CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION PAPER

SUBJECT: CERTIFICATE IN ROCK MECHANICS PAPER 3.1 : HARD ROCK TABULAR **SUBJECT CODE:** COMRMC **EXAMINATION DATE:** OCTOBER 2017 **TIME**: 14:30 – 17:30	**EXAMINER:** MCB STANDER **MODERATOR:** KR BRENTLEY **TOTAL MARKS:** [100] **PASS MARK:** (60%)

NUMBER OF PAGES: 4

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

SPECIAL REQUIREMENTS:

1. Only answer **5 (FIVE)** of the 6 (SIX) 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. Hand-held electronic calculators may be used for calculations. Reference notes may not be programmed into calculators.
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. GENERAL

1.1 Define the following terms?	(10)

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder P363 – P366

- Local Magnitude

Answer:

*Magnitude is a **relative measure of the strength** of a seismic event based on **measurements of maximum ground displacement at a given frequency** at multiple seismic sites. A unit increase in magnitude corresponds to a 10-fold increase in amplitude of ground displacement.*

Or

*Magnitude = A*log(Mo) + B*log(En) + C*
*Is a **measure of source strength** that reflects seismic energy release as well as forces in the source area and the overall source dimension. (Factors A, B, C are area dependant)*

- Seismic Moment

Answer:

*A **scalar that measures the coseismic inelastic deformation at the source.** Since seismic moment is proportional to the integral of the far field displacement pulse, it can easily be derived from recorded waveforms*
A mark allocated where the Formula M_o=GxAxR was provided.

- Seismic Energy

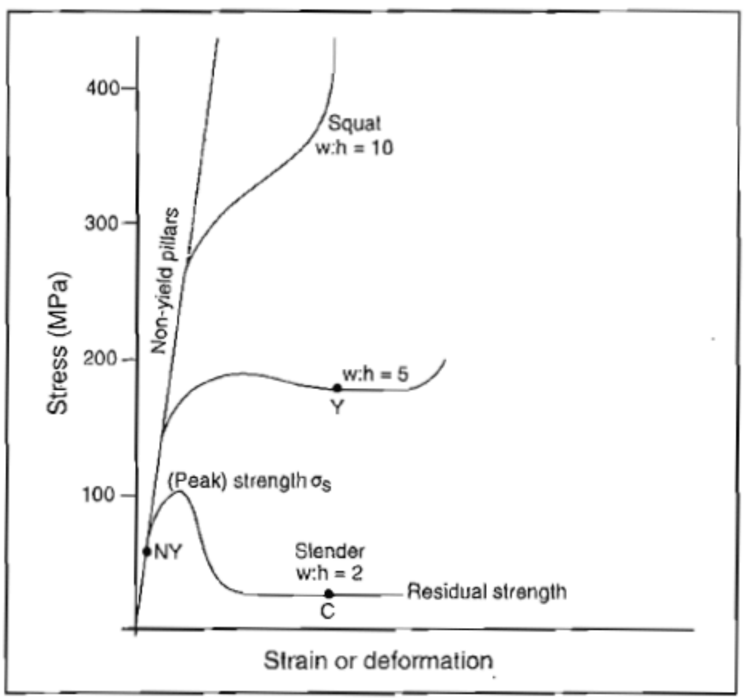
Answer:

*The **portion of the energy released or work done at the source that is radiated as seismic waves.** Seismic energy is proportional to the integral of the squared velocity spectrum in the far field and can be derived from recorded waveforms. Radiated seismic energy increases with stress drop, seismic moment and with the traction rate.*

- Apparent Volume

Answer:

The ‘apparent volume’ also scales the volume of coseismic inelastic strain in terms of stress drop over rigidity.

• Energy Index **Answer:** *The notion of comparing the radiated energies of seismic events of similar moments can be translated into a practical tool called Energy Index (EI) - the ratio of radiated energy of a given event (E) of moment M_O to the energy E derived from the regional LogE vs LogM_O relation.*	
1.2 With the aid of an annotated sketch indicate the Stress-Strain behaviour of hard-rock pillars with varying w:h-ratios of 10 (ten), 5 (five) and 2 (two)? Indicate on the sketch the typical operating points for Non-yield, Yielding and Crush Pillars? A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder P56 maybe **Answer:**  **Figure 3.2.11a** Stress:strain behaviour of hard-rock pillars of different w:h ratios. Typical operating points are shown for NY (non-yield), Y (yield) and C (crush) pillars.	(5)

1.3 Describe two criteria that have been found to be useful with the design of bracket pillars? Refer to burst prone dykes and fault slip? (5)

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder P66

Answer:

Two criteria have been found useful in the **design of bracket pillars.**

(1) For **bursting dykes**, the *stress:strength* ratio should be kept below about unity:

$\sigma_1/\sigma_{cd} < 1$

where σ_1 is the stress at the edge of the dyke when the face is stopped to leave the bracket pillar, and σ_{cd} is the UCS of the dyke material. Often, only strong young dykes with UCS > about 280 MPa are classified as burst-prone and so requiring bracket pillar protection.

(2) For **faults (or some dykes)** prone to shear-type seismic events, the *excess shear stress (ESS)* criterion – section 3.2.3 – may be invoked to assist in the design of bracket pillar widths and layouts. Here, the option of leaving pillars *normal* to the feature ('*buttress pillars*') should not be overlooked – by these means, the ESS lobes may be efficiently fragmented and the *magnitude* of possible seismic events thereby restrained. If a standard bracket pillar is to be left butting against the weak feature, it is also usually impractical to attempt the elimination of *all* positive ESSs. Rather, the width of the pillar should be chosen to limit the likely maximum *magnitude* of seismic activity to some accepted limit tolerable to the support systems in use. [In principle, ESS modelling is able to estimate the seismic moment and hence magnitude associated with slip on a given, appropriately quantified, plane of weakness.]

[20]

QUESTION 2. GEOTECHNICAL CHARACTERISTICS

2.1	List and briefly describe the influence of the 6 (six) parameters used to classify a rock mass when using the Geomechanics Classification or the Rock Mass Rating (RMR) system?	(8)

Answer:

The following six parameters are used to classify a rock mass using the RMR system:

1. ***Uniaxial compressive strength of rock material.*** *– Obtained from the Uniaxial compression of cylindrical specimens prepared from drill core. It provides a general scale of the strength of the material contained in the rock mass. Except for very weak rock masses it is considered acceptable to derive this parameter from field tests such as Point load tests.*

2. ***Rock Quality Designation (RQD).*** *– RQD is defined as the percentage of intact core pieces longer than 100 mm in the total length of core. Scales the in-situ quality of the rock mass.*

3. ***Spacing of discontinuities.*** *– In this context, the term joints is used to describe all discontinuities. This parameter scales the continuity of the rock mass.*

4. ***Condition of discontinuities.*** *– This parameter accounts for the separation or aperture of discontinuities, their continuity or persistence, their surface roughness, the wall condition (hard or soft) and the nature of any in-filling materials present.*

5. ***Groundwater conditions.*** *– An attempt is made to account for the influence of groundwater pressure or flow on the stability of underground excavations in terms of the observed rate of flow into the excavation, the ratio of joint water pressure to major principal stress, or by a general qualitative observation of groundwater conditions.*

6. ***Orientation of discontinuities.*** *– The orientation of structure relative to the orientation of excavations will strongly influence the possible modes of rockmass failure of the rock mass surrounding an excavation. The orientation of structure intersection relative to the direction of excavation may have a strong influences on the overall stability of the excavation.*

2.2 List and briefly describe the influence of the parameters used to define the 3 (three) quotients of the Rock Tunnelling Quality Index? (Q-System) (8)

Practical Rock Engineering - E Hoek. Chapter 3 p12 & 13

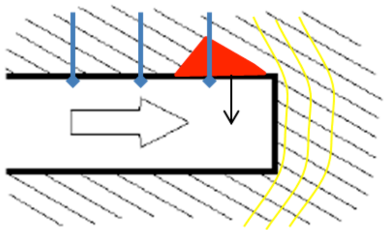
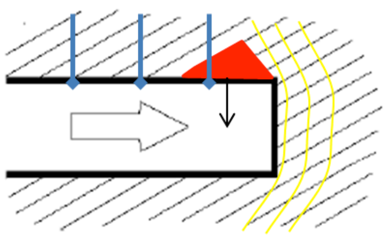
Answer:

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

- ***The first quotient rock block size (RQD/Jn)*** *- representing the* ***structure*** *of the rock mass, is a crude measure of the* ***block or particle size****, with the two extreme values (100/0.5 and 10/20) differing by a factor of 400. If the quotient is interpreted in units of centimetres, the extreme 'particle sizes' of 200 to 0.5 cm are seen to be crude but fairly realistic approximations. Probably the largest blocks should be several times this size and the smallest fragments less than half the size. (Clay particles are of course excluded).*

- ***The second quotient (Jr/Ja)*** *represents the* ***roughness and frictional characteristics*** *of the joint walls or filling materials.* ***This quotient is weighted in favour of rough, unaltered joints in direct contact.*** *It is to be expected that such surfaces will be close to peak strength, that they will dilate strongly when sheared, and they will therefore be especially favourable to tunnel stability. When rock joints have thin* ***clay mineral coatings and fillings****,* ***the strength is reduced significantly.*** *Nevertheless, rock wall contact after small shear displacements have occurred may be a very important factor for preserving the excavation from ultimate failure.* ***Where no rock wall contact exists, the conditions are extremely unfavourable to tunnel stability****. The* ***'friction angles' are a little below the residual strength values for most clays****, and are possibly down-graded by the fact that these clay bands or fillings may tend to consolidate during shear, at least if normal consolidation or if softening and swelling has occurred. The swelling pressure of montmorillonite may also be a factor here.*

- ***The third quotient (Jw/SRF)*** *consists* ***of two stress parameters****. SRF is a measure of: 1) loosening load in the case of an excavation through shear zones and clay bearing rock, 2) rock stress in competent rock, and 3) squeezing loads in plastic*

2.3 Consider a well bedded rockmass, with the average dip of the bedding planes at approximately 20 degrees. Tunnels are developed in the direction of dip as well as against the direction of dip. Which tunnel layout would have more favourable conditions and why? **Note: Annotated sketches may be used to assist with your explanation.** **Answer:**  Drive with dip *More favourable orientation. Rock layer are bound together with support. Centre of gravity of possible wedges are located within the support system. Orientation of Stress fractures similar in orientation to natural bedding.*  Drive against dip *Least favourable orientation. Centre of gravity of possible wedges are located between the support system and the face. Orientation of Stress fractures cut across bedding and delineate possible wedge boundaries.*	(4)
	[20]

QUESTION 3. **MINING SUPPORT STRATEGIES**

3.1	Briefly describe strategies to support tunnels under the following conditions: - Low stress with joint controlled behaviour; - High stress where stress fractures dominate stability; - Changing stress cycles and environments over time; - Seismic and rockburst conditions. A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder P208 - 220 **Answer:** • ***Low stress with joint controlled behaviour;*** *Support system should be able to **penetrate through blocks** delineated by structure and **suspend** the mass of the **block in more solid rock mass above.*** *Support strategies to incorporate **active and stiff non-yielding support types** to **prevent block separation**.* *Where **closely spaced structures** are present the support strategies may **incorporate the creation of re-enforced beams** through the installation of closely spaced tensioned tendons **to enhance the frictional properties of the structures and build a beam**. **Anchorage of the beam beyond estimated unstable zones may be required to prevent deformation.*** • ***High stress where stress fractures dominate stability;*** *Three strategies may be applied,* 1. *Creation of a re-enforced shell with closely spaced tendons surrounding the excavation. The tendons do not penetrates beyond the fractured zone and functions by binding rock layers delineated by stress fractures to function as a self-supporting beam.* 2. *Support systems should be sufficient in length to penetrate beyond the zone of failure surrounding an excavation.* 3. *A combination of 1 and 2. Where a re-enforced shell is created and the support system is enhanced by anchoring the shell beyond the zone of failure. Stiff passive support types may be used and support loads are rapidly generated as dilation start with fracture growth.* • ***Changing stress cycles and environments over time;*** *The initial support strategy must cater for the anticipated conditions during initial development. Prior to exposure to stress change either in magnitude or orientation of stress. Secondary support should be installed to prevent unravelling of the rock mass in conditions where high stress creates fracturing and once the stress*	(8)

is released a fractured rock mass may remain without stabilizing clamping stresses. Similar to a reverse situation where tunnels are devolved in a low to moderates stress environment and stresses are increased to high levels where abutments may be located above or below tunnels. *Due consideration to the answers provided by candidates is considered in this respect.* • ***Seismic and rockburst conditions.*** *Support systems must be able to* ***yield and allow the rockmass to deform*** *while* ***maintaining the integrity of the excavation.*** *This generally requires a combination of support elements, which are designed to link all the units of a support system.*	
3.2 You are required to recommend a support strategy and sequence for a large pump chamber that is planned to be developed. The chamber will be located in a shallow dipping, competent and wide quartzite body that is well bedded? The chamber dimensions are planned to be 20m wide, 50m long and 15m high. The chamber is located at a depth of 1500m below surface. With due consideration to a basic mining methodology for excavating large chambers, provide detail regarding the required support and comment on the sequence of installation? A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder P232 - 235 **Answer:** *Candidates should consider the logical sequence of mining. The chamber is wide and high and requires to be created in stages.* *During the establishment of the roof cut, a tunnel with a limited span is developed along the roof elevation. This is generally along the centre of the excavation. During this phase of development primary support should cater for the span across the initial cut, bearing in mind that the support system will also be applied to create a reinforced beam across the final roof of the excavation.* *After the initial development along the hanging wall, the installation of sufficiently long tendons should be installed to suspend the re-enforced beam above a possible zone of instability. These additional longer tendons are considered as the primary support of the chamber.* *The chamber is then systematically widened with beam building tendons as excavation primary support tendons being installed. Tendons should be tensioned and should be full column grouted to ensure that pre tensioning along the tendons are lock in as scaling behind face plates of tensioned tendons that may cause a loss of support resistance.*	(8)

Once the roof cut has been established and the primary support for beam building and longer primary support for the excavation is installed. Surface liners should be applied. This may either be in the form of fabric support such as meshing and lacing or liners such as shotcrete or a combination of both.

This chamber will serve as a pump camber. The candidates should consider that conditions may be damp and humid. Thus corrosion protection should also be considered. Special type meshes or possibly covering support units with shotcrete

.

Fundamentally the complete final support system for the roof must be completed, prior to increasing the height of the excavation. The support system along the top portions of the side wall must also be completed to the final required support system.

Then the remainder of the excavation should be extracted with cuts. Ensuring that the final support system of the sidewalls is completed prior to advancing to the next cut.

Each answer is judged on merit and assessed against indicated logic.

3.3 State the empirical design rules for determining the length and spacing of required tendon support in the hanging wall, and sidewalls of a tunnel? (4)

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder P221

Answer:

Length of tendon = 0.5 x span or height of excavation in which they are to be installed.
Spacing of tendon = 0.5 x length of tendon.

[20]

QUESTION 4. INVESTIGATION TECHNIQUES

4.1	Occam's razor is a problem-solving principle attributed to William of Ockham (c. 1287–1347), who was an English Franciscan friar, scholastic philosopher, and theologian. His principle states that among competing hypotheses, the one with the fewest assumptions should be selected. In your own words, explain how this principle should be applied to Numerical Modelling in Rock Engineering?	(6)

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder P330 and P331

Answer:

Occam's Razor is a conceptual model of the modelling process frequently used by modellers. William of Occam was a fourteenth century philosopher who is remembered in the modelling fraternity for having written 'Entities should not be multiplied unnecessarily'. In modelling parlance this is interpreted as 'eliminate all unnecessary information relating to the problem that is being analysed'. However, it is important to eliminate only *unnecessary* data and not that which is required for the correct analysis. Occam's razor should be applied at all stages of modelling but particularly at the very early stages. A model that is developed that includes extraneous detail, results in excessive processing time and over complex input and output. On the other hand, of course, a model that excludes any of the real governing factors pertaining to the problem at hand leads to incorrect, and probably misleading, conclusions.

The inclusion of unnecessary detail often results from the assumption that in order to understand the behaviour of a given system it is necessary to include *all* the available data relating to that system: 'the more data the more accurate the model'. Taken to the limit, this assumption results in including all aspects of the system being modelled down to the micro-mechanical level. The model becomes the reality being modelled,

and results in the same degree of difficulty in understanding the model as in understanding the reality itself. Before this limiting case is reached the modeller will have lost all intellectual control and the model will simply have become a tool to confuse.

4.2 Explain the differences between physical, empirical and numerical models? (6)

Answer:

Physical models *are often scaled replications of conditioning or situations. Laboratory testing is often preferred in studies of fundamental rock behaviour since it offers quantifiable results obtained under controlled loading conditions. Models prepared from rocks, and in some cases from artificial mixtures with known material characteristics, can be tested in specially designed test rigs under controlled conditions.*

Empirical models *are defined though the study of recurring conditions and outcomes. It may be considered as models developed though trial an error.*

Numerical models *apply mathematical equations to simulate and predict the behaviour of the rock mass for estimated loading conditions. Rock mass conditions are represented using finite number of well-defined components. The behaviour of each component then can be calculated using mathematical solutions.*

4.3 List 8 (eight) steps that are suggested as an outline for a disciplined modelling methodology that can be applied to a wide range of problem solving situations encountered in Rock Engineering? (8)

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder P344 and P345

Answer:

11.4.6 A Modelling Methodology

The following steps are suggested as an outline for a disciplined modelling methodology that can be applied to a wide range of problem-solving situations encountered in rock engineering.

1. Identify problem areas and the potential problem. 2. Design a number of potential mining strategies to alleviate the problems. 3. Define relevant design criteria. 4. Develop a model that incorporates necessary detail to assess the mining strategies in terms of the design criteria. 5. Choose a relevant tool or tools to test the proposed mining strategies based on the model. 6. Perform simulations on each strategy using the model and the specified design criteria. 7. Analyse the results of the simulations in terms of the specified design criteria. 8. Select a mining strategy based on the analyses, or propose new/modified mining strategies and go back to 4.	
	[20]

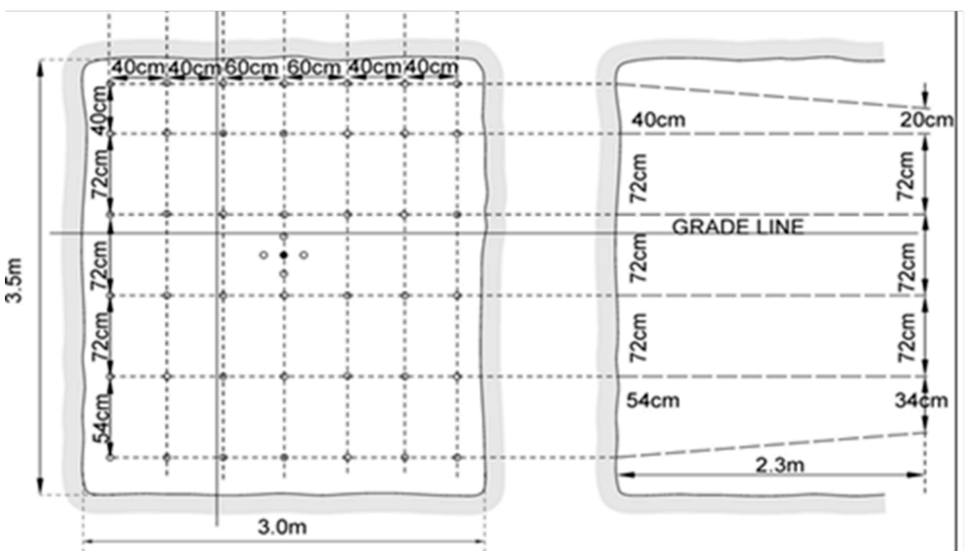
QUESTION 5. ROCKBREAKING IN HARD ROCK

5.1 Sketch and describe the two different drilling rounds used in tunnel development? (8)

Answer:

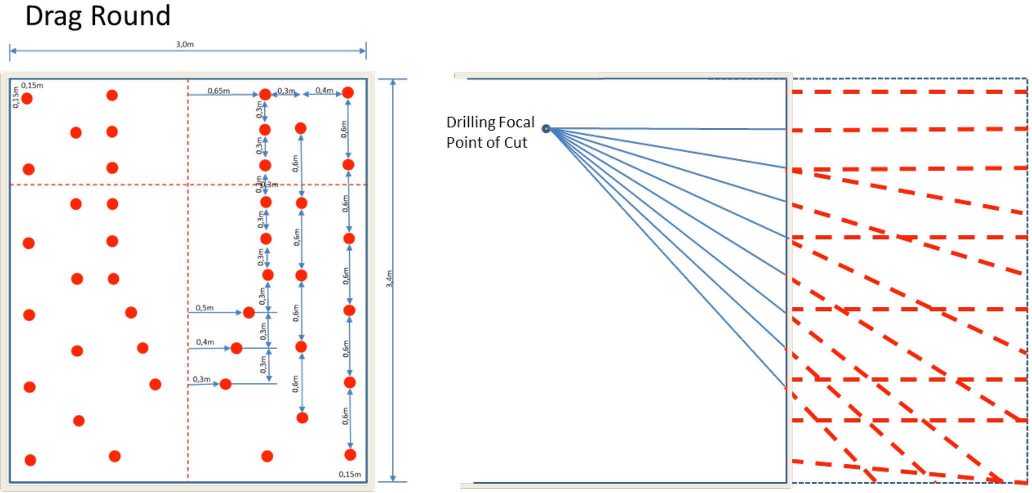
Various drilling rounds used in tunnel development exist. The candidate may draw any two rounds. Commonly known drilling rounds are, Burn cuts, Drag Rounds and Wedge cuts. Important in the candidate description is to identify the cut, easer holes and perimeter holes and state the purpose of the each. Examples of drilling rounds are depicted below.

Burn Cut Round

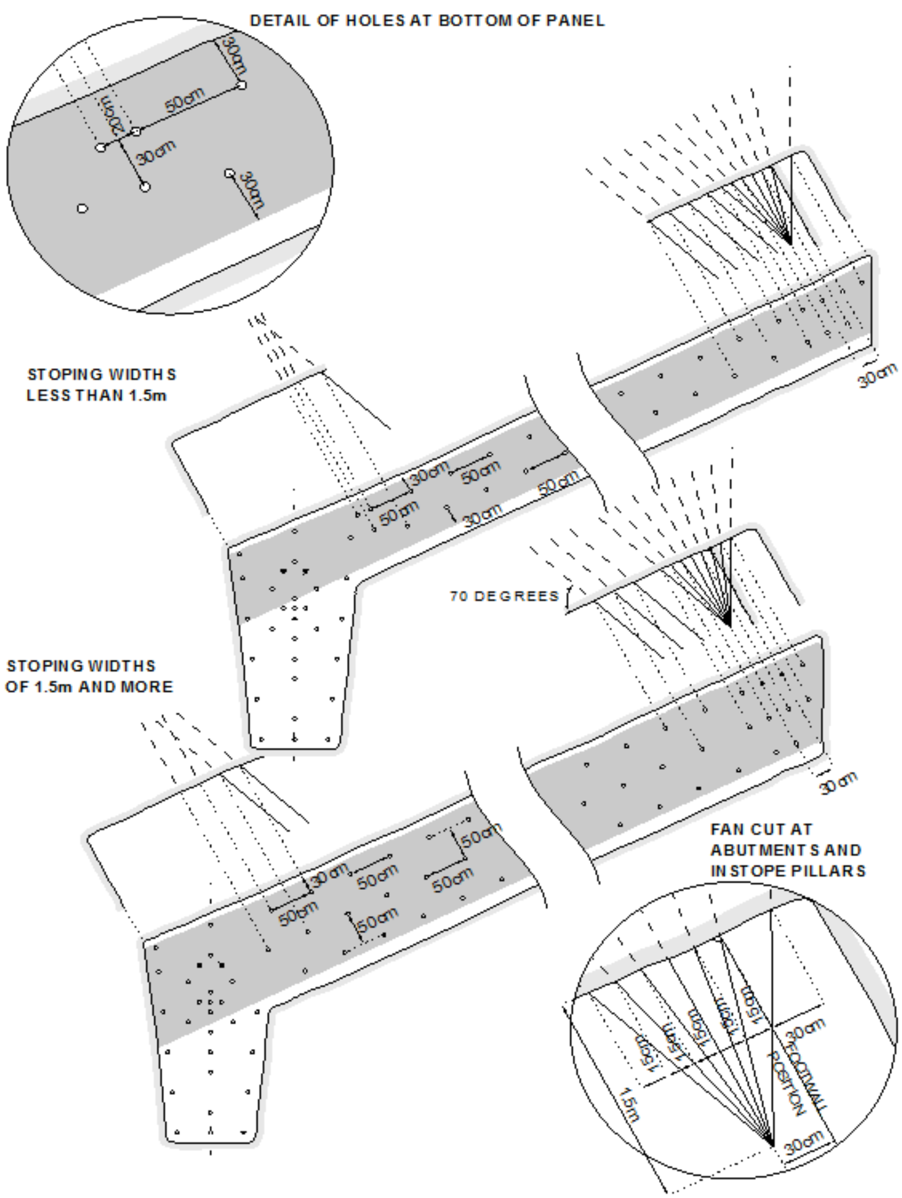


Front View Section View

Drag Round



Front View Section View

5.2 Sketch and describe blast hole layouts used in narrow tabular stopes? **<u>Answer:</u>** *Various drilling rounds used may be used in narrow tabular stopest. The candidate may draw any round. Important aspect is to discuss the fan cut to ensure that top of the panel breaks square. There should be some means of creating a free breaking face. The pattern within the stope should be discussed, whether it is a box or staggered pattern. An example is depicted below.* 	(6)

5.3 Describe the objectives and effects of de-coupling explosives? **Answer:** *Decoupled charges, in which the objective is to restrict the development of a rose of cracks around a blast hole.* *Decoupling of explosives reduces the effects of generated gas pressure from excessively extending initial fractures created by shock energy of the explosive.* *This is sought by isolating the explosive charge from the blasthole surface, using a charge diameter appreciably less than the blasthole diameter,* *The use of spacers to locate the charge axis along the hole axis.* *Special explosives may be formulated and packaged, to ensure stable detonation of the explosive at relatively low charge diameter.*	(6)
	[20]

QUESTION 6. **MINING STRATEGIES IN DIFFICULT CIRCUMSTANCES**

6.1	You are the Responsible Rock Engineer on a narrow tabular mine. A panel in one of the mines sections collapsed and you are required to advise the Manager on a strategy to re-establish the panel? With the aid of annotated sketches explain the factors that you would consider prior to making your recommendation?	(10)

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder P104

Answer:

3.5.3 Re-Establishing Panels

Re-establishing panels after massive falls of ground and rockbursts is commonly achieved by open-raising within the confines of the existing excavation, or by re-raising beyond the collapsed panel.

The positioning of on-reef re-development is determined largely by the magnitude of the stresses ahead of the stope, the fracture zone and the general ground conditions. At all depths, the size of any pillar left between the re-raise and the stope face should be small enough for it to yield in a stable manner, or be large enough not to become burst-prone. Local knowledge, past experience and computer modelling can be used to help determine pillar size, excavation dimensions and development geometry for each situation. A further general consideration is that mining on neighbouring panels should not be such as to affect re-development operations unfavourably.

Re-raising, and re-development in high stress situations, should preferably be by means of well-supported wide-ends. Heading leads, if any, should be kept to a minimum. These considerations are illustrated in Figures 3.5.2 and 3.5.3.

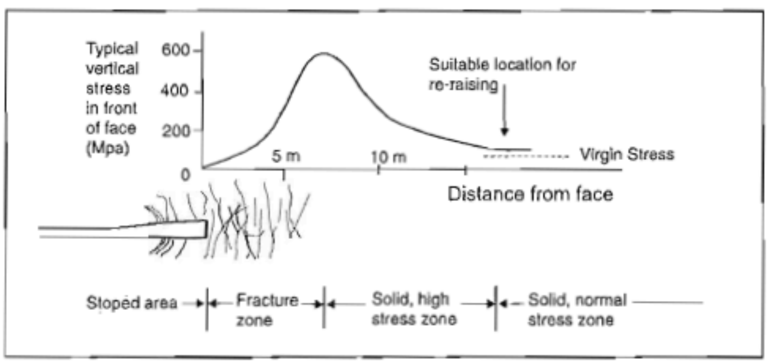


Figure 3.5.2 Fracture zone and stresses in front of typical deep face.

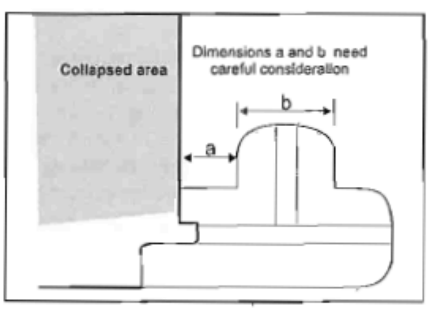


Figure 3.5.3
Re-developing on reef in high stress situations.

6.2 Explain the procedure that you would recommend to assess and declare special areas on your mine? A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder P101 to P112 **Answer:** ***Procedure for the assessment of special areas:*** *Special areas are deemed areas where different of adverse conditions exist that requires alternative methodologies are implemented to ensure acceptable levels of risk is maintained.* *The assessment of special area's may incorporate permanent physical conditions, such and high stress environments, the presence or negotiation of adverse geological structures, seismic prone areas, mining of steep dipping sections on a mine, areas where multi reef or wide reef extraction may be implemented.* *Short term problem areas may be declared as special areas, such as, Working places experiencing high occurrences of accidents or incidents, areas with increased risk ratings, areas with an elevated short term seismic hazard, etc.* *Assessment should not only deal with the identification of special areas but also mention routine assessments whether it incorporates increased visitation, improvement of monitor systems, conducting investigative numerical modelling, etc.* ***Procedure for the Declaration of special areas:*** *Each answer will be reviewed on merit, considering that some procedure must be discussed detailing the declaration of special areas. Mention of risk assessment, appointment so special managerial and supervisory teams, arrangement of special area meetings involving role players, communication with work teams, development of specific strategies, limitation of exposure etc. are dealt with.*	(10)
	[20]

Total Mark = [100]