UNISA university of south africa

EXAMINATION PAPER

SUBJECT: CHAMBER OF MINES OF SOUTH AFRICA CERTIFICATE IN ROCK MECHANICS PAPER 3.1 (HARD ROCK TABULAR) **SUBJECT CODE:** COMRME **EXAMINATION DATE:** OCTOBER 2010	**EXAMINER:** Mr. T RANGASAMY **MODERATOR:** Dr. M.K.C Roberts **TOTAL MARKS:** [100] **PASS MARK:** 60%

NUMBER OF PAGES: 9

SPECIAL REQUIREMENTS:

1. **Answer _ALL FOUR_ questions**
2. References other than those provided are not permitted.
3. Hand-held electronic calculators may be used.
4. Put your examination number on the outside cover of each book used and on any graph paper or other loose sheets handed in.

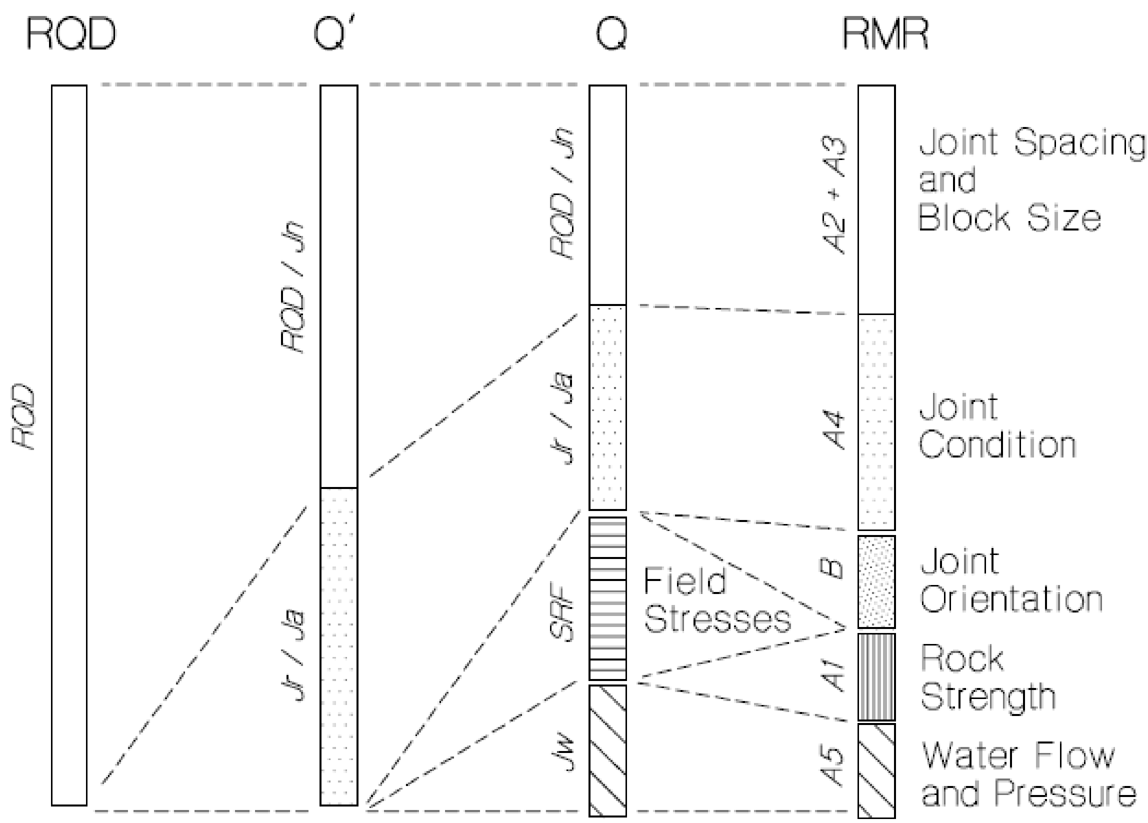
NB: your name must not appear on any answer book or loose sheets.

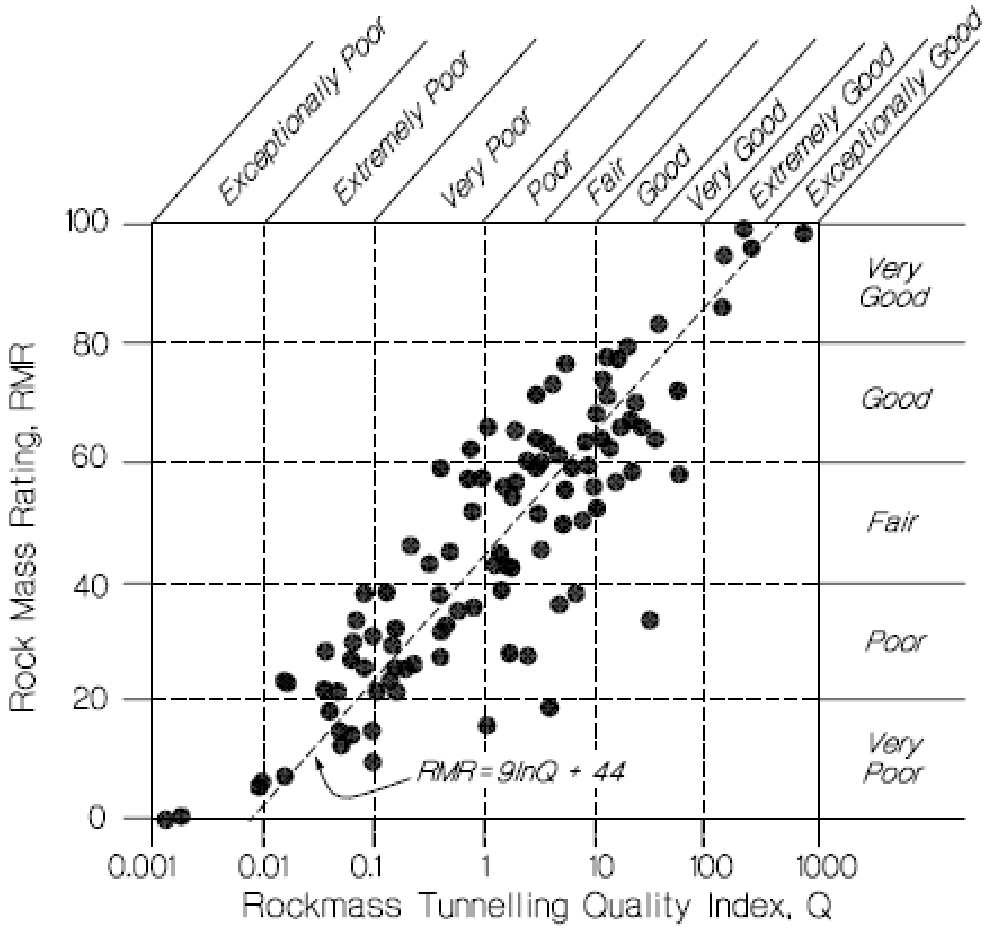
5. **Write in ink on the RIGHT HAND SIDE of the paper only (only the right hand pages will be marked).**
6. Show all calculations on which your answers are based.
7. Illustrate your answers by sketches or diagrams wherever possible.
8. In answering these questions, full advantage should be taken of your practical experience, where appropriate.
9. Answers must be given to an accuracy that is typical of practical conditions, unless stated otherwise.

QUESTION 1

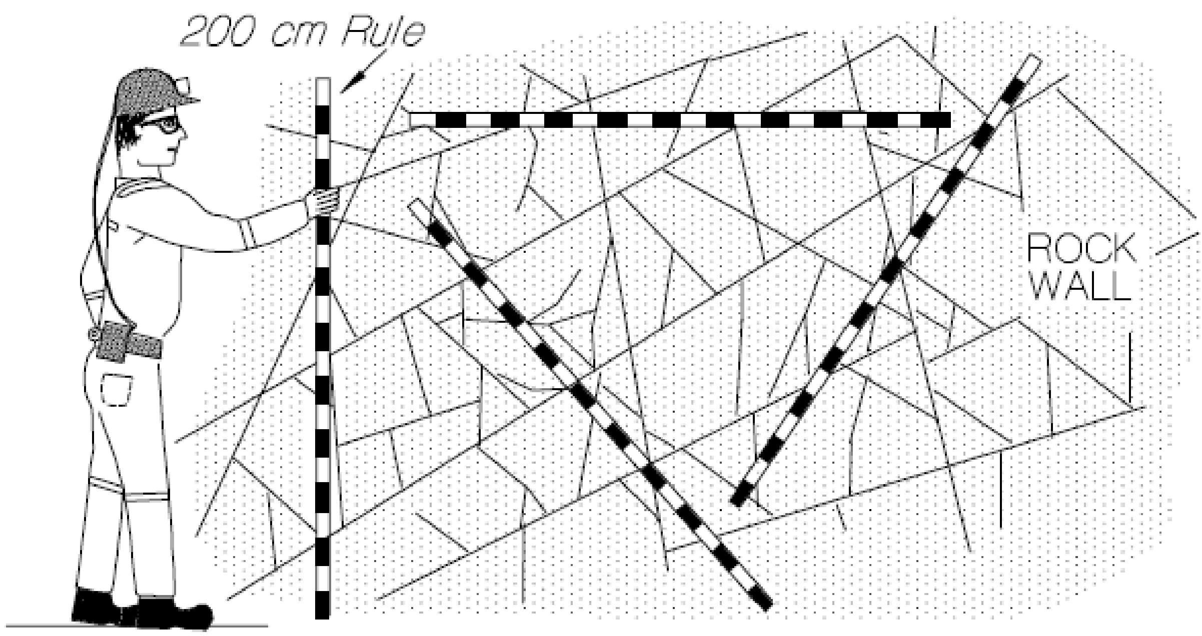
One of the most potentially complex tasks assigned to a Rock Engineer is the determination of representative mechanical properties of a rock mass. While tests have been devised to quantify strength, stiffness and other properties of laboratory rock specimens, it is a much more daunting task to evaluate the quality and expected behaviour of a rock mass in the field. Fortunately, numerous researchers have developed empirical methods to quantify the relative integrity of a rock mass and thereafter to estimate mechanical properties for excavation and support design. Describe the <u>value and limitations</u> provided to you as a practicing Rock Engineer by each of the commonly used empirical classification schemes <u>using the figures, schematics and graphs</u> that are attached below.

(25 marks)

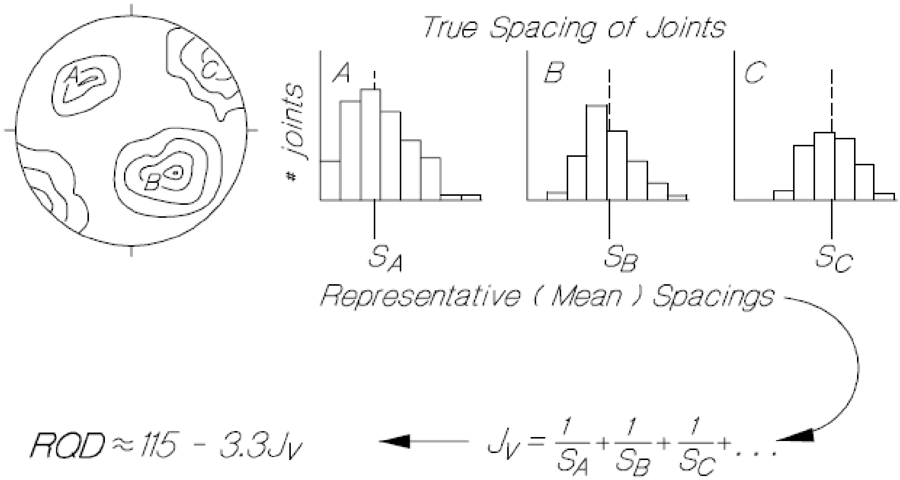




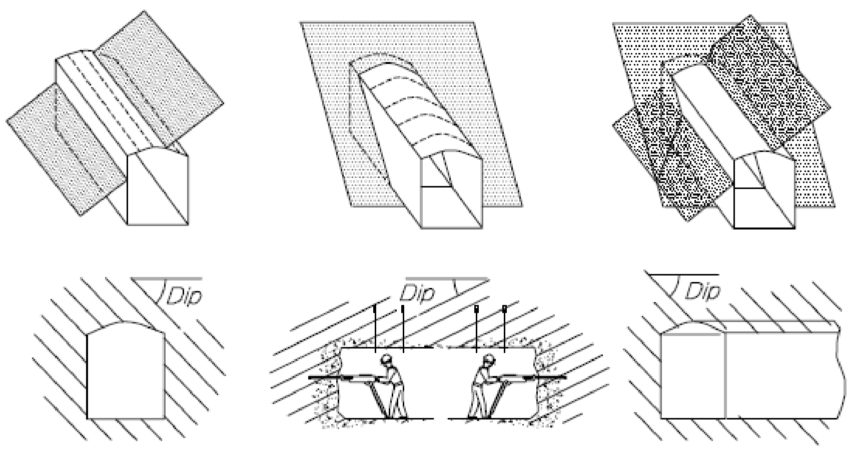
Exceptionally Poor
Extremely Poor
Very Poor
Poor
Fair
Good
Very Good
Extremely Good
Exceptionally Good
Very Good
Good
Fair
Poor
Very Poor
RMR=9lnQ + 44
Rock Mass Rating, RMR
Rockmass Tunnelling Quality Index, Q
100
80
60
40
20
0
0.001
0.01
0.1
1
10
100
1000



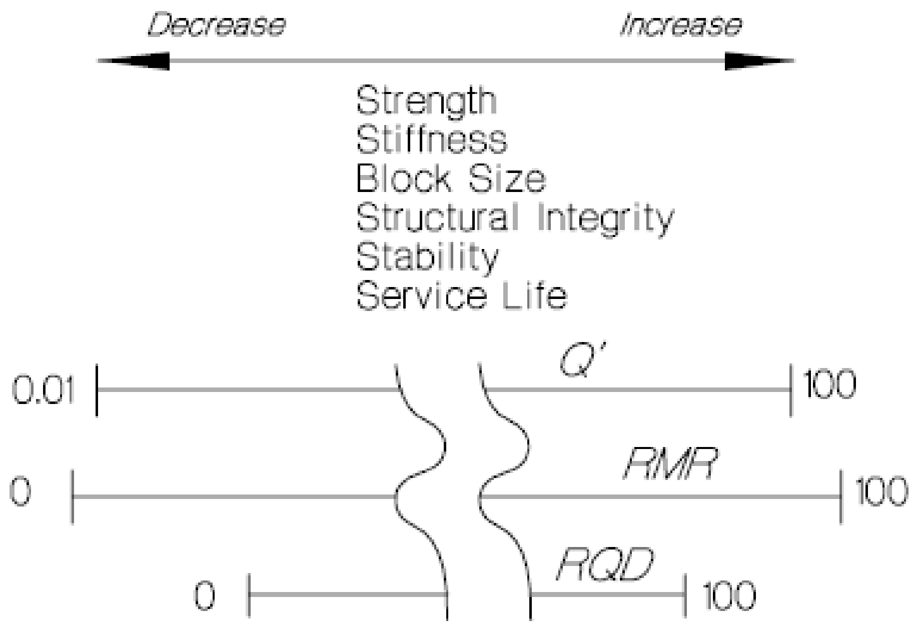
200 cm Rule
ROCK
WALL

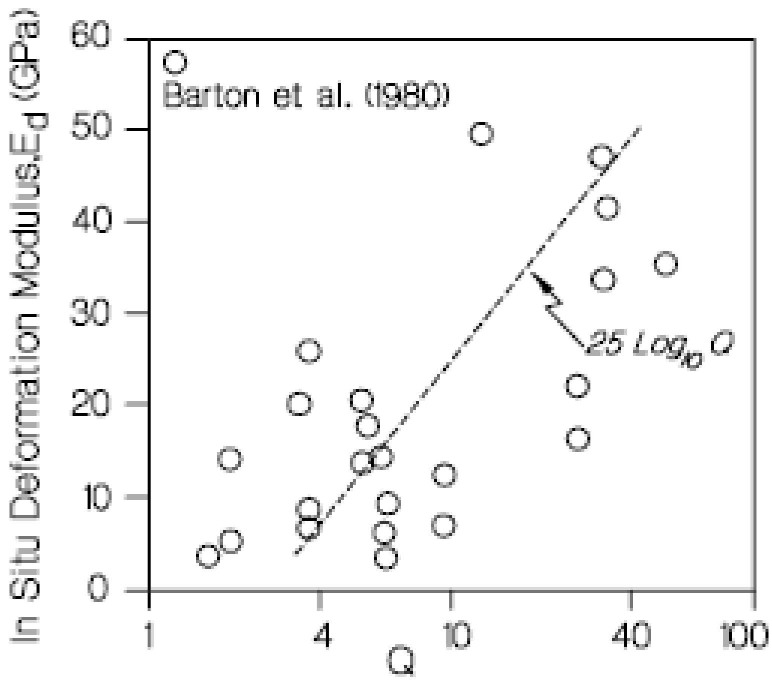


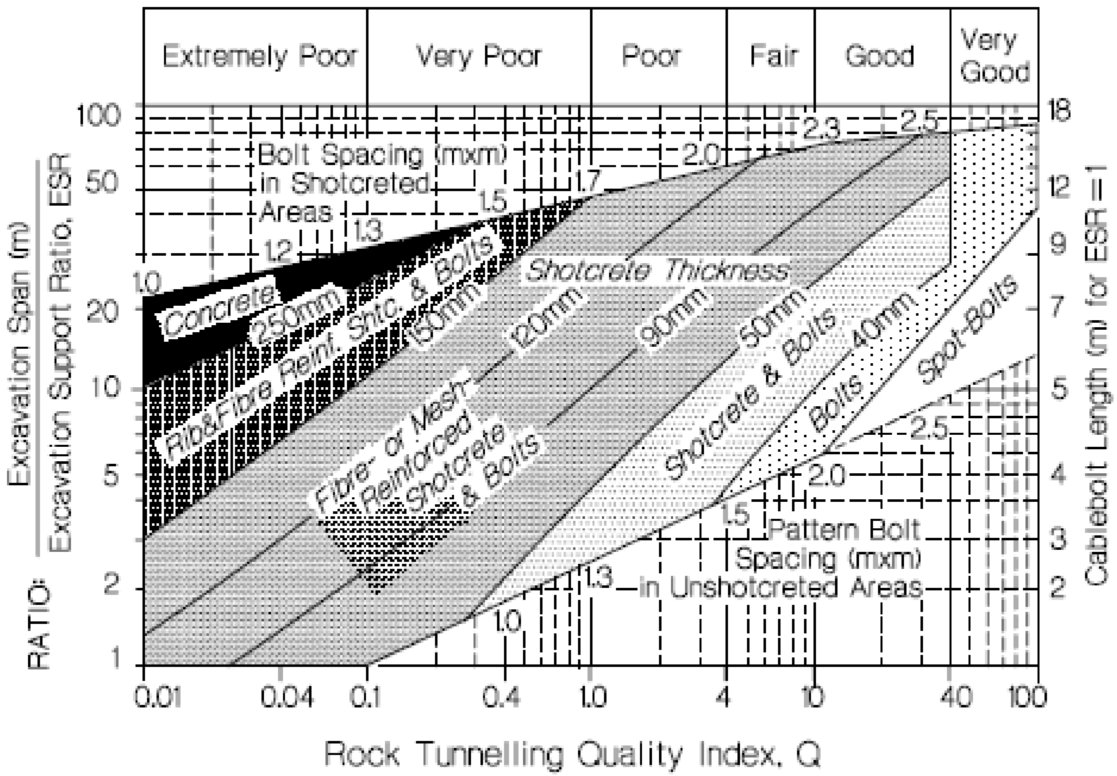
STRIKE OF JOINT WITH RESPECT TO EXCAVATION AXIS



DIP (degrees)	PARALLEL	PERPENDICULAR: DRIVE WITH DIP	PERPENDICULAR: DRIVE AGAINST DIP	ANY STRIKE
45 - 90	Very Favourable	Very Favourable	Fair	n/a
20 - 45	Fair	Favourable	Unfavourable	n/a
0 - 20	Fair	Fair	Fair	Fair


Decrease
Increase
Strength
Stiffness
Block Size
Structural Integrity
Stability
Service Life
Q'
0.01
100
RMR
0
100
RQD
0
100


In Situ Deformation Modulus E_d (GPa)
Barton et al. (1980)
25 Log_{10} Q
Q
60
50
40
30
20
10
0
1
4
10
40
100



Solution

1. Rock mass classification description (5 marks)

The candidate should provide a brief description of the four rock mass classification systems although not specifically requested by the question. The descriptions should be brief and would set the scene for answering the question.

The four schemes to be described are:

- Rock Quality Designation developed by Deere et al
- Rock mass rating or Geomechanical Classification developed by Bieniawski
- Mining or Modified Rock Mass Rating developed by Laubscher
- The Norwegian Geotechnical Institutes Q Rating system

A very brief description of the make-up of the systems should be provided i.e. the rating parameters and the way they are assembled to produce a rating value.

2. Value and limitations of schemes with reference to supporting information provided

A simple concise table highlighting the values and limitations would have best suited the candidate since it will provide a quick reference for all schemes rather than comparing text within reams of paragraphs. The candidate will be allocated a maximum of 2 marks for presentation of the answer. The values and limitations provided for each scheme would be allocated 5 marks. The marks will be allocated as follows:

- 4 marks for values and limitations
- 1 mark for use of figures and graphs to assess values and limitations
- The 2 marks allocated for presentation of the answer is a bonus
- The total marks for this component of the answer is 20 with an additional 2 marks allocated for presentation
- The candidate will be assessed on the salient rather than all aspects detailed below
- The solution table is provided as detailed as possible to serve as future reference material for candidates

Classification Scheme	Values	Limitations	Supporting information
Rock Quality Designation	• Quick and objective method of obtaining estimated quality from drill core • Suited to early initial exploration phases of a project • Simple and efficient to implement and can be done by non-geotechnical personnel • If measured after a time period on the same drill core, it can provide an estimate of time-dependent effects on rock	• Strength and stiffness of the rock as tested in the laboratory has little relevance • Does not accurately depict rock mass conditions when joint spacings are greater than 0.3m • RQD is highly directional i.e. a fracture set parallel with the hole direction is completely discounted • RQD is a measure of undisturbed and insitu rock mass conditions and negates the influence of artificial effects	First figure shows tendency of RQD to only account for joint spacing and block size Third and fourth figure shows use of directional RQD to determine representative rock quality and remove bias offered through drill core RQD Fourth figure illustrates Palmstroms methodology for calculating RQD from exposures

	• Can be applied to rock wall exposures and calculated using volumetric joint counts • Inexpensive	• Very limited in rocks with clay infilling since stability is dominated by the infilling rather than spacing • RQD is not scale dependent i.e. there is a big difference between the stability of small tunnels and say large caverns •	
Rock mass rating (Geomechanics classification)	• Easy to use • Classification parameters easily obtained from drill core or underground data • Can be used in tunnelling or slopes i.e. versatile • Accounts for engineering judgement • Related to other schemes such as Hoek-Brown criteria and Q rating • Can provide initial estimates of support requirements • Can be adjusted for use in excavating by applying orientation adjustments	• Based on coal mines, shallow tunnels and slopes and not extended to deep excavations • Does not account for applied loads • Does not account for primary support systems but caters for permanent support • Does not account for tunnel shape and size • Limited range of material types for which the system can be used i.e. difficult to extrapolate results in very soft and hard rock combinations • Transfer to other rating systems using empirical formulation is often difficult	Figure 1 shows the absence of accounting for field stresses in the overall formulation of the rating system Correlations between RMR and Q shows a fair degree of scatter and correlations are best formulated on a site and rock type specific basis (Figure 2)
Q Rating	• Simple to use • Accounts for field stress or active stress • Comprehensive list of Q ratings versus support design charts are available • Accounts for excavation size • Empirical estimates of support pressure, bolt	• Joint orientations are not included in the system • Recommended for tunnels and caverns with a arched roof • Subjective judgement required to identify critical joint sets upon which parameters are based	Relationship between Q and suggested support applications are shown in Figure 8

	spacing and insitu rock strength can be made • First estimates of rock properties can be made i.e. strength, velocity, deformation modulus • Formulation of system was extended to case studies ranging between 5-2500 mbs with the most common depths being 50-250 mbs		
MRMR	• Guidelines for choice of parameters are provided • Provides design rock mass strength based on perceived in situ conditions that are used for rating adjustments • Based on the basic RMR parameters and is thus simple to use	• Choice of adjustment parameters based on judgement at the initial project stage and needs to be validated once mine design parameters have been updated • Been extended for use in open pit overall slope angle derivation but lacks sufficient detail to allow for complete reliance in the method. Suggested only for concept level design but often used out of context	None

QUESTION 2

A platiniferous room and pillar mine is to be opened at a depth of 100 m below surface in a rock mass whose unit weight is approximately 27 kN/m^3. The design of the mine calls for a factor of safety of 2 against compressive failure of the pillars. The substantial body of data regarding the design of pillars in these types of orebodies shows that their compressive strength may be calculated from the expression:

$$\sigma_c\,(Pillar) = 10 + 45e^{-0.18A}$$

Where A is the plan area of the pillar in square metres

(a) What is the Uniaxial compressive strength of the reef as measured in the laboratory **(3)**

When A, is very small, the equation tends to 55 MPa. The candidate should try substituting the typical area of a laboratory specimen (50mm diameter) into the formula and check the ensuing value.

(b) What is the field strength of the pillars **(3)**

Similar to Question (a), when the area becomes very large (e.g. a 5m x 5m pillar = 25 m^2), the equation tends to 10 MPa.

(c) For operational reasons, the rooms must have a minimum width of 5.0m. What is the greatest extraction ratio that can be achieved with this size of opening? ***(Hint: The equation cannot be manipulated)*** **(15)**

Room and pillar designs are usually produced using the concept of Tributary Area Theory and the formula:

$$\frac{\sigma_v}{\sigma_p} = \frac{w^2{}_p}{(w_o + w_p)^2}$$

Where σ_v is the vertical stress which for this case = 2.7 MPa. W_o is the opening width and W_p is the pillar width.

The maximum stress that a square pillar can subjected to is given by (where F is the Safety Factor):

$$\sigma_p = \frac{1}{F}(10 + 45e^{-0.18 w_p{}^2})$$

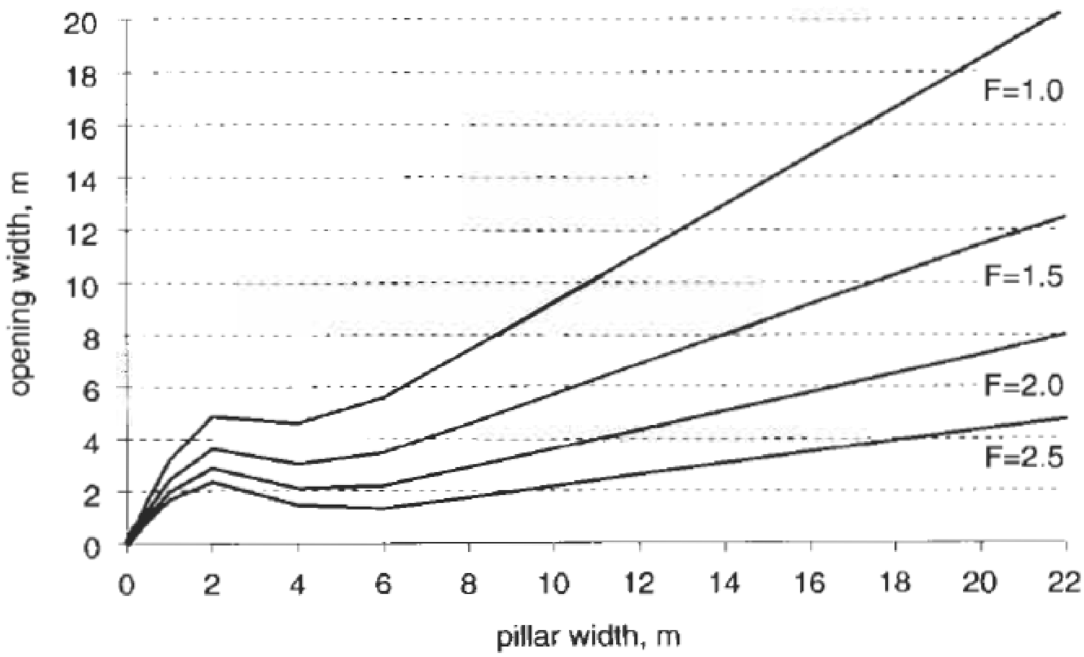
The above two equations can be combined to determine the pillar width for a given set of parameters. Re-arranging the first equation gives:

$$w_o = w_p(-1 \pm \sqrt{\frac{\sigma_p}{\sigma_v}})$$

Hence,

$$w_o = w_p\left[-1 \pm \sqrt{\frac{1}{\sigma_v}\frac{\left(10 + 45\exp(-0.18 w_p^2)\right)}{F}}\right]$$

The resulting curves of opening width versus pillar width in terms of SF are shown below:



We can see that at a SF = 2, the minimal pillar width for an opening of 5m is 14 m. The extraction ratio is thus 0.46 or 46%.

(d) List and describe the limitations of using the Hedley & Grant pillar formula for calculating the strength of hard rock pillars **(4)**

The formula is based on case studies done in Canadian Uranium mines and has simply been applied in SA hard rock mines.

The formula has limited applicability in very weak rock constituting the pillar material

The formula has limited applicability in pillar material where the mode of failure is defect rather than rock failure driven.

The choice of the bulk strength factor (k) is often subjective and not clearly understood.

The formula does not account for limiting width to height ratios under which it can be applied.

The formula is based on strength to stress ratio and does not account for system stiffness required to assess rockburst potential of pillars.

(25 marks)

QUESTION 3

To sustain production rates at 50 ktpm at the RemGold gold mine the executive committee has requested you to develop a rock engineering strategy document that is aimed at minimising the rock related risk associated with remnant extraction between the last two operating levels of the mine. Shaft bottom is at 3000 mbs. Vertical level spacings are nominally 60m. Production levels below 2000 mbs are serviced by a twin tertiary shaft system. The tertiary shaft has been rehabilitated on several occasions to reinforce cracked concrete and replace deformed bunton sets.

The mine is divorced from its neighbouring mines (which are under care and maintenance) by 18 m wide boundary pillars. Reef dips are typical of Klerksdorp type gold deposits. The mine used scattered conventional mining methods for 30 years. Flat and inclined development to the remnant blocks is envisaged. The mine has been issued with 24 section 54a/b instructions over the past three years related to rockfall and rockburst incidents. Provide descriptions and explanations for the content of the requested document.

(25 marks)

The candidate should provide a logical approach to gaining information and populating the 'strategy document' based on the information provided underlined by the guidelines for the compilation of a COP. The candidate does not have to strictly adhere to the COP guidelines but should provide ample evidence for the reasons for selection of certain parameters.

Suggested approach	**Reason**	**Information to be used**
Remnant classification or description of the form that remnants are likely to take on the mine. This could take the form of Ground Control Classification i.e. by remnant shape, risk and/or local and regional ground classification.	Remnants in the Klerksdorp area are likely to be (1) those left against or at the confluence of geological structures (2) open spans of ground left due to economic reasons (3) those abandoned due to ground instability The crude classification will provide the	Remnant depths provided Klerksdorp region and knowledge of the environment Seismic risk as provided by reports of shaft instability. The number of section 54's should provide the candidate

	candidate with an overarching impression of risk i.e. fault bound remnants may be higher risk than, ground stability related remnants which in turn are higher risk than grade related remnants	with a measure of risk being posed.
Macro elements of a remnant extraction philosophy	Establishing access to remnants which will include: • Using existing infrastructure • Using new infrastructure • Establishing remnant faces using existing and/or new faces • Mining the remnants	Methods to rehabilitate primary access routes i.e. shaft Level access to remnants via haulages and crosscuts. Assumptions need to be made about inclined access. Knowing that the mine is 30 years old, this should indicate mature and possibly aging infrastructure. Consideration should be given to rehabilitation or a limited amount of new development traded off against costs
Remnant stoping strategies	This should include aspects such as: • Minimum stoping widths • Maximum face lengths • Rate of advance • Inter-panel leads/lags • Blasting strategies	Candidate should assume a continuation of conventional stoping strategies but should consider aspects that aim to minimise rockburst and rockfall risks
Support strategies for remnants	Aspects should include: • Support resistance and energy absorption criteria • Support types to be selected • Support spacing	Knowledge of current support practice in the Klerksdorp Goldfields is paramount
Remnant instrumentation and monitoring strategies	Aspects should include: • Observational monitoring techniques i.e. who, when and how • Numerical monitoring techniques • Seismic monitoring • Instruments	Candidate should mention briefly what aspects should be monitored and what instruments suites would be considered
Remnant risk management strategies	Aspects would include: • Risk identification measures • Parameters and criteria used to assess risk • Procedures to manage risk	Generic parameters are to be briefly mentioned. Comprehensive write-ups are not required.
Back analyses of risk and failures	Bonus marks	

QUESTION 4

Numerical modelling is an essential tool for any Rock Engineer due in large to the complex morphology and mechanical properties of South African hard rock mines. Answer the following questions related to numerical modelling.

4.1 List two underlying assumptions that form the basis for most boundary element models **(2)**

- Rock is linearly elastic – i.e. has the same loading and unloading path
- Rock is infinitely strong – i.e. no yielding or failure takes place
- Rock is homogeneous – rock mass consists of the same material throughout
- Rock is isotropic – rock mass has the same physical properties (Young's Modulus, Poisson's ratio) in all directions

4.2 Describe the philosophy of 'Occam's Razor' **(2)**

Simplification of modelling reality whereby those parameters that are most likely to influence the solution are incorporated in the model without losing the essence of the model. Those parameters that are least likely to influence the end results are ignored.

4.3 Describe and provide motivation for the modelling type one would choose, input parameters and results one would analyse to project scaling of new pillar dimensions from known measurements of smaller pillars **(15)**

Model choice

Obvious choice is non-linear or failure models such as UDEC and FLAC or ELFEN since these models can depict failure of the outer skin of pillars, allow one to remove the failed material and project new pillar loads or stress post failure.

Input parameters

Elastic modulus, poisson's ratio, density, cohesion, friction, tension, residual values for all or certain Mohr Coulomb parameters, joint properties, stress gradient, boundary or loading conditions, strain softening parameters, constitutive laws for joints and rock blocks

Results

- Apply Occam's Razor to limit modelling scenarios
- Use models to establish scaling of pillars from known results by performing sensitive analyses or parameterised studies on influence of changing input parameters on scaling results
- Once back analysis is performed and yields desired results, model new pillars and assess the following:
  - Radial deformation of pillars
  - Axial deformation
  - Load shedding of pillars
  - Comparative stress-strain behaviour of pillars i.e. small and big pillars

4.4 Write the full names for the acronyms BESOL, FLAC and UDEC **(6)**

BESOL – Boundary element solution

FLAC – Fast Lagrangian analysis of Continua

UDEC – Universal Distinct Element Code

(25 marks)