



CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION PAPER

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

NUMBER OF PAGES:

QUESTION 1. **GEOTECHNICAL CHARACTERISTICS.**

- 1.1 The Bushveld Complex and Witwatersrand Basin were formed through different geological processes. Briefly describe each process? (4)

Answer:

The Bushveld Complex:

The layered intrusions consist of rocks which cooled slowly from molten magma, deep within the earth. Silicate minerals in fixed proportions crystallised and aggregated to form the final igneous rocks. **The composition of the minerals changed with the slow drop in temperature in the magma brought about by cooling.** The first silicate minerals which crystallised and settled out are rich in magnesium and iron (the 'mafic' parts of the magma), whereas at the lower temperatures, calcium, aluminum and sodium silicates crystallised (the more 'silicic' facies). This regular change in composition is called fractionation. **As more magma is intruded and cools, the cycle is repeated, and this can re-occur many times until several thousand metres of solid rock have been formed.**

The Witwatersrand Basin:

Part of the Witwatersrand Supergroup. The precise age unknown, **rocks were deposited by sedimentation** approximately 2700 mil years ago, before the age of fossils. Reef horizons situated within the upper Witwatersrand conglomerates of the Main-Bird and Kimberly-Elsburg series. **Rocks of the upper witwatersrand conglomerates are sediments made up of quartzites (deposited river sands), conglomerates (deposited river gravel) and relatively few shales (deposited mud).** **The gold bearing reefs of the wits basin vary widely, but majority are conglomerates.** The conglomerates have pebble of chert and quartz within a matrix of quartz grains, silicates and vary sulphide (mainly pyrite).

- 1.2 The host rocks in which South African mining is carried out are generally competent (4)
but are certainly not entirely homogeneous. There are several practical effects of the
presence of such inhomogeneities. Briefly describe four practical effects?

Answer:

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA
Ryder P15.

- i) **Fracturing** in service excavations, pillar and abutments is affected, due to the
induction of tensile stresses and resultant fracturing in the **stiffer rock layers
adjacent to softer ones**.
- ii) The presence of shale layers, tuffaceous lava, or other **weak materials** in the
immediate hangingwall or footwall can **cause special mining and strata control
difficulties**; particularly in the neighbourhood of abutments or pillars.
- iii) **Dyke**, many of which are strong and brittle and which seem to be associated with
abnormal virgin stress fields, can fail violently and thus are often associated with
enhanced levels of seismicity and rockbursting in deeper mines.
- iv) Footwall haulages need to be carefully sited to avoid traversing **incompetent rock
strata**. Crosscuts, which necessarily traverse different strata horizons, can require
tailored intensities of support along their lengths.

- 1.3 Name two rock types common to each of the two regions mentioned in question 1.1 (2)
and provide typical elastic and strength properties in terms of Young's Modulus,
Poisson's Ratio and Uniaxial Compressive Strength?

Answer:

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA
Ryder P16

Witwatersrand Basin.

The candidate may list two rock types typically found in the Witwatersrand Basin and quote
similar figures as per Table 1.3.1 below

Bushveld Complex.

The candidate must list two rock types typically found in the Bushveld Complex and quote similar figures as per Table 1.3.1 below

Table 1.3.1 summarises representative properties of a number of common rock types.

Table 1.3.1 Typical rock elastic and strength properties

	E(GPa)	ν	σ_c (MPa)	β
Quartzite (90 %qtz)	80	0.12	200-300	10
Quartzite (60 %qtz)	70	0.20	150-200	5
Shale	40-80	0.25	80-200	2-5
Lava	80	0.21	200-500	5
Soft Lava	65	0.22	80-160	4
Dolomite	75	0.27	300	5
Dyke/Sill	80	0.25	90-300	5
Pyroxenite	60-120	0.15-0.25	100-180	4-10
Anorthosite	90	0.22	230	8
Norite	60-100	0.18-0.25	100-250	6-10
Chromitite	80-110	0.22	50-150	6-9

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QUESTION 2. **ROCK AND ROCKMASS BEHAVIOUR.**

- 2.1 For three generic geotechnical regions (shallow, intermediate and deep) indicate how stoping layouts and support strategies may vary to deal with the influence of stress, geological structure and rockmass deformation? (9)

Answer:

Geotechnical Region	Stress Influence	Geological Structure	Rockmass Deformation
Shallow (0-1000m)	Stoping Layouts: Low stress and large tensile zones. Stoping layout incorporate unmined blocks of ground as pillar with limited mining spans Support Strategies: Very strong non-yield pillars to support tensile zones and subsidence close to surface. Local support systems robust and designs based on support resistance to cater for the absence of confining forces. Regional support incorporates non-yielding pillars to control deformation and compartmentalize mining area's	Stoping Layouts: Governs mining spans and mining directions. Influences extractions sequences and positioning of final remnants. Support Strategies: Stiff support systems positive confinement and aimed at preventing severe collapse. Bracket pillars required on faults/dykes. Degree of jointing dictates support spacing.	Stoping Layouts: Small mining spans to prevent deformation, subsidence and back-breaks. Support Strategies: Very stiff support systems. Extensive use of non-yield pillars required shallower than 400m below surface. Incorporation of crush pillars to support large tensile zones 600-1000m below surface.

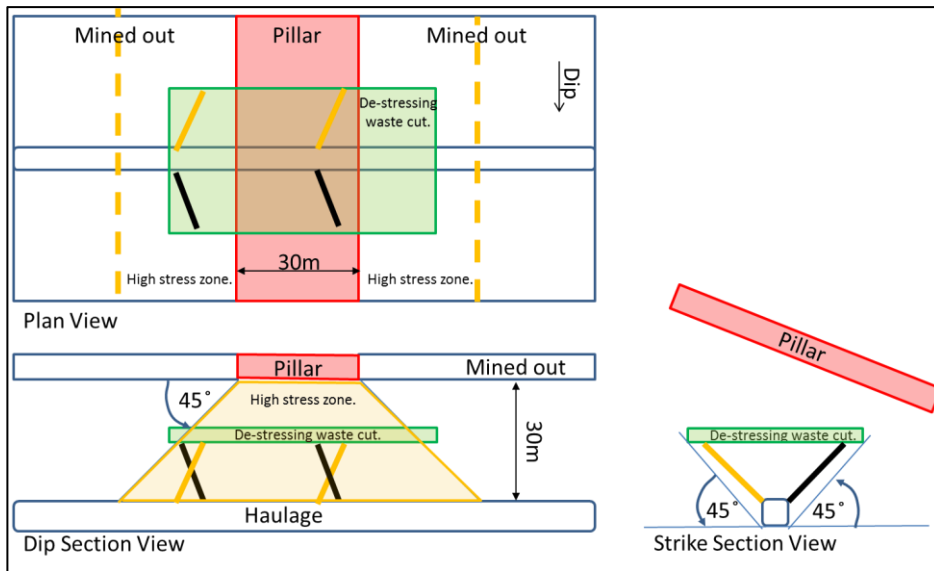
Intermediate (1000m – 2250m)	Stoping Layouts: Mine towards solid. Positioning of final remnants away from major infrastructure. Limit ERR. Support Strategies: Stiff and Yielding support systems. Increase support densities and methodologies during final extraction stages.	Stoping Layouts: Governs mining spans and geological structures may become seismically active in deeper ranges and where final remnants are planned. Angle of approach > 35 deg. Support Strategies: Bracket pillars based on ESS criterion. Yielding local support to cater for energy absorption. Additional support at minor geological structure intersections.	Stoping Layouts: Regional spans controlled with yielding pillars. Focused on preservation of access way. Limiting mining spans to influence convergence in deeper section. Support Strategies: Face fracturing and resulting dilation stabilise hangingwall. In-stope pillars range from crush pillars to assist with local support stiffness to none required at deeper ranges. Local support becomes more yielding in nature to allow for elastic convergence.
Deep (2250m – 3500m)	Stoping Layouts: Limiting mining spans to reduce overall face stress and reduce ERR levels	Stoping Layouts: Seismically active structure may be left in large bracket pillars.	Stoping Layouts: Limited mining spans aimed at controlling convergence and influencing ERR.

	Lead/lag control essential to limit stress induced fracturing. Support Strategies: Regional support is design to limits elastic convergence. Local support design methodologies cater for stress change and energy absorption. Support design based on energy absorption criteria.	Where structures are negotiated steep approach angles requires alterations to overall mining configurations. Support Strategies: Bracket pillars along geological structures and incorporated in regional support systems. (ESS) Local support provides positive confinement and provides energy absorption capabilities and yield properties to cater for deformation and stress change.	Careful consideration of extraction sequence. Support Strategies: Use of Backfill to reduce convergence levels. Yielding support to deform with the rock mass and prevent the fractured rockmass from unravelling.
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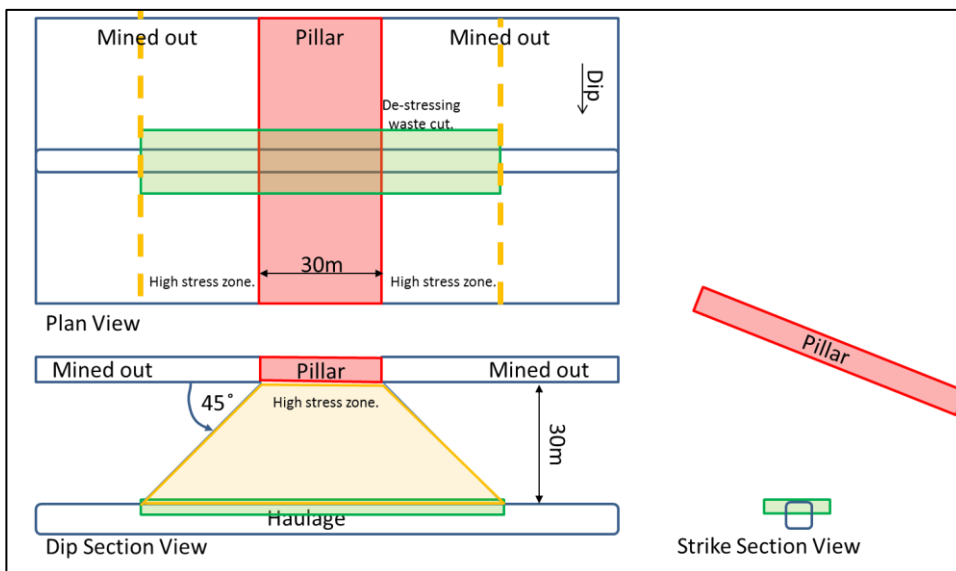
2.2 With the aid of annotated sketches explain two methods that may be implemented to provide long term protection and ensure stability of a haulage planned to mine through a high stress zone. The haulage is located 30m in the footwall of the reef and must mine under a 30 m wide stability pillar left on the reef horizon? (6)

Answer:

De-stressing slot/Umbrella slot: A de-stressing slot is mined either on reef or between the reef elevation and tunnel location. The slot creates a de-stressed zone through which the tunnel may be developed in a low stress environment. Stopping and starting positions should be determined by means of numerical modelling.



T-Shape: The tunnel is developed with shoulders similar to a wide heading. Stress is removed from the excavation sidewall and the potential for sidewall failure is reduced by limiting the sidewall exposure height. Rock mass damage is removed from the desired tunnel side walls.



Extensive support: Cognisance will also be taken of protection methodologies incorporating elaborate or extensive support systems and replacement strategies with relocation of haulages to deeper sections from the reef horizon.

2.3 List and briefly describe five (5) parameters, derived from recorded waveforms that are routinely used to quantify seismic events? (5)

Answer:

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder Pages 291 and 292

1. Time of the event. t – This defines when the seismic events occur.
2. Location $X = x, y, z$ – The positioning relative to excavations on the mines co-ordinate system.
3. Seismic Moment M_0 and its tensor, which defines the overall direction of principal stresses acting at the source and the nature of coseismic strain change in terms of its isotropic and deviatoric components.
4. Radiated seismic energy E , and/or seismic stress drop $\Delta\sigma$
5. Characteristic size of the event M_L – This is presented in term of local magnitude and derived from the recorded energy and moment.

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QUESTION 3. MINING LAYOUT STRATEGIES.

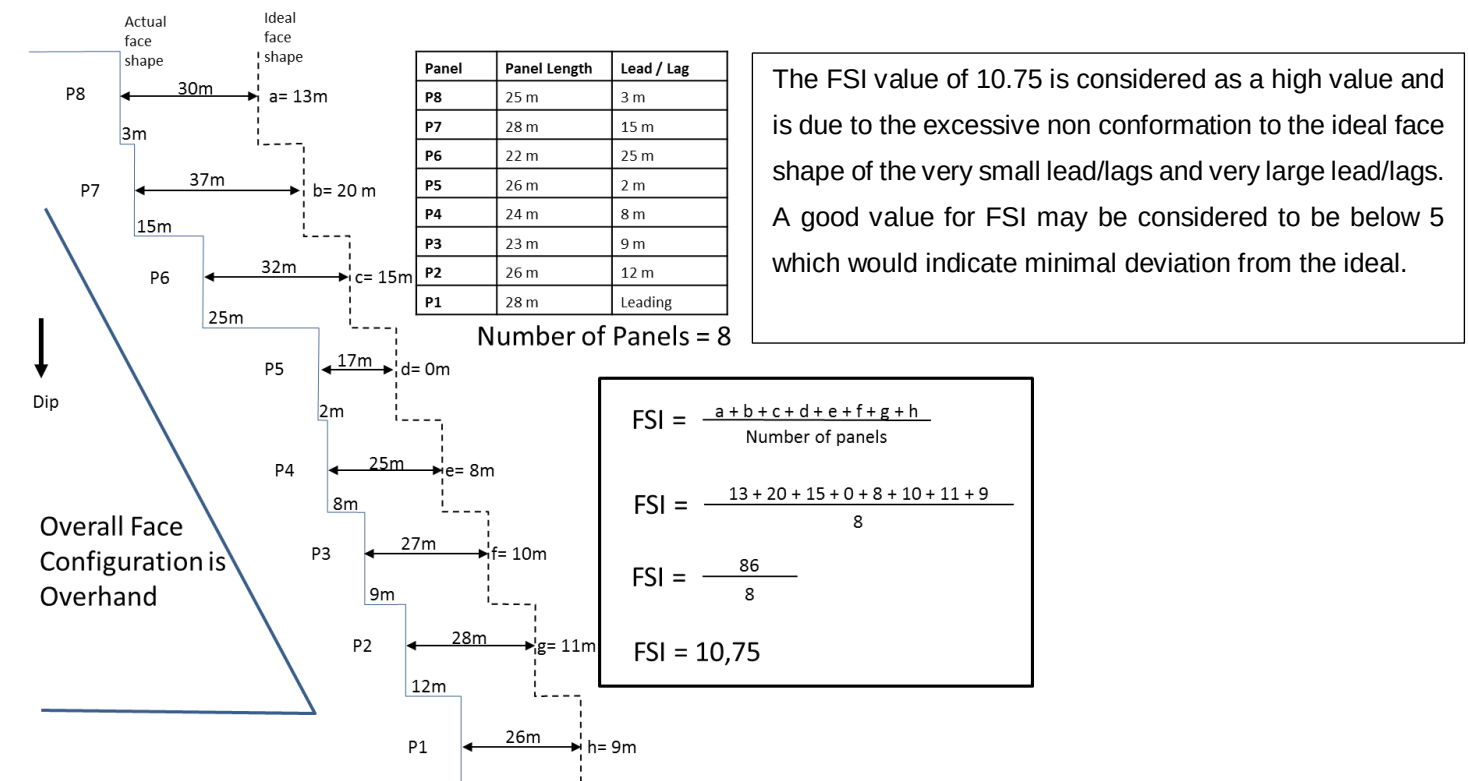
- 3.1 A longwall consisting of eight (8) panels, similar in face length, is mining with an overall overhand face configuration in an eastern direction. The following lead/lag distances exist between the panels: (4)

Panel	Panel Length	Lead / Lag
P8	25 m	3 m
P7	28 m	15 m
P6	22 m	25 m
P5	26 m	2 m
P4	24 m	8 m
P3	23 m	9 m
P2	26 m	12 m
P1	28 m	Leading

If the desired lead/lag distance between the panels is 10m calculate the Face Shape Index (FSI) and comment on your result?

Answer:

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder P55



- 3.2 During the project definition phase of the planned mining of a shaft pillar located approximately 1200 m below surface you are requested to provide advice regarding the extraction sequence. The shaft must remain operational following the extraction. Briefly describe the **extraction sequence that you would recommend taking factors such as; shaft barrel protection, geological structure, regional support and seismicity into consideration?** (10)

Answer:

SHAFT PILLAR EXTRACTION IN SOUTH AFRICAN GOLD MINES. A GUIDEBOOK BASED ON PAST PRACTICE. - T O Hagan, M K Kiboko, F M C C Vieira and T Rangasamy. Pages 32 -36

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder Pages 245 - 248

When the shaft is to remain operational, the first objective should be to reduce and control damage to the shaft and its ancillary excavations. Current best practice for stoping of the shaft pillar (after damage control strategies have been implemented for the shaft/s) is to **stope out the inner pillar first and then progress towards the boundary of the shaft pillar**. The radius from the shaft defining the inner pillar varies between 10 m and 50 m but seldom exceeds 50 m. The size of the inner pillar is normally determined from numerical modelling, considering factors such as;

- Area to be stoped where the influence of deformations, strains and stresses on the shaft diminishes.
- Area to be stoped where orepasses and other major excavations are stress relieved.

Shaft Barrel Protection:

Ideally the immediate reef slot may have been extracted during the shaft sinking phase. If not the case the extraction sequence must consider the **removal of the shaft lining** from within the shaft outwards or where adequate protection of the lining have been installed to remove the lining systematically from within the shaft pillar during the extraction of the inner pillar.

Geological Structure:

A decision will be required whether **geological structures will be clamped** in bracket pillar or in the case of **small throw structures extracted**. When decided to mine out **geological structure it would**

be ideal to ensure that these areas are mined following the extraction of the inner pillar and deformation may still be limited.

Waste cuts have to be planned to stress relieve geological structures that traverse the shaft pillar in areas where pillars cannot be left. These should be **planned early in the mining sequence**.

Regional Support:

Since the creation of remnants is inevitable, the designed sequence should limit the siting of remnants to the periphery of the shaft pillar if possible.

If unpay blocks of ground are within the zone of influence of stresses and deformations imposed on the shafts, these blocks must be mined.

If unpay blocks are outside the zone of influence of stresses and deformations imposed on the shaft, they could be incorporated into the design of pillars. The influence of pillar sizes and positioning on reducing stresses and deformations should be investigated using numerical modelling.

Seismicity:

Seismicity may likely be driven by the rate of extraction. The extraction sequence should consider mining volume.

Ideally scheduled to mine adjacent to area's where seismicity is anticipated, such as seismically active geological structures, first to ensure excess shear stress on the structures is maintained at low levels when being mined.

Ensure systematic and sequential extraction.

- 3.3 In terms of the mining of Special Areas (high stress and potentially seismically active area) list and discuss the recommendations that you will make in terms of mining layout and extraction sequence only. (6)

Answer:

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA Ryder Page 102

- a) The stoping layout should be such as to **mine towards the largest or closest solid area**.
- b) In general, the stoping layout should attempt to minimise seismic or ground control hazards. This may be achieved by **mining away from geological features** or by **approaching minor features obliquely (angle of approach 35°)**. Particular care should be taken when mining near structures known to be hazardous.

- c) Remnants should **not be spilt** and mined in two different directions.
- d) **Panels should not approach each other** from either side of the remnant. One side should be stopped and suitably supported.
- e) **Large lead/lags** between panels should be avoided.
- f) When remnants are elongated, consideration should be given to **mine in the direction of elongation**. This reduces the size of ESS lobes and thus the likely magnitude of seismic activity.
- g) Particular consideration should be given to **changing the direction of mining during the final** stages of remnant extraction, for example, final up-dip mining of a dip-orientated remnant.
- h) **Joint sets and fracturing** from previous mining should be considered in the **choice of mining direction**.

QUESTION 4. MINING SUPPORT STRATEGIES.

4.1 During one of your underground investigations to an narrow tabular deep underground (10) stope (2500m below surface) you noticed that the elongates installed on a 1.0m dip and 1.5m strike spacing are failing in the 10th row from the stope face. You observed that these elongates have yielded beyond their yielding range of 200 mm. On average elongates are installed 2.0m from the face before the blast. The mining span at the time of your observation was 200m. The rock mass properties are defined by:

- Modulus of Elasticity of 60 GPa
- Poisons Ratio of 0.25
- Overburden Density of 2800 kg/m³

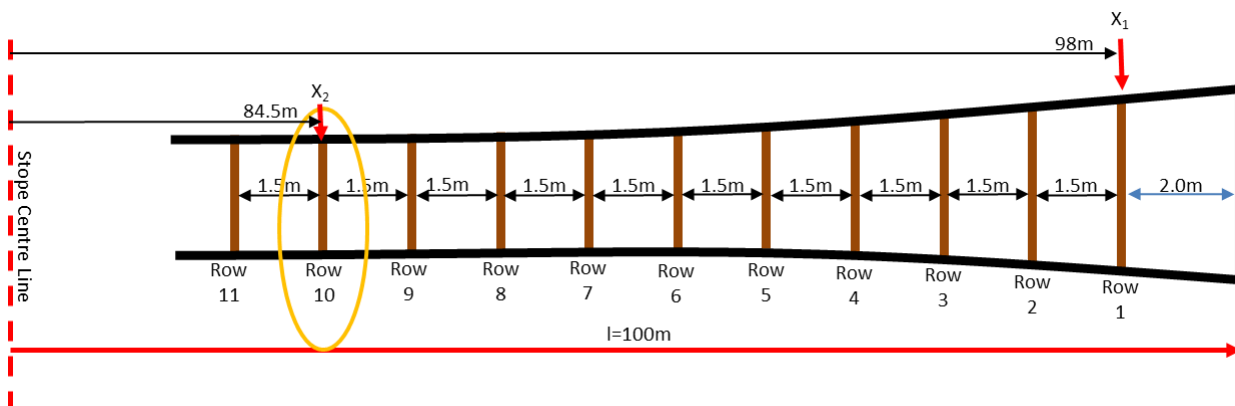
Use analytical calculations in an attempt to find an answer for the failure of elongates and comment the results you obtain?

Ensure to state any assumptions that you may be required to make clearly.

Formulas:

$$\begin{aligned} q &= \rho g H & E &= \frac{\sigma}{\varepsilon} & G &= \frac{E}{2(1+\nu)} \\ s_z &= \frac{2(1-\nu)q}{G} \sqrt{l^2 - x^2} & l_c &= \frac{s_m G}{2(1-\nu)q} \end{aligned}$$

Answer:



Assumption:

Gravitational acceleration = 9.81 m/s²

Rockmass Properties:

E = 60 GPa

$\nu = 0.25$

$\rho = 2800 \text{ kg/m}^3$

Other provided information:

H = 2500 m

Span = 200 m thus $l = 100 \text{ m}$

Elongate Spacing = 1.0 m dip x 1.5 m strike

Elongate installation distance = 2.0 m from face.

Elongate yield = 200mm

$$q = \rho g H$$

$$q = 2800 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 2500 \text{ m}$$

$$q = 2800 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 2500 \text{ m}$$

$$q = 68.67 \text{ MPa}$$

$$G = \frac{E}{2(1+\nu)}$$

$$G = \frac{60 \text{ GPa}}{2(1+0.25)}$$

$$G = 24 \text{ GPa}$$

Convergence at Installation (X1)

$$s_z = \frac{2(1-\nu)q}{G} \sqrt{l^2 - x^2}$$

$$S_z = \frac{2(1+0.25) \times 68.67 \text{ MPa}}{24\,000 \text{ MPa}} \times \sqrt{(100 \text{ m})^2 - (98 \text{ m})^2}$$

$$S_z = 0.085 \text{ m}$$

Convergence at 10th Row (X2)

$$s_z = \frac{2(1-\nu)q}{G} \sqrt{l^2 - x^2}$$

$$S_z = \frac{2(1+0.25) \times 68.67 \text{ MPa}}{24\,000 \text{ MPa}} \times \sqrt{(100 \text{ m})^2 - (84.5 \text{ m})^2}$$

$$S_z = 0.2295 \text{ m}$$

The difference between X2 and X1 provides the amount of elastic deformation of the rockmass between the 1st and 10th row and thus the deformation of the elongates.

$$\begin{aligned} \text{Elongate deformation} &= 0.2295 \text{ m} - 0.085 \text{ m} \\ &= 0.1445 \text{ m} \end{aligned}$$

Comment:

The analytical equations calculates elastic convergence and inelastic deformation is not accounted for. Thus the additional deformation may be due to the inelastic deformation rockmass possibly caused by rockmass failure or bedding/layer separation.

4.2 List and briefly describe four (4) types of backfill?

(4)

Answer:

**Rock Mechanics for underground mining. –Third Edition. BHG Brady & ET Brown
Pages 410 to 416.**

Or

Safety in Mines Research Advisory Committee. Final Report. Best practice rock engineering handbook for “other” mines. - T R Stacey Pages 114 -116

Five alternative backfill systems that can be considered for mining operations are:

- crushed waste fill;
- classified cycloned tailings (CCT) fill (with or without binder addition);
- cemented full plant tailings;
- dewatered or paste fill;
- slurry fill.

CRUSHED WASTE BACKFILL

This is a low technology type of fill, dumped under gravity, and spread with suitable equipment if necessary. It will usually be a “loose” fill unless some cementitious binder is added. In its loose form it must be contained by pillars or barriers. Failure of such containing pillars or barriers could be hazardous and lead to dilution of ore at deeper levels.

CLASSIFIED CYCLONED TAILINGS

Classified cycloned tailings (CCT), sometimes called sandfill, is prepared from concentrator tailings by hydrocyclone treatment to remove the slimes or clay-sized fraction. In most cases, the highest proportion of the fill product lies in the 40-150 μ m range of particle size and the proportion of <10 μ m material is less than 4%. The <10 μ m fraction is most critical in terms of percolation and must be removed by hydrocycloning.

SLURRY BACKFILL

Slurry backfill, with gravity as the prime mover, offers almost all the desired features of paste fill. The secret of this system is chemistry, whereby cementitious additives are added to the fill material in order to achieve the desired performance underground.

PASTE FILL

Paste backfill is a **high density backfill using full plant tailings**. Full plant tailings are preferred since well-graded tailings are generally easier to pump in paste form than uniform-graded tailings. Paste fill systems can be regarded as the “Rolls Royce” of backfill systems and their popularity is increasing. They are high-capital and operating cost systems which require high-tech paste pumps, disc or belt filters and other capital intensive equipment.

Paste fill systems normally use a 20cm slump product. **Moisture content influences not only the slump of the product, but also the pressure gradient**, and must be well controlled. For example, a 2% reduction in moisture content from 24% to 22% by mass can result in an increase in friction loss in the pipeline from 10kPa to 20kPa per metre. **Control of the moisture content is thus the most critical aspect of the backfilling operation.**

If a full plant tailings product is essential in order to prevent a shortfall of backfill material, paste fill is attractive.

- 4.3 List and describe the support strategies in terms of local and regional support that you (6)
would consider with multi reef mining during subsequent and simultaneous extraction
strategies in shallow mining conditions.

Answer:

A handbook on Rock Engineering Practice for Tabular Hardrock mines – AJ Jager and JA
Ryder P186 – 190.

Subsequent Extraction:

Local Support

If the **lower reef is being mined after the upper**, convergence will be minimal and a **stiff support system** is required. Depending on the actual middling dimension, the support of the bottom reef **may have to cater for the entire middling thickness as a fallout height**. Additional instope pillars or cemented backfill may be used to control the mining span and limit middling instabilities.

If the **upper reef is being mined after the lower**, then the bottom mined out stope should be **backfilled using stiff cemented fill to prevent sag**. The backfill will however not alter any tensile stresses created by the lower reef mining, hence active support (e.g. pre-stressed tendons) may be required.

Regional Support

Superimposed regional pillars designed to carry the entire over-burden.

Simultaneous Extraction:

Local Support

Middling stability is a major consideration. If instability is anticipated, support on the lower reef must be capable of supporting the **full deadweight of the middling**. Support must be stiff, and cater for the lead/lag strategy employed (e.g. grout packs for in-line faces or cemented backfill on the lower reef when it leads or lags the upper).

Regional Support

Superimposed regional pillars designed to carry the entire over-burden.

QUESTION 5. INVESTIGATION TECHNIQUES.

5.1 The mine you are working on have various accesses from surface and general mining (15) takes place in a shallow and intermediate environment. The orebody is accessed via a range of decline and vertical shafts. The decline shafts from surface were developed from box-cuts with weathered weak rock up to a depth of 15m from surface. The deeper sections of the mine are seismically active and vertical shafts have been placed in major fault losses. You are required to implement a monitoring strategy for the main access ways. Discuss your strategy that you will recommend in terms of monitoring locations, the rockmass characteristics to be monitored, and applicable instrumentation?

Answer:

**Rock Mechanics for underground mining. –Third Edition. BHG Brady & ET Brown
Chapter 18**

	Monitoring Locations	Rockmass Characteristics	Applicable instrumentation
Vertical Shafts	Major Structure intersections. Shaft lining and steelwork.	Ground motion induced by seismicity. Rockmass strain and deformation. Shaft tilt due to rockmass strain or potential seismic damage	Accelerometers or Geophones fixed to the shaft lining or nearby service excavations to monitor ground motion and incorporated with the seismic system Strain gauges on steel work. Extensometers installed through the lining and structures to monitor potential dilation. Wireline stressmeters and tilt meters Fixed Lazer scanners.
Decline Shafts	Boxcut slopes Porthole	Box-cut slope deformation. Rockmass dilation and deformation. Bed separation. Subsidence.	Extensometers installed through the rockmass above the porthole to monitor potential bed separation. TDR. Slope prisms or fixed lazer of slope radar scanning

5.2 There are basically two types of analyses associated with numerical modelling, (5)
namely, Eulerian and Lagrangian analyses. Provide a brief description of each?

Answer:

- When measuring the properties of a fluid, one tends to immerse **a stationary measuring point** in to the fluid and the **material is free to move in respect to that point**. An example is placing a thermometer in water to measure the water temperature. This observation is of a **type based on a fixed point in a moving continuum. This is termed Eulerian analysis**.
- In the case of solids one tends to apply an alternative method of observation whereby **the observation is fixed to a point and is allowed to move with that point in the solid**. This method is termed **Lagrangian analysis**

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QUESTION 6. SURFACE EFFECTS.

6.1 Subsidence due to underground mining can take two forms. List and briefly describe (4)
these two forms.

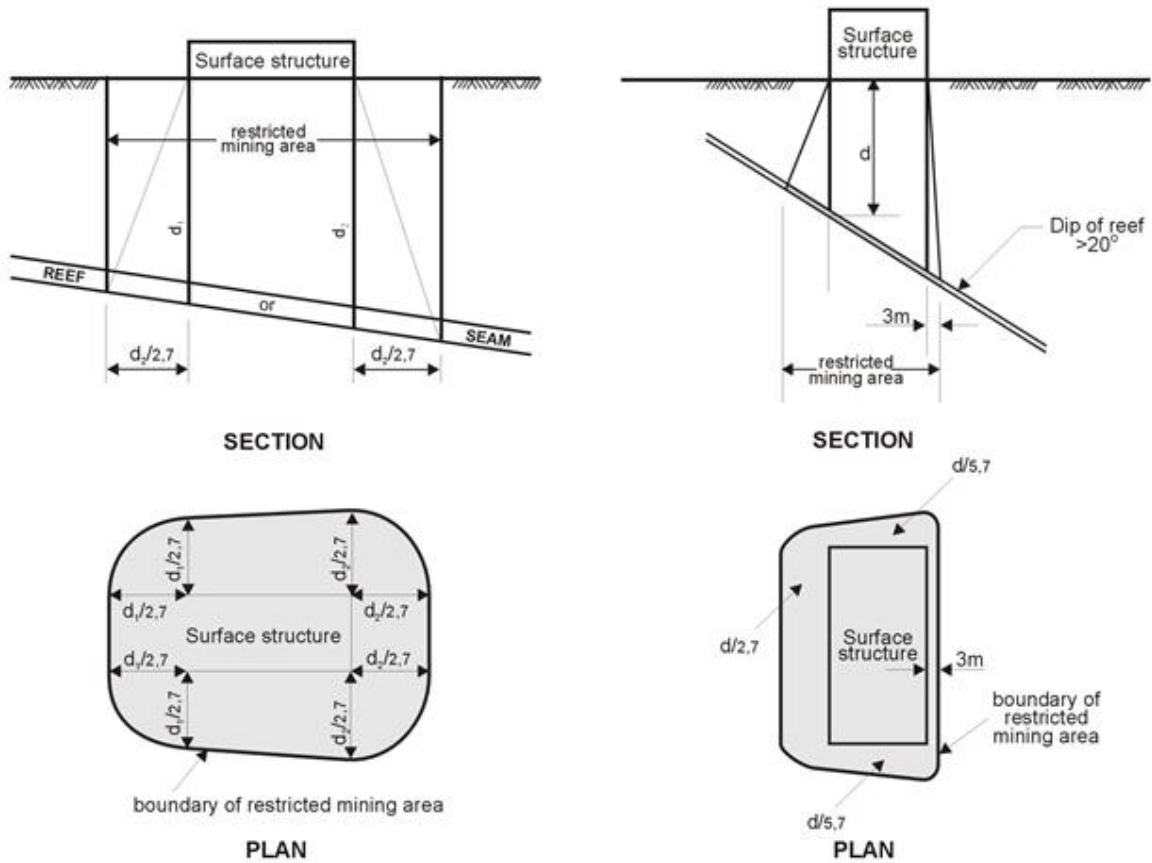
Answer:

Safety in Mines Research Advisory Committee. Final Report. Best practice rock engineering handbook for “other” mines. - T R Stacey Page 54

- **continuous subsidence resulting from regular closure** of underground workings and competent or continuum hangingwall behaviour;
- **discontinuous subsidence resulting from collapse of underground workings**, failure of pillars or a combination of both. Intentional subsidence, such as occurs in caving mining methods, also falls into this category.

- 6.2 In shallow mining conditions where reef or seam mining is likely to influence surface infrastructure restrictions on mining are imposed. With the aid of annotated sketches depict these restrictions. (6)

Answer:



[10]

Total Mark = [100]