CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION PAPER

SUBJECT: CERTIFICATE IN ROCK MECHANICS PAPER 3.3 : MASSIVE UNDERGROUND MINING (HARD AND SOFT ROCK) **SUBJECT CODE:** COMRME **EXAMINATION DATE:** OCTOBER 2017 **TIME**: 3 HOURS	**EXAMINER:** DR PJ LE ROUX **MODERATOR:** W JOUGHIN **TOTAL MARKS:** [100] **PASS MARK:** (60%)

NUMBER OF PAGES: 4 (incl)

THIS IS NOT AN OPENBOOK EXAMINATION – ONLY REFERENCES PROVIDED ARE ALLOWED

SPECIAL REQUIREMENTS:

1. Answer **all questions**. Answer the questions **legibly** in English.
2. Write your **ID 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.

3. Show all calculations **and check calculations on which the answers are based.**
4. **NO** hand-held electronic calculators may be used for this exam.
5. Write **legibly** in ink on the **right hand page** only – **left hand pages will not be marked**.
6. Illustrate your answers by means of sketches or diagrams wherever possible.
7. **Final answers** must be given to an accuracy which is typical of practical conditions, However be careful not to use too few decimal places during your calculations, as rounding errors may result in incorrect answers

   NB Ensure that the correct unit of measure (SI unit) are recorded as marks will be deducted from answers if the incorrect unit is used. (even if the calculated value is correct).
8. In answering the questions, full advantage should be taken of your practical experience as well as data given.
9. Please note that you are not allowed to contact your examiner or moderator regarding this examination.
10. Cell phones are **NOT** allowed in the examination room.

QUESTION 1

In the mining industry the modified and generalised Hoek-Brown criteria for estimating the field strength of jointed rock masses are used to determining input parameters for limit equilibrium analyses and numerical modelling in rock mechanics. Answer the following questions related to the Hoek-Brown criteria.

1.1 Give the definitions for the following Hoek-Brown input parameters and typical values assigned for good, average and weak rock mass conditions:

(a) Disturbance factor **[3]**

D is a factor which depends upon the degree of disturbance to which the rock mass has been subjected by blast damage and stress relaxation. It varies from 0 for undisturbed in situ rock masses to 1 for very disturbed rock masses.

Weak 0.7-1.0 Average 0.3-0.7 Good 0-0.3

(b) Geological Strength Index (GSI) **[3]**

The concept of the Geological Strength Index (GSI) is a replacement for Bieniawski's RMR. It had become increasingly obvious that Bieniawski's RMR is difficult to apply to very poor quality rock masses and also that the relationship between RMR and m and s is no longer linear in these very low ranges. It was also felt that a system based more heavily on fundamental geological observations and less on 'numbers' is needed.

Weak ≤ 25, average 25-50, Good 50-75

(c) m_i value **[3]**

Material constant based on rock type. Weak 1-10 Average 10-20 Strong 20-30

1.2 How would one apply Bieniawski's RMR_{76} and RMR_{89} rating values to obtain GSI values **[4]**

GSI_{89} = [(RMR_{89} values>23)–5] provided dry conditions are assumed in the ratings and no adjustments are made for joint orientation

GSI_{76} = [(RMR_{76} values>18)] provided dry conditions are assumed in the ratings and no adjustments are made for joint orientation

1.3 Provide a basic definition for the following numerical modelling terms or input scripts and an example of a modelling application where one would apply the following:

1.3.1 Strain softening **[4]**

The modelling formulation whereby the Mohr-Coulomb parameters cohesion, friction and dilation are allowed to evolve as inelastic damage accumulates. The measure of damage is related to plastic strain.

Application: modelling of post peak behaviour of materials e.g. obtain the full stress displacement curve of a pillar. Measure of damage through use of plasticity indicators

1.3.2 Stress tensor **[4]**

Stress is a tensor because the rules which govern the changes in the stress components as the reference axes are changed are those of a tensor. More mathematically, a tensor is a "multilinear differential form invariant with respect to a group of permissible co-ordinate transformations in n-space". Stress at a point inside a rock has three components acting perpendicular to the faces of a cube, and six stress components acting along the faces. The way in which these components vary as the cube is rotated means that stress is a tensor quantity and it must be specified in the three-dimensional case by six independent components. The normal and shear stresses acting on planes at different orientations inside the rock mass are required for rock engineering design studies and can be calculated using transformation equations.

Application: Input of 6 or 9 components of stress in programmes such as Minsim or MAP3D to fully describe the stress field

1.3.3 Off-reef field points **[4]**

Benchmark windows defined by single or stacked line points onto which data is written to for analysing rock engineering problems.

Application: Induced stresses and strains for calculation of distortion of shaft barrels

[25 MARKS]

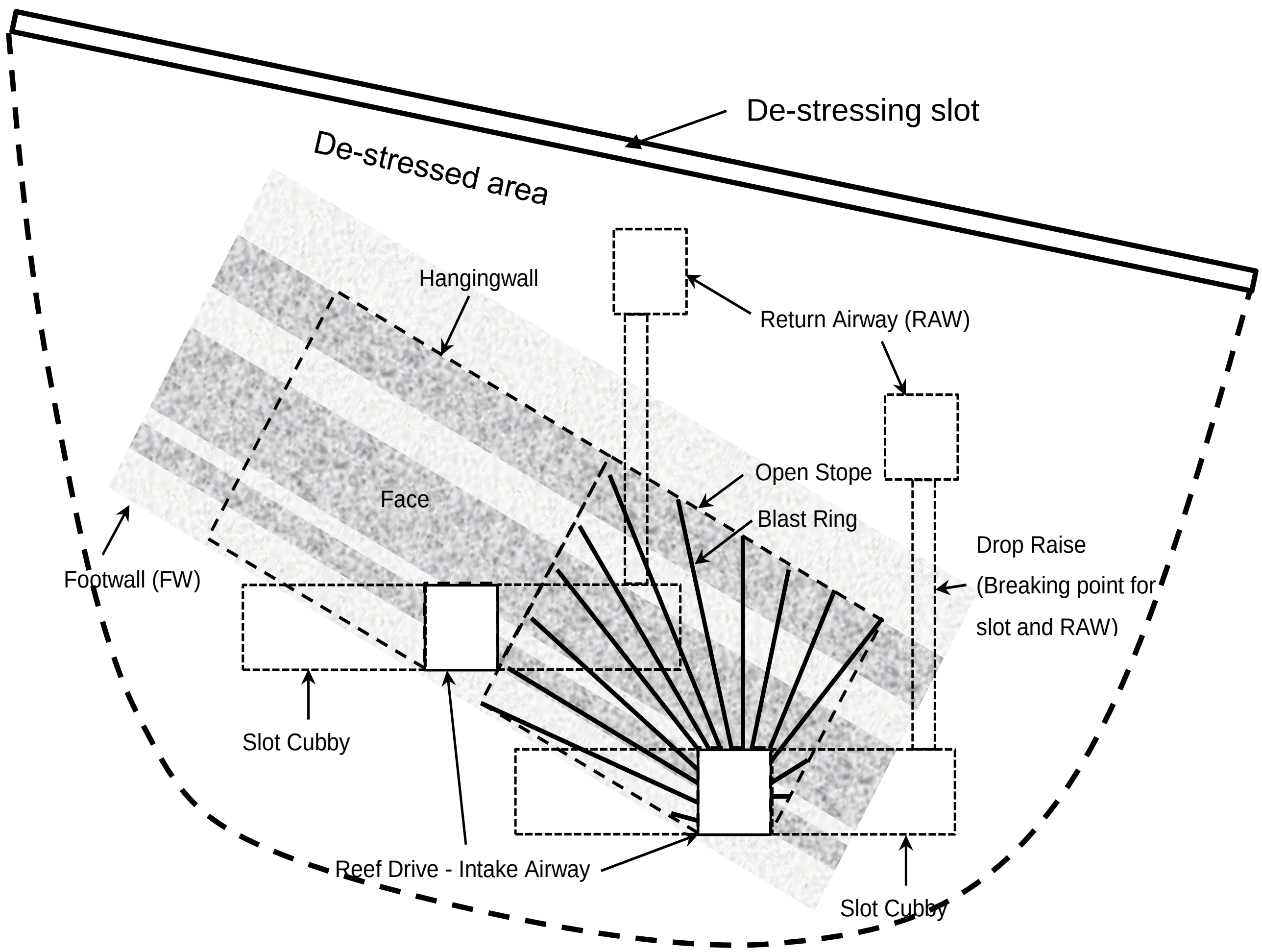
QUESTION 2

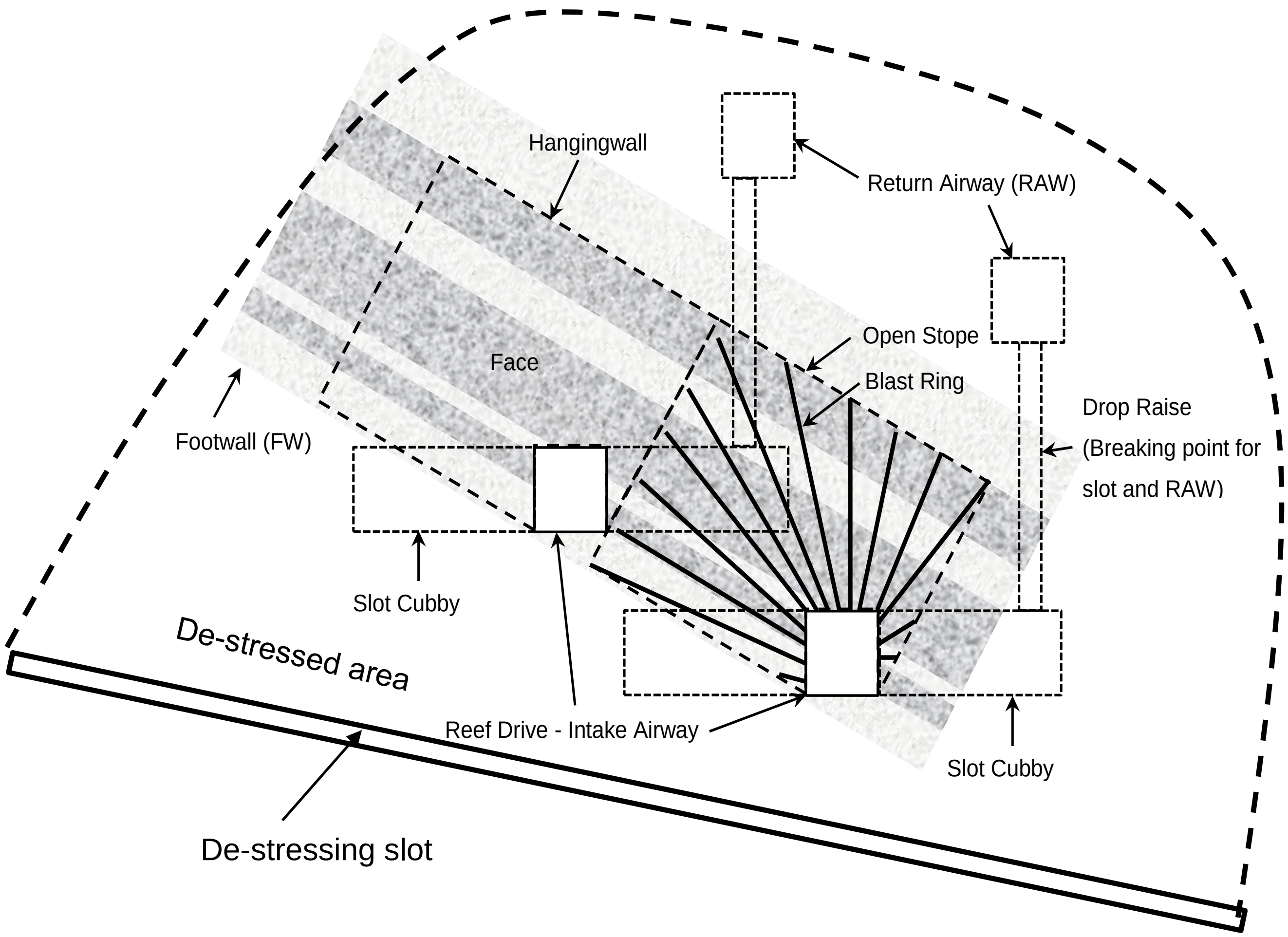
A massive tabular orebody is dipping at about 30° to 80° at a depth of 2200 m to 2500 m below surface. The mineralized zone is on average 25 m thick and 1500 m on strike. The mineralization lies between Quartzite's and an overlying Lava, 600 m in thickness. The UCS of the Quartzite's is 250 MPa and Lavas 350 MPa respectively.

It is intended to mine the orebody using open stoping, drilling upward from drilling and loading drives on the contact and using remote controlled loading.

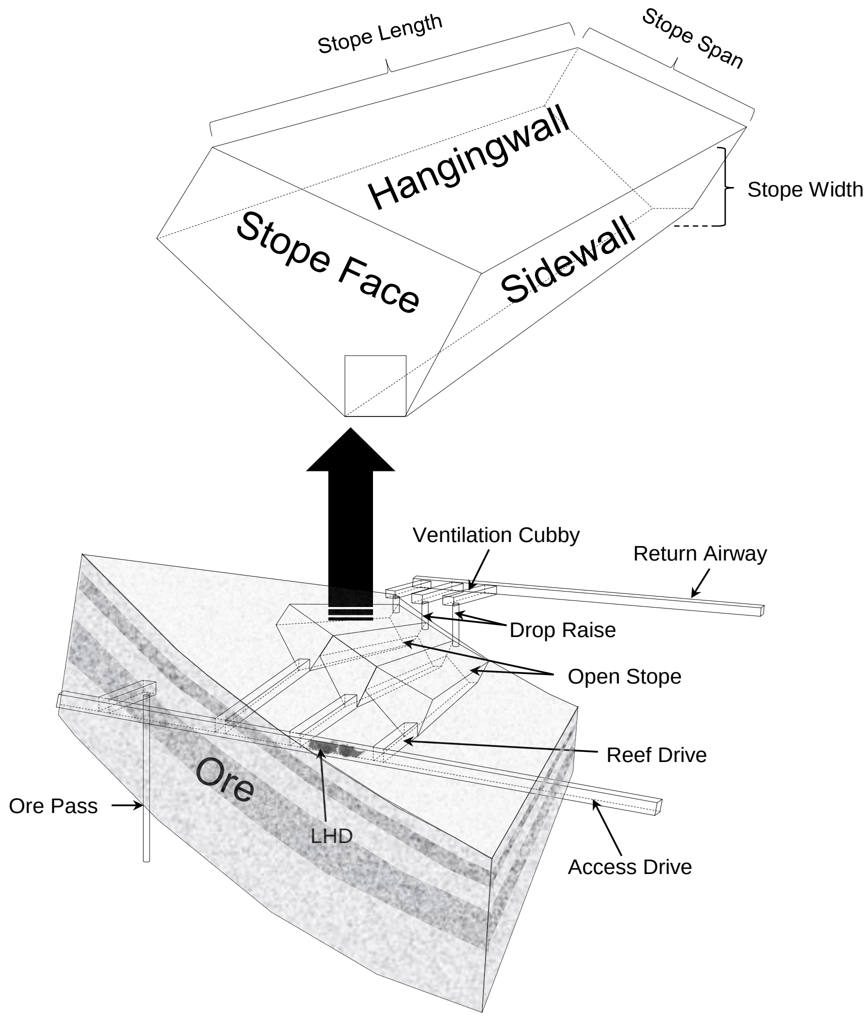
a) Draw the mining layout in plan and section. **[6]**

25m thick, Quartzite's and an overlying Lava must be very competent to expose full width – would probably go for a layout like one below:





- De-stress with a top cut or bottom cut by means of narrow reef mining or drift and fill mining as to create a shallow mining environment
- If not de-stressed the long holes drilled for the blast rings will close



b) Describe the geotechnical investigations required to assess the stable spans which can be mined and what failures could be expected. **[6]**

Green fields: geotechnical borehole logging – Q' and laubscher's RMR

Determine critical joints or bedding plane orientation and spacing in immediate h/w

Joint orientations – possible orientated core at this depth – or wireline logging.

Geophysical – geological structure

Laboratory UCS tests and filed point load tests on different rock types

Geotechnical Mapping (window and line mapping of early excavations in sandstone) to determine joint orientations and Q' and Laubscher's RMR.

Stress measurements if possible

Geotechnical mapping of top drives during mining to confirm design

Observations of conditions in stope to verify conditions and surveys to determine dilution

c) Describe how you would assess the stable span of the hangingwall. **[8]**

Determine Q' from logging

Determine A from stress to strength ration – run simple model to determine stress

Determine Joint orientation factor B

Determine Gravity adjustment factor C

Determine stability number

Use empirical stability chart to determine hydraulic radius

Optimise stope dimensions to meet

d) How would you control the hangingwall span considering the mining method. **[5]**

Post backfilling or leave suitably designed pillars presumably a strike pillar between levels

[25 MARKS]

QUESTION 3

Assume a shale layer that is 0.8m thick, overlain by a thick quartzite beam is supported with 20mm diameter resin bolts. The diameter of the hole is 26mm, the yield strength of the steel is 480MPa and the density of the shale is 2480kg/m^3.

3.1 Calculate the yield load of the roof bolt? **[2]**

3.2 Determine the minimum support density required to support the shale layer? **[2]**

3.3 What will the maximum bolt spacing be for a factor of safety of 1.0? **[2]**

3.4 Given that the resin-steel bond strength is 5MPa and the resin-rock bond strength is 2000kPa. Determine the critical bond length. **[3]**

3.1.1 Load = stress x area

= 480 MPa x π x 10mm^2

= 150.8 kN

3.1.2 Support density Required = ρgt

= 2480kg x 9.81m/s^2 x 0.8m

= 19.5 kN/m^2

Bolts per m2 = 19.5 kN/m^2 / 150.8 kN

= 0.129 bolt/m^2

3.1.3 One bolt support 7.7m^2

Required bolt spacing = $\sqrt{7.7m^2}$

= 2.8m x 2.8m

3.1.4 Bond length (L) = 150.8 kN / (20mm x π x 5 MPa)

= 0.48m

Bond length (l) = 150.8 kN / (26mm x π x 2 MPa)

= 0.92m

Critical bond length = 0.92m

3.5 Discuss and show with the aid of sketches how geological structures can impact on rock mass behavior and tunnel stability in the following manners:

3.5.1 Bedding planes **[4]**

3.5.2 Joints **[4]**

3.5.3 Faults **[4]**

3.5.4 Dykes **[4]**

Structure	Rock mass behaviour	Tunnel stability
Bedding planes	Beam creation in hangingwall Laminated (thin beams) rock mass allows easy separation	Beam stability is affected by direction of development and exposure of beam (along strike of tunnel as in Figure 25a or 'factory roof' shapes) Additional planes to allow creation of blocky conditions with stress fractures Laminated material collapse to stable shape (arch) if left unsupported
Joints	Create wedges in excavation perimeter Reduce rock mass quality and increase deformation under stress as rock mass becomes softer	Single blocks may have to be supported individually or a system of support units are required to ensure stability Increased deformation due to poorer and thus softer rock mass requires appropriate support systems to maintain stability, as small yield range units may fail prematurely (while excavation is still needed)
Faults	Form source of seismic activity, resulting in increase closure and newly created fractures Create wedges that might allow separation Changing joint properties (orientation, spacing, infilling) reduces rock mass quality Could cause local field stress changes due to tectonic stress	Large displacements and large energy release is associated with seismic events, damaging support and rock material around an excavation Potential FOG from fault planes require support installationSmaller blocks require increased support density Poorer rock mass quality creates softer rock mass, increased deformation and straining of support units. FOG due to support failure may result. Stress changes (refer to "LEARNING OUTCOME 3.2.9")

Structure	Rock mass behaviour	Tunnel stability
Dykes	Form source of seismic activity, resulting in increase closure and newly created fractures Create wedges that might allow separation Changing joint properties (orientation, spacing, infilling) reduces rock mass quality Changing rock material properties (weaker of more competent) Could cause local field stress changes due to tectonic stress	Large displacements and large energy release is associated with seismic events, damaging support and rock material around an excavation Potential FOG from fault planes require support installation Smaller blocks require increased support density Poorer rock mass quality creates softer rock mass, increased deformation and straining of support units. FOG due to support failure may result. Changing rock properties require additional / other support to maintain stability and remain optimum Stress changes (refer to "LEARNING OUTCOME 3.2.9")

[25 MARKS]

QUESTION 4

With reference to the research project for the evaluation of the performance of shotcrete with and without fibre reinforcement under dynamic and quasi-static loading conditions (SIM 040204):

4.1 Name the steps in the process to determine the inputs required for the design of shotcrete. **[6]**

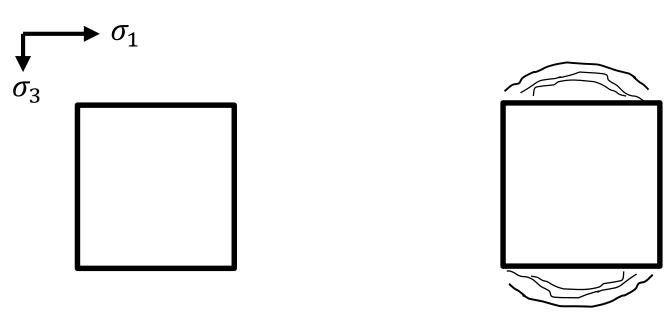
a) Field stress and stress changes
b) Seismicity
c) Rock mass characteristics
d) Excavation characteristics and requirements
e) Tendon support design
f) Shotcrete characteristics

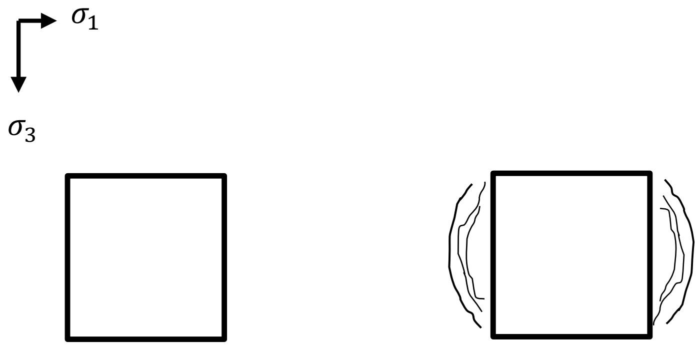
4.2 What inputs are required for elastic modelling. **[4]**

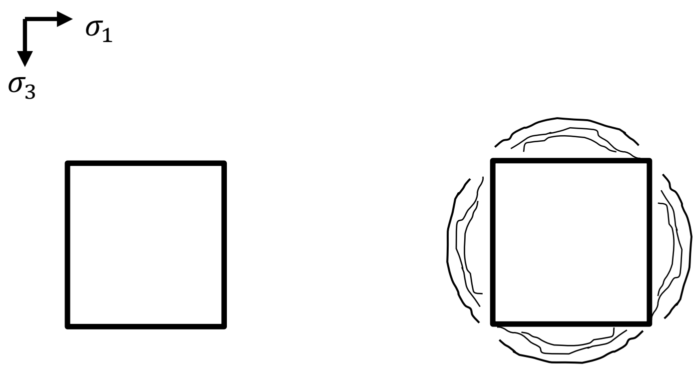
a) Virgin stress state
b) Elastic parameters
c) Mine geometry
d) Mining sequence and layout

4.3 The main access ramp follows a continuous downward spiral inclined at 9^0 to access the underground workings. Which orientations of the tunnel will experience greater stress-driven fracturing? What strategies could you suggest to the mine manager to minimise the effects of high stress concentrations? How will this benefit the operation in terms of cost, safety and productivity? **[4]**

Which orientations of the tunnel will experience greater stress-driven fracturing?
Dependent on stress orientation:

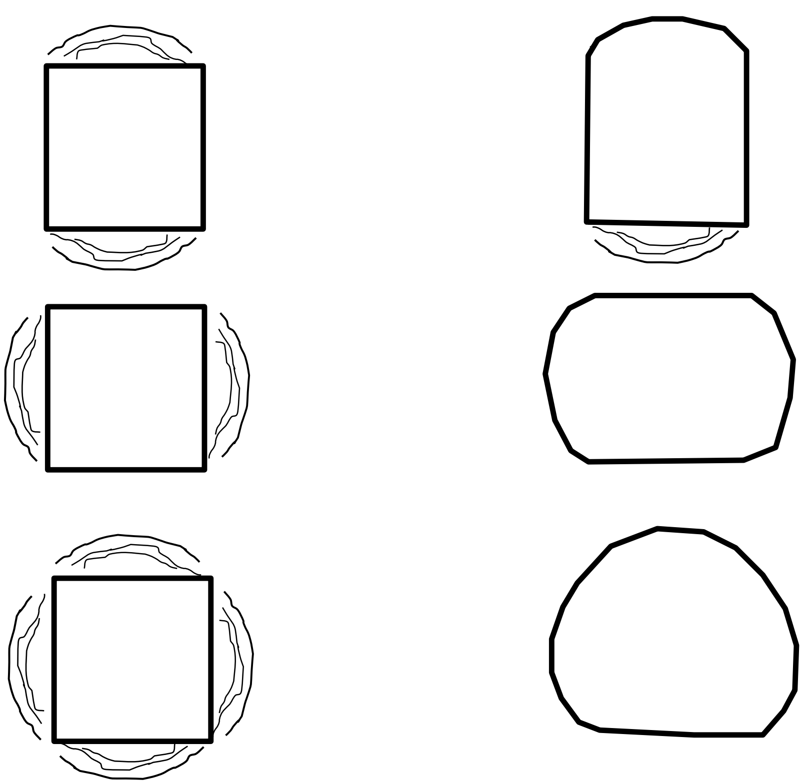






What strategies could you suggest to the mine manager to minimise the effects of high stress concentrations?

Develop the excavation to the final shape expected after stress fracturing



How will this benefit the operation in terms of cost, safety and productivity?

- Reduce support costs and re-support installation
- Removing fall of ground risk
- Increase production rates

4.4 The rock mass characteristics should be determined for the geotechnical domain or ground control district in which the tunnel is situated. Name the important aspects to consider. **[6]**

- Geological drilling programme to be defined by geologist. Geological logging and orebody definition by geologist.
- Sample appropriate number of boreholes for geotechnical logging (core orientation as necessary).Geotechnical logging to be carried out to determine rock mass characteristics, geological weaknesses and joint orientations.
- Mapping of rock exposures where available (eg open pit or outcrops). Joint orientations and characteristics, rock mass classifications)
- Laboratory testing of intact rock (UCS, TCS, shearbox on joints)
- Empirical estimation of stable stope dimensions or cavability - required for mining method selection.
- Empirical evaluation of tunnels and service excavation stability and support requirements.
- Numerical analysis as required.

4.5 It is important to consider not only the size of excavations, but the function and importance of an excavation. Name the important aspects to consider. **[5]**

When siting tunnels, good practice suggests the following:

- A good understanding of the current and future stress levels:
  - Siting of tunnels such that current and future stress levels will be as low as possible, but also that stress changes are limited. Stress changes refer to situations where an excavation can be stressed and then de-stressed. This has been shown to be quite detrimental to the stability of the tunnel as rock crushed by the high stress levels displaces into the

tunnels when stress levels are removed. This is usually associated with extreme closing of the tunnel as crushed rock sags into the excavation.

- Knowledge on the possibility for and level of seismic activity:
    - Placement remote from seismic sources reduces the potential for damage. If an excavation must traverse a potential seismically active structure, precautions in terms of limiting exposure distance, changing tunnel shapes and support upgrading is required.
- Agreement on the expected life of the tunnel:
    - The effort put into the siting of the tunnel is determined by the tunnel's expected life. Placement of a short life excavation is less critical while a life of mine tunnel will require substantial investigation before placing the tunnel.

[25 MARKS]

TOTAL MARKS: [100]