Implementation of GPAC Software on the Calculation of Geotechnical Indices in the Mining Environment

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Summary: Newly developed geotechnical logging software GPAC automates the calculation of geotechnical indices (Rock Quality Designation RQD, Rock Mass Rating RMR, Quality Index Q and Coal Mine Unit Rating CMUR) in a fraction of the time that manual calculation previously required, along with a higher degree of accuracy and standardisation and the removal of errors associated with data entry and calculation.

This paper will provide an overview of the computation of RQD, RMR, Q Index and CMUR. These geotechnical factors are of major importance to the coal mining industry, but are also widely used in other civil engineering and mining industries worldwide. In addition, a case study will present a comparison of the new automated GPAC calculated values with the traditional manually calculated values. The computation assists with modelling and with eliminating the personal rating variance in rock mass characterization. The application of the GPAC program will provide engineers and geologists with quick, efficient and reliable data for use in the planning stage of mines. GPACs computed indices are a step forward in the geomechanics industry ensuring that the engineers and geologists can fully and effectively utilise the results that are investigated.

INTRODUCTION

GPAC (Geological Plotting and ASCII Collection) software is a logging system, database and automated geotechnical index calculator. Calculation of geotechnical indices is fully automated which provides a standardised methodology and an increase in accuracy. The paper provides an overview of GPAC computation for the geotechnical indices RQD, RMR, CMUR and Q index. The software is designed to calculate indices in a manner similar to manually calculated values, which provides an easy to understand and follow methodology.

A comparison is presented in order to show the correlation of manually calculated indices with GPAC computed indices. RQD, RMR, CMUR and Q index are examined from 720m of core supplied by Mine A in the Bowen Basin. The benefits of automatic calculation can be shown through time saving, decrease in errors and a simple output to be used in modelling of ground conditions. These values provide data that can be used in the mining development stage ensuring safer and more productive workings.

ROCK MASS CLASSIFICATION

Rock Quality Designation RQD

RQD was originally designed as an indictor of rock condition for civil engineering design purposes. Created in 1967 by Deere *et al*, it is now one of the most common rock mass classification systems used world wide in the mining and civil industry. The calculation of RQD is simply the total length of core pieces greater than or equal to 100 mm in length divided by the core run length (usually 1.5m to 3m). (AS 1726, 1993). The Rock Quality Designation number is used as a parameter in all other classification systems explained in this paper.

Rock Mass Rating RMR

Rock Mass Rating RMR was created in 1976 by Bieniawski to be used as an additional tool for tunnel design in civil engineering. Since this time the Australian mining and civil industries have adopted this tool to use as an indicator of ground condition in underground workings. The Rock Mass Rating system is based on five parameters, each given a weighted percentage based on their influence on the rock mass unit. The RMR is expressed as a percentage calculated from the sum of these parameters, Rock Substance Strength + RQD index + Joint Spacing + Joint Condition + Groundwater. There is a rating in place for discontinuity and tunnel orientation but it is not used in GPAC. It could be applied at a later stage in the mining process.

Coal Mine Roof Rating CMRR and Coal Mine Unit Rating CMUR

The Coal Mine Roof Rating was created by Mark and Molinda, NIOSH (American National Institute of Safety and Health) in 1994 to ensure that layered sedimentary rock was taken into account in classification systems. The stratigraphic factors that the coal industry faced with a layered mine roof meant that a rating system needed to be created to address the bedded sedimentary rocks and concentrate on the bolted interval and its ability to form a stable mine. CMRR identifies these stratigraphic factors and weighs them against their influence on the rock mass unit.

The Coal Mine Roof Rating and CMUR can be determined from underground mapping or from core. The later method is used in GPAC. The CMUR is calculated from the parameters of RQD, fracture spacing, diametral strength and uniaxial compressive strength (UCS). In the GPAC program the Coal Mine Unit Rating is calculated for each individual rock mass unit whereas the Coal Mine Roof Rating is calculated for the borehole. The CMUR indicates the relative strength of the individual units, which then determines a CMRR over a nominated bolted roof horizon rating on a scale from 0 to 100.

Norwegian Tunnelling Quality Index Q

The Tunnelling Quality Index was created to assist the civil tunnelling industry and has also been adopted by the Australian mining and civil industries. Created in 1974 by Barton, it provides an indication of rock mass unit conditions. When used alone or in conjunction with the other rock mass classification systems it presents a very good impression of the rock conditions. The calculation of Q involves the determination of six parameters, (RQD/Joint Set Number) * (Joint Roughness/Joint Alteration) * (Joint Water Factor/Stress Reduction Factor).

AUTOMATION OF GEOTECHNICAL INDEX CALCULATIONS USING GPAC

Rock Quality Designation RQD and Fracture Spacing

When determining RQD in GPAC the mid-points of discontinuities are used to calculate the length of core piece. The software is programmed to ignore drill induced and cemented defects ensuring that the number is the same as would be calculated in the field by the geologist. The user is required to record core loss and crushed zones in the defect entry panel so that all values are taken into consideration in the determination of the rock quality designation. The RQD value is calculated per core run, or per rock mass unit.

Fracture Spacing is used in RMR and CMUR. The average fracture spacing is computed for each rock mass unit (RMU). GPAC treats the From and To depths of the RMU as discontinuities for the calculation. In Figure 1 the Fracture Spacing = (a+b+c)/3

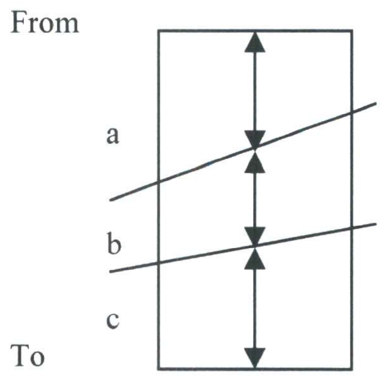

Figure 1. GPAC calculation of Fracture Spacing

Rock Mass Rating RMR

Rock mass parameter ratings are determined from the original RMR tables. GPAC doesn't calculate RMR on a sliding scale. When GPAC has calculated the parameters needed for Rock Mass Rating the computer then compares these numbers to the appropriate rating in Table 1. Below are descriptions of methods used by GPAC to calculate the RMR parameters.

- Rock Quality Designation - GPAC calculates RQD using a weighted average over the RMU.
- UCS - Values for the uniaxial compressive strength are computed from laboratory test data, point load test data, sonic derived UCS and field strength estimates. The program seeks the required data set and if

it does not exist it moves onto the next data set. GPAC determines the weighted average UCS for a RMU and from this number the UCS rating is determined.

- Fracture Spacing/Spacing of Discontinuities - The methodology for computing fracture spacing has been described above. Once this number has been calculated the fracture spacing rating is determined from Table 1.
- Ground Water - The Ground Water Condition is entered for each RMU and the rating is taken from Table 1.
- Joint Condition - In order to obtain a single value for a RMU the lowest rating that is recorded from each component of joint condition is added together.

Table 1. Rock Mass Ratings Calculated by GPAC

RQD	90<RQD≤ 100	75<RQD≤ 90	50<RQD≤ 75	25≤RQD≤50		25>RQD	
Rating	20	17	13	8		3	
UCS MPa	250<UCS	100<UCS≤ 250	50<UCS≤ 100	25<UCS≤ 50	5<UCS≤25	1<UCS ≤5	1≥UCS
Rating	15	12	7	4	2	1	0
Fracture Spacing m	2<FS	0.6<FS≤2	0.2<FS≤0.6	0.06<FS≤0.2		0.06≥FS	
Rating	20	15	10	8		5	
Ground Water	CD-Dry	DA-Damp	W-Wet	DR-Dripping		FL-Flowing	
Rating	15	10	7	4		0	
Joint Condition							
Extent m	1>E	1≤E≤3	3<E≤10	10<E≤20		20<E	
Rating	6	4	2	1		0	
Separation	0	0<S<0.1mm	0.1≤S≤1mm	1<S≤5mm		5mm<S	
Rating	6	5	4	1		0	
Roughness	VR-Very Rough	RR-Rough	SR-Slightly Rough	SS-Smooth		SL-Slickensided	
Rating	6	5	3	1		0	
Infill Thickness	0	0<T<5mm	5mm≤T	0<T<5mm AND infill type is CL (clay)		5mm≤T AND infill type is CL (clay)	
Rating	6	4	2	2		0	
Weathering	Fresh	Slightly Weathered	Medium Weathered	Highly Weathered		Extremely Weathered	
Rating	6	5	3	1		0	

Coal Mine Unit Rating CMUR

GPAC calculates a coal mine rating for each rock mass unit. This number provides an indication of the strength of the unit. The GPAC methodology for calculating CMUR involves the summation of Discontinuity Rating, Unit Strength Rating, Moisture Sensitivity Deduction and Slickenside Deduction. GPAC uses the latest equations, in metric units, from NIOSH.

- Discontinuity Spacing Rating - The weighted RQD and fracture spacing (FS) are used in the discontinuity spacing rating. GPAC must determine which rating is the correct to use for the CMUR from Table 2.
- Diametral Point Load Test (PLT) Rating - The Diametral Strength rating is determined from Table 2. Diametral strength can only be obtained by diametral point load testing which gives a Is(50) MPa value. The Is(50) value is taken as a weighted average of interpolated midpoint values of diametral test data for each rock mass unit.
- The Discontinuity Rating is defined as the lower of the Diametral PLT rating or the Discontinuity Spacing Rating.
- Unit Strength Rating - The UCS is used to determine the unit strength rating. The UCS is the weighted average for the RMU. GPAC calculates the UCS using laboratory test data, point load test data, sonic derived UCS and lastly field strength estimates. Once the UCS is determined the rating is calculated from the equations in Table 2.

- Moisture Sensitivity Deduction - The Moisture Sensitivity should be determined from the immersion test (explained in Mark & Molinda, 1994). Moisture Sensitivity is calculated for each RMU.
- Slickensided Defects - In GPAC a -5 deduction is in place if there are any slickensided defects in a RMU. This deduction was based on correspondence with Mark and Molinda (pers.comm).

Table 2. Coal Mine Unit Ratings Calculated by GPAC

Metric Specification	**Formula to use**
FS<63.5mm or RQD<50	RQD
63.5mm≤FS≤203.2mm and 50≤RQD≤90	Minimal rating of RQD or FS
RQD>90 or 203.2mm<FS≤1219.2mm	Minimal rating of FS or DS
1219.2mm<FS	DS
Fracture Spacing Rating	5.64 * ln(FS) + 5.8
RQD Rating	10.5 * ln(RQD) - 11.6
RQD Rule: If RQD rating is less than or equal to 20, RQD rating equals 20	
Diametral PLT Rating Formulas	**Rating**
Is(50)<0.239MPa	25
0.239MPa<Is(50)<1.296MPa	20 + 20.88 * Is(50)MPa
1.296MPa<Is(50)<2.151MPa	27.5 + 15.08 * Is(50)MPa
2.151MPa<Is(50)	60
Unit Strength Rating Formulas	**Rating**
UCS<34.48MPa	5 + 0.218 * UCS
34.48MPa≤UCS≤147MPa	7 + 0.157 * UCS
147MPa<UCS	30
Moisture Sensitivity Deduction	**Rating**
N-Not Sensitive	0
S-Slightly Sensitive	-3
M-Moderately Sensitive	-7
V-Severely Sensitive	-15

Norwegian Tunnelling Quality Index Q

The Q index involves intensive programming in GPAC. This section will attempt to summarise the rules that the program follows.

RQD - The simplest parameter of Q index uses the direct weighted RQD value for the RMU. If the RQD is less than or equal to 10%, then 10 is used.

Joint Set Number Jn - GPAC has to determine the joint set number. In order to accomplish this, the program separates the defect type, surface type and dip direction. Defect types are bedding, joints, faults, shears and crushed zones. Any slickenside defect is given extra weighting by being separated out as a joint set. Defects within 10 degrees of each other are considered a joint set.

Table 3. Joint Set Number Jn

Joint Set Number	**Jn Rating**	**GPAC rule**
Massive	0.5	No joints present
Few joints	1	1-3 defects (differing angles) present in entire RMU (bedding or joint defect types only)
One joint set	2	
One joint set plus random	3	
Two joint sets	4	
Two joint sets plus random	6	
Three joint sets	9	
Three joint sets plus random	12	
Four or more joint sets, heavily jointed	15	
Crushed rock, earthlike	20	75-100% of unit is crushed

Joint Roughness Number Jr - The joint set or random joint with the lowest joint roughness number is used in the Q index equation.

Table 4. Joint Roughness Number Jr

Joint Roughness Number	Jr Rating	GPAC rule
Discontinuous joints	4	If there are less than 3 joints in RMU with extent <0.5m or if no joints present
Rough and undulating or irregular	3	Rough, very rough and undulating or irregular
Smooth and undulating or irregular	2	Smooth, slightly rough and undulating or irregular
Slickenside and undulating or irregular	0.5	Slickenside and undulating or irregular
Rough and planar	1.5	Rough, very rough and planar
Smooth and planar	1.0	Smooth, slightly rough and planar
Slickenside and planar	0.5	Slickenside and planar
No rock wall contact across gouge	1.0	If separation <1mm

Joint Water Factor Jw - The ground water condition is recorded for each RMU and GPAC gives a rating based on the following table:

Table 5. Joint Water Factor Jw

Joint Water Factor	Rating Jw	GPAC rule for Ground Water Condition
Dry or minor inflow	1.0	CD-Completely dry
Medium inflow	0.66	DA-Damp
Large flow in sound rock	0.5	W-Wet
Large flow washing out joint infills	0.33	DR-Dripping
Very high flows	0.125 (mid-point)	FL-Flowing

Joint Alteration Number Ja - The joint set or random joint with the highest joint alteration number is used in the Q equation.

Table 6. Joint Alteration Number

Joint Alteration Number	Ja Rating	GPAC rule (Infill type)
Rock wall in contact		Infill thickness <1mm
Tightly healed hard, non softening impermeable filling	0.75	CE
Unaltered joint walls, surface staining only	1	OP, ST
Slightly altered joint walls, non softening mineral coatings, sandy particles, clay-free disintegrated rock	2	CD, CA, FE, QU, MN, PY, CB
Silty or sandy clay coatings, small clay-fraction (non-softening)	3	CS, SA, CT
Softening or low-friction clay mineral coatings, i.e. kaolinite, mica also chlorite, talc, gypsum and graphite etc and small quantities of swelling clays (discontinuous coatings, 1-2mm or less)	4	CL, CH, LI, CO
Rock Wall Contact before 10cm shear		Infill thickness <5mm
Sandy particles, clay free, disintegrating rock	4	SA,CA,FE,QU,MN,PY,CB
Strongly over-consolidated, non-softening clay mineral fillings (continuous <5mm thick)	6	CS, CT
Medium or low over-consolidation, softening clay minerals (continuous <5mm thick)	8	CH, LI, CO
Swelling clay fillings ie montmorillonite (continuous <5mm thick)	10	CL
No rock wall contact when sheared		Infill thickness >5mm
Sandy particles, clay free, disintegrating rock	6	SA,CA,FE,QU,MN,PY,CB
Thick continuous zones or bands of clay	11.5 (mid-point)	CL, CS, CT, CH, LI, CO

open	stained	Coated	cemented	calcite	iron oxide	quartz	chlorite	manganese
OP	ST	CD	CE	CA	FE	QU	CH	MN
pyrite	limonite	Coal	clay stiff	clay sandy	carbonaceous	breccia	clay soft and swelling	
PY	LI	CO	CT	CS	CB	SA	CL	

Stress Reduction Factor SRF - The Stress Reduction Factor is determined from a number of factors in GPAC. The table shows the rules that GPAC follows to establish the SRF.

Table 7. Stress Reduction Factor

Stress Reduction Factor		SRF	GPAC rules
Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated			
Multiple occurrences of weakness zones containing clay, very loose surrounding rock (any depth)		10.0	If infill type is CS, CT, CL, CH, LI, CO and 9≤Jn<15
Multiple shear zones in competent rock (clay free) loose surrounding rock (any depth)		7.5	If infill type is OP,ST,CD,CE,CA,FE,QU, MN PY,CB, SA and 9≤Jn<15
Single weakness zones containing clay, or chemically disintegrated rock (excavation depth<50m)		5.0	If depth of RMU <50m and infill type is CS,CT,CL,CH,LI,CO and 3≤Jn<9
Single weakness zones containing clay, or chemically disintegrated rock (excavation depth >50m)		2.5	If depth of RMU >50m and infill type is CS,CT,CL,CH,LI,CO and 3≤Jn<9
Single shear zone in competent rock, clay free (depth of excavation <50m)		5.0	If depth of RMU <50m and infill type is OP,ST,CD,CE,CA,FE,QU,MN,PY,CB, SA and 3≤Jn<9
Single shear zone in competent rock, clay free (depth of excavation >50m)		2.5	If depth of RMU >50m and infill type is OP,ST,CD,CE,CA,FE,QU,MN,PY,CB, SA and 3≤Jn<9
Loose open joints, heavily jointed (any depth)		5	If Jn ≥ 15
Competent rock, rock stress problems	UCS/major stress MPa		Only relevant if jointing is minimal Jn<3 and OP,ST,CD,CE,CA,FE,QU, MN,PY,CB,SA
Low stress, near surface	>200	2.5	If UCS >200
Medium stress	200-10	1.0	If 11≤UCS≤200
High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability)	10-5	1.25 (mid point)	If 5≤UCS≤10
Mild rockburst (massive rock)	5-2.5	7.5	If 2.5≤UCS≤4
Heavy rockburst (massive rock)	<2.5	15	If UCS <2.5
Swelling/Squeezing rock, plastic flow of incompetent rock under influence of high pressure or water			
Mild squeezing/swelling rock pressure		7.5	If 8<Ja<10
Heavy squeezing/swelling rock pressure		15	If 10≤Ja

Once GPAC has calculated each parameter for the RMU they are then used in the quality index equation to determine the rock mass ground conditions.

THE IMPLEMENTATION OF GPAC IN THE EXPLORATION AND MINING ENVIRONMENT

As boreholes are logged straight into the GPAC program the time taken to calculate the Geotechnical Indices is negligible. This saves a good deal of time and money since the geologist or engineer is not required to re-evaluate boreholes to determine the rock condition. Coding sheets are programmed into GPAC which disallows any incorrect codes providing a validation process.

GPAC has been tested on boreholes in the Bowen Basin region at several mines, including Mine A. There is a high correlation between GPAC computation and manually calculated indices. Twelve boreholes have been imported into GPAC with core ranging from 90m to 280m. The geotechnical indices were calculated for 720m of core manually and by GPAC. The following graphs show the comparison for RQD, RMR, CMUR and Q.

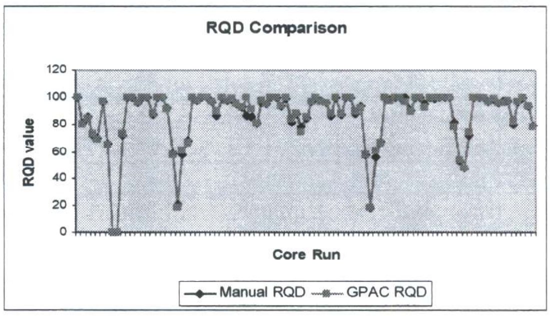

Figure 2. RQD Comparison Graph

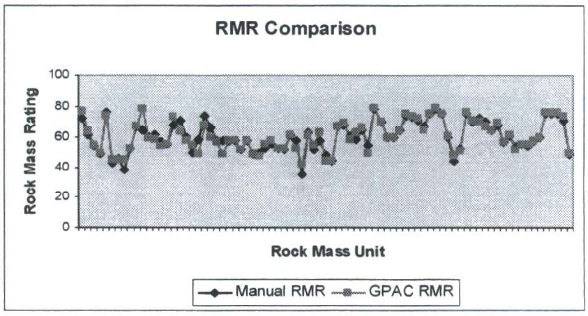

Figure 3. RMR Comparison Graph

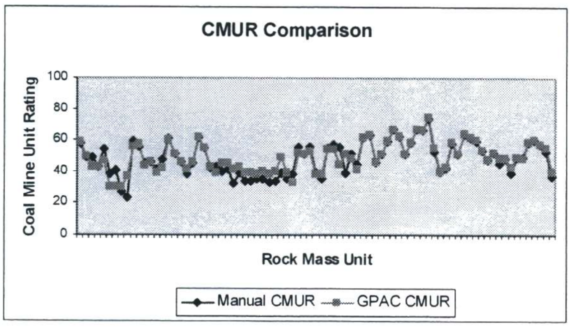

Figure 4. CMUR Comparison Graph

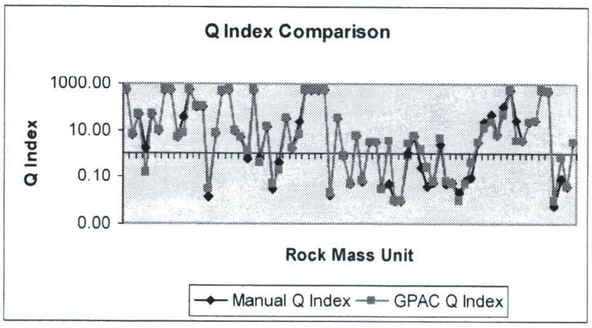

Figure 5. Q Index Comparison Graph

The output, in CSV format, of the geotechnical indices from GPAC allows for easy import into mining software. The information is presented in a format that can be used in modelling for the planning stage of mine development. The geotechnical indices provide an indication of ground conditions which assists engineers with anticipating poor ground where more rock support may be required.

An example of the use of geotechnical indices is contouring CMRR, CMUR, RMR and Q indices for the bolting horizon of a working roof or contouring 1 m of floor below a working section. These contours will provide the development planners with an idea of the ground conditions. This allows for more detailed planning and a decrease in risk of unplanned rock falls.

CONCLUSIONS

The GPAC geotechnical index calculations have been based on how they would be calculated manually. This makes the GPAC geotechnical index process easy to understand. The results from Mine A boreholes have shown that the manually calculated and GPAC calculated values show a strong correlation for RQD, RMR, CMUR and Q index. GPAC standardises the methodology and provides more objective accurate values when compared to people calculating indices. The speed with which the software computes the indices provides not only time saving benefits but also increased accuracy.

The output from GPAC will provide development planners with data that is simple to acquire and model. The geotechnical indices can be contoured on proposed operational areas and demonstrate variable ground conditions and hence ground support requirements.

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