sides	Bolts (tg) 1-1.5m long and wire mesh, 150mm shotcrete	Patterned grouted bolts at 0.7m spacing 700mm reinforced concrete or yielding steel arches	Steel arches at 1m spacing with lagging
6	Limestone	Spot bolting	No support required	No support required	Patterned grouted bolt at 1m spacing